Overview Research Activities 2000

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. CWI is a Member of the World Wide Consortium (W3C) and runs the W3C Office in The Netherlands.

General Director

G. van Oortmerssen

Colophon

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Stichting Mathematisch Centrum/Centrum voor Wiskunde en Informatica

visiting address	Kruislaan 413, 1098 SJ Amsterdam, The Netherlands
postal address	P.O. Box 94079, 1090 GB Amsterdam, The Netherlands
telephone	+31 20 592 9333
telefax	+31 20 592 4199
website	www.cwi.nl

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This Overview Research Activities is complementary to the Jaarverslag SMC (in Dutch) and CWI Annual Report (in English).

They can be ordered at CWI.
Please contact mrs. D.C.M. Amende (phone +31 20 592 4128; email `Thea.Amende@cwi.nl`).

PREFACE

This Overview is a supplement to CWI Annual Report 2000, which highlights CWI research in 2000. This overview reports extensively on the various activities in 2000 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:

  - Biography of Aad van Wijngaarden – SEN0
  - Interactive Software Development and Renovation – SEN1
  - Specification and Analysis of Embedded Systems – SEN2
  - Coordination Languages – SEN3
  - Evolutionary Systems and Applied Algorithmics – SEN4

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

  Themes:

  - Applied Analysis and Scientific Computing for PDEs – MAS1
  - Computational Fluid Dynamics – MAS2
  - Mathematics of Finance – MAS3

- **Information Systems – INS**

  Themes:

  - Applied Logic and Digital Libraries – INS0
  - 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, colloquia, 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 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. Seven 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 the research institute EURANDOM. 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
  - S. Brand
  - M.H. van Emden
  - S. Etalle
  - T. Fleiner
  - B. Fortz
  - L. Di Gaspero
  - R. Gennari
  - F. Goualard
  - W.J. van Hoeve
  - A. Kotlov
  - M. Laurent
  - E. Monfroy
  - F. van Raamsdonk
  - R. Rizzi
  - A. Schrijver
  - J.-G. Smaus
  - A.G. Steenbeek
  - L. Stougie
- 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. Litjens
- M. Mandjes
- R. Núñez Queija
- M.A. Remiche
- S.L. Ricker
- M.J.G. van Uitert

- Stochastics – PNA3

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

- Signals and Images – PNA4

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

- Secretaries:

  - W.J.B. van Ojik (until September 1)
  - L.M. Schultze
  - J.J.D. Deen-de Klerk (from September 1)

CWI Reports

PNA-R0001. J.H. van Zanten. *The stable central limit theorem for local martingales with bounded jumps via Skorohod embedding.*

PNA-R0002. M.R.H. Mandjes, M.J.G. van Uitert. *Transient analysis of traffic generated by bursty sources and its application to measurement-based admission control.*

PNA-R0003. H.J.A.M. Heijmans, R. van den Boomgaard. *Algebraic framework for linear and morphological scale-spaces.*

PNA-R0004. S.C. Borst, O.J. Boxma, P.R. Jelenković. *Induced burstiness in Generalized Processor Sharing queues with long-tailed traffic flows.*

PNA-R0005. E. Altman, K. Avrachenkov, C. Barakat, R. Núñez Queija. *State-dependent M/G/1 type queueing analysis for congestion control in data networks.*

PNA-R0006. J.H. van Zanten. *Uniform convergence of curve estimators for ergodic diffusion processes.*

PNA-R0007. M.J.G. van Uitert, S.C. Borst. *A reduced-load equivalence for Generalised Processor Sharing Networks with heavy-tailed input flows.*

PNA-R0008. M.N.M. van Lieshout, E.W. van Zwet. *Maximum likelihood estimation for the bombing model.*

PNA-R0009. R. Núñez Queija. *Note on the GI/GI/1 queue with LCFS-PR observed at arbitrary times.*

PNA-R0010. J.W. Cohen. *Random walk with a heavy-tailed jump distribution.*

PNA-R0011. J.H. van Zanten. *Rates of convergence and asymptotic normality of curve estimators for ergodic diffusion processes.*

PNA-R0012. T.-Q. Deng, H.J.A.M. Heijmans. *Grey-scale morphology based on fuzzy logic.*

PNA-R0013. J.H. van Zanten. *New limit theorems for regular diffusion processes with finite speed measure.*

PNA-R0014. T.-Q. Deng. *Fuzzy logic and mathematical morphology.*

PNA-R0015. S.C. Borst, A. Mandelbaum, M.I. Reiman. *Dimensioning large call centers.*

PNA-R0016. S.C. Borst, O.J. Boxma, P.R. Jelenković. *Reduced-load equivalence and induced burstiness in GPS queues with long-tailed traffic flows.*

PNA-R0017. L.C.G.J.M. Habets, J.H. van Schuppen. *A control problem for affine dynamical systems on a full-dimensional simplex.*

PNA-R0018. J. van den Berg, B. Tóth. *A signal-recovery system: asymptotic properties, and construction of an infinite-volume limit.*

Networks and Logic – Optimization and Programming – PNA1

Staff

- Prof. dr. ir. A.M.H. Gerards, theme leader (0.8)
- Prof. dr. K.R. Apt, senior researcher (0.8)
- S. Brand, M.Sc., PhD student (as of September 1)
- Prof. dr. M.H. van Emden, guest researcher (as of September 1)
- Dr. S. Etalle (UM), researcher (0.1, as of July 15)
- T. Fleiner, M.Sc. (NWO), PhD student (until May 31)
- Dr. B. Fortz, postdoc (until August 31)
- L. Di Gaspero, M.Sc. (Un. Udine), PhD student (as of October 1)
- R. Gennari (UvA), PhD student (0.4, as of June 1)
- Dr. F. Goualard, ERCIM Fellow (as of September 1)
- Drs. W.J. van Hoeve, PhD student (0.8, as of October 1)
- Dr. A. Kotlov (NWO), postdoctoral researcher (until September 30)
- Dr. M. Laurent (also Ecole Normale Supérieure, Paris), senior researcher (0.68)
- Dr. E. Monfroy, postdoctoral researcher (until September 30)
- Dr. F. van Raamsdonk (VU), researcher (0.2)
- Dr. R. Rizzi, postdoc (April 17–June 17)
- Prof. dr. A. Schrijver, senior researcher (0.4)
- Dr. J.-G. Smaus, ERCIM Fellow (as of July 1)
- A.G. Steenbeek, programmer (0.9)
- Dr. L. Stougie (TUE), senior researcher (0.2)

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 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).

A new development within PNA1 is the investigation of computational and combinatorial problems arising in molecular biology. The first objective is to build up knowledge in this modern field rich in potential applications of techniques from discrete mathematics and combinatorial optimization. January 1, L. Stougie (Eindhoven University of Technology) joined PNA1 for one day a week, in order to lead the subtheme *Algorithmic and Combinatorial Methods for Molecular Biology* (PNA1.3, to be founded January 1, 2001).

Networks & Optimization – PNA1.1

Disjoint paths and cycles

A. Schrijver found a new, short proof of Mader's theorem on the maximum number of vertex-disjoint S-paths (to appear in *Journal of Combinatorial Theory, Series B*).

Together with A. Caprara and A. Panconesi, R. Rizzi extended on their previous work on the approximability and nonapproximability of the cycle packing problem. This work was meant to serve as a completion on previous work on the approximability and nonapproximability of the cut packing problem by A. Caprara & A. Panconesi and R. Rizzi.

Lift-and-project methods for integer programming

M. Laurent has studied how a lift-and-project method introduced by Lovász and Schrijver (1991) applies to the max-cut problem. She shows that if a graph has k edges whose contraction produces a graph with no K_5 minor, then its cut polytope can be found after k iterations of the basic N operator applied to the metric polytope of the graph. Thus $n - 4$ iterations suffice for a graph on n nodes and m edges, instead of the bound m provided by the general theory. Under some connectivity assumption, the bound becomes $n - \alpha(G) - 3$, thus giving an analogue of the Lovász-Schrijver result for the maximum

stable set problem in the more general context of max-cut.

Constraint & Integer Programming PNA1.2

Constraint programming

K.R. Apt and E. Monfroy extended their previous work on constraint satisfaction problems that are based on predefined, explicitly given finite constraints to provide an account of rule-based constraint programming. In this approach the computation process is limited to a repeated application of simple rules, combined with labeling. (To appear in *Theory and Practice of Logic Programming.*)

E. Monfroy extended his previous framework for constraint propagation by integrating into it a distributed splitting mechanism. This technique has three main advantages: in a single distributed and generic framework, propagation and splitting can be interleaved in order to realize complete distributed solvers; by changing only one agent, we can perform different kinds of search; and splitting of variables can be dynamically triggered before the fixed point of a propagation is reached.

Together with L. Granvilliers, E. Monfroy presented a family of constraint propagation strategies as instances of a single algorithm shown to be correct, finite, and strategy-independent. The main idea is to separate complex reasoning processes from basic fixed-point algorithms.

E. Monfroy realized a control-driven coordination-based version of the Generic Iteration Algorithm for Compound Domains of K.R. Apt.

K.R. Apt showed an equivalence in an appropriate sense between Boolean constraint propagation and unit propagation, a form of resolution for propositional logic. Also, he characterized one set of such rules by means of the notion of hyper-arc consistency used in constraint programming.

Constraint solver collaboration

With C. Castro, E. Monfroy proposed a strategy language for designing schemes of constraint solver collaborations: a set of strategy operators enables one to design several kinds of collaborations. The use of this language is examplified by describing some well-known techniques for solving constraints over finite domains and nonlinear constraints over real numbers via collaboration of solvers.

Real constraints and interval arithmetic

F. Goualard worked on the definition of new local consistencies for solving nonlinear real constraints. It has recently been shown that local consistency notions currently in use are not able to ensure reasonably good performances on every constraint system. Most notably, linear real constraint systems are usually not efficiently solved. Recent work by F. Goualard and other authors led to a new consistency notion subsuming some of the already known ones, and to an efficient algorithm to enforce it. Connexions with the Gauss-Seidel method have been pointed out and should eventually lead to the definition of a new consistency to efficiently solve both nonlinear an linear real constraints. An implementation in the form of a C++ library of the general framework to make cooperate algorithms associated to different consistencies began at the end of the year.

Together with T. Hickey, M. van Emden clarified certain fundamental problems in interval arithmetic: the correct definition of interval division, the status of the so-called 'Fundamental Theorem of Interval Arithmetic', and the single-occurrence theorem. They also derived interval arithmetic as a mathematically sound solution to the problem of performing real arithmetic on a digital computer.

M. van Emden started SHRINC, a project to develop open-source software, in the form of a library of C++ classes, to include the state of the art in correctness and efficiency for basic interval computations. This project is precipitated by the recent withdrawal by ILOG of the Numerica package from the market. So far rough drafts exist for rational notation of intervals and, together with W.J. van Hoeve, functions for rounding in software have been written. Other tested software includes bitwise synthesis of several constants essential in floating-point computation.

F. Goualard devised an interval arithmetic library for the C++ language which should be made widely available soon.

Alma

K.R. Apt worked on the semantics for the declarative fragment of his programming language Alma-0. To this end he provided a denotational semantics for first-order logic. The semantics combines a number of well-known ideas from the areas of semantics of imperative programming languages and logic programming and clarifies

the links between these two styles of programming.

Additionally, by allowing an assignment of a nonground term to a variable he introduced in this framework logical variables. This research shows that the language Alma-0 when extended by logical variables could retain its support for declarative programming. Currently, he is pursuing this research line with J. Smaus.

Term rewriting
Jointly with G. Barthe (INRIA, Sophia-Antipolis), F. van Raamsdonk discussed and compared various methods for proving termination of higher-order rewriting, in particular the higher-order version of the recursive path ordering (defined by Jouannaud and Rubio in Lics '99). They further present another format of higher-order rewriting, namely the one of combinatory reduction systems (CRSs), and study the relationship between HRSs and CRSs. (This will be published in a chapter of a forthcomming book.)

PhD Thesis

TAMAS FLEINER. *Stable and Crossing Structures.* Eindhoven University of Technology, November 8, A.M.H. Gerards (promotor), A. Schrijver (second promotor).

Books

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.

Special Editorial Activities K.R. Apt

K.R. Apt founded the new journal *ACM Transactions on Computational Logic.* He was also involved in his capacity of the President of the Association for Logic Programming in organizing a proper transition from the *Journal of Logic Programming* of Elsevier to *Theory and Practice of Logic Programming* (TPLP) of Cambridge University Press. The entire editorial board left the former journal and founded TPLP. Its price is 60 % cheaper. The information about the circumstances in which the TPLP was founded became widely known and recently it was also reported in the New York Times (see `http://www.nytimes.com/2000/12/25/business/25JOUR.html`).

Knowledge Transfer

- M. Laurent presented the minicourse 'Positive semidefinite matrix completions and ℓ_1-metrics' at the winter school 'New methods in discrete mathematics', Alpe d'Huez, France, March 20–24.
- E. Monfroy was consultant at LCN.

Organization of Conferences, Workshops, Courses, etc.

- Twenty-Fifth Conference on the Mathematics of Operations Research, Lunteren, The Netherlands, January 11–14: A.M.H. Gerards, member Organizing Committee.
- Workshop 'Constraint Programming & Integer Programming', Dagstuhl, Germany, January 17–21: K.R. Apt (co-organizer).
- EIDMA Minicourse 'Packing and Covering' by G.P. Cornuéjols, Eindhoven University of Technology, The Netherlands, January 17–21: L. Stougie (organizer).
- The 2000 CIRM-DONET Workshop on Graph Theory, Levico, Italy, May 7–12: A.M.H. Gerards (co-organizer).
- 5th International Conference on High Performance Optimization Techniques (HPOPT), Rotterdam, The Netherlands, June 7–9: L. Stougie (organizer and member Program Committee).
- 'ERCIM/COMPULOG Workshop on Constraints', Padova, Italy, June 19–21: K.R. Apt, E. Monfroy.
- RTA '00, United Kingdom, July 9–13: F. van Raamsdonk (member Program Committee).
- First International Conference on Computational Logic (CL2000), London, UK, July 24–28: S. Etalle (workshop Chair), F. van Raamsdonk (Publicity Chair).
- International Summer School in Computational Logic, Maratea, September 2–8: S. Etalle (co-organizer).
- Second Workshop on Rule-Based Constraint Reasoning and Programming, Satellite workshop of the 'Sixth International Conference on Principles and Practice of Constraint Programming' (CP'2000), Singapore, September 22: E. Monfroy (organizer).

- Workshop on Techniques foR Implementing Constraint programming Systems (TRICS). Satellite workshop of the 'Sixth International Conference on Principles and Practice of Constraint Programming' (CP'2000), Singapore, September 22: E. Monfroy (organizer).
- Tenth International Workshop on Logic-based Program Synthesis and Transformation (LOPSTR 2000), London, United Kingdom, July 24–28: S. Etalle (member Program Committee).
- Twelfth Belgium-Netherlands Artificial Intelligence Conference (BNAIC 2000), Kaatsheuvel, The Netherlands, November 1–2: S. Etalle (member Program Committee).

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

- ORBEL XIV, Fourteenth Conference on Quantitative Methods for Decision Making, Mons, Belgium, January 20–21: B. Fortz.
- Tagung Kombinatorik, Oberwolfach, Germany, January 2–8: A.M.H. Gerards, M. Laurent, A. Schrijver.
- ETL, Tsukuba, Japan, January 9–29: F. van Raamsdonk (working visit; lectures at Tsukuba University and at the Mita logic seminar Tokyo University).
- Twenty-Fifth Conference on the Mathematics of Operations Research, Lunteren, The Netherlands, January 11–14: A.M.H. Gerards.
- Workshop 'Constraint Programming & Integer Programming', Dagstuhl, Germany, January 17–21: A.M.H. Gerards.
- Linear, Semidefinite Programming and Randomization Methods for Combinatorial Optimization Problems, Dagstuhl, Germany, January 23–28: M. Laurent.
- University 'La Sapienza', Rome, Italy, February 24–29: L. Stougie (working visit).
- IRIN (Institut de Récherche en Informatique de Nantes), Nantes, France, February: E. Monfroy (working visit).
- CIAC, Rome, Italy, March 1–3: L. Stougie.
- The 2000 ACM Symposium on Applied Computing (SAC'2000), Villa Olmo, Como, Italy, March 19–21: E. Monfroy.
- Winter School 'New Methods in Discrete Mathematics', Alpe d'Huez, France, March 19–24: T. Fleiner, M. Laurent, A. Schrijver.
- Ecole Polytechnique Féderale de Lausanne, Lausanne, Switzerland, March 30–April 5: A.M.H. Gerards (working visit).
- 7th International Workshop on Project Management and Scheduling, Osnabrück, Germany, April 17–19: A. Schrijver.
- Technion, Haifa, Israel, April 23–May 7: T. Fleiner (working visit; lecture: *Monotonic functions and stable matchings*).
- AMORE-meeting, Lyngby, Denmark, May 3–5: A.M.H. Gerards.
- In Pursuit of Simplicity, Symposium to mark the retirement of Professor Edsger Wybe Dijkstra, Department of Computer Sciences, The University of Texas at Austin, USA, May 12–13: K.R. Apt.
- The 2000 CIRM-DONET Workshop on Graph Theory, Levico, Italy, May 12–17: T. Fleiner, A.M.H. Gerards, M. Laurent, R. Rizzi, A. Schrijver, L. Stougie.
- DONET Spring School 'Computational Combinatorial Optimization', Dagstuhl, Germany, May 15–19: B. Fortz.
- DeduGIS meeting, Ascona, Switzerland, May 22–25: E. Monfroy.
- Benelux Workshop on Computational Logic, Peer, Belgium, May 25–26: K.R. Apt, R. Gennari.
- Fifth ERCIM/Compulog Net Workshop on Constraints, Padova, Italy, June 19–21: R. Gennari.
- University of Padova, Italy, June 19: R. Gennari (working visit).
- University of Padova, Italy, June 17–24: A.M.H. Gerards (working visit).
- Workshop 'Perspectives on Mathematics', Goslar, June 18–24: A. Schrijver.
- COTIC meeting, Udine, Italy, June 22–23: E. Monfroy.
- IFIP Meeting, RTA '00, and WESTAPP, East Anglia, UK, July 9–13: F. van Raamsdonk.
- The Fifth International Conference on Artificial Intelligence and Symbolic Computation (AISC'2000), Madrid, Spain, July 17–19: E. Monfroy.
- Computational Logic Conference (CL2000), London, U.K., July 24–28: K.R. Apt (invited talk: *A denotational semantics for first-order logic and Alma-0 language*), F. van Raamsdonk, S. Etalle, R. Gennari, J.-G. Smaus.
- International Symposium on Mathematical Programming, Atlanta, USA, August 7–11: B. Fortz, A. Schrijver, L. Stougie (lecture: *A fast randomized approximation algorithm for stochastic programming*).
- International Summer School in Computational Logic, Maratea, September 2–8: S. Etalle.

- Workshop on discrete optimization, Bonn, Germany, September 4–8: B. Fortz, A.M.H. Gerards, M. Laurent, A. Schrijver.
- Conference on Principles and Practice of Constraint Programming, Singapore, September 18–22: R. Gennari, F. Goualard.
- Confer workshop in Cambridge, UK, September 14–15: F. van Raamsdonk (lecture: *Constructor subtyping in the calculus of inductive constructions*).
- AMORE Research seminar om railway optimization problems, University of Konstanz, Germany, October 16–20: A.M.H. Gerards.
- Université Joseph Fourier, Grenoble, France, October 23–27: A.M.H. Gerards (working visit).
- ADVIS'2000, First Biennial International Conference on Advances in Information System October 25–27, Izmir, Turkey: K.R. Apt (invited lecture: *Constraint Programming viewed as Rule-based Programming*).
- OZSL Autumn School, Nunspeet, The Netherlands, October 23–27: R. Gennari.
- Microsoft Research, Redmond, Washington, USA, October 1–30: A. Schrijver (working visit).
- Twelfth Belgium-Netherlands Artificial Intelligence Conference (BNAIC 2000), Kaatsheuvel, The Netherlands, November 1–2: S. Etalle.
- University of Pisa, Italy, November 13–20: M.H. van Emden (working visit).
- University of Oldenburg, November 24: K.R. Apt (working visit; during this visit K.R. Apt gave a Laudatio in connection with awarding the honoris causa title to Prof. Amir Pnueli at the University of Oldenburg).
- University of Freiburg, Germany, November 24–28: J.-G. Smaus (working visit).
- University of Parma, Italy, November 26–30: K.R. Apt (working visit; lectures: *The Alma project or how first-order logic can help us in imperative programming; Constraint propagation revisited*).
- CNO Workshop, Trier, Germany, November: B. Fortz.
- SAT day in the Netherlands, Amsterdam, November 3: R. Gennari.
- Tableaux System Workshop, Eindhoven-Tilburg, December 1: R. Gennari.
- INRIA, Rocquencourt, France, December: J.-G. Smaus (working visit).

Memberships of Committees and Other Professional Activities

Professorships

- 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.

PhD Committees

- T. Fleiner, University of Eindhoven, November 8: K.R. Apt, A.M.H. Gerards, M. Laurent, A. Schrijver, L. Stougie.

Organizational Activities

- NWO Special Year on Mathematical Biology, 2001: L. Stougie, organizer and coordinator.
- Cutting Planes and Integer Programming, Eindhoven University of Technology, April 26, 2001: A.M.H. Gerards, co-organizer.
- IPCO 2001, Utrecht, The Netherlands, June 2001: A.M.H. Gerards, member Organizing Committee, chair Program Committee; M. Laurent, member Program Committee.
- Third International Conference on Principles and Practice of Declarative Programming (PPDP 2001). Firenze, Italy, September 5–7, 2001: S. Etalle, member of Program Committee.
- Tagung 'Geometric convex combinatorics' Mathematisches Forschungsinstitut Oberwolfach, Oberwolfach, Germany, June 16–22, 2002: A.M.H. Gerards, co-organizer.
- ERCIM Working Group on Constraints: E. Monfroy, secretary.
- Association for Logic Programming: K.R. Apt, President.
- 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.
- KNAW Akademie Raad voor de Wiskunde: A. Schrijver, member.
- Koninklijke Nederlandse Akademie van Wetenschappen: A. Schrijver, member.
- Landelijk Netwerk Mathematische Besliskunde: A.M.H. Gerards, A. Schrijver, member Governing Board.
- Mathematical Programming Society: M. Laurent, Council member-at-large, A. Schrijver, member Symposium Advisory Committee.

- Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO): A. Schrijver, member Programma Commissie Netwerken.
- Stieltjes Instituut voor Wiskunde: A. Schrijver, member Science Council.
- Technische Universiteit Eindhoven: A. Schrijver, member Raad van Advies voor de Wiskunde.
- ERCIM Working Group on Constraints: E. Monfroy, secretary.
- Webmaster of the ALP webpage: E. Monfroy.

Editorial Activities

- *ACM Transaction on Computational Logic*: K.R. Apt, editor-in-chief and founding editor.
- *Combinatorica*: A. Schrijver, editor-in-chief.
- *CWI Tracts, CWI Syllabi*: A.M.H. Gerards, editor.
- *Discrete Applied Mathematics*: A. Schrijver, editor.
- *Discrete Mathematics and Theoretical Computer Science*: A.M.H. Gerards, editor.
- *Fundamenta Informaticae*: K.R. Apt.
- *Information and Computation*: K.R. Apt.
- *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.
- *Mathematical Programming, Series A*: A.M.H. Gerards, associate editor.
- *Mathematics of Operations Research*: A. Schrijver, associate editor.
- *North-Holland Mathematical Library*: A. Schrijver, advisory editor.
- *Science of Computer Programming*: K.R. Apt, editor.
- *SIAM Journal on Discrete Mathematics*: A.M.H. Gerards, editor; A. Schrijver, editor.
- *SIAM Journal on Optimization*: M. Laurent, editor.
- *SIAM Monographs on Discrete Mathematics and Applications*: A. Schrijver, member editorial board.
- *Statistica Neerlandica*: L. Stougie, associate editor.
- *Theory and Practice of Logic Programming*: K.R. Apt.
- *Wiley/Teubner Series in Computer Science*: K.R. Apt.

Visitors

- Leonid Libkin, Bell Labs, Murray Hills, NJ, USA, March 29–30.
- J.F. Geelen, University of Waterloo, Canada, April 8–22.
- I. Percival, Queen Mary and Westfield College, London, UK, June 8–9.
- Igor E. Shvetsov, Novosibirsk, Russia, September 28–October 8.
- Edsger W. Dijkstra, University of Texas, Austin, USA, October 10.

Software Developed

- Automated generation of constraint solvers for finite domain: E. Monfroy.
- Software for scheduling of trainee posts for medical students, for Vrije Universiteit, Amsterdam: A. Steenbeek.

Books

K.R. Apt, A.C. Kakas, E. Monfroy and F. Rossi (eds.) (2000). *New Trends in Constraints*, *LNAI* **1865**, Springer, x + 339 pages.

B. Fortz (2000). *Design of Survivable Networks with Bounded Rings*, Volume 2 of *Network Theory and Applications*, Kluwer Academic Publishers.

Papers in Journals and Proceedings

K.R. Apt (2000). A denotational semantics for first-order logic. *Proceedings of the Computational Logic Conference (CL2000)*, *LNAI* **1861**, Springer, 53–69.

K.R. Apt, A. Schaerf (2000). Programming in Alma-0, or imperative and declarative programming reconciled. D. M. Gabbay, M. de Rijke (eds.). *Frontiers of Combining Systems* **2**, Research Studies Press/Wiley, 1–16.

K.R. Apt (2000). Some remarks on Boolean constraint propagation. *New Trends in Constraints*, *LNAI* **1865**, Springer, 91–107.

F. Arbab, E. Monfroy (2000). Distributed splitting of constraint satisfaction problems. A. Porto, G.-C. Roman (eds.). *Proceedings of 4th International Conference, COORDINATION 2000*, Limassol, Cyprus, *LNCS* **1906**, Springer, 115–132.

C. Areces, R. Gennari, J. Heguiabehere, M. de Rijke (2000). Tree-based heuristics in modal theorem proving. *Proceedings of the 14th European Conference on Artificial Intelligence (ECAI 2000)*, IOS Press, 199–203.

Y. Bartal, S. Leonardi, A. Marchetti Spaccamela, J. Sgall, L. Stougie (2000). Multiprocessor scheduling with rejection. *SIAM Journal on Discrete Mathematics* **13**, 64–78.

G. Barthe, F. van Raamsdonk (2000). Constructor subtyping in the Calculus of Inductive Constructions. *Proceedings of FOSSACS 2000, LNCS* **1784**, Springer, 17–34.

S. Bistarelli, R. Gennari, Y. Georget, F. Rossi (2000). Constraint propagation for soft constraint satisfaction problems: generalization and termination conditions. *Proceedings of the 6th International Conference on Principles and Practice of Constraint Programming, LNCS*, Springer, 83–97.

A. Bossi, S. Etalle, S. Rossi (2000). Semantics of input-consuming programs. J. Lloyd, V. Dahl, U. Furbach, M. Kerber, K.-K. Lau, C. Palamidessi, L.M. Pereira, Y. Sagiv, P.J. Stuckey (eds.). *Proceedings First International Conference on Computational Logic (CL2000), LNAI* **1861**, Springer, 194–208. An abstract of this work appeared also in the proceedings of the Twelfth Belgium-Netherlands Artificial Intelligence Conference (BNAIC 2000).

M. Conforti, A.M.H. Gerards, A. Kapoor (2000). A theorem of Truemper. *Combinatorica* **20**, 15–26.

B. Fortz, M. Labbé, F. Maffioli (2000). Solving the two-connected network with bounded meshes problem. *Operations Research* **48**, 866–877.

B. Fortz, M. Thorup (2000). Internet traffic engineering by optimizing OSPF weights. *Proceedings 19th IEEE Conference on Computer Communications (INFOCOM)*, 519–528.

R. Gennari (2000). Arc consistency via subsumed functions. *Proceedings of Computational Logic 2000 (CL2000), LNAI* **1861**, Springer, 358–372.

J. Geelen, A.M.H. Gerards, A. Kapoor (2000). The excluded minors for GF(4)–representable matroids. *Journal of Combinatorial Theory, Series B* **79**, 247–299.

L. Granvilliers, E. Monfroy (2000). Declarative modelling of constraint propagation strategies. *Proceedings of the First Biennial International Conference on Advances in Information Systems, LNAI* **1909**, Springer, 201–215.

L. Granvilliers, E. Monfroy (2000). Modèlisation déclarative de stratégies de propagation de contraintes. *Actes des 9ièmes Journées Francophones de Programmation en Logique et par Contraintes*, 2000, Marseille, France, Hermès, 205–219.

J. Keijsper, R. Pendavingh, A. Schrijver (2000). Adjacency, inseparability, and base orderability in matroids. *European Journal of Combinatorics* **21**, 487–502.

A. Kapoor, R. Rizzi (2000). Edge-coloring bipartite graphs. *Journal of Algorithms* **34**, 390–396.

J. Koolen, M. Laurent, A. Schrijver (2000). Equilateral dimension of the rectilinear space. *Designs, Codes and Cryptography* **21**, 149–164.

A. Kotlov (2000). Bulky subgraphs of the hypercube. *European Journal on Combinatorics* **21**, 503–507.

A. Kotlov (2000). Spectral characterization of tree-width-two graphs. *Combinatorica* **20**, 147–152.

E. Monfroy (2000). Control-driven constraint propagation. *Journal of Applied Artificial Intelligence* **15** (Special Issue: Coordination Models and Languages in AI), 79–103.

E. Monfroy (2000). A coordination-based chaotic iteration algorithm for constraint propagation. *Proceedings of the 2000 ACM Symposium on Applied Computing (SAC'2000)*, 2000, Villa Olmo, Como, Italy, ACM Press, 262–270.

E. Monfroy, F. van Teeseling (2000). Fixing, completing and mapping information using constraints. *Proceedings of the Second International Conference and Exhibition on The Practical Application of Constraint Technology and Logic Programming (PACLP'2000)*, 2000, Manchester, UK, The Practical Application Company Ltd, 271–290.

E. Monfroy (2000). The constraint solver collaboration language of BALI. D.M. Gabbay, M. de Rijke (eds.). *Frontiers of Combining Systems 2, Studies in Logic and Computation* **7**, Research Studies Press/Wiley, 211–230.

C. Ringeissen, E. Monfroy (2000). Generating propagation rules for finite domains: a mixed approach. K.R. Apt, A.C. Kakas, E. Monfroy, F. Rossi (eds.). *New Trends in Constraints, LNAI* **1865**, Springer, 150–172.

R. Rizzi (2000). A short proof of Kőnig's matching theorem. *Journal of Graph Theory* **33**, 138–139.

R. Rizzi (2000). On minimizing symmetric set functions. *Combinatorica* **20**, 445–450.

R. Rizzi (2000). A note on range-restricted circuit covers. *Graphs and Combinatorics* **16**, 355–358.

A. Schrijver (2000). Total dual integrality of matching forest constraints. *Combinatorica* **20** (5), 575–588.

A. Schrijver (2000). A combinatorial algorithm minimizing submodular functions in strongly polynomial time. *Journal of Combinatorial Theory, Series* **B 80**, 346–355.

J.-G. Smaus, F. Fages, P. Deransart (2000). Using modes to ensure subject reduction for typed logic programs with subtyping. S. Kapoor, S. Prasad (eds.). *Proceedings of the 20th Conference on the Foundations of Software Technology and Theoretical Computer Science*, *LNCS*, Springer, 214–226.

Other Publications

K.R. Apt (2000). Editorial. *ACM Transactions on Computational Logic* **1** (1), 1–2.

B. Fortz, M. Thorup (2000). *Increasing Internet Capacity Using Local Search.* Technical Report IS-MG 2000/21, Université Libre de Bruxelles.

J.F. Geelen, A.M.H. Gerards, G. Whittle (2000). *Branch Width and Well-Quasi-Ordering in Matroids and Graphs.* Research Report 00-14, School of Mathematical and Computing Sciences, Victoria University, Wellington, New Zealand.

M. Laurent (2000). *Tighter Linear and Semidefinite Relaxations for Max-Cut Based on the Lovász-Schrijver Lift-and-Project Technique* (preprint).

F. van Raamsdonk (2000). *Higher-Order Rewriting* (preprint).

J.-G. Smaus, P. Deransart (2000). *Well-typed Programs Are Not Wrong.* Technical report DSEE-TR-2000-6 of the University of Southampton.

L. Stougie, A.P.A. Vestjens (2000). *Randomized Algorithms for On-Line Scheduling Problems: How Low Can't You Go?.* COSOR-Memorandum, Eindhoven University of Technology.

Traffic and Communication – Performance and Control – PNA2

Prof. dr. ir. J.W. Cohen passed away on November 12, 2000, at the age of 77. As an advisor of CWI (1/1/82–31/12/98), he has played an important role in the development of the research group BS2 and, later, research theme PNA2. The Annual Report 2000 contains a brief obituary.

Staff

- Prof. dr. ir. J.H. van Schuppen (program leader and senior researcher; part time 0.6; at VUA part time 0.2; at TUE part time 0.2)
- Dr. J. van den Berg (0.1; 0.9 at theme PNA3)
- Prof. dr. ir. S.C. Borst (part time 0.6; part time 0.2 at TUE and 0.2 with Lucent Technologies)
- Prof. dr. ir. O.J. Boxma (part time 0.2 from TUE)
- Dr. R.J. Boucherie (part time 0.4, funded by STW and affiliated with UvA till November, since then at UT)
- Dr. ir. L.C.G.J.M. Habets (part time 0.2 from TUE)
- Dr. B. Hanzon (advisor)
- Ms. D. Jibetean
- Drs. R. Litjens (KPN; part time 0.2 since 1 December)
- Prof. dr. M. Mandjes (since 1 October; part time 0.6; part time 0.2 at UT and 0.2 with Lucent Technologies)
- Drs. R. Núñez Queija (since 1 June part time 0.5 and part time 0.5 at TUE)
- Dr. M.A. Remiche (part time 0.4, 1 April - 1 August)
- Dr. S.L. Ricker (ERCIM Fellow; from 1 June till 31 December)
- W.R.W. Scheinhardt (1 October; part time 0.2; 0.8 at TUE)
- Drs. M.J.G. van Uitert (part time 0.8; part time 0.2 at KPN Research)

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, TCP/IP, LAN's, wireless); freeway traffic (ramp-metering, routing, network management); railway traffic; transportation of goods; manufacturing systems.

The research effort of 2000 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 2000 in control was directed to reachability of hybrid systems, to failure diagnosis of timed discrete-event systems, to hierarchical control of discrete-event systems, and to the stochastic realization problem for σ-algebra families.

PNA2.1 – Communication and computer networks

Project LT

S.C. Borst, O.J. Boxma and *P.R. Jelenković (Columbia)* extended the queueing analysis of long-tailed traffic flows under the Generalized Processor Sharing (GPS) discipline (CWI Report PNA-R0016). GPS-based scheduling algorithms, such as Weighted Fair Queueing, play a major role in achieving differentiated quality-of-service in integrated-services networks. They showed a sharp dichotomy in qualitative behaviour, depending on the relative values of the weight parameters. For certain weight combinations, an individual flow with long-tailed traffic characteristics is effectively served at a *constant* rate. The effective service rate may be interpreted as the maximum average rate for the flow to be stable, which in many situations simply equals the link rate reduced by the aggregate average rate of the other flows. This confirms that GPS-based scheduling algorithms provide a potential mechanism for extracting significant multiplexing gains, while isolating individual flows. For other weight combinations 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 weight parameters.

S.C. Borst and *A.P. Zwart (TUE)* analyzed the queueing behaviour of a mixture of light-tailed and heavy-tailed traffic flows. Earlier studies have found a 'reduced-load equivalence' in situations where the peak rate of the heavy-tailed flows plus the mean rate of the light-tailed flows is larger than the link rate. Here, the focus is on the opposite case where the peak rate of the heavy-tailed flows plus the mean rate of the light-tailed flows is *smaller* than the link rate. Under mild assumptions, it is proven that the workload distribution is asymptotically equivalent to that in a somewhat 'dual' reduced system, multiplied with a certain pre-factor. The reduced system now consists of only the *light*-tailed flows, served at the link rate reduced by the *peak* rate of the *heavy*-tailed flows. The pre-factor represents the probability that the heavy-tailed flows have sent at their peak rate for more than a certain amount of time, which may be interpreted as the 'time to overflow' for the light-tailed flows in the reduced system.

O.J. Boxma investigated (together with, respectively, J.W. Cohen, Q. Deng, and I. Kurkova) the influence of heavy-tailed input distributions on the asymptotic behaviour of waiting times and workloads in queueing systems. The role of the service discipline was also taken into account.

M. Mandjes and *N.K. Boots (VU)* analyzed queues fed by a large number of (possibly heavy-tailed) sources. Large-deviations estimates were used to develop fast simulation methods for estimating small overflow probabilities. Also, the impact of the traffic characteristics on experienced performance were assessed. The main conclusion is that this impact is strongly determined by the performance requirement imposed: if there is a strict delay requirement, then heavy tails hardly affect network performance, whereas under 'loose' performance constraints these characteristics affect loss and delay significantly.

A.P. Zwart (TUE), S.C. Borst and *M. Mandjes* analyzed a fluid queue fed by multiple On-Off flows with heavy-tailed (regularly varying) On-periods. Under fairly mild assumptions, it is proven that the workload distribution is asymptotically equivalent to that in a reduced system. The reduced system consists of a 'dominant' subset of the flows, with the original service rate subtracted by the mean rate of the other flows. The dominant set consists of a 'minimally-critical'

set of On-Off flows with regularly varying On-periods. It is described how a dominant set may be determined from a simple knapsack formulation. Combined with the reduced-load equivalence, the results for the reduced system provide a characterization of the tail of the workload distribution for a wide range of traffic scenarios.

Project QFN-IS
E. Altman (INRIA), K. Avrachenkov (INRIA), C. Barakat (INRIA) and *R. Núñez Queija* analyzed the throughput capacity of a TCP (Transmission Control Protocol) flow ('connection') subject to clustered random losses. TCP is the leading protocol for data transfer in the Internet. TCP users probe for available bandwidth by increasing their 'window size', i.e., the rate at which they transmit data, until a 'congestion signal' is received. In today's Internet these signals result from the loss of a transmitted data segment followed by a negative acknowledgment from the receiver of the TCP flow. A congestion signal could, however, very well be generated by the network itself, as is the case with the ABR (Available Bit Rate) service in ATM (Asynchronous Transfer Mode) networks. After having received a congestion signal, the data source reduces its window by a constant factor (equal to 2 in current TCP implementations). Viewing the arrivals of congestion signals as a stochastic point process gives rise to a stochastic model of TCP's window size evolution. Altman et al. (see CWI Report PNA-R0005, accepted for publication in the IEEE INFOCOM 2001 proceedings) present a detailed analysis of such a model allowing for clustering of congestion signals, a phenomenon observed in practice but not specifically accounted for in previous studies. The model is also relevant for the design of new protocols to support real-time applications in an Internet-like environment. Such applications do not allow for large variations in the available bandwidth, but rather need a (more or less) constant bandwidth. To set the transmission rate of real-time services fairly with respect to TCP(-like) traffic, the rate may be chosen equal to the long-run throughput of TCP connections as computed in the above discussed model. Moreover, by appropriately choosing the parameters of window increase (during congestion-free periods) and window reduction, one obtains a less aggressive transmission control mechanism which itself may be a candidate to support real-time traffic.

P. Nain (INRIA) and *R. Núñez Queija* considered the computation of exact performance measures under possibly heavy-tailed traffic phenomena (see also Project LT above). The model at hand is an M/M/1 queue in a random environment which alternates between two possible states, say 0 and 1. The sojourn times in the two 'environment' states are assumed to constitute two independent i.i.d. sequences of random variables having general distribution functions, one of them possibly having a heavy tail. When the random environment is in state i, the arrival rate of new work into the queue is λ_i and the service rate is μ_i. When $\mu_0 = \mu_1$, the model may be seen as a discretized version of widely studied fluid on-off models. When $\lambda_0 = \lambda_1$ it is the service rate that fluctuates, possibly due to bandwidth demand from other sources. Previous analyses of similar models focused on asymptotics of, for instance, the queue length distribution. Based on the solution of a boundary value problem, Nain and Núñez Queija derived closed-form expressions for the queue length distribution.

Project QFN-PS
M.J.G. van Uitert and *S.C. Borst* have continued their study of Generalized Processor Sharing (GPS) networks with heavy-tailed input (CWI Report PNA-R0007, accepted for publication in the IEEE INFOCOM 2001 proceedings). 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.

S.C. Borst, M. Mandjes and *M.J.G. van Uitert* have analyzed a queue fed by a mixture of light-tailed and heavy-tailed traffic. The two traffic flows are served in accordance with the GPS discipline. They derived the asymptotic workload behaviour of the light-tailed traffic flow under the assumption that its GPS weight is larger than its traffic intensity. The GPS mechanism ensures that the workload is bounded above by that in an isolated system with the light-tailed

flow served in isolation at a constant rate equal to its GPS weight. Using probabilistic bounds, they showed that the workload distribution is in fact asymptotically equivalent to that in the isolated system, multiplied with a certain pre-factor, which accounts for the interaction with the heavy-tailed flow. Specifically, the pre-factor represents the probability that the heavy-tailed flow is backlogged long enough for the light-tailed flow to reach overflow. The results provide crucial qualitative insight in the typical overflow scenario.

S.C. Borst, O.J. Boxma and *M.J.G. van Uitert* initiated the study of two coupled M/G/1 queues. The service request distribution at one queue is exponentially distributed and at the other queue is regularly varying. Whenever both queues are non-empty, they are served by their own servers at unit speed. However, if one of the servers has no work in its own queue, it assists the other working server, resulting in increased service speeds. This system is closely related to generalized processor sharing. They analyze the workload of both queues using transform techniques, finding qualitatively similar results as described under the previous item.

Project MOBILECOM

R.J. Boucherie. Research in the project MOBILECOM has focused on network models for cellular networks, dynamic channel allocation (borrowing) protocols for on-line capacity allocation, and data handling capacity in GSM-updates. For network models, (approximations of) call blocking probabilities were investigated both for systems in equilibrium, and for systems with time-varying parameters. The latter results were invoked for the prediction of blocking probabilities for systems in which subscribers move according to fluid models for road traffic, resulting in on-line capacity borrowing algorithms that take into account the shape of e.g. traffic jams for their decision for capacity re-allocation. In contrast with voice calls, for which blocking probabilities are the main performance characteristic, for data calls the throughput is of key-importance. For GSM-updates, such as GSM/HSCSD and GSM/GPRS, fair capacity sharing algorithms for capacity allocation to data services have been analyzed in detail.

Research not associated with any particular project within PNA2.1

S.C. Borst, A. Mandelbaum (Technion) and *M.I. Reiman (Bell Labs)* developed a framework for asymptotic optimization of a queueing system (CWI Report PNA-R0015). The motivation is the staffing problem of call centers with 100's of agents (or more). Such a call center is modeled as an M/M/N queue, where the number of agents N is large. They determined the asymptotically optimal staffing level N^* that trades off agents' costs with service quality: the higher the latter, the more expensive is the former. As an alternative to this optimization, they also developed a constraint satisfaction approach where one chooses the least N^* that adheres to a given constraint on waiting cost. Either way, the analysis gives rise to three regimes of operation: quality-driven, where the focus is on service quality; efficiency-driven, which emphasizes agents' costs; and a rationalized regime that balances, and in fact unifies, the other two. Numerical experiments reveal remarkable accuracy of the asymptotic approximations: over a wide range of parameters, from the very small to the extremely large, N^* is *exactly* optimal, or it is accurate to within a single agent.

M. Mandjes, D. Mitra (Bell Labs) and *W.R.W. Scheinhardt* considered feedback (Markov) fluid models. These were used to analyze bandwidth sharing schemes for the access network. Sources are always allowed to send at a guaranteed rate r. If the number of active clients is low, they can send at a higher rate (where the bandwidth is shared according to a processor sharing discipline), but their rate can never exceed the line speed p of their access link. The buffer content distribution follows from a system of (inhomogeneous) linear differential equations, together with a set of boundary conditions. Explicit approximations for the case of many clients are derived.

E. Altman (INRIA), T. Jimenez (INRIA), R. Núñez Queija and *U. Yechiali (Tel Aviv University)* studied the routing of jobs between two parallel queues with exponential servers when the length of only one of the two queues can be observed. Such a situation may arise in high-speed networks where information from a down-stream node may only become available after a considerable delay, thus making that information obsolete when a routing decision is made. The analysis concentrates on randomized threshold policies,

where new jobs that arrive when X others are in the observable queue are routed to that queue if $X < n$ and to the other queue if $X > n$. If $X = n$ a random choice is made. For a given randomized threshold policy the distribution of the joint queue lengths is derived. This enables the numerical computation of the parameters minimizing, for instance, the expected delay of individual jobs. The model is also studied in a game-theoretic setting. It is shown that in some cases no threshold policy is optimal for an individual job when all other customers follow a common threshold policy, i.e., a Nash equilibrium may not exist.

R. Núñez Queija studied the GI/GI/1 queue with the Last-Come First-Served Preemptive-Resume service discipline (CWI Report PNA-R0009, accepted for publication in *Probability in the Engineering and Informational Sciences)*. Under this discipline, a newly arriving customer is immediately taken into service. If upon arrival of the new customer there is a customer in service, then this service is interrupted, to be resumed at the moment that the new customer leaves the system. Intuitive explanations are given for the geometric nature of the stationary queue length distribution and the mutual independence of the residual service requirements of the customers in the queue, both considered at arbitrary time points. These distributions were previously established in the literature by either first considering the system at arrival instants or using balance equations. However, using direct arguments relying on renewal theory, provides further understanding of the above mentioned properties of the stationary distributions.

PNA2.2 – Traffic networks

Project CONTROL
L.C.G.J.M. Habets and *J.H. van Schuppen.* A reachability problem was solved for an affine dynamic system on a simplex and on a general polytope. The problem is part of a project on control of hybrid systems. A paper was submitted for presentation at a workshop and has since then been accepted for publication. Another paper has been submitted to a journal. Lectures on this research were presented at two meetings of the EU-ESPRIT-LTR Project Verification of Hybrid Systems (VHS). A lecture on this has also been presented at SZTAKI. The research is financially supported by the EU ESPRIT LTR project Verification of Hybrid Systems (VHS).

J.H. van Schuppen. With S.L. Ricker a model was formulated for a decentralized timed discrete-event system. For a failure diagnosis problem a factorization problem for the diagnoser was treated. Two papers have been submitted for presentation at conferences.

With A. Al-Falou (University of Groningen) algorithms have been formulated for the decomposition of a discrete-event system into a hierarchical discrete-event system. A publication is in preparation.

PNA2.3 – Control and system theory

Project RESI
J.H. van Schuppen. A stochastic realization problem for a σ-algebra family was solved. A lecture was presented on this research at the International Symposium MTNS2000 in Perpignan, France and at a university in Budapest.

With L. Gerencser (SZTAKI) problems for stochastic realization and system identification for finite stochastic systems were discussed. An approximation problem has been formulated.

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. Optimization problems appear frequently in areas like system identification and model order reduction. They are particular in the sense that they often involve multivariable polynomial or rational functions and finding the global optimum is crucial. For that purpose, the problem of minimizing a polynomial multivariable function was considered and an algorithm was designed. The algorithm is guaranteed to find the global minimum and together with it (at least) one point where the minimum is attained. All points of minimum are found if there is a finite number of them.

Investigation was started on the problem of global identification and an algorithm was proposed.

PhD Thesis

R. NÚÑEZ QUEIJA. *Processor-Sharing Models for Integrated-Services Networks.* It was defended

on January 20 at the TUE. Thesis advisors: O.J. Boxma and S.C. Borst.

Knowledge Transfer

- NGB Call Center Seminar, Jaarbeurs, Utrecht, May 23. S.C. Borst (invited presentation).
- Philips Research Labs, Eindhoven, June 14. R. Núñez Queija (invited presentation).
- Philips Informatica Colloquium, Philips Research Labs, Eindhoven, November 15. S.C. Borst (invited presentation).
- KPN Research, Leidschendam, October 31. M.J.G. van Uitert (invited presentation).

Organization of Conferences, Workshops, Courses, etc.

- Twenty-Fifth Conference on the Mathematics of Operations Research (Lunteren, January 11–14): S.C. Borst, A.M.H. Gerards.
- EURANDOM workshop on 'Stochastic Geometry and Teletraffic'. (Eindhoven, April 25–26): O.J. Boxma.
- Queueing Colloquium (CWI, June 7): S.C. Borst.
- Symposium Stochastic Operations Research – Now and Then (Eindhoven, June 23, in honor of Jaap Wessels): O.J. Boxma, J. van der Wal.
- Queueing Colloquium (CWI, November 29): S.C. Borst.
- EURANDOM workshop on 'Fluid Queues' (Eindhoven, September 25–27): O.J. Boxma.
- Meeting of Project VHS, CWI, Amsterdam, February 23–25: J.H. van Schuppen.

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

- Twenty-Fifth Conference on the Mathematics of Operations Research, Lunteren, January: R.J. Boucherie, S.C. Borst, O.J. Boxma, R. Núñez Queija, M.J.G. van Uitert (lecture).
- Working visit to CMG Public Sector, The Hague, January 21: J.H. van Schuppen.
- Working visit to IRISA, Rennes, France, January 24–28, J.H. van Schuppen. Lectures *Stochastic realization of a σ-algebra family* and *Control and system theory of hybrid systems.*
- Nationale Wiskunde Dagen, Noordwijkerhout, February 4: J.H. van Schuppen. Lecture (invited) *Wiskunde voor het regelen van autosnelwegverkeer.*
- Working visit to Verimag, Grenoble, France, February 7–11: J.H. van Schuppen. Lecture *Decentralized control of discrete-event systems.*
- Working visit INRIA (Sophia Antipolis, France, February 8 – June 2): R. Núñez Queija.
- Seminar (Delft University, February 9): S.C. Borst (lecture).
- Meeting of Project VHS, CWI, February 23–25: L.C.G.J.M. Habets, J.H. van Schuppen.
- Benelux Meeting on Systems and Control, Mierlo, March 1–3: L.C.G.J.M. Habets, B. Hanzon, D. Jibetean, J.H. van Schuppen. Lecture L.C.G.J.M. Habets *Behavioural controllability of time-delay systems with incommensurable delays.*
- Third international workshop on retrial queues, March 13–15, Tinbergen Instituut, Amsterdam. Lecture R.J. Boucherie: *Mobile communications networks with redialing customers.*
- Working visit Technion (Haifa, Israel, March 24–26): S.C. Borst.
- Working visit Hebrew University (Jerusalem, Israel, March 27): O.J. Boxma.
- Working visit University of Haifa (Haifa, Israel, April 2–5): O.J. Boxma (lecture).
- IEEE INFOCOM 2000 Conference (Tel-Aviv, Israel, March 28–30): S.C. Borst (lecture), O.J. Boxma (lecture), M.J.G. van Uitert.
- Workshop on 'Advanced Stochastic Modeling in Telecommunications' (Dagstuhl, Germany, April 10–14): S.C. Borst (lecture).
- Working visit to University of Amsterdam, 12 April: J.H. van Schuppen. Lecture (invited) *System theory and system identification.*
- Participation in the Workshop Stochastic Geometry and Teletraffic, EURANDOM, April 25–26: S.C. Borst, R.J. Boucherie, O.J. Boxma, M.A. Remiche, J.H. van Schuppen (only April 25), M.J.G. van Uitert.
- Participation in the Workshop Hybrid Control and Automotive Applications, Lund Institute of Technology, Lund, Sweden, May 5–6: J.H. van Schuppen. Lecture (invited) *Control of piecewise-linear hybrid systems.*
- Modelling mobility in cellular mobile networks, CWI Scientific Meeting, May 26: R.J. Boucherie.
- Participation in the Colloquium Dynamic Traffic Management organized by the research school TRAIL, Delft University of Technology, Delft, June 5: J.H. van Schuppen.
- Participation in the HPOPT 2000, Rotterdam, June, 7–9: B. Hanzon, D. Jibetean.

- Participation in the day 'Concurreren met ICT kennis', The Hague, June 7: J.H. van Schuppen.
- Participation in a VHS meeting, Centro Stephano Franscini, Monte Verita, Switzerland, June 8–10: L.C.G.J.M. Habets and J.H. van Schuppen. Lecture by L.C.G.J.M. Habets, *Control of piecewise-linear hybrid systems.* Lecture by J.H. van Schuppen *Modeling and control of a juice processing plant.*
- Stochastic network models for mobile communications systems, Colloquium Stochastiek, UvA, June 19: R.J. Boucherie.
- Participation in the International Symposium MTNS 2000, Perpignan, France, June 19–23. B. Hanzon, D. Jibetean, and J.H. van Schuppen. Lecture by J.H. van Schuppen *Stochastic realization of σ-algebras.* J.H. van Schuppen was chairman of a session and participated in the meeting of the Steering Committee of MTNS.
- Working visit to INRIA, Sophia Antipolis, France, June 26–27: D. Jibetean, B. Hanzon.
- Queueing Colloquium (CWI, June 7): S.C. Borst, R.J. Boucherie, O.J. Boxma, J.W. Cohen, R. Núñez Queija, M.A. Remiche (lecture), M.J.G. van Uitert.
- Conference and workshop on Stochastic Networks (University of Wisconsin, Madison WI, USA, June 19–30): R. Núñez Queija (lecture).
- Symposium Stochastic Operations Research – Now and Then (Eindhoven, June 23, in honor of Jaap Wessels): S.C. Borst, O.J. Boxma.
- Arrival first networks of queues with product form solution, QNETs 2000: Fourth International Workshop on Queueing Networks with Finite Capacity, Craiglands Hotel, Ilkley, West Yorkshire, UK, July 20–21: R.J. Boucherie.
- Working visit Bell Laboratories (Murray Hill NJ, USA, July 31–August 11): M.J.G. van Uitert.
- Working visit to SZTAKI, Budapest, Hungary August 14–18: J.H. van Schuppen. Lecture at SZTAKI on 16 August *Decentralized control of discrete-event systems.* Lecture at the Eötvös Lorand University, on August 17 *Stochastic realization of a σ-algebra family.*
- Participation in the Workshop on Discrete Event Systems 2000 (WODES2000), University of Gent, Gent, Belgium, August 21–23: L. Ricker, J.H. van Schuppen. J.H. van Schuppen was chairman of the panel discussion and chairman of a session.
- Workshop Applied Probability (Novosibirsk, August 21–25): O.J. Boxma (lecture).
- Working visit INRIA (Sophia Antipolis, France, August 21 – September 1): R. Núñez Queija.
- Participation in the Workshop Systems with time-domain constraints, Eindhoven University of Technology, Eindhoven, The Netherlands, August 30–September 1: L.C.G.J.M. Habets and J.H. van Schuppen. The latter was chairman of a session.
- Seminar (Delft University, September 13): R. Núñez Queija (lecture).
- EURANDOM workshop on 'Fluid Queues' (Eindhoven, September 25–27): S.C. Borst, R.J. Boucherie, O.J. Boxma, R. Núñez Queija (lecture), M.J.G. van Uitert (lecture).
- Participation in the ERNSI Workshop System Identification, Vadstena, Sweden, September 25–27: B. Hanzon, D. Jibetean, J.H. van Schuppen. Lecture B. Hanzon *Computer algebra for linear systems.* Van Schuppen was chairman of a session.
- Mid-Term Review of EU.
  TMR Project System Identification, Vadstena, Sweden, September 27. J.H. van Schuppen (Project coordinator), lecture with overview of project.
- Working visit to Department of Electrical Engineering, University of Linköping, Linköping, Sweden, September 28. Discussions with T. Glad and L. Ljung. D. Jibetean, J.H. van Schuppen.
- Participation in the CWI-in-Bedrijf-Dag, CWI, October 6: J.H. van Schuppen. Lecture: *Regelen met computers (Embedded systems).*
- Participation in the Open-Dag, CWI, October 8: J.H. van Schuppen.
- Participation in the Analysis Conference in Honor of Ciprian Foias, Vrije Universiteit, Amsterdam, October 19: J.H. van Schuppen
- Working visit to EURANDOM, Eindhoven, October 20: D. Jibetean, B. Hanzon.
- Participation in the Academy Colloquium, Amsterdam, November 1–3: B. Hanzon, D. Jibetean. Lecture by Hanzon, co-author D. Jibetean *Global minimum of a polynomial using a matrix method.*
- Seminar (EURANDOM, Eindhoven, November 9): R. Núñez Queija (lecture).
- Participation in the CWI Colloquium 'Crossroads of Mathematics, Informatics, and Life Sciences', CWI, November 10: J.H. van Schuppen.

- Participation in a meeting of project Verification of Hybrid Systems (VHS) Berg en Dal, November 27–28: L.C.G.J.M. Habets, S.L. Ricker, J.H. van Schuppen. Lecture by Habets: *Control of piecewise-linear hybrid systems on simplices and polytopes.* Lecture by S.L. Ricker: *Incorporating Knowledge into the Analysis of Decentralized Discrete-Event Systems.*
- Queueing Colloquium (CWI, November 29): S.C. Borst, R.J. Boucherie, O.J. Boxma, M. Mandjes, R. Núñez Queija, W.R.W. Scheinhardt, M.J.G. van Uitert.
- Working visit to SZTAKI, Budapest, Hungary, December 8–12: J.H. van Schuppen. Lecture *Control of piecewise-linear systems on simplices and polytopes.*
- Participation in 39th IEEE Conference on Decision and Control (CDC2K), Sydney, Australia, December 12–15: S.L. Ricker (Co-Chair of one session and two lectures).
- Working visit Microsoft Labs, and Workshop on Stochastic Networks (Cambridge, December 14–15): M. Mandjes.

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, Winter course. System and Control Theory of Nonlinear Systems, Utrecht Spring course, Computer Algebra in System Theory, Utrecht, Spring course.
- M.J.G. van Uitert, Courses LNMB *Landelijk Netwerk Mathematische Besliskunde*, Combinatorial Optimization-2, Stochastic Optimization-2 and Convex Optimization, Utrecht.

Memberships of Committees and Other Professional Activities

S.C. Borst:
- Professor of Stochastic Operations Research (part-time), Eindhoven University of Technology.
- Member of Technical Staff (part-time), Bell Laboratories, Lucent Technologies, Murray Hill, USA.
- Associate editor of the journal *Operations Research Letters.*
- Associate editor of the journal *Performance Evaluation.*
- Member of IFIP Working Group 7.3.
- Second thesis advisor of R. Núñez Queija.
- Member of the PhD committee of J.W.C.H. Visschers (TUE).
- Member of the program committee of the SPIE 2000 conference (Boston, November).
- Member of the program committee of the SIGMETRICS 2000 conference (Santa Clara, June).
- Member of the program committee of the Performance 2001 / SIGMETRICS 2001 conference (Boston, June 2001).

O.J. Boxma:
- Professor of Stochastic Operations Research, Eindhoven University of Technology.
- Area editor of the journal *Operations Research Letters.*
- Associate editor of the journals *Markov Processes and Related Fields; Mathematics of Operations Research; Queueing Systems.*
- Member of IFIP Working Group 7.3 (also of its membership election committee).
- Member of the International Advisory Committee of the International Teletraffic congresses.
- Project leader SWON project 'Regular variation in broadband ISDN'.
- One of the leaders of the SWON groot project 'Stochastic networks'.
- Coordinator 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 Scientific (daily) board of research school Stieltjes.
- Member of the Management Team of research school BETA.
- Member of the daily board of LNMB.
- Thesis advisor of R. Núñez Queija.
- Member of the PhD committees of M.J.E. Smeets (TUE) and J.W.C.H. Visschers (TUE).
- Member of the NWO-committee 'Networks'.
- Member of the NWO Gebiedsbestuur Exacte Wetenschappen.

B. Hanzon:
- Associate professor Vrije Universiteit.

R. Núñez Queija:
- Assistant professor of Stochastic Operations Research (parttime, starting June 1, 2000), Eindhoven University of Technology
- Member of the research schools Stieltjes and BETA.

M. Mandjes:

- Professor of Stochastic Operations Research (part-time, starting October 1, 2000), University of Twente.
- Member of Technical Staff (parttime), Bell Laboratories, Lucent Technologies, Murray Hill, USA.
- Member of the PhD committee of P.T. de Boer (UT).

J.H. van Schuppen:

- Editor-in-Chief of the journal *Mathematics of Control, Signals, and Systems* since 1994.
- Department Editor of the journal *Discrete Event Dynamic Systems* from 1990 till 1 September 2000.
- 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:
  - Ir. J.J.H. Fey, Ontwerpersopleiding, 7 November, Eindhoven University of Technology.
  - Dr. ir. P.L. De Leenheer, 13 November and 22 December, University of Gent, Belgium.
  - Dr. ir. G. Stremersch, 13 November and 21 December, University of Gent, Belgium.
- Project leader NWO-Mathematics/Informatics project COCON. J.H. van Schuppen.
- 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, from March 1997 till April 2000.
- Member of IFAC Technical Committee on Stochastic Systems since 1994.
- Member of Scientific Committee of the Workshop on Discrete Event Systems 2000 (WODES2000).
- Member of Program Committee of the Workshop Hybrid Systems – Computation and Control 2001.
- Member of the Dutch Institute of Systems and Control (DISC), since September 1995.
- Member of the Thomas Stieltjes Institute for Mathematics, since October 2000.

M.J.G. van Uitert:

- Member of Technical Staff (parttime) KPN Research, Leidschendam.

Visitors

- L. Flatto (Bell Laboratories, Murray Hill, USA), March 9–22 (two lectures).
- A. Rantzer (Lund Institute of Technology, Lund, Sweden), April 3–4. Lecture *Analysis and control of hybrid systems.*
- P.L. De Leenheer (Universiteit Gent, Gent, Belgium), May 29–30. Lecture *Homogeneous cooperative systems.*
- L. Gerencsér (SZTAKI, Budapest, Hungary), July 3–14 . Lecture *A randomization procedure for noise-free optimization.*
- K. Sigman (Columbia University, New York, USA), October 20.

Papers in Journals and Proceedings

Borst, S.C., Boxma, O.J., Jelenković, P.R. (2000). Asymptotic behaviour of Generalized Processor Sharing with long-tailed traffic sources. *Proceedings INFOCOM 2000*, 912–921.

Borst, S.C., Boxma, O.J., Jelenković, P.R. (2000). Coupled processors with regularly varying service times. *Proceedings INFOCOM 2000*, 157–164.

Borst, S.C., Coffman, E.G., Gilbert, E.N., Whiting, P.A., Winkler, P.M. (2000). Time slot allocation in wireless TDMA. E. Gelenbe (ed.). *System Performance Evaluation, Methodologies, and Applications*, (CRC Press, Boca Raton), 203–213.

Borst, S.C., Whiting, P.A. (2000). Achievable performance of dynamic channel assignment schemes under varying re-use constraints. *IEEE Transactions on Vehicular Technology* **49**, 1248–1264.

Boucherie, R.J., Litjens, R. (2000). Evolutie van mobiele cellulaire telecommunicatie netwerken. *Proceedings Symposium Wiskunde Toegepast*, Universiteit Maastricht, April 27.

Boucherie, R.J., van Dijk, N.M. (2000). On a queueing network model for cellular mobile communications networks. *Operations Research* **48**, 38–49.

BOUCHERIE, R.J., VERWIJMEREN, S., MANDJES, M. (2000). Asymptotic evaluation of blocking probabilities in a hierarchical cellular mobile network. *Probability in the Engineering and Informational Sciences* **14**, 81–99.

BOUCHERIE, R.J., LITJENS, R. (2000). Radio resource sharing in a GSM/GPRS network. P.J. EMSTAD (ed.). *Proceedings ITC Specialists Seminar on Mobile Systems and Mobility*, March 22–24, Lillehammer, Norway, 261–274.

BOXMA, O.J., DENG, Q. (2000). Asymptotic behaviour of the tandem queueing system with identical service times at both queues. *Mathematical Methods in Operations Research* **52**, 307–323.

BOXMA, O.J., KURKOVA, I. (2000). The $M/M/1$ queue in a heavy-tailed random environment. *Statistica Neerlandica* **54**, 221–236.

BOXMA, O.J., COHEN, J.W. (2000). The single server queue: Heavy tails and heavy traffic. K. PARK and W. WILLINGER (eds.). *Self-similar Network Traffic and Performance Evaluation*, (Wiley, New York), 143–169.

FABRE, E., BENVENISTE, A., JARD, C., SMITH, M., RICKER, L. (2000). Distributed state reconstruction for discrete-event systems. *Proceedings of 39th IEEE Conference on Decision and Control*, Sydney, Australia.

HANZON, B., PEETERS, R.L.M. (2000). Balanced parametrizations of stable SISO All-Pass systems in discrete time. *Math. Control, Signals, Systems* **13**, 240-276.

NÚÑEZ QUEIJA, R. (2000). Sojourn times in a processor-sharing queue with service interruptions. *Queueing Systems* **34**, 351–386.

OVERKAMP, A., SCHUPPEN, J.H. VAN (2000). Maximal solutions in decentralized supervisory control. *SIAM J. Control and Optim.* **39**, 492–511.

RICKER, S.L., RUDIE, K. (2000). Know means no: incorporating knowledge into discrete-event control systems. *IEEE Transactions on Automatic Control* **45**, 1656–1668.

RICKER, S.L., RUDIE, K. (2000). Distributed knowledge in communicating decentralized discrete-event systems. *Proceedings of 39th IEEE Conference on Decision and Control*, Sydney, Australia.

RICKER, S.L., FABRE, E. (2000). On the construction of modular observers and diagnosers for discrete-event systems. *Proceedings of 39th IEEE Conference on Decision and Control*, Sydney, Australia.

SCHUPPEN, J.H. VAN (2000). Stochastic realization of σ-algebras. *Proceedings of the International Symposium MTNS2000*, Perpignan, France, June 19–23, on CD-ROM only.

J.H. VAN SCHUPPEN (2000). Control for a class of hybrid systems, M.K. INAN and R.P. KURSHAN (eds.), *Verification of digital and hybrid systems*, Springer, Berlin, 332–354.

WAAL, P.R. DE, SCHUPPEN, J.H. VAN (2000). A class of team problems with discrete action spaces: Optimality conditions based on multimodularity. *SIAM J. Control and Optim.* **38**, 875–892.

ZWART, A.P., BOXMA, O.J. (2000). Sojourn-time asymptotics in the M/G/1 processor sharing queue. *Queueing Systems* **35**, 141–166.

CWI Reports

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

PNA-R0002	PNA-R0004	PNA-R0005
PNA-R0007	PNA-R0009	PNA-R0010
PNA-R0015	PNA-R0016	PNA-R0017

Other Publications

ADAN, I.J.B.F., BOXMA, O.J., VAN DER WAL, J. (2000). Guest editorial. Special issue on Stochastic Operations Research, in honor of Jaap Wessels. *Statistica Neerlandica* **54**, 113–115.

ADAN, I.J.B.F., BOXMA, O.J., RESING, J.A.C. (2000). *Queueing Models with Multiple Waiting Lines.* SPOR Report 2000-03, Eindhoven University of Technology. To appear in: *Queueing Systems.*

BORST, S.C., MANDELBAUM, A., REIMAN, M.I. (2000). *Dimensioning Large Call Centers.* Technical Memorandum 10009626-000925-35TM, Bell Labs, Lucent Technologies. Submitted for publication.

BORST, S.C., WHITING, P.A. (2000). *Dynamic Rate Control Algorithms for HDR throughput Optimization.* Technical Memorandum 10009626-000828-21TM, Bell Labs, Lucent Technologies. Shortened version to appear in: *Proc. INFOCOM 2001.*

BORST, S.C., ZWART, A.P. (2000). *A Reduced-Peak Equivalence for Queues with a Mixture of Light-Tailed and Heavy-Tailed Input Flows.* SPOR Report 2000-04, Eindhoven Uni-

versity of Technology. Submitted for publication.

BOUCHERIE, R.J., LITJENS, R. (2000). *Elastic Calls in an Integrated Services Network: the Heavier the Tail the Better the Quality-of-Service.* Report AE 1/00, Institute of Actuarial Sciences & Econometrics, University of Amsterdam.

BOUCHERIE, R.J., ULE, A. *On the Distribution of Customers in a Wireless Network Driven by Fluid Traffic.* Tinbergen Institute Discussion Paper, TI 2000-052/4.

BOXMA, O.J. (2000). *Heavy Tails and Queues. Biennial Report 1998 & 1999*, Thomas Stieltjes Institute for Mathematics, 'Research Highlights'.

BOXMA, O.J. (2000). *Files van files – WWW en de wondere wereld van de wachtrij* (in Dutch). Inaugural lecture, Eindhoven University of Technology, October 13, 2000.

BOXMA, O.J., KELLA, O., PERRY, D. (2000). *An Intermittent Fluid System with Exponential on-Times and Semi-Markov Input Rates.* EURANDOM Report 2000-023. To appear in: *Probability in the Engineering and Informational Sciences.*

BOXMA, O.J., PERRY, D., STADJE, W. (2000). *Clearing Models for $M/G/1$ Queues.* SPOR Report, Eindhoven University of Technology.

BOXMA, O.J., SCHLEGEL, S., YECHIALI, U. (2000). *A Note on an $M/G/1$ Queue with a Waiting Server, Timer and Vacations.* EURANDOM Report.

SCHUPPEN, J.H. VAN (2000). Verkeersstromen (in Dutch). *ITW Nieuws 9* (2000, nummer 3–4, maart), 4–10.

SCHUPPEN, J.H. VAN (2000). Control and system theory: Introductions. *ERCIM News* **40**, January, 16.

SCHUPPEN, J.H. VAN (2000). Dynamic route control for motorway networks. *ERCIM News* **40**, January, 18–20.

SCHUPPEN, J.H. VAN (2000). Control of discrete-event systems. *ERCIM News* **40**, 26–27.

SCHUPPEN, J.H. VAN (2000). Subspace identification algorithms and stochastic realization. *ERCIM News* **40**, January, 33.

ZWART, A.P., BORST, S.C., MANDJES, M. (2000). *Exact Asymptotics for Fluid Queues Fed by Multiple Heavy-Tailed On-Off Flows.* SPOR Report 2000-14, Eindhoven University of Technology. Shortened version to appear in: *Proc. INFOCOM 2001.*

Stochastics – PNA3

Staff

- Dr. J. van den Berg, theme leader (0.9 fte)
- Dr. K.O. Dzhaparidze, senior researcher (0.8 fte)
- Dr. R. Helmers, senior researcher
- R. van der Horst, programmer (0.75 fte)
- Prof. dr. M.S. Keane, senior researcher (0.2 fte)
- Drs. B. Lemmens (VU), PhD student (NWO, 0.2 fte)
- A. Lukács, postdoctoral fellow (NWO, until September 1)
- I W. Mangku, PhD student (Indonesian cooperation)
- Dipl.-math. S.W.W. Rolles, PhD student (EURANDOM, 0.2 fte)
- Dr. P.J.C. Spreij (UvA), senior researcher (0.2 fte)
- B. Tarigan, PhD student (Indonesian Cooperation) (since September)
- Prof. dr. S.M. Verduyn Lunel (VU) advisor (0.2 fte)
- Drs. M.R. Vervoort, PhD student (NWO, 0.2 fte, until September)
- Drs. J.H. van Zanten, PhD student (NWO)

Scientific Report

Remark: Part of M.S. Keane's research activities in 2000 are listed under MAS3.

Highlights

Keane has given his inaugural lecture as foreign member of the Chilean Academy of Sciences. He also presented a Huygens Lecture at the French Academy of Sciences in Paris.

Keane has received an invitation to visit the Sackler Institute for Advanced Study in Tel Aviv as a Sackler Scholar.

The European Research Training Network DYNSTOCH has started September 1. In 2001 two young researchers will start at CWI in the framework of this project.

Probability – PNA 3.1

Van den Berg and *H. Kesten* (Cornell University) have improved their earlier joint results on coalescing random walks: for a large class of cases the 'correct' asymptotic particle density can now be proved for any dimension ≥ 3. The

improvement is based on a sharper upper bound for the variance of a weighted sum of particles. The proof of this bound involves a combination of many techniques; a paper is in preparation.

Van den Berg and *Meester* (Utrecht) have formulated several concrete interesting problems concerning certain epidemics and forest-fire models. We expect that these models have a very interesting form of self-organized critical behaviour. For the case where the underlying medium has a tree structure (in which case the proper interpretation is in terms of signal transmission in networks of neurons, rather than epidemics) interesting progress has been made, but much more work is needed.

Van den Berg and *B. Tóth* (Budapest) have completed a paper on a 1-dimensional process inspired by the above models. The main result is the construction of an infinite-volume dynamics with very delicate properties (roughly speaking, infinite strings of 'on'-nodes try to form all the time but are destroyed (turned into 'off'-nodes) immediately. We hope this paper gives more insight in certain problems posed by *D. Aldous* (Berkeley) in his recent paper on percolation models in which infinite clusters are 'frozen'. Discussions with A. Jarai (who was a postdoctoral visitor here for two months) have led to a better understanding of the above mentioned 'frozen-percolation' model.

Van den Berg and *Lukács* have started to write a paper on the BKR inequality ('disjoint occurrence' of events) and its interpretation in terms of negative dependence properties. *Lukács* has also studied Kasteleyn's problem concerning percolation on mirror symmetric graphs, and the type-problem of edge-reinforced random walks on grids.

Keane and *Rolles* have submitted a paper to Acta Hungarica in which they prove recurrence of Directed-edge-reinforced Random Walk on graphs which are essentially one-dimensional at infinity. The interest lies in the reformulation as a Random Walk in Random Environment and the subsequent identification of the corresponding Lyapunov exponents.

Rolles has completed two articles now and a third is in progress, concerning reinforced random walks. Her thesis defence will take place in 2002.

Statistics – PNA3.2

Helmers published a paper (with *A.J. van Es* (Amsterdam) and *M. Hušková* (Prague)) on bootstrapping elementary symmetric polynomials, and a paper on inference on rare errors in Biometrika.

Helmers and *Mangku* published a survey paper on statistical estimation of Poisson intensity functions in the Proceedings of a conference held in Yogyakarta (Indonesia).

Joint with *R.Zitikis* (Winnipeg) they almost completed a paper on kernel type estimation of a cyclic Poisson intensity function. The paper will be submitted for publication.

I W. Mangku completed his PhD research on statistical estimation of the intensity function of a cyclic Poisson process. The PhD defence will take place on January 22, 2001, at the University of Amsterdam. (*M.S. Keane* thesis advisor; *R. Helmers* co-advisor).

In September *B. Tarigan* started her PhD research on statistical methods for compound sums, with applications in insurance and accountancy.

Together with *R. van der Horst*, *Helmers* completed a final report for the Ministry of Transport and Public Works (RWS) on estimating the intensity of oil pollution in the Dutch part of the North Sea.

With support of the Limperg Institute Helmers and Van der Horst worked on an improvement of the well-known Stringer bound (in statistical auditing) by means of bootstrap calibration.

Keane has, in cooperation with *J.-L. Philoche*, completed the paper 'Maximun Likelihood Estimation in Principal Component Analysis with Noise Perturbation: a Gaussian Model' (submitted to Statistics Letters). This paper clarifies a claim of Muirhead concerning identification of the most significant principal values.

Stochastic Analysis – PNA3.3

The European Research Training Network 'Statistical Methods for Dynamical Stochastic Models' (DYNSTOCH) started September 1. The Dutch participant is CWI. The Dutch research team includes apart from *Dzhaparidze*, *Van Zanten* and *Spreij* also researchers from other universities. *Spreij* acts as the scientist in charge of this team. The network started its activities with a workshop in Padova (September 21–23). *Spreij* gave a lecture on joint work with *Dzhaparidze* and *Valkeila* (Helsinki). At this meeting also teams from Berlin, Copenhagen, Freiburg, Helsinki, Padova, London and Paris were present. The CWI team intends to participate in the next

workshop scheduled for June 2001 in Paris. In 2001 CWI will also welcome two researchers that are funded by this network.

K.O. Dzhaparidze, P.J.C. Spreij and *E. Valkeila* (Helsinki) have continued their joint research that resulted in the work titled 'Information Processes in Filtered Experiments', splitted in two parts that appeared as technical reports of the University of Helsinki. Yet another paper, 'On Exponential Families of Filtered Statistical Experiments', by the same authors is under preparation.

Spreij also continued his research in applications of Linear Algebra to Time Series Analysis with *A. Klein*. The paper 'On Stein's Equation, Vandermonde Matrices and Fisher's Information Matrix of Time Series Processes, Part I: The Autoregressive Moving Average Process' will appear in *Linear Algebra and its Applications*.

Research on Markov chains has been finished by the publication of the paper 'On the Markov Property of a Finite Hidden Markov Chain', which will appear in *Statistics and Probability Letters*.

Dzhaparidze concluded his research on Interpolation Problems with the acceptance of the paper 'On Interpolation Series Related to the Abel-Goncharov Problem' by *Indagationes Mathematicae*.

Within the framework of the general theory of statistical inference for stochastic processes, *K.O. Dzhaparidze* and *J.H. van Zanten* completed a report (CWI report PNA-9912) on Bernstein-type inequalities. The material has been revised and is accepted for publication in the *Journal Stochastic Processes and Applications*.
CWI report PNA-9909 has been accepted by the *Journal Statistical Inference for Stochastic Processes* under the title 'On the Uniform cCnvergence of the Empirical Density of an Ergodic Diffusion'. The paper 'A Note on Consistent Estimation of Multivariate Parameters in Ergodic Diffusion Models' has been accepted by the Scandinavian *Journal of Statistics*. Revised versions of the technical reports PNA-R0001, PNA-R0006, PNA-R0011 and PNA-R0013 have been submitted to various international journals in the field of mathematical statistics. The cited work of *J.H. van Zanten* is currently being transformed into a PhD thesis that will be finished in 2001.

Applications to finance
In collaboration with A.J. van Es (University of Amsterdam) research has been conducted on applications of nonparametric statistical methods to financial models. A paper with the working title 'Nonparametric Deconvolution for Stochastic Volatility Models' is in preparation.
K.O. Dzhaparidze published the book 'Introduction to Option Pricing in a Securities Market'
The survey paper 'Some Aspects of Modelling and Statistical Inference for Financial Models', by *K.O. Dzhaparidze, P.J.C. Spreij* and *J.H. van Zanten*, appeared in *Statistica Neerlandica*.
Other work in Mathematical Finance has been done by *Spreij*. A paper (in Dutch) 'Risicomanagement in Financiële Instellingen' (with F. Boshuizen of ING) will appear in *StatOR*. The work on application of Extreme Value Theory to problems in Finance by Spreij in collaboration with a group of econometricians has resulted in an article entitled 'An Analytic Approach to Credit Risk of Large Corporate Bond and Loan Portfolios' (with A. Lucas, P. Klaassen en S. Straetmans) that has been accepted by the *Journal of Banking and Finance* (2000).

Ergodic Theory and Dynamical Systems – PNA 3.4

Keane and *J. Serafin* (Wroclaw) have submitted a paper on generators to Comptes Rendus (Paris). This paper is a sequel to their study of generators which appeared in 1998, and contains an elementary proof of a deep theorem of Krieger which forms one of the motivations for symbolic dynamics. Long-term problems on which work by Keane is in progress are:

- Integer tilings by translation (number theory, with E.M. Coven (Middletown).
- Homomorphisms and isomorphisms of noncommutative Bernoulli schemes (ergodic theory, with T. Hamachi (Fukuoka).
- Consistent polymer measures (statistical physics, with R. van der Hofstad (Delft).

In addition, several projects in which Keane is involved as advisor for Philips Research Laboratories in Eindhoven, are in progress.

In September 2000, *M. Vervoort* successfully defended his doctoral dissertation under the direction of Keane and Van Lambalgen at the University of Amsterdam. This thesis provides solutions or partial solutions to a wide variety of problems; one of the most noteworthy results is

the recurrence of once reinforced random walk on the ladder for large values of reinforcement, unexpectedly using techniques from non-standard analysis.

Lemmens will defend his dissertation in 2001. The draft has been approved and sent to the PhD committee.

Van Dantzig 2000

David van Dantzig, September 23, 1900 – July 22, 1959, paved the way for mathematical statistics as an academic endeavour for mathematicians in The Nederlands. He was one of the four founders of the Mathematisch Centrum (the present CWI). Writing on the notion of mathematical modelling he showed new roads for the application of mathematics. In 2000 GMFW, the national working party on the History and Social Function of Mathematics, initiated the programme *Van Dantzig 2000*, on the occasion of the centennary of his birth. The programme was sponsored by NWO (the national science foundation), CWI and the University of Amsterdam (in particaular its mathematical institute, Korteweg - de Vries instituut, and its section on management and industrial statistics, IBIS). The work was in fact done at CWI, hosted by PNA3.

Results

Key event of the program was the conference *Uitbeelden in wiskunde* (expressing in mathematics) held at September 22, 2000, at the University of Amsterdams great hall. The well-attended event, 175 vistors registered, was very well recieved. Half of the visitors ordered in advance the three books published on the occasion, the biography, the conference proceedings and the Scientific Family Tree compiled by C. van Eeden. Next to the meeting of September 22 the program Van Dantzig 2000 offered a symposium at the Dutch Mathematical Congress and contributions to the National Mathematics Days, to the Annual Meeting on Statistics, and to a history of science meeting (GEWINA-symposium).

Spin-off results

- An important spin-off of the program Van Dantzig 2000 the opening of the David van Dantzig archive which will now be transfered to the National Archives (in its Haarlem establishment).
- Inspireerd by Van Dantzig 2000 the Nieuw Archief voor Wiskunde is publishing a series of articles on the rise of mathematical modelling in the twentieth century: a century of mathematics and the real world.
- Yet to come are a seminar, the CWI-Van Dantzig colloquium on mathematical modelling, and
- the publication of an inventory of the Van Dantzig archive

Conferences

- Talk at the Nationale Wiskundedagen, Noordwijk, 5 February 2000 *Het begrip wiskundig modelleren volgens Van Dantzig* (the notion of mathematical modelling according to Van Dantzig), Gerard Alberts.
- Talk presented at the Statistische Dag 2000, April 17, 2000, Utrecht *Statistici, hun verenigingen en hun geschiedenis (statisticians, their societies and their history)*, Gerard Alberts.
- GMFW-symposium at the 36-th Dutch Mathematical Congress, Maastricht, *De maatschappelijke functie van wiskundige modellen* (The social function of mathematical models), April 28, 2000.
- Conference Van Dantzig 2000: *Uitbeelden in Wiskunde*, September 22, 2000, Amsterdam.
- *Wetenschap en maakbaarheid*, GeWiNa-symposium, October 14, 2000: Gerard Alberts, *Wiskundigen, wederopbouw en rationalisatie (Mathematicians, postwar reconstruction and rationalization)*.

Announcements

- Folders or full-page announcements appeared in *Nieuw Archief voor Wiskunde*, *STAtOR*, *Gewina*, *Tijdschrift voor Geschiedenis*.
- Announcements appeared in *Folia*, *STAtOR*, *NAW*, *Delft Integraal*, *Spiegel Historiael*, *Amstelodamum*, *Akademie-nieuws (KNAW)*, *HG-nieuws*, *Historisch Nieuwsblad*, *nieuwsbrief Huizinga Instituut*.
- Posters were distributed among the mathematical community.

Articles

H.J. Smid (2000). David van Dantizg en de Leer der Vergelijkingen. *Euclides* **2000**-1, 64-67.

M. Keulemans (2000). David van Dantzig (1900–1959). *Folia* **54**–3, 9.

G. ALBERTS (2000). Het kroonjuweel van de bruikbare mathematica. *Folia* **54**–6, 16–17

G. ALBERTS (2000). Kansdroom. David van Dantzigs vroege schreden op stochastisch pad. *STAtOR* **1**–2, 4–11

G. ALBERTS (2000). Van Dantzig en de hedendaagse maatschappelijke functie van het wiskundig modelleren, Gerard Alberts – report symposium Van Dantzig 2000. *STAtOR***1**–3, 22–24

H. OUD, GERARD ALBERTS. Een statisticus moet ook wel eens geluk hebben. Interview met Jan Hemelrijk, *STAtOR* **1**–3

H. OUD, G. ALBERTS. Van de buitenwereld heb ik me nooit veel aangetrokken. Interview met Constance van Eeden. *STAtOR* (to appear).

G. ALBERTS (2000). Wiskundige tegen de stroom in. David van Dantzig (1900-1959) in Delft *Delft Integraal***16**–4, 26–29. - G. ALBERTS (2000). De opkomst van het wiskundig modelleren. *Nieuw Archief voor Wiskunde* - Vijfde Serie 5/1 nr.1, 59–67.

G. ALBERTS (2000). David van Dantzig, wiskundig omnivoor. *Nieuw Archief voor Wiskunde* - Vijfde Serie 5/1 nr. 3, 288–293.

A. VAN DEN BOGAARD (2000). Het CPB, wiskunde en praktijk in wording, *Nieuw Archief voor Wiskunde* - Vijfde Serie 5/1 nr.3, 294–300.

T. KOETSIER (2000). Vlak David niet uit – report symposium Van Dantzig 2000. *Nieuw Archief voor Wiskunde* - Vijfde Serie 5/1 nr. 4, 352.

H. MELISSEN (2000). Honderd jaar Van Dantzig. *ITW-nieuws* **10**-3, 17-21.

D. VAN DELFT (2000). Uit de ivoren toren. David van Dantzig was pionier op gebied van wiskundig modelleren. *NRC-Handelsblad 30-12-2000*, p. 45 (Wetenschap & Onderwijs)

Reports

SEN-N0001. See page 39 for the complete title.

Books

G. ALBERTS (2000). *Twee geesten van de wiskunde. Biografie van David van Dantzig. (The two spirits of mathematics. Biography of David van Dantzig).* CWI, Amsterdam.

G. ALBERTS EN HENDRIK BLAUWENDRAAT (eds) (2000). *Uitbeelden in wiskunde. Proceedings of the symposium Van Dantzig 2000.* CWI, Amsterdam.

C. VAN EEDEN (2000). *The Scientific Family Tree of David van Dantzig.* CWI, Amsterdam.

PhD Thesis

M.R. VERVOORT (2000). *Games, Walks and Grammars: Problems I've Worked On.* PhD defence on September 19 at the University of Amsterdam. Thesis advisor: M.S. Keane.

Knowledge Transfer

Advisory positions M.S. Keane

- Advisory positions at Philips Research Laboratories, Eindhoven (1 day/week), Hewlett-Packard Laboratory, Bristol (1 month/year) and EURANDOM, Eindhoven (1/2 day/week)
- Spring School Course in Ergodic Theory, Master Class MRI, Utrecht (8 lectures)

Van den Berg:

- Probability course (for 4th year undergraduate students) at the University of Amsterdam

Organization of Conferences, Workshops, Courses, etc.

J. van den Berg:

- Co-organizer (with R. Meester (Utrecht)) of a colloquium on Probability and Statistics in the Life Sciences, held at CWI on November 10
- Co-organizer (with O. Häggström (Gothenburg) of a workshop on Discrete Probability, to be held in June 2002 at Eurandom (Eindhoven)
- Co-organizer (with M. van Lieshout) of the Spatial Stochastics Seminar at CWI

M.S. Keane:

- Co-organizer Bijeenkomst Stochastici, Lunteren (with De Gunst and Gill)
- Scientific Committee, Torun Conference on Ergodic Theory.

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

- Workshop on Phase Transitions, Probability Theory and Computational Complexity, Cortona (Italy), June 19–23 (invited lecture by Van den Berg).
- Eurandom Probability Seminar (regular visits by Van den Berg).
- Mark Kac seminar (lecture by Van den Berg on December 1).
- Working visit to Technical University Budapest (Van den Berg, 1 week in September).
- Stochastics seminar Delft (lecture by Van den Berg, October 27).

- Working visit Université de Provence, Marseille (December 20–21, lecture by Van den Berg).
- Search and communication complexity and Information theory in Mathematics, twin conferences, Balatonlelle, Hungary, July 1–7 (Lukács).
- Concentrated Advanced Course on Percolation Theory and Applications in Statistical Mechanics, Augustus 14–18, Copenhagen (Lukács).
- Annual Lunteren Stochastics meeting, November 13–15. (All members).
- German Open Conference on Probability and Statistics, March 21–24, Hamburg, Germany; R. Helmers (with lecture).
- Meeting on Scientific Questions concerning oil pollution Activities, Brugge, Belgium, May 9–11, R. Helmers (invited lecture).
- Invited lectures M.S. Keane: 15 lectures in France, Germany, Hungary, Ukraine, USA, Chile, Poland, and The Netherlands. Two of these lectures were special: *Inaugural lecture as foreign member of the Chilean Academy of Sciences*, and the *Huygens lecture for the French Academy of Science in Paris.*
- Working visits M.S. Keane: Santiago (2 weeks), Wroclaw (2 weeks), Bristol (1 month).
- Workshop DYNSTOCH 2000, Padova (Italy), September 21–23. Lecture: *Representation of information in filtered experiments.* (Dzhaparidze and Spreij).
- 5th World Congress of the Bernoulli Society for Probability and Mathematical Statistics 2000, Guanajuato (Mexico), May 15–20 (Lectures by Spreij and Van Zanten).
- Seminarium Kansrekening en Statistiek TU Delft (Lectures by Sprey and Van Zanten).
- Colloquium kansrekening Amsterdam (Lecture by Spreij).

Memberships of Committees and Other Professional Activities

J. van den Berg:
- Member of the PhD committee for M. Vervoort (UvA).
- Member of the PhD and the reading committee for R. Marchand (Marseille).
- Co-organizer of a Dutch-Hungarian cooperation project, supported by NWO.

R. Helmers:
- Member Steering committee Research Statistical Auditing of the Limperg Institute, the Inter University Research Institute for Accountancy in the Netherlands.
- Project leader 'Mathematical Statistics and Probability' of the priority programme 'Applied Mathematics' of the KNAW, as part of the scientific cooperation between the Netherlands and Indonesia.
- Member of PhD committee of I. Alberink, January 26, Catholic University Nijmegen.

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: M. Vervoort, P. Oonincx and A. Trip (UvA), E. Verbitski (RUG).
- Gutachter Sonderforschungsbereich Dynamik, DFG.
- Evaluation of Santiago Dynamics Center for CONICYT (Chilean national research funding council).

K.O. Dzhaparidze:
- Member of the committee FWA (Financiële Wiskunde Amsterdam).
- Member of the Research Training Network DYNSTOCH.

P.J.C. Spreij:
- Director of FWA (Financiële Wiskunde Amsterdam).
- Leader Stieltjes theme group on Financial Mathematics.
- Scientist in charge of Dutch team of EU project DYNSTOCH.
- Member of board of the section Mathematical Statistics of the VVS (Dutch Society for Statistics and Operation Research).
- Steering Committee Eurandom programme 'Financial Stochastics'.

J.H. van Zanten:
- Member of the Research Training Network DYNSTOCH.

Visitors

- Long-term visitors (more than one month): M. Smorodinsky (Tel Aviv), A. Jarai (postdoctoral visitor) and M. Balazs (Budapest).

- Other visitors: M. Bloznelis (Vilnius), J. Memin (Rennes), K. Simon, D. Szász and B. Tóth (Budapest), E. Soewono (Bandung), W. Werner (Paris), R.M. Burton (Corvallis), M. Taksar (Stony Brook), D. Steinsaltz (Berkeley), P. Wilmott (Oxford), M. Smorodinsky (Tel Aviv), P. Shields (Toledo, Seattle), C.T. Sparrow (Cambridge), A. Burbanks (London), U. Yechiali (Tel Aviv), J. Serafin (Wroclaw).

Papers in Journals and Proceedings

J. VAN DEN BERG and H. KESTEN (2000). Asymptotic density in a coalescing random walk model. *Ann. Probab.* **28**, 303–352.

J. VAN DEN BERG and R. BROUWER (2000). Random sampling for the monomer-dimer model on a lattice. *J. Math. Phys.* **41**, 1585–1597.

A.J.VAN ES, R. HELMERS and M. HUŠKOVÁ (2000). On a crossroad of resampling plans: bootstrapping elementary symmetric polynomials. *Statistica Neerlandica* **54**, 100–110.

R. HELMERS (2000). Inference on rare errors using asymptotic expansions and bootstrap calibration. *Biometrika* **87** (3), 689–694.

R. HELMERS and I W.MANGKU (2000). Statistical estimation of Poisson intensity functions. *Proceedings of the SEAM-GMU conference on Mathematics and its Applications*, Yogyakarta, Indonesia, July 1999, 9–21.

J.H. VAN ZANTEN (2000). A multivariate central limit theorem for continuous local martingales. *Statistics and Probability Letters* **50** (3), 229–235.

K. DZHAPARIDZE (2000). On interpolation series related to the Abel-Goncharov problem. *Indagationes Mathematicae* **11** (4), 1–17.

K. DZHAPARIDZE, P.J.C. SPREIJ and J.H. VAN ZANTEN (2000). Introduction to pption pricing in a securities market – III: Gaussian approximation. *Statistica Neerlandica* **54** (1), 265–292.

M.S. KEANE, R.M. BURTON and J. SERAFIN (2000). Residuality of dynamical morphisms. *Colloq. Math.* **84/85**, 307–317.

M.S. KEANE and S.W.W. ROLLES (2000). Edge-reinforced random walks on finite graphs. PH. CLÉMENT et al. (eds.). *Infinite dimensional stochastic analysis*, KNAW Verhandelingen, Afdeling Natuurkunde, *Eerste Reeks* **52**, 217–234.

M.S. KEANE, R. GER and J.K. MISIEWICZ (2000). On convolutions and linear combinations of pseudo-isotropic distributions. *Journal of Theoretical Probability* **13**, 977–995.

CWI Reports

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

PNA-R0001 PNA-R0006 PNA-R0011
PNA-R0013 PNA-R0018

Other Publications

R. HELMERS (2000). Bootstrap methods. *Encyclopedia of Mathematics. Supplement* **II**, 80–82.

R. HELMERS (2000). Review of 'Decoupling, From Dependence to Independence' by VICTOR H. DE LA PEÑA and E.GINÉ (2000). *Journal of the American Statistical Association* **95**, 1017.

K. DZHAPARIDZE, P.J.C. SPREIJ and E. VALKEILA (2000). *Hellinger and Information Processes in Filtered Experiments, Part I: General Concepts.* Report of the Department of Mathematics, University of Helsinki, Preprint 264 (submitted to *Ann. Probab.*)

K. DZHAPARIDZE, P.J.C. SPREIJ and E. VALKEILA (2000). *Hellinger and Information processes in Filtered Experiments, Part II: Explicit Representations and Examples.* Report of the Department of Mathematics, University of Helsinki, Preprint 265 (submitted to *Ann. Probab.*).

J.H. VAN ZANTEN (2000). Bespreking van het boek 'Essentials of Stochastic Processes' van Rick Durrett. *Kwantitatieve Methoden* **64**, 157–158.

A. KLEIN and P.J.C. SPREIJ (2000). *On the Application of Vandermonde Matrices to Time Series Analysis.* preprint 00-18, Universiteit van Amsterdam.

Book

K.O. DZHAPARIDZE (2000). *Introduction to Option Pricing in a Securities Market.* CWI Syllabus **47**, CWI, Amsterdam.

Signals and Images – PNA4

Staff

- H.J.A.M. Heijmans, theme leader
- T.Q. Deng (NUFFIC), visitor
- L. Kamstra, PhD student

- A.A.M. Kuijk, senior researcher
- A.J. Lenstra (0.1 – Eurandom), senior researcher
- M.N.M. van Lieshout (0.8 PNA4; 0.2 CWI Bureau), senior researcher
- P.J. Oonincx, senior researcher
- E.J. Pauwels, senior researcher
- G. Piella, PhD student
- B.A.M. Schouten, PhD student
- A.G. Steenbeek, scientific programmer
- A. Stein (WUR, ITC Enschede), visiter
- B.J. Whitcher (0.2 – Eurandom, up to August 2000), senior researcher
- P.M. de Zeeuw, scientific programmer

Scientific Report

General

One aspect of image processing that makes it such an interesting topic of study is the amazing diversity of potential applications. The internet in particular has brought a flood of instant information to an increasing percentage of businesses and homes. A great deal of this information comes in the form of graphics, pictures, and video. As a result, there is an increasing need for tools to code, transmit, store and transform visual information. This has resulted in a growing interest in sophisticated mathematical models and theories.

The research in this theme is subdivided into three subthemes. The subtheme 'Content-Based 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 and intelligent retrieval of images. The subtheme 'Wavelets and Morphology' (PNA4.2) deals with various multiresolution techniques in signal and image processing, such as wavelet analysis, mathematical morphology, and image scale-spaces, as well as with specific applications such as image and video coding and compression, data fusion, and image filtering. The third subtheme 'Stochastic Geometry' (PNA4.3) 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 (both national and international) as well as researchers from other national institutes (NLR, TNO) and industry. External financing comes from the Dutch NWO and STW programme, EU 5th FP, and NATO.

Research Highlights

- Completion of work on fractal feature extraction
- Development of PARISS, an intelligent interface for image-retrieval
- Organization of national seminar 'Wavelets and their Applications'
- Construction of adaptive lifting schemes
- Development of new morphological grey-scale operators using concepts from fuzzy logic
- Completion of a book by Van Lieshout on Markov point processes
- New results on likelihood based inference for random sets

Content-Based 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 acute for image databases as there is no general set of canonical features that adequately captures the variety and wealth of visual information.

Content-Based Image Retrieval (CBIR) aims at designing algorithms and interfaces that will assist the user in this task. Research conducted within PNA4.1 subtheme addresses a number CBIR-related problems, such as image-segmentation, interfaces and models for user-feedback, feature extraction and indexing.

With regard to image segmentation, *Pauwels* has investigated a principled approach based on feature histograms. The idea is to use linear or non-linear real-valued functions that map pixels to 1-dimensional histograms. Multimodality in such histograms is indicative of salient regions in the original image. The research focused on using distribution-free statistics (such as Kolmogorov-Smirnov or Cramer-von Mises) to partition these histograms reliably. The image-segmentations thus obtained yield important information for further content-extraction.

A second CBIR-related research theme is the development of PARISS, an intelligent interface for image-retrieval that learns from observing examples and counter-examples supplied by the

user. The actual learning is achieved by gradually refining a probabilistic model that predicts the relevance of each image in terms of its features. By comparing these predictions to the positive and negative feedback obtained from the user, the model parameters can be tuned resulting in an enhanced performance. This work is done by *E. Pauwels*, in collaboration with *Kuijk* and *Schouten* at CWI and *G. Caenen* and *G. Frederix* at KU Leuven (Belgium).

Schouten and *De Zeeuw* continued and completed their work on fractal feature extraction. Their feature extractor uses the fractal transform of an image to extract information about the texture within the image. Features based on the fractal transform have been introduced and shown to be invariant under various image transforms. The above led to the completion of a computer code: FracFeat. It presently includes tools for adding images and the integrated computation of features together with facilities for querying. Moreover, a graphical user interface (Vadim Zaitsev) has been built on top of the code. FracFeat is aimed at the domain of textiles and fashion.

Wavelets and Morphology – PNA4.2

Heijmans continued his collaboration with *J. Goutsias* (Johns Hopkins University, Baltimore) on the 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. Two major papers on this topic have appeared in the *IEEE Transactions on Image Processing*. In the near future, the results will be applied in the context of video coding. Recently, a European project (MASCOT) with seven partners has been approved by the European Commission. The goal of MASCOT is to improve the quality and efficiency of video coding systems by exploiting metadata information. Furthermore it seeks to design an intrinsically scalable video coding scheme providing fully progressive bitstreams by exploiting novel morphological and adaptive wavelet decomposition methods, and by the development and optimization of advanced and dedicated prediction schemes.

Piella and *Heijmans* worked on a new family of wavelets constructed by adaptive lifting. Many signals (and images) in real life are non-stationary, with the structure varying significantly within each scale. In order to overcome this problem, local adaptivity is needed. Our strategy consists of either making the prediction coefficient vary with time so that the prediction error (or other parameter) is minimized, or switching between different filters according to some criterion. The latter seems the most suitable in practice, but it requires a bookkeeping of the filters which have been used at the analysis step in order to be able to reconstruct the signal at the synthesis step. The objective of this research is to find decompositions for which such bookkeeping is not necessary: in such cases it is possible to recover the decisions at the synthesis step. Some interesting results have been obtained sofar and a couple of papers are in preparation.

The research of *Lute Kamstra* has been focused on multiresolution decompositions of signals with function values in a finite set that is not necessarily a ring. He has defined a discrete wavelet transform of such finite valued signals and derived strong necessary conditions on such transforms. This makes it possible to give explicit examples of linear and non-linear discrete wavelet transforms of binary signals without using the so-called lifting scheme. Current research aims at applying this theory in the field of lossless compression of binary signals and images.

The work of *Heijmans* with *Kresch* (HP Laboratories, Haifa) on the construction of self-dual morphological operators using complete inf-semilattices was continued. New applications in the direction of curve evolution and scale-spaces are currently explored.

The work by *Heijmans* (partially in collaboration with Van den Boomgaard of the University of Amsterdam) on scale-spaces was further continued. Currently he is exploring the relationships between the axiomatic approach and the PDE approach that is often encountered in the literature.

Deng (whose visit to CWI was made possible through a NUFFIC grant) collaborated with Heijmans on new family of grey-scale operators based on concepts from fuzzy logic. Two technical reports were produced, and the research efforts in this direction have been finished after the departure of *Deng* to his home institute in Harbin, China.

Stochastic Geometry – PNA4.3

Van Lieshout, Molchanov (Glasgow) and *Zuyev* (Strathclyde) worked on optimization problems within the framework of cluster analysis for spatial point processes. The cluster centres to be

detected were modelled as a Poisson process with unknown intensity function. A Ward style clustering criterion was derived which, under the Poisson assumption, could easily be evaluated explicitly in terms of the intensity function. Asymptotically, i.e. for increasing total intensity, the optimal intensity function turned out to be proportional to a dimension dependent power of the density of the observations. For fixed finite total intensity, steepest descent methods were implemented, which, since the criterion to be minimized is convex in the intensity function, converge to a global optimum.

Van Lieshout and *Van Zwet* (Berkeley) studied likelihood based statistical inference for the Boolean model of discs. As an interesting by-product, they constructed an exact simulation algorithm using coupling from the past to draw from the conditional distribution of interior discs. A follow-up study extending this approach to more complicated germ-grain models was initiated in collaboration with Møller (Aalborg).

During Stein's sabbatical at CWI, jointly with Van Lieshout, he studied the spread of witchweed in semi-arid tropical countries by image analysis techniques.

Van Lieshout paid a working visit to the department of theoretical statistics at Aarhus University. In collaboration with Hahn, Vedel-Jensen and Stougaard Nielsen, locally rotation invariant random set models were constructed. Examples include transformations of the conditional intensity of a Markov point process, modifications of the second order interaction function, and local scaling of the grains in Boolean models. Moreover, the effect of the above operations on the influence zones of the underlying point process model, respectively the capacity functional of the random set, was assessed.

PhD Thesis

P.J. Oonincx. *Mathematical Wavelet Analysis: Wavelets, Wigner Distribution and a Seismic Application.* University of Amsterdam, February. Thesis advisor: T.H. Koornwinder.

Knowledge Transfer

- Heijmans was one of the lecturers at the 'Vakantiecursus 2000'. This year's course, directed towards teachers at secondary schools, was entitled 'Is wiskunde nog mensenwerk?'
- Oonincx gave a teaching course 'Fourier Analysis' at the University of Amsterdam. He was advisor of practical work MSc students at the University of Amsterdam and he was a tutor at a master course on 'Mathematics and Sound' at the University of Amsterdam.
- Kuijk has been an advisor of the group Computer Graphics at Philips Research from May 1st until December 31 for 2 days a week. The knowledge transfer is on graphics architectures and algorithms.
- Pauwels gave a teaching course entitled: *Technologie en Economische Sectoren* at Katholieke Universiteit Brussel (Belgium)
- Pauwels delivered a lecture at 'CWI in Bedrijf' entitled: *To see or not to see, that's the question! – Visuele Expert Systemen.*

Organization of Conferences, Workshops, Courses, etc.

- CWI in Bedrijf: Investment in Knowledge Infrastructure, CWI, October 8, 1999. Lecture *To see or not to see, that's the question!*) about Content Based Image Retrieval and Visual Expert Systems: E.J. Pauwels.
- Wavelet Seminar May 17, CWI Amsterdam. Main speaker: Wim Sweldens (Bell Labs) November 17, RU Groningen. Main speaker: Michael Unser (EPFL Lausanne).
- Organizer of the 'Workshop on Stochastic Geometry in Spatial Statistics', Eurandom, Eindhoven, April 27–29: M.N.M. van Lieshout.
- Organiser of the Spatial Stochastics Seminar and the PNA colloquium (CWI Amsterdam): M.N.M. van Lieshout.
- Signals and Images Seminar: organized biweekly: P.J. Oonincx.

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

H.J.A.M. Heijmans:

- Workshop 'Frontiers of Mathematical Morphology', April 17–20, Strassbourg (France) (invited lecture).
- International Symposium on Mathematical Morphology ISMM'2000, June 25–29, Palo Alto (lecture).
- Working visit to Johns Hopkins University, Baltimore, USA, June 30–July 7.
- IEEE Signal Processing Society International Conference on Image Processing, Vancouver, Canada, September 10–13 (lecture).

L. Kamstra:
- Workshop 'Frontiers of Mathematical Morphology', April 17–20 Strassbourg (France).

G. Piella:
- 3rd International Conference on Information Fusion, July 10–13, Paris, France.
- School on Mathematical Problems in Image Processing, September 4–22, Trieste, Italy.

M.N.M. van Lieshout:
- Nationale Wiskunde Dagen, Noordwijkerhout, February 4. Invited talk *Analyse van beelden en andere ruimtelijke data.*
- 3rd Danish-French Workshop on Spatial Statistics and Image Analysis in Biology, Luminy, France, March 6–10. Invited talk *Indices of dependence between types in multivariate point patterns.*
- Workshop on Stochastic Geometry in Spatial Statistics, Eurandom, Eindhoven, April 27–29. Talk: *Maximum likelihood inference for a random set model.*
- Accuracy 2000, Amsterdam, July 12–14. Talk: *Propagation of spatial interaction under superposition.*
- Statistical sensing of the Environment, ITC, Enschede, October 11. Invited talk *Stochastic geometry for image analysis.*
- Bijeenkomst Stochastici, Lunteren, November 13–14.
- Models and inference in HSSS: recent developments and perspectives, Luminy, France, November 15–18. Invited discussant of session *Image Analysis.*
- Working visit E.B. Vedel-Jensen, University of Aarhus, Denmark, November 21–December 20. Talk: *Spatial cluster analysis using point processes* on 11 December.
- Working visit J. Møller, University of Aalborg, Denmark, December 7. Talk: *Spatial cluster analysis using point processes.*

P.J. Oonincx:
- FNRS Wavelet meeting, Namur, Belgium, May 11: (invited speaker).
- 45th annual SPIE meeting, San Diego, USA, July 30–August 4.

Other PNA4 members

- ICPR 2000, 15th International Conference on Pattern Recognition, September 3–7, Barcelona (presentation by P.M. de Zeeuw, joint work with B.A.M. Schouten); lecture *Fractal Transforms and Feature Invariance.*
- Siggraph2000, New Orleans, USA, July 23–28 (A.A.M. Kuijk).
- New York: 'Excavating the archive', June 3. Lecture: *Content-Management Systems for Image Databases* (B. Schouten).
- International Conference on Image Processing (ICIP 2000), Vancouver, September 10–13. Lecture: *Image Databases, Scale and Fractal Transforms* (B. Schouten).
- International Conference on Image Processing ICIP 2000, September 10–13, Vancouver. Poster: PARISS-interface (G. Caenen, A. Kuijk, E. Pauwels, B. Schouten).
- Strategic Conference Concurreren met ICT-competenties: 'Kennis en innovatie voor De Digitale Delta', June 7: organized by Min. EZ, Congresgebouw Den Haag (E. Pauwels and B. Schouten).
- 6th European Conference on Computer Vision (ECCV 2000), Dublin, June. Talk: *Image Segmentation by Nonparametric Clustering Based on the Kolmogorov-Smirnov Distance.* (E.J. Pauwels in collaboration with G. Frederix, KU Leuven).
- IMA workshop on Low-level vision (Minneapolis, USA), October 14–20. Talk: *Segmentation based on distribution-free statistics* (E. Pauwels).
- International Conference on Visual Information Systems (Visual 2000), Lyon, November 2–4. Talk: *Show me what you mean: PARISS: a CBIR-interface that learns by example.* (Talk: E. Pauwels, in collaboration with A. Kuijk, B. Schouten and G. Caenen, G. Frederix, KU Leuven).
- Workshop on Colour Imaging and Vision, UvA, Amsterdam, November 22. Talk: *Colour segmentation based on distribution-free feature statistics.* (E. Pauwels).

Memberships of Committees and Other Professional Activities

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; appeared in 2000).
- Coordinator of EU MASCOT project.
- Member of Programme Committee of the sixth International Conference on Computer Graphics and Image Processing (GKPO2000), Podlesice, Poland, May 15–19.

- Member of Technical Committee of 15th International Conference on Pattern Recognition (ICPR 2000), Barcelona, Spain, September 3–8.
- Member of Technical Committee of IEEE Conference on Image Processing (ICIP 2000), Vancouver, USA, September 10–13.
- Member of Technical Committee of Fifth International Symposium on Mathematical Morphology (ISMM2000), Palo Alto, USA, June 25–29.

M.N.M. van Lieshout:

- Member steering committee Complex Stochastic Models, Eurandom.
- Member programme committee on behalf of the Institute of Mathematical Statistics of the joint statistical meeting to be held in Atlanta, August 5–9, 2001. Organizer of a session on 'Spatial statistics':
- Member reading and promotion committee PhD J. Lund, The Royal Veterinary and Agricultural University Copenhagen, Denmark, February 25 2000; 'Statistical inference and perfect simulation for point processes observed with noise'.
- Member reading committee PhD R.S. Stoica, University of Nice, France; 'Détection de lignes en traitement d'image en utilisant des modèles bayésiens'.
- For the CWI Bureau, Van Lieshout catalogued research expertise within the framework of the ERCIM Vital Statistics project.

P.M. de Zeeuw:

- Secretary of the Dutch-Flemish Numerical Analysis Society.

A.A.M. Kuijk:

- Member program committee 2000 Siggraph/Eurographics Workshop on Graphics Hardware.

Visitors

- V. Tsurkov, Computing Center of the Academy of Sciences, October.
- M. Nachtegael, RU Gent, March 14–15.
- W. Sweldens, Lucent, May 16–17.
- P. Schellekens, Vrije Universiteit Brussel, December 20.
- J. Zerubia, INRIA, Sophia-Antipolis, 26 April.
- A. Stein, Landbouwuniversiteit Wageningen, May 8–12 and June 19–30.
- J.P. Antoine, Louvain-la-Neuve, February 8–9.
- L. Latecki, University of Hamburg, July 21–24.
- E.H. Blake, University of Cape Town, May 24–June 17.

Software Developed

- *Fracfeat*: a textural image feature extractor (B.A.M. Schouten and P.M. de Zeeuw).
- *PARISS*: Panoramic, Adaptive, Reconfigurable Interface for Similarity Search: Pauwels and Kuijk in collaboration with G. Caenen, KU Leuven.
- *Matlab Fusion Toolbox*: under development: Piella and De Zeeuw.

Books

J. Goutsias, H.J.A.M. Heijmans (2000). *Mathematical Morphology*, IOS Press, Amsterdam.

M.N.M. van Lieshout (2000). *Markov Point Processes and their Applications*. Singapore: Imperial College Press/World Scientific Publishing, 2000.

Papers in Journals and Proceedings

A.V. Tuzikov and J.B.T.M. Roerdink and H.J.A.M. Heijmans (2000). Similarity measures for convex polyhedra based on Minkowski addition. *Pattern Recognition* **6** (33), 979–995.

J. Goutsias and H.J.A.M. Heijmans (2000). Nonlinear multiresolution signal decomposition schemes: Part I: morphological pyramids. *IEEE Transactions on Image Processing* **9** (11), 1862–1876.

H.J.A.M. Heijmans and J. Goutsias (2000). Nonlinear multiresolution signal decomposition schemes: Part II: morphological wavelets. *IEEE Transactions on Image Processing* **9** (11), 1897–1913.

H.J.A.M. Heijmans and J. Goutsias (2000). Morphological pyramids and wavelets based on the quincunx lattice. J. Goutsias and L. Vincent and D.S. Bloomberg (eds.). *Mathematical Morphology and its Applications to Image and Signal Processing (ISMM2000)*, Kluwer Academic Publishers, Boston, 273–281.

R. van den Boomgaard and H.J.A.M. Heijmans. Morphological scale-space operators: an algebraic approach. J. Goutsias and L. Vincent and D.S. Bloomberg (eds.). *Mathematical Morphology and its Applications to Image and Signal Processing (ISMM2000)*, Kluwer Academic Publishers, Boston, 283–290.

H.J.A.M. Heijmans and R. Kresch (2000). First steps towards a self-dual morphology. *Proceedings of ICIP 2000*, Vancouver.

J. Goutsias and H.J.A.M. Heijmans (2000). Fundamenta Morphologicae Mathematicae. *Fundamenta Informaticae* **41** (1–2), 1–31.

M.N.M. van Lieshout (2000). Propagation of spatial interaction under superposition. G.B.M. Heuvelink and M.J.P.M. Lemmens (eds.). *Accuracy 2000, Proceedings of the 4th International Symposium on Spatial Accuracy Assessment in Natural Resources and Environmental Sciences*, 687–694. Delft: Delft University Press, 2000.

P.J. Oonincx and H.G. ter Morsche (2000). Integral representations for metaplectic operators: energy localization problems. *Proc. SPIE, Adv. Sig. Proc. Alg.* **X**, San Diego.

B.A.M. Schouten, P.M. de Zeeuw (2000). Fractal Transforms and Feature Invariance. A. Sanfeliu, J.J. Villanueva, M. Vanrell, R. Alquézar, T. Huang, J. Serra, (eds.). *Proceedings 15th International Conference on Pattern Recognition* (*ICPR 2000*), September 3–7, 2000, Barcelona, **3**, 992–997, Publ. IEEE Computer Society.

B.A.M. Schouten, P.M. de Zeeuw (2000). Image Databases, Scale and Fractal Transforms. *Proceedings International Conference on Image Processing* (*ICIP 2000*), September 10–13, Vancouver, CDROM ISBN 0-7803-6300-0.

E.J. Pauwels and G. Frederix (2000). Image Segmentation by Nonparametric Clustering Based on the Kolmogorov-Smirnov Distance. *Proc. of ECCV 2000, 6th European Conference on Computer Vision*, Dublin, June 2000, 85–99.

G. Frederix, Geert Caenen and Eric J. Pauwels (2000). PARISS: Panoramic, Adaptive and Reconfigurable Interface for Similarity Search. *Proceedings of ICIP 2000 International Conference on Image Processing*, WA 07.04 (v.III, 222–225), Vancouver, September 2000.

G. Caenen, G. Frederix, A.A.M Kuijk, E.J Pauwels and B.A.M Schouten (2000). Show me what you mean! PARISS: A CBIR-interface that learns by example. *Proceedings of VISUAL 2000: Fourth International Conference on Visual Information Systems*, Lyon, November, 257–268.

CWI Reports

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

PNA-R0003 PNA-R0008 PNA-R0012 PNA-R0014

Other Publications

J. Goutsias and H.J.A.M. Heijmans (2000) (guest eds.). Special issue of *Fundamenta Informaticae* **41**, issues 1–2.

H.J.A.M. Heijmans (2000). Rekenen aan beelden: is een plaatje duizend woorden waard? *CWI Syllabus* **48**, 21–40.

M.N.M. van Lieshout, I.S. Molchanov and S.A. Zuyev (2000). *Clustering Methods Based on Variational Analysis in the Space of Measures.* Research Report, Glasgow University, May. `http://www.stats.gla.ac.uk/~ilya/research/reports.html`

M.N.M. van Lieshout (2000). Review of Image textures and Gibbs random fields by G.L. Gimel'farb. *Nieuw Archief voor Wiskunde* **5/1**, 443–444, December (In Dutch).

SOFTWARE ENGINEERING

General Overview

The research of cluster SEN in the year 2000 was organized around four themes: SEN1 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. Its research was concentrated in four areas: language prototyping, software renovation, optimization of software, and interactive visualization environments. The work of SEN2 was mainly concentrated around techniques for the improvement of the quality of software components typically found in embedded systems such as telecommunication systems or communication protocols. The main vehicle consisted of the language μCRL: the micro common representation language; others were timed automata and modal logics. Supporting foundational studies were concerned with process algebra, term rewriting, distributed algorithms, and model checking and BDDs. In several industrial case studies, many of the methodologies listed above were applied. SEN3 dealt with coordination models and languages focusing on such key issues in Component Based Software (CBS) as specification, interaction and dynamic composition of components. The main subthemes were: development of formal models for coordination and CBS, study of the foundations of computation, notably operational semantics and coalgebraic methods, and developments and experimental use of the coordination language 'Manifold'. The group SEN4 focused on evolutionary algorithms, neural networks, and discrete algorithms, especially for problems related to management, economics and E-commerce. A key topic is that of complex adaptive systems, in which adaptive (learning) agents interact with each other, giving the system its own behaviour and organization. Discrete algorithms were applied, e.g., in online process management and quality of service investigations. In the area of neural networks, special attention was paid to spiking neural networks.

Selected facts

- The SEN staff produced approximately 80 papers in journals and proceedings, 40 reports and 20 other publications. Four books appeared, viz. one text on Process Algebra (W.J. Fokkink), one book on the railway interlocking language LARIS (W.J. Fokkink et al, editors) and two conference proceedings in the Lecture Notes series by Springer, one on Visualization (W. de Leeuw and R. van Liere, eds.) and one on Virtual Reality (J. Mulder and R. van Liere, eds.).
- Three PhD theses were awarded to (former) SEN members/visitors: E. Saaman, *Another Formal Specification Language*, RUG; P.A. Olivier, *A Framework for Debugging Heterogeneous Applications*, UvA; W.O.D. Griffioen, *Studies in Computer Aided Verification of Protocols*, KUN. Further particulars are mentioned in the SEN1 and SEN2 sections.
- 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, respectively. Klop was furthermore assigned part-time to a project at the KUN. Arbab, Baltag and Bonsangue taught courses at UL, UvA and UL. 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 2000 these included drs. J. den Hartog (VUA), dr. S. Mauw (TUE), dr. V. van Oostrom (UU), dr. A Ponse (UvA), and dr. H. Zantema (UU).
- 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 Weidmüller). Much 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).

- Bilateral cooperation with ERCIM institutes took place with GMD and SZTAKI.
- Numerous SEN projects were funded by NWO, in particular by the section on Informatics of the Physical Sciences Council, and by the PROGRESS programme.
  One project (S.P. Luttik) was completed (PhD expected in 2001), and two projects were terminated due to departure of the project researchers (R. Lämmel, R. Manniesing). The ongoing projects of S. Orzan and J. Pang (both PROGRESS), M. van der Zwaag, R. van Stee, F. Alkemade, M.B. de Jong, A. Baltag and F. Bartels were all continued. Four new NWO projects were awarded to the project leaders:

  - F. Arbab (jointly with K.R. Apt, PNA)
  - J. Rutten (jointly with J. van Schuppen, PNA)
  - J. Rutten (jointly with B. Jacobs (KUN), Y. Venema (UvA))
  - W.J. Fokkink, J. van de Pol (jointly with J.F. Groote and H. Zantema (both TUE)).

- Since August 1. A. Kurz worked as ERCIM fellow in SEN3 (on Coalgebras and Modal Logic).
- On September 1, dr. Jan Friso Groote accepted a position as (full) professor at Eindhoven University of Technology, and stepped down as theme leader of SEN2. He was succeeded by dr. Wan Fokkink.
- The start-up company Software Improvement Group BV (SIG) was established in the second quarter of 2000. Preparations for this occurred in close cooperation with SEN1. Several of its members were seconded for some months at SIG, and a major part of its initial activities were concerned with DocGen, a system for generating hypertext documentation from COBOL legacy systems. DocGen was originally designed by a number of SEN1 members.
- On May 1, dr. Gerard Alberts started an NWO sponsored project with as goal the writing of a biography of A. van Wijngaarden, Dutch computer pioneer and former director of the Mathematical Centre. Since this project is not part of the work of one of the themes SEN1 to SEN4, its report is included below under the heading SEN0.

Staff

- Biography of Aad van Wijngaarden – SEN0

  - G. Alberts

- Interactive Software Development and Renovation – SEN1

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

- Specification and Analysis of Embedded Systems – SEN2

  - J.F. Groote
  - J.A. Bergstra
  - S.C.C. Blom
  - W.J. Fokkink
  - J.W. Klop
  - I.A. van Langevelde
  - B. Lisser
  - S.P. Luttik
  - R. Manniesing
  - S. Mauw
  - V. van Oostrom
  - S. Orzan
  - J. Pang
  - J.C. van de Pol
  - A. Ponse
  - Y.S. Usenko
  - J.J. van Wamel
  - A.G. Wouters
  - 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

- J.V. Guillen Scholten
- J. den Hartog
- A. Kurz

- Evolutionary Computation and Applied Algorithms – SEN4

  - J.A. La Poutré
  - F. Alkemade
  - S.M. Bohté
  - D.D.B. van Bragt
  - E. Gerding
  - H. Halfmouw
  - M.B. de Jong
  - J.N. Kok
  - E. Kutschinski
  - W.B. Langdon
  - G. Pieri
  - K.J. Shaw
  - R. van Stee
  - R.W.T. Wildenberg

- Secretary:

  - J.J. Bruné-Streefkerk

CWI Reports and Notes

SEN-R0001. J.C. van de Pol and H. Zantema. *Binary decision diagrams by shared rewriting.*

SEN-R0002. M.B. van der Zwaag. *Time-stamped actions in pCRL algebras.*

SEN-R0003. M.G.J. van den Brand, H.A. de Jong, P. Klint and P.A. Olivier. *Efficient annotated terms.*

SEN-R0004. D.D.B. van Bragt, C.H.M. van Kemenade and J.A. La Poutré. *The influence of evolutionary selection schemes on the iterated prisoner's dilemma.*

SEN-R0005. E.H. Gerding, D.D.B. van Bragt and J.A. La Poutré. *Scientific approaches and techniques for negotiation. A game theoretic and artificial intelligence perspective.*

SEN-R0006. J.F. Groote and J.C. van de Pol. *Equational binary decision diagrams.*

SEN-R0007. J.W. Klop, V. van Oostrom and R. de Vrijer. *A geometric proof of confluence by decreasing diagrams.*

SEN-R0008. J.F. Groote and J.C. van de Pol. *State space reduction using partial τ-confluence.*

SEN-R0009. J.F. Groote and H. Zantema. *Resolution and binary decision diagrams cannot simulate each other polynomially.*

SEN-R0010. J. Heering. *Application software, domain-specific languages, and language design assistants.*

SEN-R0011. M.G.J. van den Brand and J. Scheerder. *Development of parsing tools for CASL using generic language technology.*

SEN-R0012. W.J. Fokkink and S.P. Luttik. *An ω-complete equational specification of interleaving.*

SEN-R0013. D.D.B. van Bragt, E.H. Gerding and J.A. La Poutré. *Equilibrium selection in alternating-offers bargaining models – the evolutionary computing approach.*

SEN-R0014. M.G.J. van den Brand, J. Heering, P. Klint and P.A. Olivier. *Compiling language definitions: the ASF+SDF compiler.*

SEN-R0015. P.F.G. Dechering and I.A. van Langevelde. *Towards automated verification of Splice in μCRL.*

SEN-R0016. R. van Stee and J.A. La Poutré. *Partial servicing of on-line jobs.*

SEN-R0017. T. Kuipers and L. Moonen. *Types and concept analysis for legacy systems.*

SEN-R0018. A. van Deursen, T. Kuipers and L. Moonen. *Legacy to the extreme.*

SEN-R0019. J.F. Groote, A. Ponse and Y.S. Usenko . *Linearization in parallel pCRL.*

SEN-R0020. F. Arbab, M.M. Bonsangue and F.S. de Boer. *A logical interface description language for components.*

SEN-R0021. F.S. de Boer and M.M. Bonsangue. *A compositional model for confluent dynamic data-flow networks.*

SEN-R0022. W.B. Langdon. *Natural language text classification and filtering with trigrams and evolutionary nearest neighbour classifiers.*

SEN-R0023. J.J.M.M. Rutten. *Behavioural differential equations: a coinductive calculus of streams, automata, and power series.*

SEN-R0024. E.H. Gerding, D.D.B. van Bragt and J.A. La Poutré. *Multi-issue negotiation processes by evolutionary simulation: validation and social extensions.*

SEN-R0025. M.M. Bonsangue, J.N. Kok and G. Zavattaro. *Comparing coordination models and architectures using embeddings.*

SEN-R0026. E. Bach, J. Boyar, L. Epstein, L.M. Favrholdt, T. Jiang, K.S. Larsen, G.-H. Lin and R. van Stee. *Tight bounds on the competitive ratio on accommodating sequences for the seat reservation problem.*

SEN-R0027. F. Arbab and E.B.G. Monfroy. *Distributed splitting of constraint satisfaction problems.*

SEN-R0028. L. Epstein and R. van Stee.

New results on flow time with resource augmentation.

SEN-R0029. M.G.J. VAN DEN BRAND and C. RINGEISSEN. *ASF+SDF parsing tools applied to ELAN.*

SEN-R0030. J.A. BERGSTRA and M.G.J. VAN DEN BRAND. *Syntax and semantics of a high-level intermediate representation for ASF+SDF.*

SEN-R0031. A. VAN DEURSEN and L.M.F. MOONEN. *Exploring legacy systems using types.*

SEN-R0032. A. VAN DEURSEN, P. KLINT and J. VISSER. *Domain-specific languages.*

SEN-R0033. J.C. VAN DE POL. *Expressiveness of basic Splice.*

SEN-R0034. J.F. GROOTE, M.A. RENIERS, J.J. VAN WAMEL and M.B. VAN DER ZWAAG. *Completeness of timed μCRL.*

SEN-R0035. J.A. BERGSTRA, A. PONSE and M.B. VAN DER ZWAAG. *Branching time and orthogonal bisimulation equivalence.*

SEN-R0036. S.M. BOHTÉ, J.A. LA POUTRÉ and J.N. KOK. *Unsupervised clustering with spiking neurons by sparse temporal coding and multi-layer RBF networks.*

SEN-R0037. S.M. BOHTÉ, J.A. LA POUTRÉ and J.N. KOK. *Error-backpropagation in temporally encoded networks of spiking neurons.*

SEN-R0038. M.B. VAN DER ZWAAG. *The cones and foci proof technique for timed transition systems.*

SEN-R0039. C.T.H. EVERAARS, F. ARBAB and B. KOREN. *Parallel, distributed-memory implementation of sparse-grid methods for three-dimensional fluid-flow computations.*

SEN-R0040. A. KURZ and D. PATTINSON. *Coalgebras and modal logic for parameterised endofunctors.*

SEN-R0041. T. KUIPERS and J. VISSER. *Object-oriented tree traversal with JJForester.*

SEN-R0042. F. ALKEMADE, D.D.B. VAN BRAGT and J.A. LA POUTRÉ. *Stabilization of tag-mediated interaction by sexual reproduction in an evolutionary agent system.*

SEN-R0043. F. BARTELS. *Generalised coinduction.*

SEN-R0044. A. BALTAG. *A logic for suspicious players: epistemic actions and belief-updates in games.*

SEN-N0001. J. SIEGENBEEK VAN HEUKELOM and G. ALBERTS. *Correspondentie David van Dantzig – Gerrit Mannoury historische notitie SEN, 1.*

Biography of Aad van Wijngaarden – SEN0

Aad van Wijngaarden (1916–1987), founding father of computer science in The Netherlands and former director of CWI, is the subject of a historical research project. The leading theme in the composition of a scientific biography is *Mathematical beauty and a taste for language.* In his scholarship Van Wijngaarden, engineer by training, was strongly guided by mathematical beauty. It made him consider scientific computing in its own right (1946), made him turn towards programming languages (1958) and reared his preferences in the design of ALGOL 68.

Research in this postdoc NWO-EW project is done by G. Alberts, supervised by J.W. de Bakker; further advisors are K. van Berkel (RUG), J.C.H. Blom (NIOD/UvA) and Th.J. Dekker (em. UvA). Publication of a monograph is planned for 2003. The project has started May 2000 with archival search and interviews. Important themes in this stage of research are Van Wijngaarden's personal background and his professional training (in the Delft subculture of Biezeno) to proficiency in scientific computing. Also, Alberts recovered Van Wijngaarden's trip report, spring 1946, presenting a survey of computing activities in the UK. This report may well be regarded as the very beginning of computer science in The Netherlands. In-depth study of the construction and use of pioneer computers in The Netherlands occasioned consulting for an exhibition of such machines and a study of the sounds they made.

Organization of Conferences, Workshops, Courses, etc.

- Computer pioneers. Exhibition on Dutch computerpioneers: 'Nederlandse computerpioniers 1945–1965' at the Techniek Museum Delft, 25–11–1999 till 30–4–2000: Gerard Alberts (historical advice on the exhibition).
- Rekentuig. 'Delfts Rekentuig. Spektakeldag Nederlands computerpioniers' Delft, TMD, January 19: Gerard Alberts (organization and presentation of a manifestation on the role of sound in the operation of pioneer computers).
- NMC36. GMFW symposium *De maatschappelijke functie van wiskundige modellen* at the 36th 'Nederlands Mathematisch Congres', Maastricht, April 27–28: Gerard Alberts (organization, chair).

- Dirk Struik. The historian of mathematics Dirk J. Struik died on October 21th, 2000, at the age of 106. The CWI scientific meeting of October 27 was devoted to the memory of the author of *A concise history of mathematics*. An obituary and a further article were published. Speaking were Marjolein Kool (*Personal recollection*) and Gerard Alberts (*Dirk Struik, history of mathematics and his roots in Dutch historiography*).

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

- ICHC. International Congress on the History of Computing 'Mapping the History of Computing – Software Issues', Paderborn HNF, April 5–8: Gerard Alberts (chair in the session on *Software as Science*)

Memberships of Committees and other Professional Activities

G. Alberts:

- Editorial Board Member *Nieuw Archief voor Wiskunde*.
- Secretary GMFW, landelijk werkcontact Geschiedenis en Maatschappelijke Functie van de Wiskunde (working party History and Social Function of Mathematics).
- Member of Werkgroep Verzamelbeleid Computerhistorie.
- Member PhD committee Ruud van Dael, University of Nijmegen (beroepsontwikkeling informatica).
- Member PhD committee Danny Beckers, University of Nijmegen (propaedeutic mathematics and the rise of pure mathematics in The Netherlands around 1800).
- Coordinator of the Science and Society research programme, University of Nijmegen.

Papers in Journals and Proceedings

G. Alberts (2000). Rekengeluiden. De lichamelijkheid van het rekenen, *I&I* **18**-1, 42–47.

G. Alberts (2000). In memoriam Dirk Struik (1894–2000). *Nieuw Archief voor Wiskunde – Vijfde Serie* **1** nr.4 (December), 354–355.

CWI Note

See page 39 for the complete title.

SEN-N0001.

Other papers

G. Alberts (2000). Computergeluiden; de lichamelijkheid van het rekenen. G. Alberts, Ruud van Dael (eds.). *Netwerken met M.a.r.c.* Amsterdam, Otto Cramwinckel, 7–9.

Books

Collectie Nederlands Oude Computers, Gerard Alberts. Tilburg: Werkgroep Verzamelbeleid Computerhistorie (Scryption), 2000.

Interactive Software Development and Renovation – SEN1

Staff

- Prof. dr. P. Klint, theme leader
- Dr. A. van den Bergh, project member (till July 31)
- 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. H.A. de Jong, project member
- Drs. M. de Jonge, project member
- Dr. A.S. Klusener, postdoc (till July 31)
- Drs. T. Kuipers, project member
- Dr. R. Lämmel, postdoc
- Dr. W.C. de Leeuw, postdoc
- Ir. R. van Liere, project leader
- Drs. L.M.F. Moonen, project member
- Dr. J.D. Mulder, postdoc (till July 31)
- Drs. P.A. Olivier, PhD student/postdoc
- Drs. J. Scheerder, project member (till July 31)
- Drs. J.J. Vinju, project member (from February 1)
- Drs. J. Visser, project member

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 2000, research focused on the area of program understanding, and addressed the following questions:

- What sort of information should be derived from legacy systems.
- How should this information be extracted from legacy systems, using parsing and lexical analysis.
- 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.
- 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 the newly established Software Improvement Group BV (SIG). From April until October A. van Deursen, T. Kuipers, and L. Moonen spent part of their time doing work for SIG. This particularly involved work on DocGen, a system for generating hypertext documentation from COBOL legacy systems. CWI assisted in turning the initial prototype into a mature commercial product.

Optimization of Scientific Software – SEN1.2

Heering: Language Design Assistants (LDAs) incorporating significantly more knowledge about programming and domain-specific languages than current language development systems would be desirable meta-tools to aid in the development of domain-specific languages (report SEN-R0010). An immediate question is whether LDAs may profitably be viewed as knowledge-based systems, and in particular whether production system languages used to implement knowledge-based systems would be suitable to describe the semantics of DSLs. An investigation of this issue was started. Work on the reimplementation of the CodeBoost source-to-source optimizer for PDE solvers written in a 'coordinate-free' style was continued in cooperation with E. Visser (University of Utrecht), M. Haveraaen, and O. Bragge (both University of Bergen, Norway). A comprehensive description of the new ASF+SDF compiler was finished (report SEN-R0014, with M.G.J. van den Brand, P. Klint, and P.A. Olivier).

Lämmel–supported by NWO project *Generation of Program Transformation Systems*: The main thread of research in cooperation with C. Verhoef (UvA/VU Amsterdam) and G. Wachsmuth (University of Rostock) was 'Grammar Engineering' with emphasis on grammar recovery, grammar transformation, and grammar testing. Grammar engineering is concerned with the systematic engineering and renovation of (large) grammars for programming and other formal languages. Furthermore, in cooperation with P. Forbrig (University of Rostock) work was done on design patterns and their role in programming; in cooperation with J. Harm (DEBIS) work was done on the subject of testing language definitions, especially attribute grammars; and, finally, in cooperation with J. Visser and J. Kort (UvA) language support for paramorphic traversals and functional traversal strategies in Haskell were investigated.

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 data and information visualization and virtual reality.

J.D. Mulder and R. van Liere continued work on enhanced viewing methods in fishtank virtual environments. This work resulted in two papers presented at *IEEE VR* and *VRAIS*. The work was applied to various applications, including joint work with members of the MAS cluster.

H. Huitema started work on time dependent molecular visualization in virtual environments. This work, which was done in the context of the CWI/GMD scientific collaboration, was presented at *EG Virtual Environments and IEEE Visualization*

W.C. de Leeuw and R. van Liere continued work on the project 'Analysis of biological structures with virtual reality techniques'. This work was presented at *IEEE Visualization*.

R. van Liere and W.C. de Leeuw initiated work on information visualization by developing a technique which enables the interactive visualization of multi-dimensional feature spaces. This work was done in the context of the ICES-KIS project.

R. van Liere, J.D. Mulder, and W.C. de Leeuw acted as conference chairs for the Eurographics *Virtual environments '00* and *EG/IEEE Visualization* VisSym '00 conferences. The objectives on the visualization group are to study, develop, and put into practice methods for interactive scientific visualization. Primary areas of interest are data and information visualization and virtual reality.

ASF+SDF – SEN1.4

The objective of the ASF+SDF group is to realize a redesign and reimplementation of the ASF+SDF Meta-Environment. The ASF+SDF Meta-Environment is an interactive development environment for the automatic generation of interactive systems for manipulating programs, specifications, or other texts written in a formal language. Over the years, this system has been used in a variety of academic and commercial projects ranging from formal program manipulation to conversion of COBOL systems.

The efficiency and stability of the parser were further improved. Our parsing technology has been successfully applied to parsers for other languages like CASL and ELAN as reported in SEN-R0011 and SEN-R0029. Both languages have mixfix syntax which can easily be handled by our parsing technology.

In order to do serious program transformations in the realm of software renovation it is necessary that layout and especially comments are maintained in the transformed programs. We extended the ASF+SDF interpreter to maintain and restore layout during rewriting. Furthermore, so-called traversal functions were added to ASF+SDF, and the ASF+SDF interpreter was extended accordingly. A report on this is in preparation. In cooperation with the newly established Software Improvement Group BV (SIG) both rewriting with layout and traversal functions were used to develop a transformation tool for COBOL software in a proof of concept project for ABN-AMRO.

Based on the JAVA version of the ATerm library a number of experiments were performed to generate traversal functions in JAVA for abstract syntax trees.

The new website `www.cwi.nl/projects/MetaEnv/` for the ASF+SDF Meta-Environment and its main components was made available.

Domain-Specific Languages – SEN1.5

The aims of the research activities to be performed within the DSL project are to:

- Develop methods for selecting suitable DSL domains, and for capturing domain knowledge into a DSL and its compiler.
- Develop meta-tools for the rapid prototyping of domain-specific languages.
- Gain more experience, via case studies, with the use of domain-specific languages in a commercial setting.

In 2000, the project has resulted in

- An annotated bibliography in the area of domain-specific languages, and program understanding techniques in order to distill domain knowledge from legacy systems (see SEN1.1).
- A much improved distribution of the ASF+SDF Meta-Environment to support language prototyping (see SEN1.4).
- Case studies with industrial and academic partners. In particular, joint work with Lucent has been carried out in which maintenance tools for Lucent's dialect of SDL were developed.

The SEN1.5 group closely cooperates with SEN1.1, SEN1.2, and SEN1.4. The DSL project is sponsored by the Telematica Instituut.

PhD Thesis

P. Olivier (2000). *A Framework for Debugging Heterogeneous Applications.* PhD thesis defence on 5 December at the University of Amsterdam. Thesis advisor: P. Klint.

Knowledge Transfer

The CWI spin-off company Software Improvement Group BV (SIG) was established. It formalizes and extends previous knowledge transfer from SEN1 to industry. Its current focus is on documentation generation and program transformation.

Further details can be found at
`http://www.software-improvers.com`

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

- Working visit University of Dundee, January 14–16: H. Huitema.
- SPIE 2000, San Jose, USA, January 23–28: W.C. de Leeuw (*Interactive visualization for the exploration of large flow data sets*).
- Working visit Telematica Instituut, January 21: A. van Deursen, P. Klint (*DSL project presentation*).
- Tagung GIBU, Dagstuhl, Germany, March 5–9: R. Lämmel (*Meta-programming für die Anpassung und Erweiterung von Programmen*).
- Conseil Scientifique INRIA, Paris, France, March 16: P. Klint.
- IEEE VR 2000, New Jersey, USA, March 18–22: R. van Liere (*Virtual Fekete: Perturbing complex systems*), J.D. Mulder (*Enhancing fish-tank VR*).
- IFIP WG2.1 54th Meeting, London, UK, April 4: R. Lämmel (*A transformational approach to grammar improvement*).
- ETAPS '00, Berlin, Germany, March 28–April 1: P. Klint.
- ETAPS '00 and COFI '00, Berlin, Germany, March 29–April 2: M.G.J. van den Brand.
- IFIP W.G.2.1 meeting, London, UK, April 2–8: R. Lämmel.
- Working visit University of Bergen, Bergen, Norway, April 6–8: J. Heering (*Programming language semantics: A tool-oriented approach*).
- Working visit LORIA, Nancy, France, May 2–5: M.G.J. van den Brand, J. Scheerder.
- WSR 2000, Bad Honnef, Germany, May 11–12: R. Lämmel (*Grammar reengineering*).
- Dagstuhl Visualization Seminar, Dagstuhl, Germany, May 21–26: W.C. de Leeuw (*Visualisation of biological data*), R. van Liere (*IEEE Bibio-Visualization and An image browser*).
- COSET 2000/ICSE 2000/IWPC 2000, Limerick, Ireland, June 4–12: M. de Jonge (*A pretty-printer for every occasion*), T. Kuipers, and L.M.F. Moonen (*Types and concept analysis in legacy systems*).
- Conseil Scientifique INRIA, Paris, France, June 15: P. Klint.
- Extreme Programming 2000 (XP 2000), Cagliari, Italy, June 20–26: A. van Deursen, T. Kuipers (*Legacy to the extreme*), and L.M.F. Moonen.
- Fifth International Conference on Mathematics of Program Construction (MPC 2000), Ponte de Lima, Portugal, July 3–7: R. Lämmel, J. Visser.
- Workshop on Generic Programming (WGP '00), Ponte de Lima, Portugal, July 6: R. Lämmel (*Dealing with large bananas*), J. Visser.
- WAGA '00, Ponte de Lima, Portugal, July 7: R. Lämmel (*Testing attribute grammars*), J. Visser.
- Working visit DIKU, Copenhagen, July 22–25: R. Lämmel (*From updatable bananas to functional strategies*).
- Scottish Functional Programming Workshop, St. Andrews, Scotland, July 26–28: J. Visser (*Type-safe functional strategies*).
- International Conference on Advances in Infrastructure for Electronic Business, Science, and Education on the Internet (SSGRR2000), L'Aquila, Italy, July 31–August 6: J. Heering (*Application software, domain-specific languages, and language design assistants*).
- TOOLS '00, Santa Barbara, USA, June 31–August 2: R. Lämmel (*Programming with patterns*).
- COFI Workshop, Bremen, Germany, September 10–11: M.G.J. van den Brand.
- International Summerschool on Applied Semantics (APPSEM 2000), Caminha, Portugal, September 9–15: M. de Jonge, J. Visser.
- Principles, Logics, and Implementations of High-Level Programming Languages, (PLI2000), Montréal, Canada, September 17–22: M.G.J. van den Brand, J.J. Vinju.

- RULE 2000, Montréal, Canada, September 18–19: M.G.J. van den Brand, J.J. Vinju (*Rewriting with layout*).
- Working visit University of Bremen, Germany, September 22: R. Lämmel (*From updatable bananas to functional strategies*).
- Working visit Software Improvement Group BV, Amsterdam, September 28: R. Lämmel (*Grammar engineering*).
- Working visit Lucent, Hilversum, October 3: M. de Jonge, P. Klint (*Domain-specific tool construction*).
- IEEE Visualization 2000, Salt Lake City, USA, October 8–13: H. Huitema (*Interactive Visualizaton of protein dynamics*), W.C. de Leeuw (*Visualization of time dependent confocal microscopy data*).
- Symposium on New Paradigms in Information Visualization, Washington D.C., USA, October 9–12: R. van Liere (*Multidimensional feature spaces*).
- Generative and Component-Based Software Engineering (GCSE 2000), Erfurth, Germany, October 9–12: M. de Jonge, J. Visser (*Grammars as contracts*).
- Nordic Workshop on Programming Theory (NWPT '00), Bergen, Norway, October 11–13: J. Heering (*Language design assistants as knowledge based systems*).
- SAGA Project Meeting, Bergen, Norway, October 16: J. Heering (*Some issues in program restructuring and optimization*).
- WCRE 2000, Brisbane, Australia, October 23–25: L.M.F. Moonen (*Exploring legacy systems using types*).
- Working visit LORIA, Nancy, October 24–27: R. Lämmel (*Many-sorted generic traversals*), J. Visser (*Type-safe functional strategies*).
- ACM VRST 2000, Seoul, Korea, October 22–25: R. van Liere (*Fast perception based depth-of-field rendering*).
- Effective Implementation of Object-Oriented Programming Languages, Dagstuhl, Germany, November 6–10: M.G.J. van den Brand (*The new ASF+SDF Meta-Environment*).
- Working visit University of Maribur, November 27: R. Lämmel (*Semantics of crosscutting*).

Memberships of Committees and Other Professional Activities

M.G.J. van den Brand:
- PC member CSMR 2000, RULE 2000.

A. van Deursen:
- PC member IEEE WCRE 2000.

J. Heering:
- PC member LDTA '01.
- Co-organizer HICCS-35 DSL track.

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).
- PC member POPL '01.
- Editor *Science of Computer Programming*.
- Member 'Voorbereidingscommissie NWO programma Software Engineering'.
- Member PhD committee: F. Waes (UvA, November 3).

W.C. de Leeuw:
- Conference co-chair EG/IEEE VisSym '00.
- PC member EG/IEEE VisSym '00.

J.D. Mulder:
- Conference co-chair Eurographics Virtual Environments '00.
- PC member Eurographics Virtual Environments '00.

R. van Liere:
- Conference co-chair Eurographics Virtual Environments '00, EG/IEEE VisSym '00.
- Paper chair IEEE Vis '00 case studies.
- PC member Eurographics Virtual Environments '00, EG/IEEE VisSym '00, IEEE Vis '00, Eurographics '00, ACM NPIV, IEEE SPIE, Computing and Visualization in Science, IEEE Computer Graphics & Applications.

Visitors

- C. Ryan (University of Limerick, February 24)
- E. Visser (Unversity of Utrecht, March 2)
- F. Tip (IBM Watson Research Center, April 4)
- J. Kamperman (Reasoning, April 10)
- R. Monajemi (Lucent/Bell Labs, May)
- E. Meijer (Microsoft, September 7)
- R. Monajemi (Lucent/Bell Labs, September 21)
- D. Dhamdhere (Indian Institute of Technology, October 25)
- D. Hanson (Microsoft Research, December 7)

Software Developed
SEN1.4

- Improved SGLR parse table interpreter
- Enhanced ASF+SDF interpreter capable of dealing with traversal functions
- JAVA version of ATerm library
- Generic prettyprinting tools
- ELAN parser in cooperation with LORIA (Nancy, France).

Papers in Journals and Proceedings

M.G.J. van den Brand, H.A. de Jong, P. Klint and P.A. Olivier (2000). Efficient annotated terms. *Software – Practice & Experience* **30** (3), 259–291.

M.G.J. van den Brand and C. Ringeissen (2000). ASF+SDF parsing tools applied to ELAN. *Proceedings of Third International Workshop on Rewriting Logic and its Applications (WRLA 2000).*

M.G.J. van den Brand and J. Scheerder (2000). Development of parsing tools for CASL using generic language technology. *Proceedings of Recent Trends in Algebraic Development Techniques (WADT '99)*, *LNCS* **1827**, Springer-Verlag, 89–105.

M.G.J. van den Brand, A. Sellink and C. Verhoef (2000). Generation of components for software renovation factories from context-free grammars. *Science of Computer Programming* **36**, 209–266.

M.G.J. van den Brand and J.J. Vinju (2000). Rewriting with layout. *Proceedings of First International Workshop on Rule-Based Programming (RULE 2000).*

A. van Deursen, A. Quilici and S. Woods (2000). Program plan recognition for year 2000 tools. *Science of Computer Programming* **36**, 303–324.

A. van Deursen, P. Klint and J. Visser (2000). Domain-specific languages — An annotated bibliography. *ACM SIGPLAN Notices* **35** (6) (June).

A. van Deursen, L. Moonen and T. Kuipers (2000). Legacy to the extreme. *Extreme Programming and Flexible Processes in Software Engineering (XP2000)*, Addison-Wesley.

A. van Deursen and L. Moonen (2000). Exploring legacy systems using types. *Proceedings 7th Working Conference on Reverse Engineering.* IEEE Computer Society.

J. Heering (2000). Application software, domain-specific languages, and language design assistants, *Proceedings SSGRR 2000 International Conference on Advances in Infrastructure for Electronic Business, Science, and Education on the Internet.*

J. Heering and P. Klint (2000). Semantics of programming languages: A tool-oriented approach. *ACM SIGPLAN Notices* **35** (3) (March) 39–48.

H. Huitema and R. van Liere (2000). Interactive visualization of protein dynamics. *Proceedings IEEE Visualization 2000*, IEEE Computer Society Press, 465–468.

H. Huitema and R. van Liere (2000). Time critical computing and rendering of molecular surfaces using a zonal map. *Proceedings EG Workshop on Virtual Environments*, Springer Verlag, 115–124.

R. Lämmel (2000). Reuse by program transformation. G. Michaelson and P. Trinder (eds.). *Functional Programming Trends*, Intellect.

R. Lämmel and P. Forbrig (2000). Programming with patterns. *Proceedings of TOOLS USA 2000*, Santa Barbara, August, IEEE.

R. Lämmel and J. Harm (2000). Two-dimensional approximation coverage. *Informatica Journal* **24** (3).

R. Lämmel, J. Visser and J. Kort (2000). Dealing with large bananas. *Proceedings of WGP '00*, Ponte de Lima, July 2000, published as technical report, Dept. of Inf. and Comp. Sc., University of Utrecht.

R. Lämmel and J. Harm (2000). Testing attribute grammars. *Proceedings of WAGA '00*, Ponte de Lima, July, published as INRIA research report.

W.C. de Leeuw and R. van Liere (2000). Multi-level topology for flow visualization. *Journal for Computers and Graphics*, **24** (3), 325–331.

W.C. de Leeuw and R. van Liere (2000). Methods for interactive visualization of large flow data sets. *Proceedings of SPIE Volume 3960: Visual Data Exploration and Analyses VII*, SPIE–The International Society for Optical Engineering, 260–267.

W.C. de Leeuw, R. van Liere, P. Verschure, A. Visser, E. Manders and R. van Driel (2000). Visualization of time dependent confocal microscopy data. *Proceedings IEEE Visualization 2000*, IEEE Computer Society Press, 473–476.

R. VAN LIERE and W.C. DE LEEUW (2000). Exploration of large image collections using virtual reality devices. *Proceedings on New Paradigms for Information Visualization (NPIVM'99)*,

R. VAN LIERE and W.C. DE LEEUW (2000). Spotting structure in turbulent flow. *Scientific Visualization – Dagstuhl '97 Proceedings*, IEEE Computer Society Press, 47–53.

R. VAN LIERE, J.D. MULDER, J. FRANK and J. DE SWART (2000). Virtual Fekete: A case study in perturbing complex systems. *Proceedings of IEEE VR 2000*, IEEE Computer Society Press, 189–196.

J.D. MULDER and R. VAN LIERE (2000). Fast perception-based depth of field rendering. *Proceedings ACM Symposium in Virtual Reality Software and Technology (VRST 2000)*, ACM Press, 129–133.

J.D. MULDER and R. VAN LIERE (2000). Enhancing fishtank virtual reality. *Proceedings of IEEE VR 2000*, IEEE Computer Society Press, 91–98.

J. VAN WIJK, R. VAN LIERE and J.D. MULDER (2000). Bringing computational steering to the user. *Scientific Visualization – Dagstuhl '97*, IEEE Computer Society Press, 304–313.

CWI Reports

The following CWI reports were published by members of theme SEN1. See page 39 for the complete titles of the reports.

SEN-R0003	SEN-R0010	SEN-R0011
SEN-R0014	SEN-R0017	SEN-R0018
SEN-R0032	SEN-R0041	

Other Publications

A. VAN DEURSEN, B. ELSINGA, P. KLINT and R. TOLIDO (2000). From legacy to component: Software renovation in three steps. *CAP Gemini White Paper.*

Books

W.C. DE LEEUW and R. VAN LIERE (eds). *Data Visualization 2000 – Proceedings of the Joint Eurographics and IEEE TCVG Symposium on Visualization.* Springer Verlag.

J.D. MULDER and R. VAN LIERE (eds). *Virtual Environments 2000 – Proceedings of the Eurographics Workshop on Virtual Environments.* Springer Verlag.

Specification and Analysis of Embedded Systems – SEN2

Staff

- Prof. dr. ir. J.F. Groote, theme leader (till September 1) (seconded from September 1)
- Prof. dr. J.A. Bergstra, advisor
- Drs. S.C.C. Blom, project member (from March 1)
- Dr. W.J. Fokkink, project leader (till September 1), theme leader (from September 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) (till September 16), project member (from September 16)
- Ir. R. Manniesing, PhD student (from March 1 till December 1)
- Dr. S. Mauw, project member (seconded)
- Dr. V. van Oostrom, project member (till April 1)
- Drs. S. Orzan, PhD student (from June 1)
- Drs. J. Pang, PhD student (from August 1)
- Dr. J.C. van de Pol, project member (till September 1), project leader (from September 1)
- Dr. A. Ponse, project member (seconded)
- Drs. Y.S. Usenko, project member
- Dr. J.J. van Wamel, project member (till October 16)
- Dr. A.G. Wouters, project member
- Dr. H. Zantema, project member (seconded) (till November 1)
- Drs. M.B. van der Zwaag, junior researcher (NWO-EW) (PhD student)

Scientific Report

μCRL Toolset

Izak van Langevelde complemented a new file format for state spaces (called the SVC format), development of which was initiated in 1999, with a tight compression scheme. An implementation of the application programming interface was released, and a toolset for the analysis, visualization and manipulation of SVC files has started to grow. Bert Lisser worked on the development and implementation of the SVC tool 'bsim'. This tool performs bisimulation reductions on state

spaces in SVC format. It is based on the algorithm for solving the relational coarsest partition problem by Paige and Tarjan. Stefan Blom and Bert Lisser developed and implemented a parallel version of the instantiator. This parallel instantiator makes state space generation less time consuming. Different regions of the state space are explored at the same time by independent processes, called steppers. There is a main process which distributes states among the steppers and which stores all the states generated by those steppers. Jan Friso Groote and Jaco van de Pol devised and implemented an algorithm to use confluence of τ-transitions in the reduction of state spaces. They also devised and implemented an extension of binary decision diagrams with equalities. Stefan Blom made a prototype implementation of an instantiator for the μCRL toolset that exploits a new, more strict notion of τ-confluence that can be used to do on-the-fly state space reduction during state space generation. Jaco van de Pol implemented a theorem prover based on binary decision diagrams, to automatically generate and prove logical formulas such as invariants and confluence properties. The theorem prover has been applied successfully to prove τ-confluence properties for SPLICE, a Sliding Window Protocol, and the Dolev-Klaw-Rodeh leader election protocol. In all cases the result was a reduced state space. Arno Wouters completed a manual for the μCRL toolset.

Industrial Case Studies

Stefan Blom worked on modeling railway interlockings (safety systems) in μCRL. He implemented a tool that translates EURIS/IDEAL specifications to μCRL. The resulting state spaces were so large that as a result he started working on reduction techniques based on τ-confluence and on a parallel implementation of the instantiator. Stefan Blom was seconded for 0.2 at EESI in Eindhoven, where he worked on the design and implementation of a Java package for accessing sensors and actuators with drivers for the Lego Dacta and Fischer Technik interfaces. In collaboration with Hollandse Signaal, Jaco van de Pol and Simona Orzan investigated the expressiveness of the coordination language SPLICE, while Rashindra Manniesing worked on formal specifications of a shared dataspace architecture. In collaboration with Weidmüller, Jan Friso Groote, Jun Pang and Arno Wouters analyzed an existing distributed system for lifting trucks using μCRL. Four errors were found in the original design, among which one was unknown to the developers and found its way into the implementation. They proposed solutions for these problems and showed by means of model checking that the modified system meets the requirements. Yaroslav Usenko worked in the context of the DR-TESY project on the verification of an airborne navigation system via a combination of verification tools (in cooperation with GMD-First and MSU). Jos van Wamel collaborated with Philips to develop a test set for the HAVi specification.

Foundations of μCRL

Izak van Langevelde investigated symmetry of state spaces, for example using the fact that it is in some sense irrelevant what data is sent and received using a communication protocol, although the handling of different data is not equivalent in a strict bisimulation sense. This research aims at formulating conditions under which operations like bisimulation reduction and model checking can be performed on one 'mirroring half', after which the result is 'mirrored' to obtain the full result. Jan Friso Groote, Alban Ponse and Yaroslav Usenko developed an algorithm for the linearization of pCRL specifications. Jan Friso Groote and Jos van Wamel wrote a paper on the linearization of uniform parallel processes. Mark van der Zwaag studied time-stamped actions in pCRL algebras. Jan Friso Groote, Jos van Wamel and Mark van der Zwaag obtained a completeness result for timed μCRL (jointly with Michel Reniers). Mark van der Zwaag extended the cones and foci proof technique to timed transition systems. Bas Luttik thoroughly revised his article on the expressiveness of choice quantification. Wan Fokkink and Jan Friso Groote wrote a sizeable set of course notes on protocol verification in μCRL (joint work with Michel Reniers).

Process Theory

Wan Fokkink wrote a paper on the inaxiomatizability of nested simulation (joint work with Luca Aceto and Anna Ingólfsdóttir). He worked on two chapters for the *Handbook of Process Algebra*; one on structural operational semantics (jointly with Luca Aceto and Chris Verhoef) and one on recursive operations (jointly with Jan Bergstra and Alban Ponse). Wan Fokkink and Bas Luttik wrote a paper presenting a finite inductively complete axiomatization for interleaving. Then, they worked on an extension of this result to a

setting with handshaking communication; their aim is to prove that handshaking does not admit a finite inductively complete axiomatization. Bas Luttik wrote a paper about the unique parallel factorization theorem for a setting with communication; it contains a counterexample that shows that this theorem does not hold in a setting with both 'deadlock' and 'empty process', and it contains a proof for the setting with only the 'empty process'. Wan Fokkink worked on a new technique to derive congruence format for behavioural equivalences (jointly with Bard Bloom and Rob van Glabbeek). Jan Bergstra, Alban Ponse and Mark van der Zwaag worked on branching time and orthogonal bisimulation equivalence. Jan Bergstra and Alban Ponse studied process algebra with five-valued logic. Alban Ponse and Yaroslav Usenko worked on an equivalence of recursive equations in process algebra that is model independent. This equivalence was used to prove the correctness of the linearization algorithm for pCRL.

Term Rewriting

Jaco van de Pol and Hans Zantema described binary decision diagram calculations by means of rewriting. Jan Willem Klop continued his secondment of 0.4 at the Katholieke Universiteit Nijmegen, in the group of Henk Barendregt. For 0.2 he was seconded to the Vrije Universiteit Amsterdam. A study on proof systems for cyclic term graphs was continued. Work on sequentiality in the lambda calculus was resumed. A new study was started concerning cyclic reductions, proving that weakly normalizing orthogonal term rewriting systems admit no cyclic reductions. Most research time of Jan Willem Klop was devoted to finishing the book 'Term Rewriting Systems'. Vincent van Oostrom worked on the foundations of higher-order term rewriting.

Miscellaneous

Jan Friso Groote and Hans Zantema compared binary decision diagrams and resolution. Jan Friso Groote developed a lock free algorithm for parallel accessible hash tables which is being verified using PVS (joint work with Wim Hesselink). Sjouke Mauw worked on the foundations and application of Message Sequence Charts, resulting in several handbook chapters and publications. He developed a novel distributed algorithm for the Write-All problem; work on an algorithm with probabilistic aspects has started. A new branch of research for Sjouke Mauw concentrates on the development of a formal language for the specification and analysis of Internet applications.

PhD Thesis

W.O.D. Griffioen (2000). *Studies in Computer Aided Verification of Protocols.* Thesis advisor Prof. dr. F.W. Vaandrager, May, Katholieke Universiteit Nijmegen.

Knowledge Transfer

- W.J. Fokkink gave a μCRL course at the Vrije Universiteit Amsterdam.
- W.J. Fokkink presented a workshop on the interlocking language EURIS at the 1st IQPC Conference on Signalling Safety in London, March. (jointly with D. van der Meij).
- W.J. Fokkink presented a research seminar at the University of Cambridge, March.
- S.P. Luttik organized a seminar on the pi-calculus.
- S.P. Luttik and M.B van der Zwaag assisted at a course on 'Security of Computer Systems' at the Universiteit van Amsterdam, given by S. Mauw.
- S.P. Luttik and M.B van der Zwaag assisted at a course on 'Program Algebra' at the Universiteit van Amsterdam, given by J.A. Bergstra.
- Dr. TESY project: contacts with GOSNIAS, MSU (Moscow), GMD: Y.S. Usenko.

Organization of Conferences, Workshops, Courses, etc.

- S.P. Luttik organized a weekly seminar (PAM) on process theory, protocol verification, term rewriting and theorem proving.
- I.A. van Langevelde organized an SVC meeting at CWI, June 14.
- W.J. Fokkink, I.A. van Langevelde and J.C. van de Pol organized the 6th Dutch Testing Day, Amsterdam, November 3.

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

- *FRANCESCA meeting*, Milan, Italy, January 4–5: W.J. Fokkink.
- *Project meeting LOPSTR 2000*, Venice, Italy, January 19–21: J.W. Klop (invited lecture *Cyclic term graphs*).

- *Winter School Heriot Watt University*, Edinburgh, UK, January 29–February 3: J.W. Klop (*Cyclic term graphs*).
- *Model Checking and Program Analysis*, Tegernsee, Germany, February 20–25: W.J. Fokkink.
- *Seminar Specification of Distributed Information Systems*, Dagstuhl, Germany, February 20–25: M.B. van der Zwaag.
- *Signal SAFE*, London, UK, March 30: W.J. Fokkink (*EURIS: a specification language for interlocking systems*).
- *Engineering of Computer based Systems*, Edinburgh, UK, April 2–5: J.C. van de Pol (*Refinements in Requirements Specification and Analysis*).
- *Working visit BRICS*, Aalborg, Denmark (Luca Aceto), April 26–May 25: W.J. Fokkink.
- *SAT 2000*, Workshop on satisfiability, Renesse: J.F. Groote, H. Zantema.
- *Ukz PROF-2000*, Kiev, Ukraine, May 23–26: Y.S. Usenko (*Towards a unified toolset for embedded systems development*).
- *CONFER II meeting*, Stockholm, Sweden, June 12–15: J.W. Klop (*Proof systems for Cyclic Term Graphs*).
- *ICALP 2000*, Geneva, Switzerland, July 9–15: S.P. Luttik (*On omega-complete Equational Specification of Interleaving*).
- *Euro-Par 2000*, Munich, Germany, August 28–September 1: R. Manniesing (*Automatic SIMD Parallelization of Embedded Applications based on Pattern Recognition*).
- *MFCS 2000*, Bratislava, Slovakia, August 28–September 1: J.C. van de Pol (*Binary Decision Diagrams by Shared Rewriting / State Space Reduction using Partial τ-Confluence*).
- *Fourth International Conference on Coordination Models and Languages*, Limasol, Cyprus, September 11–13: I.A. van Langevelde (*The verification of Coordination*).
- *Final Project meeting Confer II*, Cambridge, UK, September 13–15: J.W. Klop (*Sequentiality in the Lambda calculus*).
- *PROGRESS'2000*, Utrecht, October 13: J.C. van de Pol (*Design, Tooling and Implementation of a Real-Time, Distributed Shared Dataspace*).
- *Dr. TESY Review meeting 2*, Berlin, Germany, October 18–21: Y.S. Usenko.
- *Logic for Programming and Reasoning*, Reunion Island, November 6-12: J.C. van de Pol (*Equational Binary Decision Diagrams*).
- *Alumni Meeting and Speech Robin Milner*, Swansea, UK, November 10: W.J. Fokkink.
- *IPA Fall Days*, Millingen aan de Rijn, November 20–24: J. Pang, S. Orzan.

Memberships of Committees and Other Professional Activities

W.J. Fokkink:
- Member Program Committee EXPRESS'2000, Pennsylvania, August 21.
- Member Program Committee 6th Dutch Testing Day, Amsterdam, November 3.
- Project manager Systems Validation Centre.

J.F. Groote:
- Full professor of Computer Science at the Technische Universiteit Eindhoven.
- Member Program Committee FMICS'2000, Berlin, April 3–4.
- Moderator concurrency mailing list.
- Reviewer *Zentralblatt für Mathematik*.
- Member PhD committee David Griffioen, Katholieke Universiteit Nijmegen (Studies in Computer Aided Verification of Protocols).
- Member PhD committee Richard Verhoeven, Technische Universiteit Eindhoven (Design of the Mathpad Editor).

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 CSL'2000, Munich, April 10–13.

Visitors

- Anna Ingólfsdóttir, BRICS, Aalborg, Denmark, April 5–11 (*On the two-variable Fragment of the max-sum algebra*).
- Gagan Preet and Pooja Mittal, Indian Institute of Technology, Delhi, India, May 1–August 1.
- Toshiyuki Yamada, University of Tsukuba, Japan, July 13–19 (*Higher-order Rewriting without Bound Variables*).
- Julian Rathke, University of Sussex, UK, August 7–19 (Bisimulation for Local Names).
- Roman V. Koutchakov and Konstantin O. Sasenkov, Moscow, Russia, September 15–October 15 (*DYANA-μCRL integration*).

Software Developed

- The SVC library: implementation of a compact file formal for labeled transition systems.
- Theorem prover for μCRL.
- Parallelization of the instantiator of μCRL.
- Reduction of state spaces based on confluence.
- Maintenance of the μCRL toolkit.
- Compiler of EURIS into μCRL.

Books

W.J. Fokkink (2000). Introduction to Process Algebra, *Texts in Theoretical Computer Science*, An EATCS Series, Springer Verlag.

W.J. Fokkink, J.F. Groote, M. Hollenberg, S.F.M. van Vlijmen (2000). *LARIS 1.0: LAnguages for Railway Interlocking Specifications.* CWI Publications Varia, CWI, 2000.

CWI Reports

The following CWI reports were published by members of SEN2. See page 39 for the complete titles of the reports.

SEN-R0001	SEN-R0002	SEN-R0006
SEN-R0007	SEN-R0008	SEN-R0009
SEN-R0012	SEN-R0015	SEN-R0019
SEN-R0033	SEN-R0034	SEN-R0035
SEN-R0038		

Papers in Journals and Proceedings

Z.M. Ariola, J.W. Klop, D. Plump (2000). Bisimilarity in term graph rewriting. *Information and Computation*, **156** 2–24.

A.G. Bahmurov, V.I. Chervin, M.V. Chistolinov, J.F. Groote, V.A. Kostenko, R.L. Smeliansky, D.V. Tsarkov, Y.S. Usenko, K. Winter, V.A. Zakharov (2000). Towards a unified toolset for embedded systems development. *Scientific Journal Problems of Programming* **1-2**, 316–322.

J.A. Bergstra, A. Ponse (1998). Bochvar-McCarthy logic and process algebra. *Notre Dame Journal of Formal Logic* **39(4)**, 464–484 (issue appeared in 2000).

J.A. Bergstra, A. Ponse (2000). Process algebra with four-valued logic *Journal of Applied Non-Classical Logics* **10**, (1) 27–53.

I. Bethke, J.W. Klop, R.C. de Vrijer (2000). Descendants and origins in term rewriting. *Information and Computation* **159**, 59–124.

B. Bloom, W.J. Fokkink, R.J. van Glabbeek (2000). Precongruence formats for decorated trace preorders. *Proceedings of LICS'2000.* Santa Barbara, IEEE Computer Society Press, 107–118.

M.V. Chistolinov, I.V. Epatko, J.F. Groote, R.V. Konchakov, A.S. Peshko, R.L. Smeliansky, D.V. Tsarkov, Y.S. Usenko, K. Winter, V.A. Zakharov (2000). The development and verification of distributed real time embedded computer systems for avionics (Project DrTesy). *Proceedings of INPRIM'2000* **II**, Novosibirsk, Publishing House of Institute of Mathematics, 128–129.

P.F.G. Dechering, I.A. van Langevelde (2000). The verification of coordination. *Proceedings of COORDINATION'2000*, Limasol, *LNCS* **1906**, 335–340, Springer.

L.M.G. Feijs, N. Goga, S. Mauw (2000). Probabilities in the TorX test derivation algorithm. *Proceedings of SAM'2000* VERIMAG, IRISA, 173–188, SDL Forum Society.

W.J. Fokkink, S.P. Luttik (2000). An omega-complete equational specification of interleaving. *Proceedings of ICALP'2000*, Geneva, *LNCS* **1853**, 729–743, Springer.

W.J. Fokkink, J.F.Th. Kamperman, H.R. Walters (2000). Lazy rewriting on eager machinery. *ACM Transactions on Programming Languages and Systems* **22** (1), 45–86.

W.J. Fokkink (2000). Rooted branching bisimulation as a congruence. *Journal of Computer and System Sciences* **60**, (1) 13–37.

W.J. Fokkink (2000). Language preorder as a precongruence. *Theoretical Computer Science* **243** (1/2), 391–408.

J.F. Groote, J.C. van de Pol (2000). State space reduction using partial τ-confluence. *Proceedings of MFCS'2000, LNCS* **1893**, 383–393, Springer.

J.F. Groote, J.C. van de Pol (2000). Equational binary decision diagrams. *Proceedings of LPAR'2000, LNAI* **1955**, 161–178, Springer.

J.F. Groote, J.P. Warners (2000). The propositional formula checker HeerHugo. *Journal of Automated Reasoning* **24** (1/2), 101–125.

J.F. Groote, J.P. Warners (2000). The propositional formula checker HeerHugo. *Proceedings of SAT'2000, Intelligence and Applications* **63**, IOS Press.

J.W. Klop, V. van Oostrom, R.C. de Vrijer (2000). A geometric proof of confluence

by decreasing diagrams. *J. Logic Computat.* **10** (3), 437–460.

R. Manniesing, I. Karkowski, H. Corporaal (2000). Automatic SIMD parallelization of embedded applications based on pattern recognition. *Proceedings of Euro-Par'2000*, München, *LNCS* **1900**, 349–356, Springer.

J.C. van de Pol, H. Zantema (2000). Binary decision diagrams by shared rewriting. *Proceedings of MFCS'2000, LNCS* **1893**, 609–618, Springer.

H. Vranken, T. Garcia, S. Mauw, L. Feijs (2000). IC design validation using Message Sequence Charts. *Proceedings of DSD'2000*, 122–127.

R. de Vries, J. Tretmans, A. Belinfante, J. Feenstra, L. Feys, S. Mauw, N. Goga, L. Heerink, A. de Heer (2000). Côte de Resyste in PROGRESS. *Proceedings of PROGRESS'2000*, Utrecht, 141–148.

H. Zantema, A. Geser (2000). A complete characterization of termination of $0^p1^q \rightarrow 1^r0^s$ Applicable Algebra in Engineering. *Communication and Computing* **11** (1), 1–25.

Other Publications

J.C.M. Baeten, H.M.A. van Beek, S. Mauw (2000). *Specifying Internet Applications with DiCons.* Technical Report 00-19, Department of Computing Science, Eindhoven University of Technology.

J.A. Bergstra, I. Bethke, A. Ponse. *Basic Multi-Competence Programming.* Report P0001, Programming Research Group, University of Amsterdam.

J.F. Groote, M.A. Reniers (2000). *Algebraic Process Verification.* Technical Report 00-05, Department of Computing Science, Eindhoven University of Technology.

J.F. Groote, J. van Wamel (2000). *The Parallel Composition of Uniform Processes with Data.* Technical Report 00-06, Department of Computing Science, Eindhoven University of Technology.

J.F. Groote, H. Zantema (2000). *Resolution and Binary Decision Diagrams cannot Simulate each other Polynomially.* Technical Report UU-CS-2000-14, Department of Computer Science, Utrecht University.

S. Mauw, M.A. Reniers (2000). *A Process Algebra for Interworkings.* Technical Report 00-03, Department of Computing Science, Eindhoven University of Technology.

S. Mauw, M.A. Reniers, T.A.C. Willemse (2000). *Message Sequence Charts in the Software Engineering Process.* Technical Report 00-12, Department of Computing Science, Eindhoven University of Technology.

E. Rietjens, B. Lisser, J. Springintveld, J.F. Groote (2000). *Black-Box Testing from ISpec Interface Specifications (confidential).* Nat.Lab. Technical Note TN 2000/047, Philips.

M. Voorhoeve, S. Mauw (2000). *Impossible Futures and Determinism.* Technical Report 00-14, Department of Computing Science, Eindhoven University of Technology.

H. Zantema (2000). *Termination of Term Rewriting.* Technical Report UU-CS-2000-04, Department of Computer Science, Utrecht University.

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/GE PhD student
- Drs. C.L. Blom, programmer
- Dr. M.M. Bonsangue, postdoc
- F.J. Burger, programmer
- M. Coccia, Erasmus student (until February 29)
- Drs. C.T.H. Everaars, programmer
- J.V. Guillen Scholten, trainee (from August 1)
- Drs. J. den Hartog, VU seconded (until September 1) and NWO/GE PhD student (from September 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. In particular, the research of this theme has concentrated on:

- Development of formal models for coordination, components, and component based software.
- Study of the foundations of computation, notably operational semantics and coalgebraic methods.

- Development of and experiments with the coordination language 'Manifold' and its visual programming and debugging environment;
- Using the Manifold system to work on real applications of coordination programming in numerical computing.

The theme has cooperated with many internal and external partners, including MAS2 (Piet Hemker and Barry Koren), PNA1 (Krzysztof Apt), PNA2 (Jan van Schuppen), TNO-FEL (H.F.R. Arciszewski), UU (Frank de Boer), UL (Joost Kok), UvA (Yde Venema, Johan van Benthem), KUN (Bart Jacobs), and many universities abroad. The year 2000 has been particularly successful regarding external funding: all three NWO/GE applications we have been involved in, have been granted (yielding approximately 8 man years); a joint project with TNO-FEL has been awarded; and an ERCIM fellowship has been assigned to our theme.

Formal methods for coordination languages – SEN3.1

Within this subtheme, F. Arbab and M. Bonsangue have started, in collaboration with F. de Boer from Utrecht University, studies of component-based systems, both from the formal and engineering points of view. The aim is to develop a programming environment to support component-based design and compositional verification of large application programs. More specifically, a model has been proposed based on a notion of component that allows for encapsulation of its internal data-processing aspects as well as composition by means of mobile asynchronous channels. A compositional semantics and assertional methods have already been developed for this formal model, reflecting the above separation of concerns between internal data-processing aspects and data-communication.

Further, preliminary studies have been undertaken in order to provide the formal underpinnings of a development process for component-based systems based on visual languages like UML (Unified Modeling Language). Work in this direction involves the development of behaviour diagrams for individual components, extending the UML's statechart diagrams and the definition of a component constraint logic, improving the OCL (Object Constraint Language) logic language.

Juan Scholten (Leiden University) has started to work for his master thesis on a distributed implementation in Java of the proposed model for mobile asynchronous channels.

F. Arbab developed a new family of general Distributed Termination Detection Algorithms, called Back To The Future (BTTF), with significantly improved performance. These algorithms take advantage of system-wide apparent causal relationships that can be established among messages exchanged in a distributed system, using only the externally observable behaviour of each of its components. This work includes the underlying formalism for the BTTF algorithms, an outline of their correctness proofs, and a detailed analysis of their performance.

C.L. Blom and F. Arbab implemented specialized versions of the BTTF algorithms in Manifold. A full Java implementation of these algorithms was started by C.L. Blom in the end of the year 2000 and is in progress.

Experimental testbed for control-oriented coordination – SEN3.2

The planned improvements and enhancements to the Manifold system were completed in 2000. The higher-level atomic process interface functions interface was completed and is being used in the implementation work on the Distributed Constraint Programming application. The Manifold system is now stable and further work on its maintenance and enhancements will continue in 2001 as an activity under our on-going work on coordination applications.

Coordination applications – SEN3.3

The work on the application of Manifold in parallelization and distribution of numerical computation (with MAS2) under the project BINGO (Everaars, Arbab, and Koren) funded by NCF was completed in 2000. The final report of this project was submitted. The work with PNA1 on coordination of distributed constraint systems (E. Monfroy, K. Apt, C.L. Blom, and F. Arbab) continued in 2000. Specifically, we extended our previous results to incorporate splitting schemes and search strategies for distributed constraint programming within the same coordination environment. Our NWO proposal for the continuation of this work was granted in 2000. Dr. E. Monfroy left CWI at the end of the spring and joined the University of Nantes, France. His departure and our inability to fill one of the two OIO position vacancies created by the NWO project, slowed

down our activity. C.L. Blom investigated adaptations of the BTTF algorithms for distributed termination detection in the context of our constraint programming environment.

Exploratory research:
Coalgebraic models of computation – SEN3.4

The theory of coinduction and coalgebra was studied and applied to various topics in computer science and mathematics, including specification, modal logic, and control theory. The future for this all in all rather fundamental type of research was further secured by our participation in two recently granted NWO projects, together with UvA (Venema, Van Benthem) and KUN (Jacobs), on coalgebra and modal logic, and together with PNA 2 (Van Schuppen), on coalgebra and control. The coalgebra group of CWI continues to play an active role in the further development of coalgebra as a discipline worldwide, amongst others by the involvement of Baltag and Rutten in the CMCS workshop series.

The research of Bartels, in the context of NWO project Promacs in which also TUE (Prof. dr. J. Baeten) participates, was focused on generalized definition and proof principles for coalgebras. This was done mainly to provide abstract categorical means to cover techniques in use for concrete dynamical systems. As a particular example, composition operators as they are used in Process Algebra were studied. The results have been published as a CWI report under the name 'Generalised Coinduction'.

Baltag, another member of the Promacs project, worked on modal logics for coalgebras and on dynamic-epistemic logic and its various applications to game theory, communication, and control theory. On the first line of research, previous work on coalgebraic simulation was improved using 'co-algebraic logic' that generalizes standard modal logic.

Model-theoretic properties of this logic were studied, and a general method for obtaining modal logics from coalgebraic logics was developed. Previous work on a logic of epistemic actions was generalized as to include nondeterministic actions and probabilistic epistemic actions. These notions were used to characterize and study various game-theoretic concepts. The resulting theory was applied to games with cheating and deceiving, issues related to communication and security protocols, and some issues in control theory.

The research of Kurz dealt with the following topics: Together with Dirk Pattinson (LMU, München) coalgebras for parameterized signatures and their logics were investigated. Together with Rolf Hennicker (LMU, München) and Michel Bidoit (LSV, France) the duality of observability and reachability in algebraic specification was formalized and a new concept of constructor-based specifications was introduced. Moreover, an abstract study of logics for coalgebras was undertaken.

Jerry den Hartog worked part time at CWI until September 1st, at which time he entered full time employ. He continued his research on adding probabilistic choice to semantical models and to verification methods. In particular, a probabilistic Hoare-style logic was developed. In joint work with De Bakker and De Vink (formerly VUA), the combination of the operations probabilistic choice and action refinement was also studied. Besides this research, he has also been working on writing his thesis, under the guidance of De Bakker, Rutten, and De Vink.

Continuing his work on applications of coinduction in computer science and mathematics, Rutten further developed a calculus of formal power series in several (non-commutative) variables, based on the notion of input-derivative and behavioural differential equation. Special attention was given to the special case of streams (here: infinite sequences of real numbers), paving the way for applications to control theory, difference and differential equations, and probabilistic transition systems.

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. The following presentations were given:
  - January 25: *Semantics of sigma pi*, Marcello Bonsangue.
  - February 8: *Combinators for hyperedge replacement graph rewriting*, Matteo Coccia.
  - March 7: *A Generalized Scheme for Coinductive Definitions*, Falk Bartels.
  - March 28: *Modeling continuous probabilistic choice using stochastic kernels*, Jerry den

Hartog.
- April 11: *Information update and epistemic actions*, Alexandru Baltag.
- May 9: *Stream calculus*, Jan Rutten.
- May 16: *Back To The Future: A Family of DTD Algorithms*, Farhad Arbab.
- June 13 and 20: *A logical interface description language for components*, Marcello Bonsangue.
- September 12: *On the Duality of Observability and Reachability*, Alexander Kurz.
- September 19: *On the Duality of Modal and Equational Logic*, Alexander Kurz.
- October 3: *Modeling Games using Probabilistic-Epistemic Processes and Modal Logic*, Alexandru Baltag.
- October 17: *Towards Quantitative Verification of Systems: a Metric Approach*, Franck van Breugel.
- October 31 and November 21: *Back To The Future: A Family of Algorithms for Termination Detection in Distributed Systems*, Farhad Arbab.
- November 14: *Semantical Principles in the Modal Logic of Coalgebras*, Dirk Pattinson.
- December 19: *Infinite intersection and union types for the lazy lambda calculus*, Marcello Bonsangue.

- Coordina meeting Pisa-Amsterdam, CWI, Amsterdam, January 12–13. Following an earlier meeting, one year before, in Pisa, another joint mini-workshop was held, at which presentations were given on formal methods and models for coordination and component-based software engineering. Participants were members of the research group of Prof. dr. U. Montanari (Univ. of Pisa) and members of our theme.
- Coordina meeting, CWI, Amsterdam, November 6–7.
- A. Baltag tought a course 'Advanced Modal Logic' at the UvA (with Yde Venema), in the Spring semester of 2000.

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

- Pisa meets Amsterdam Colloquium, Amsterdam, January 13–14: J.W. de Bakker, F. Arbab, M. Bonsangue (*The semantics of a simple language for mobile programming*), C.T.H. Everaars, C. Blom (*An implementation in Manifold of a chaotic iteration algorithm*), F.J. Burger, J.J.M.M. Rutten.
- Seminar, Leiden Institute for Advanced Computer Science, University of Leiden, January 31: F. Arbab.
- Invited lecture at GROLOG Seminar, University of Groningen, February 17: A. Baltag (*A Logic of Epistemic Actions*).
- Visits and Talks, Indiana University, Stanford University, University of Chicago, USA, February 20–27: A. Baltag (*Logics for Information Updates*).
- Theoriedag NVTI 2000, March 10: F. Arbab, J.W. de Bakker, F. Bartels, A. Baltag, M.M. Bonsangue, J.J.M.M. Rutten.
- PC meeting ICALP 2000, Geneva, Switzerland, March 17–18: J.J.M.M. Rutten.
- SAC 2000 15th annual ACM Symposium on Applied Computing, Como, Italy, March 19–21: F. Arbab, M.M. Bonsangue (*A Coordination language for mobile components*).
- CMCS 2000 (Third international workshop on Coalgebraic Methods in Computer Science), Berlin, Germany, March 25–26: A. Baltag (*A Logic for Coalgebraic Simulation*), F. Bartels, J.J.M.M. Rutten.
- MFPS 2000 Mathematical Foundations of Programming Semantics, Hoboken, USA, April 13–16: J.J.M.M. Rutten (*Coalgebra and control*).
- Coordina Semantics Workshop, London, UK, April 13–14: F. Arbab, J.W. de Bakker, J. den Hartog (*A Hoare like logic for verifying probabilistic programs*).
- Second Workshop GLLC '00 (Games in Logic, Language and Computation), ILLC, UvA Amsterdam, April 14: A. Baltag (*Logics for Games*).
- IPA Springs days on UML, Eindhoven, April 26–28: M.M. Bonsangue.
- ZIC, Zuidelijk Interuniverstitair Colloquium (Drs. R. Bloo and Dr. D. Dams, hosts), TUE, Eindhoven, May 2: J.J.M.M. Rutten (*Regular expressions revisited*, invited lecture).
- PC meeting MFCS 2000, Bratislava, Slowakia, May 20–21: J.J.M.M. Rutten.
- INCO-DC KIT projectmeeting, Cyprus, June 7–9: F. Arbab.
- PDPTA 2000, Las Vegas, USA, June 26-29: F. Arbab.
- Logic and Foundations of Game and Decision Theory, Torino, Italy, June 30-July 2: A. Baltag (*A logic for suspicious players: epistemic actions and belief-update in games*).
- MPC 2000 (Fifth international conference on the Mathematics of Program Construction), Ponte de Lima, Portugal, July 3–5: J.J.M.M. Rutten (*Regular Expressions Revisited: a Coinductive Approach to Streams, Automata, and Power Series.* Invited lecture).

- Summerschool on Formal Methods and Performance Analysis, Nijmegen, July 3–7: F. Bartels.
- PhD Defence, Graduation of Ms. Ladan Pooyan (Prof. B. Mahr, thesis advisor), TU Berlin, July 6: J.J.M.M. Rutten (external examiner).
- Barcelona Logic Meeting, Barcelona, Spain, July 5–9: A. Baltag (*Model Theory of Coalgebraic Logic: Characterization, Preservation, Definability*).
- Seminar on Coalgebras and Modal Logic, ILLC, UvA, Amsterdam July 18: A. Baltag (*Coalgebraic Logic*).
- First Irish Conference on the Mathematical Foundations of Computer Science and Information Technology MFCSIT 2000, Cork, Ireland, July 20–21: J.W. de Bakker *(Fixed Points in Metric Semantics*, invited lecture), J. den Hartog *(Combining Probabilistic Choice and Action Refinement in a Metric Setting)*.
- FICS 2000 (Fixed points in Computer Science), Paris, France, July 22–23: J.J.M.M. Rutten (*Behavioural differential equations in stream calculus*, invited lecture).
- Logic Colloquium 2000, Paris, France, July 23–31: A. Baltag (*Universal Set Theory and Strong Modal Reflection Principles*).
- WODES 2000 (*5th Workshop on Discrete Event Systems*), Ghent, Belgium, August 21–23: J.J.M.M. Rutten (*Coalgebra, Concurrency, and Control*).
- PhD Defence, Graduation of Ms. Corina Cirstea (Dr. G. Malcolm and Dr. L. Ong, thesis advisors), University of Oxford, UK, August 28: J.J.M.M. Rutten (external examiner).
- Colloquium of the Computing Laboratory Oxford (Dr. O. de Moor, host), University of Oxford, August 28: J.J.M.M. Rutten (*Behavioural differential equations*, invited lecture).
- MFCS 2000 International Symposium on Mathematical Foundations of Computer Science, Bratislava, Slowakia, August 27–31: M.M. Bonsangue (*A compositional model for confluent dynamic data-flow networks*).
- Coordination 2000, Cyprus, September 10–15: F. Arbab.
- Meeting IFIP Working Group 2.2, Oldenburg, Germany, September 27–29: J.W. de Bakker.
- Meeting Steering Committee European Educational Forum, Haarlem, October 6–7: J.W. de Bakker.
- *Working visit University of Munich*, Munich, Germany (Prof. R. Hennicker), October 12–17: A. Kurz.
- Ozsl School Week (Dutch research school in logic), Nunspeet, October 24–25: A. Baltag, J.J.M.M. Rutten (*An introduction to coalgebra, and: Stream calculus.* Invited course).
- Invited Lecture at Foundations of Formal Sciences II, Bonn, Germany, November 10–13: A. Baltag (*Modal Logic for Games: Tools for studying the dynamics of knowledge and belief*).
- AT Computing Course on Java, November 16–21: C.T.H. Everaars, C.L. Blom.
- IPA Fall days, Millingen a.d. Rijn, November 20–24: F. Bartels.
- Fourth Workshop GLLC'00, Groningen University, November 21: A. Baltag (*Games and Epistemic Actions*).
- Eighteenth Annual Victorian Algebra Conference, Melbourne, Australia, November 23–24: J.J.M.M. Rutten (*An introduction to coalgebra*, invited lecture).
- Honorary Doctorate Ceremony for A. Pnuel, University of Oldenburg, Germany, November 24: J.W. de Bakker.
- La Trobe University, Department of Mathematics (Dr. Brian Davey, host), Melbourne, 27 November–6 December: J.J.M.M. Rutten (12 lectures on behavioural differential equations and quantitative bisimulation. Invited intensive course).
- Working visit, Dept. of Electrical and Electronic Engineering (Prof. Iven Mareels, host), The University of Melbourne, Australia, 5 December: J.J.M.M. Rutten (*Coalgebra and the control of discrete event systems*).
- *Working visit* to Dr. Pierre America, Philips, December 21: F. Arbab, M. Bonsangue.
- *Working visits*, Ordina Institute (host: E. Proper), Gouda, several occasions: F. Arbab, M.M. Bonsangue.

Memberships of Committees and Other Professional Activities

F. Arbab:

- Member IPA, Dutch Graduate School Institute for Programming and Algorithmics.
- Member of the Esprit Working Group 24512 Coordina.
- Track Chair, PDPTA 2000 conference, Las Vegas, June 26–29.

- Associate Editor *Proceedings of the International Conference on Parallel and Distributed Processing Techniques and Applications*, Las Vegas, Nevada, USA, June 26–29.
- Program committee member, ISADS: International Symposium on Advanced Distributed Systems, Guadalajara, Jalisco, Mexico, March 8–10.
- Program committee member, HPCN 2000, Amsterdam, May 8–10.
- Program committee member, Coordination 2000, Limasol, Cyprus, September 11–13.
- Editorial Board Member *Parallel Computing* journal.
- Coordinator, ESPRIT INCO-DC EC project 962144.
- Advisory Board Member, *Euro-Par 2000.*
- PhD Committee Outside Member for Andrea Sosio, University of Milan, Italy.

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*
- 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 steering Committee European Educational Forum (IPA, BRICS, TUCS and four further consortia).
- Member ESPRIT Working Group Coordina
- Member of IFIP Technical Committee 1 on Foundations of Computer Science.
- Member selection committee:
  - Chair Information Systems, VUA.
  - Chair Multimedia and Internet Technology, TUE
  - Chair E-business, Electronic Markets and Informatics, TUE
- Member uhd assessment committee VUA, TUE.
- (Co)project leader NWO/EW project Biography of Aad van Wijngaarden.

A. Baltag:
- Member of the LIC group (Logic in Communication), ILLC, UvA.
- Member of the program committee of CMCS'01 (the fourth international workshop on 'Coalgebraic Methods in Computer Science').
- Member of the SION project 'ProMACS – Probabilistic Methods for the Analysis of Continuous Systems'.

F. Bartels:
- Member IPA, Dutch Graduate School Institute for Programming and Algorithmics.

M.M. Bonsangue:
- Member IPA, Dutch Graduate School Institute for Programming and Algorithmics.
- Member of the Esprit Working Group 24512 Coordina.
- External supervisor master thesis of Matteo Coccia from Scuola Normale, Pisa, Italy.
- Supervisor of master thesis of Juan Scholten from Leiden University.

J.J.M.M. Rutten:
- Project leader of the SION 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 committees of ICALP 2000, MFCS 2000, CMCS 2000, DMTCS 2001, CMCS 2001.
- External examiner PhD theses of L. Pooyan-Weihs, Technical University, Berlin; C. Cirstea, University of Oxford.

Papers in Journals and Proceedings

J.W. de Bakker, F.C. van Breugel (2000). From Banach to Milner: Metric semantics for second order communication and concurrency. G.D. Plotkin et al (eds.). *Proof, Language, and Interaction, Essays in Honour of Robin Milner*, MIT Press, 99–132.

K. Everaars, F. Arbab and B. Koren (2000). Dynamic process composition and communication patterns in irregularly structured applications. *Concurrency: Practice and Experience* **12**, John Wiley & Sons, Ltd., 157–174.

Pascal Bouvry, Farhad Arbab and Franciszek Seredynski (2000). Distributed evolutionary optimization in Manifold: Rosenbrock's function case study. *Information Sciences* **122**, 141–159.

G.A. Papadopoulos and F. Arbab (2000). Dynamic reconfiguration in coordination languages. *Proc. of the 8th International Conf. on High Performance Computing and Networking, HPCN Europe 2000*, Amsterdam, *LNCS* **182**, 197–206.

G.A. Papadopoulos and F. Arbab (2000). Coordinating electronic commerce activities in Manifold. *Netnomics* **2**, 101–116.

M.M. Bonsangue, F. Arbab, J.W. de Bakker, J.J.M.M. Rutten, A. Scutella and G. Zavattaro (2000). A transition system semantics for the control-driven coordination language MANIFOLD. *Theoretical Computer Science* **240** (1), 3–47.

F. Arbab, M.M. Bonsangue and F.S. de Boer (2000). A coordination language for mobile components. J. Carrol, E. Damiani, H. Haddad and D. Oppenheim (eds.). *Proceedings of the 2000 ACM Symposium on Applied Computing (SAC 2000)*, 166–173, ACM press.

F.S. de Boer and M.M. Bonsangue (2000). A compositional model for dynamical data-flow networks. M. Nielsen and B. Rovan (eds.). *Proceedings of the 25nd MFCS*, Bratislava, Slovakia, *LNCS* **1893**, 212–221, Springer-Verlag.

F. Arbab, M.M. Bonsangue and F.S. de Boer (2000). A logical interface description language for components. A. Porto and G.-R. Roman (eds.). *Proceedings of COORDINATION 2000 LNCS* **1906**, 249–266.

J.J.M.M. Rutten (2000). Universal coalgebra: a theory of systems. *Theoretical Computer Science* **249**(1), 3–80.

J.J.M.M. Rutten (2000). Coalgebra, concurrency, and control. R. Boel and G. Stremersch (eds.). *Discrete Event Systems (analysis and control), Proceedings of WODES 2000* (5th Workshop on Discrete Event Systems), Kluwer, 31–38.

A. Baltag (2000). A logic for coalgebraic simulation. H. Reichel (ed.). *Proceedings of Third Workshop on Coalgebraic Methods in Computer Science* (CMCS'00, Berlin, Germany) March 2000, *ENTCS* **33**, 41–60. Elsevier Science B.V.

Visitors

- U. Montanari, G. Ferrari, R. Bruni, E. Tuosto, C. Montangero, L. Semini, University of Pisa, January 12–16.
- Dr. P.H.M. America, Philips Research, February 4.
- Prof. dr. S. Micali, MIT, Boston, March 9–10.
- Prof. dr. A. Pnueli, Israel, March 9–10.
- Dr. D. Hislop, Army Research Office, USA, April 3.
- Prof. M. Mahoney, Princeton University, June 14.
- Dr. F. van Breugel, York University, Toronto, October 7–22.
- Dr. Erika Abraham-Mumm, University of Kiel, October 22–24.
- Dr. Davide Martineghi, Paris, October 23.
- November 6–7. Preparation meeting for an EC project proposal. Attenders: Paolo Ciancarini, Univ. Bologna; Gianluigi Ferrari, Univ. Pisa; Luis Monteiro, Univ. Nova De Lisboa; Gianluigi Zavattaro, Univ. Bologna; Franz Ackermann, Univ. Bern; George Papadopoulos, Univ. Cypres; Erik Proper, Ordina Inst.; Andries Stam, Ordina Inst.; Alan Wood, Univ. York; Herbert Wiklicky, Imperial College; Chris Hankin, Imperial College; Antonio Porto, Univ. Nova De Lisboa; Andrea Omicini, Univ. Bologna; Joost Kok, Univ. Leiden; Ciaran Bryce, Univ. Geneva; Robert Tolksdorf, Tech. Univ. Berlin; Jose Fiadeiro, Univ. Lisbon; Frank de Boer, Univ. Utrecht; Luis Caires, Univ. Nova De Lisboa,
- Dr. D. Pattinson, University of Munich, November 13.

CWI Reports

The following CWI reports were published by members of SEN3. See page 39 for the complete titles of the reports.

SEN-R0020	SEN-R0021	SEN-R0023
SEN-R0025	SEN-R0039	SEN-R0040
SEN-R0043	SEN-R0044	

Evolutionary Systems and Applied Algorithmics – SEN4

Staff

- Dr. ir. J.A. La Poutré, theme leader
- Drs. F. Alkemade, PhD student
- Drs. S.M. Bohté, PhD student

- Dr. ir. D.D.B. van Bragt, postdoc/researcher
- Drs. E.H. Gerding, PhD student
- H. Halfmouw, trainee (from May 1 till November 1)
- Drs. M.B. de Jong, PhD student
- Prof. dr. J.N. Kok, advisor
- Drs. E. Kutschinski, PhD student (from November 1)
- Dr. W.B. Langdon, researcher (till April 30)
- G. Pieri, trainee (from March 1 till May 31)
- Dr. K.J. Shaw, postdoc (from February 16 till May 15)
- Drs. R. van Stee, PhD student
- R.W.T. Wildenberg, trainee (till August 31)

Scientific Report

The theme group SEN4 focussed 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

The evolution of cooperation in a system of agents playing the iterated prisoner's dilemma (IPD) has been investigated. We obtained results for the standard two-person IPD as well as the more general N-person IPD (NIPD) game. In our computational model, agents can recognize each other and decide whether to interact or not based upon 'tags' (labels). We especially considered the evolutionary stability of the evolving populations. Previous work is extended by introducing sexual reproduction (recombination) of agents and by analyzing its influence on the evolving populations. We observed the occasional formation of very stable cooperative societies, as opposed to previous results without sexual reproduction. These cooperative societies are able to resist invasions of 'mimics' (defecting agents with the tag of a cooperating agent). (F. Alkemade, D.D.B. van Bragt, J.A. La Poutré).

In the NWO-EW project 'Evolutionary Exploration Systems for Electronic Markets,' the behaviour of evolutionary agents in a specific economical market model, the Cournot duopoly market, has been investigated. The Cournot duopoly market is modelled as a co-evolving system of interacting agents. We present results for different types of boundedly rational agents. Agent types differ both in the complexity of their strategies and the information they have available to make their decision. Some types of agents use very simple strategies to make a production decision, while other types use a quite sophisticated decision rule. All agent types are tested in a round-robin tournament. We consider the evolutionary stability of the evolving populations, especially with respect to the different equilibria of the Cournot game. Furthermore, we investigated the performance of the different agent types under changing market conditions. (F. Alkemade, J.A. La Poutré, H.M. Amman (University of Amsterdam and Eindhoven University of Technology)).

Research was performed and completed on equilibrium selection in alternating-offers bargaining models. Results from evolutionary simulations were compared with game-theoretical predictions for ultimatum and multiple round games. For multiple round games, the influence of possible breakdown in negotiations, (asymmetrical) payoff discounting, and risk aversion was studied in detail. A general conclusion of this work is that game theory can be used successfully to interpret the equilibrium-selecting behaviour observed in computational experiments with evolutionary bargaining agents. Deviations from classical game theory were, however, observed in several experiments, but could be understood in terms of boundedly-rational behaviour of agents. (D.D.B. van Bragt, E.H. Gerding, J.A. La Poutré.)

Furthermore, negotiations with multiple issues were investigated. This is a more complex type of negotiations. Here, the influence of important model settings, like the probability of breakdown in negotiations, the length of the game, as well as the proper settings of the parameters of the evolutionary algorithm (EA) were substantially investigated for multi-issue negatiations. Also, the influence of fairness on the outcome of the negotiations was studied, both for theoretical models and by evolutionary simulation. This resulted in (more) fair negotiation outcomes and several issues for further study. (E.H. Gerding, D.D.B. van Bragt, J.A. La Poutré.)

It was shown that flexible bargaining agents can be obtained using the combination of simple finite automata and EAs. Finite automata allow the bargaining agents to behave differently against different opponents. EAs can be used to adapt the agents' bargaining strategies (consisting of finite automata) in successive steps to generate more and more successful strategies in the

course of time. The performance of the evolving automata was assessed in a competition against a broad variety of bargaining strategies. Efficient bargaining strategies are discovered by the adaptive automata, demonstrating that they can indeed discriminate successfully between opponents with different bargaining tactics. Research has started on the evolution of automata which are able to negotiate successfully against a variety of co-evolving opponents with different preferences. (D.D.B. van Bragt, J.A. La Poutré.)

Research on the theoretical foundations of genetic programming was continued. This especially concerned the analysis of program search spaces, including all and random programs. It appeared to be possible to use our proof of convergence of program performance as programs increase in size with experimental studies to predict sub-quadratic length increase with time. Using the Medusa super computer, these predictions were experimentally confirmed (incidentally evolving the largest-ever programs to be deliberately evolved). (W.B. Langdon.)

Furthermore, research was continued on text classification and profiling with n-grams, together with k-nearest neighbours and genetic algorithms. Especially, a new system was proposed and developed. The system was shown to be at least as effective but substantially faster than previous systems. Also, an experimental analysis of the distribution of n-grams was further analysed theoretically, and it was shown that Zipf's law does not to apply. (W.B. Langdon.)

The possibility to use computerized auctions to solve Quality of Service (QoS) allocation problems has been investigated. First, relevant literature on economic mechanism design was studied and categorized. Building on theoretical insights from this area, a general formulation of the QoS problem was derived. This general model was then simplified due to complexity considerations. In addition, various ways were compared to solve this simplified model using (approximate) algorithms. This research was performed when L. Gulyás (from SZTAKI, Hungary) was visiting CWI. (L. Gulyás, D.D.B. van Bragt, J.A. La Poutré.)

Computational experiments with adaptive bidders have been performed for various basic auction models. We have investigated the influence of budget restrictions on the bidders' behaviour. Also, experiments have been performed in which bidding involves more than one issue. We find that bidders are capable of approaching game-theoretical predictions in this more complicated setting. (R.W.T. Wildenberg (master student of the Free University, Amsterdam), D.D.B. van Bragt, J.A. La Poutré.)

In collaboration with ROVL ('Regionaal Orgaan Verkeersveiligheid Limburg'), we studied whether a feasible software system can be developed for predicting the safety of traffic crossings based on certain types of data from proposed feature analysis forms. A first model was developed using genetic programming (GP) techniques, using data supplied by ROVL. Alternative techniques (neural networks, linear regression) were also used to validate the results obtained using the GP model. The main conclusion drawn from this feasibility study was that several types of more detailed and additional data are required on the forms to arrive at a reliable model. Recommendations were made to ROVL in this regard. (D.D.B. van Bragt, W.B. Langdon, J.A. La Poutré, S. Bohté, W.V. Vriethoff (PNS Proctor Systems), W.J.E. Dirks (ROVL), J.G.L.M. Heuschen (ROVL))

As part of the Trade Agents project, research was done addressing development and refinement of business cases, together with the partners ING, KPN and TNO. Substantial attention has been spent on the KPN-case, which consists of developing an electronic shopping mall supplying several services. A market mechanism has been developed for a specific part of the KPN case and an initial evolutionary simulation of the mechanism has also been implemented. (E.H. Gerding, S. Bohté, J.A. La Poutré).

Neural Networks – SEN4.2

The research on spiking neural networks continued to explore supervised and unsupervised algorithms for classification problems. Results show that spiking neural networks are well-suited for supervised and unsupervised classification of data. They can perform at least equally well on typical classification tasks as traditional neural networks. Traditional artifical (sigmoidal) neurons are modeled after the aggregate response of several hundred (biological) spiking neurons. In this respect, artificial spiking neurons networks model up to two orders of magnitude less spiking neurons to perform the same information-processing task. (S. Bohté, J.A. La Poutré, J.N. Kok).

Additionally, a novel architecture was developed that is based on spiking neurons. The architecture is capable of calculations that are notably hard to realize in traditional neural networks. In particular, a network was designed that is capable of dynamic binding of variables in neural networks, suitable for symbolic representation and manipulation. (S. Bohté, J.N. Kok).

Discrete Algorithms – SEN4.3

In the NWO-GBE project 'Dynamic Algorithms for On-Line Optimization,' research was performed on online bin packing. In the variable-sized online bin packing problem, one has to assign items to bins one by one. The bins are drawn from some fixed set of sizes, and the goal is to minimize the sum of the sizes of the bins used. We present the first unbounded space algorithms for this problem. We also show the first lower bounds on the asymptotic performance ratio. The case where bins of two sizes, 1 and $\alpha \in (0, 1)$, are used is studied in detail. This investigation leads us to the discovery of several interesting fractal-like curves. (R. van Stee, L. Epstein (The Interdisciplinary College, Herzliya, Israel) and S. Seiden (Louisiana State University)).

Furthermore, work was done on on-line scheduling. Especially, work has been performed on minimizing the total completion time, total flow time, total weighted completion time and total weighted flow time on a single machine, giving deterministic and randomized lower bounds for all these problems. Work has also been performed on an algorithm to minimize the total completion time on a single machine (in progress). In addition, the minimization of the total flow time on parallel machines was also addressed, studying the case where the on-line algorithm has more machines than the off-line algorithm. (R. van Stee, L. Epstein (The Interdisciplinary College, Herzliya, Israel)).

The unit-price seat reservation problem has been investigated. The seat reservation problem is the problem of assigning seat numbers on-line to requests for reservations in a train travelling through k stations. The version was considered where all tickets have the same price and where requests must be treated fairly, i.e., a request which can be fulfilled must be granted. For fair deterministic algorithms, we provide an asymptotically matching upper bound to the existing lower bound which states that all fair algorithms for this problem are $\frac{1}{2}$-competitive on accommodating sequences, when there are at least three seats. Additionally, we give an asymptotic upper bound of $\frac{7}{9}$ for fair randomized algorithms against oblivious adversaries. We also examine concrete on-line algorithms ('First-Fit' and 'Random') for the special case of two seats. Tight analyses of their performance are given. (R. van Stee, L. Epstein (The Interdisciplinary College, Herzliya, Israel), K. Larsen, J. Boyar, Lene Monrad Favrholdt (University of Southern Denmark, Odense, Denmark), E. Bach (University of Wisconsin, Madison, U.S.A.), T. Jiang (University of California, Riverside, U.S.A.), G.-H. Lin (University of Waterloo and Department of Computing and Software, McMaster University, Canada)).

In the NWO-GBE project 'Quality of Service for Multimedia Systems,' a start was made with the investigation of how to optimize the two-additive-metrics problem using the propagation of 'pricelists'. The application that this research is aiming for, is Quality-of-Service Routing. More specifically, the problem of simultaneously minimizing delay and financial costs can be formalized as a two-additive-metrics problem. The pricelists that the subsystems propagate to each other, are lists of two-tuples specifying Pareto optimal combinations of delay and price. A simulation tool was programmed that can simulate various schemes for the propagation of pricelists through a network of subsystems. A special case of the two-additive-metrics problem is the variant in which the local trade-off surfaces are convex. For solving this case, we have formulated the "equal derivative" rule, which is a necessary and sufficient mathematical condition for optimality. Using this condition, the optimal solution can easily be found in polynomial time. (M.B. de Jong, J.A. La Poutré)

Research was also done on the generalized patching problem, as occurring in a near video-on-demand setting. A heuristic method has been designed, and good progress has been made on the formal proof that this problem is NP-complete. (M.B. de Jong and J. Aerts, W. Michiels and J. Korst (Philips NatLab))

Another problem that occurs in a near video-on-demand context is what we formalized as the dynamic batching problem. This is the problem of adapting the client admission strategy to constantly changing estimates of the average system load and fluctuations (variance) in this system load. The approach we developed and further in-

vestigated for this problem is based on using multiple predictions of both the average and the variance of the system load. This concerns amongst others multiple-objective evolutionary algorithms and Pareto optimality. (M.B. de Jong, J.A. La Poutré)

Trade Agents Project

The full start was made with the integral project 'Autonomous Systems of Trade Agents in E-Commerce' ('Trade Agents'), a project funded by the Telematics Institute, and with project partners TNO, ING, and KPN. Several of the research activities described above and several of the publications stated below were (also) part of this project.

In addition, research was done on the dynamic pricing of information goods. Based on the demand for a certain type of information, a first dynamic mechanism to enable price differentiation and determination of the market price of information was designed and investigated. By finding the market price, an estimate of the actual value of the content can be made. First promising results were obtained using a simple price-update algorithm using local search. (E. Kutschinski, D.D.B. van Bragt, J.A. La Poutré.)

Knowledge Transfer

- A feasibility study has been performed by order of ROVL (Regionaal Orgaan Verkeersveiligheid Limburg). This work has focussed on the development of a traffic risk model for crossings using genetic programming techniques.
- Participation in the Trade Agents project (Autonomous Systems of Trade Agents in E-Commerce), a project together with TNO, and with the companies ING and KPN, funded by the Telematics Institute.
- S. Bohté gave a lecture at the HCC, AI Special Interest Group, on Dynamic Binding, Gouda, June 24.
- D.D.B. van Bragt gave a lecture at the HCC, on 'Digitale Evolutie Schiet Economen te Hulp', Gouda, August 24.
- J.A. La Poutré gave a lecture on agent systems and applied algorithms at the IPA fall days on applied algorithm design, Millingen aan de Rijn, November 20–24.

Organization of Conferences, Workshops, Courses, etc.

- IPA fall days on Applied Algorithm Design, Millingen aan de Rijn, November 20–24, 2000 J.A. La Poutré, program committee.

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

- *Workshop on Economic Dynamics*, Centre for Nonlinear Dynamics in Economics and Finance (CeNDEF) University of Amsterdam, Amsterdam, January 13–15: F. Alkemade, D.D.B. van Bragt, J.A. La Poutré.
- *Working visit Tel-Aviv University*, Israel (Leah Epstein), February 6–20: R. van Stee.
- *Workshop Dagstuhl*, Dagstuhl, Germany, February 13–18: W.B. Langdon (*Theory of Evolutionary Algorithms*).
- *CIEF 2000*, Fifth Joint Conference on Information Sciences, Atlantic City, USA, February 27–March 3: F. Alkemade, J.A. La Poutré (*Stabilization of Tag Mediated Interaction by Sexual Reproduction in an Evolutionary Agent System*).
- *EURO GP 2000 + Evo Workshops*, Edinburgh, UK, April 15–17: W.B. Langdon (*Seeding GP populations*).
- *ESANN'2000* European Symposium on Artificial Neural Networks, Brugge, Belgium, April 26–28: S. Bohté (*Spike-prop: Error-backprogagation in multi-layer networks of spiking neurons*).
- *Workshop on Complex behavior in Economics*, Aix-en-Provence, France, May 4–6: E. Gerding (*Multi-issue negotiation processes by evolutionary simulation: Validation and Social Extensions*).
- *HCC AI Special Interest Group*, Gouda, June 24: S. Bohté (*Dynamic Binding*).
- *University of Southern Denmark*, Odense, Denmark (Kim Larsen and Joan Boyar), June 26–July 3: R. van Stee.
- *7th Scandinavian Workshop on Algorithm Theory*, Bergen, Norway, July 5–7: R. van Stee (*Resource Augmentation in Load Balancing*).
- *Sixth International Conference on Computing in Economics and Finance (CEF2000)*, Barcelona, Spain, July 6–8: F. Alkemade (*Stabilization of Tag-Mediated Interaction by Sexual Reproduction in an Evolutionary Agent System*), D.D.B. van Bragt (*Equilibrium Selection in Alternating-Offers Bargaining Models: The*

Evolutionary Computing Approach), E. Gerding, J.A. La Poutré.
- *Workshop 'Selectivity of Neurones in Sensory and Motor Cortices': 'Static and Dynamic Properties'*, CNRS – Paris V, Paris, France, July 9–17: S. Bohté.
- *IJCNN '2000*, International Joint Conference on Neural Networks 2000, Como, Italy, July 24–27: S. Bohté (*Unsupervised Classification in a layered network of spiking neurons*).
- *GAMES '2000* 1st World Congress of the Game Theory Society, Bilbao, Spain, July 24–28: D.D.B. van Bragt (*Equilibrium Selection in Alternating-Offers Bargaining Models: The Evolutionary Computing Approach*).
- *HCC*, Gouda, August 24: D.D.B. van Bragt (*Digitale Evolutie Schiet Economen te Hulp*).
- *APPROX 2000* Third Workshop on Approximation Algorithms for Combinatiorial Optimization Problems, Saarbrücken, Germany, September 3–5: R. van Stee (*Partial Servicing of On-line Jobs*).
- *SAB 2000* Simulation of Adaptive Behavior, Paris, France, September 11–15: M.B. de Jong (*The Epsilon State Count*).
- *BNAIC '2000*, Belgium Netherlands AI Conference 2000, Kaatsheuvel, November 1–2: F. Alkemade (*Stabilization of Tag-Mediated Interaction by Sexual Reproduction in an Evolutionary Agent System*), D.D.B. van Bragt, S. Bohté (*Backpropagation of Spike-Time Errors in Artificial Neural Networks*), E. Gerding (*Multi-Issue Negotiation Processes by Evolutionary Simulation: Validation and Social Extensions*).
- *IPA fall days on applied algorithm design*, Millingen aan de Rijn, November 20–21: F. Alkemade, D.D.B. van Bragt, E.H. Gerding, M.B. de Jong, J.A. La Poutré (*Agent Systems; On-line Optimization and Quality of Service*).
- *DYNN '2000* International Workshop on Dynamical Neural Networks and Applications, Bielefeld, Germany, November 20–24: S. Bohté (*Rapid Dynamic Feature Binding in Feed Forward Spiking Neural Vector Networks*).

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 Editorial Board of *e-JEMED*, the Electronic Journal of Evolutionary Modeling and Economic Dynamics, a new electronic journal initiative (http://www.e-jemed.org/).
- Member of the program committee of the BNAIC'00 conference; the Twelfth Belgium-Netherlands Conference on Artificial Intelligence, Kaatsheuvel, November 1–2.

W.B. Langdon:
- Resource Review editor of *Genetic Programming and Evolvable Machines*.
- Member of the Program Committee and Publicity Chair of EuroGP'2000, Edinburgh, Scotland, April 15–16.
- Member of the Program and Policy Committees of the Genetic and Evolutionary Computation Conference (GECCO-2000), Las Vegas, Nevada, USA, July 10–12.
- Organizer of Graduate Student Workshop and Gene Expression Workshop of the Genetic and Evolutionary Computation Conference (GECCO-2000), Las Vegas, Nevada, USA, July 10–12.
- Member of the Programme Committee of the Foundations of Genetic Algorithms Workshop (FOGA), Charlottesville, VA, USA, July 21–23.

Visitors

- Drs. L. Gulyás, SZTAKI, Hungary, May 11-12 and October 6–December 22.
- Dr. C. Ryan, University of Limerick, Ireland, February 24.
- Dr. S. Choenni, National Aerospace Laboratory, Amsterdam, March 9.
- Dr. W.J. Kowalczyk, (Vrije Universiteit Amsterdam / Bratek), March 23.
- Dr. E. de Jong, AI Lab, Vrije Universiteit Brussel, Belgium, April 6.
- Prof. dr. S. Goyal, Erasmus University, Rotterdam, May 18.
- Prof. dr. K. Pruhs, University of Pittsburgh, USA, May 15-26.

Software Developed

- GP model for ROVL-CWI feasibility study on traffic safety.
- Java software for evolutionary computing.
- Improvements of Tauritz n-gram code for text classification, integrated into QGAME C++ GA library.

Book

R. Poli, W. Banzhaf, W.B. Langdon, J.F. Miller, P. Nordin, T.C. Fogarty (eds.). *Genetic Programming, Proceedings of EuroGP'2000, LNCS* **1802**, Edinburgh, April 15–16. Springer-Verlag.

Papers in Journals and Proceedings

F. Alkemade, D.D.B. van Bragt, J.A. La Poutré (2000). Stabilization of Tag-Mediated Interaction by Sexual Reproduction in an Evolutionary Agent System. *Proceedings of the Fifth Joint Conference on Information Sciences (CIEF '2000)* **2**, Atlantic City, USA, February 27–March 4, 945–949.

Y. Azar, L. Epstein, R. van Stee (2000). Resource Augmentation in Load Balancing. *Journal of Scheduling* **3**, 249–258.

Y. Azar, L. Epstein, R. van Stee (2000). Resource Augmentation in Load Balancing. *Proceedings of 7th Scandinavian Workshop on Algorithm Theory (SWAT 2000), LNCS* **1815**, Bergen, Norway, July 5–7, Springer Verlag, 164–174.

B. Bakker, M.B. de Jong (2000). The Epsilon State Count. J-A. Meyer et al. (ed.). *Proceedings of From Animals To Animats 6, International Conference on the Simulation of Adaptive Behavior (SAB 2000)*, Paris, France, September 11–15, 51–60.

S.M. Bohté, J.A. La Poutré, J.N. Kok (2000). Unsupervised Classification in a Network of Spiking Neurons. *Proceedings of the International Joint Conference on Neural Networks (IJCNN'2000)*, Como, Italy, July 24–28, 279–285.

S.M Bohté, J.A. La Poutré, J.N. Kok (2000). SpikeProp: Error-Backpropagation in Multi-Layer Networks of Spiking Neurons. *Proceedings of the European Symposium on Artificial Neural Networks (ESANN'2000)*, Brugge, Belgium, April 26–28, 419–425.

S.M. Bohté, J.N. Kok (2000). Rapid Dynamic Feature Binding in Feedforward Spiking Neural Vector Networks. *Proceedings of the International Workshop on Dynamical Neural Networks and Applications (DYNN'2000)*, Bielefeld, Germany, November 20–24, 85.

S.M. Bohté, H. Spekreijse, P.R. Roelfsema (2000). The Influence of Pair-Wise and Higher Order Correlations on the Firing Rate of a Post-Synaptic Neuron. *Neural Computation* **12** (1), 153–179.

M. C.J. Bot, W.B. Langdon (2000). Application of Genetic Programming to Induction of Linear Classification Trees. R. Poli, W. Banzhaf, W.B. Langdon, J.F. Miller, P. Nordin and T.C. Fogarty (eds.). *Genetic Programming, Proceedings of EuroGP'2000, LNCS* **1802**, Edinburgh, April 15–16. Springer-Verlag, 247–258.

J.A. La Poutré (2000). Maintenance of 2- and 3-Edge-Connected Components of Graphs II. *SIAM Journal on Computing* **29**, 1521–1549.

W.B. Langdon (2000). Size Fair and Homologous Tree Crossovers for Tree Genetic Programming. *Genetic Programming and Evolvable Machines* **1**, 95–119.

W.B. Langdon (2000). Genetic Programming and Evolvable Machines: Books and Other Resources. *Genetic Programming and Evolvable Machines* **1**, 165–169.

W.B. Langdon, J.P. Nordin (2000). Seeding GP Populations. R. Poli, W. Banzhaf, W.B. Langdon, J.F. Miller, P. Nordin, and T.C. Fogarty (eds.). *Genetic Programming, Proceedings of EuroGP '2000, LNCS* **1802**, 304–315, Edinburgh, April 15–16. Springer-Verlag.

W.B. Langdon (2000). Quadratic Bloat in Genetic Programming. D. Whitley, D. Goldberg, E. Cantu-Paz, L. Spector, I. Parmee, and H.-G. Beyer (eds.). *Proceedings of the Genetic and Evolutionary Computation Conference (GECCO-2000)*, 451–458, Las Vegas, Nevada, USA, July 10–12. Morgan Kaufmann.

W.B. Langdon, W. Banzhaf (2000). Genetic Programming Bloat without Semantics. M. Schoenauer, K. Deb, G. Rudolph, X. Yao, E. Lutton, J. J. Merelo, H.-P. Schwefel (eds.) *Parallel Problem Solving from Nature, 6th International Conference (PPSN VI), LNCS* **1917**, Paris, France, September 16–20. Springer Verlag, 201–210.

R. van Stee, J.A. La Poutré (2000). Partial Servicing of On-line Jobs. *Proceedings of 3rd Workshop on Approximation Algorithms for Combinatorial Optimization Problems (APPROX '2000), LNCS* **1913**, Springer Verlag, 250–261.

CWI Reports

The following CWI reports were published by members of SEN4. See page 39 for the complete titles of the reports.

SEN-R0004	SEN-R0005	SEN-R0013
SEN-R0016	SEN-R0022	SEN-R0024
SEN-R0026	SEN-R0028	SEN-R0036
SEN-R0037	SEN-R0042	

Other Publications

S.M. Bohté, E. Gerding, J.A. La Poutré (2000). *A Market Mechanism for the KPN Case* (preliminary title). Deliverable for the Trade Agents project.

S.M. Bohté, W.B. Langdon (2000). *Adaptive Profiling: A Survey.* Deliverable for the Trade Agents project.

L. DeRaedt, J.A. La Poutré, F. Verdenius (guest editors) (2000). Special issue on AI research in the Benelux. *AI Communications (AICom)* **13** (1).

R. Feldt, M. O'Neill, C. Ryan, P. Nordin, W.B. Langdon (2000). GP-Beagle: A Benchmarking Problem Repository for the Genetic Programming Community. D. Whitley (ed.). *Late Breaking Papers at the Genetic and Evolutionary Computation Conference (GECCO-2000)*, 90–97, Las Vegas, Nevada, USA.

E. Kutschinski, D.D.B. van Bragt, J.A. La Poutré (2000). *Dynamic Pricing of New Items.* Deliverable for the Trade Agents project.

W.B. Langdon (2000). Review of Evolutionary Algorithms in Theory and Practice: Evolutionary Strategies, Evolutionary Programming, Genetic Algorithms (by Thomas Bäck). *ACM SIGART Intelligence* **11** (1), 52–53.

W.B. Langdon (2000). GECCO'99 student workshop. *Robotica* **18** (1), 87.

W.B. Langdon (2000). Evolutionary Computation 1 Session at BNAIC'99. *Newsletter BVNKI* **16** (6), 168–169.

W.B. Langdon (2000). Natural Text Classification and Filtering with Trigrams and Evolutionary Nearest Neighbour Classifiers. *Late Breaking Papers at the Genetic and Evolutionary Computation Conference (GECCO-2000)*, Las Vegas, Nevada, USA, July 10–12. Deliverable for the Trade Agents project.

D.D.B. van Bragt, J.A. La Poutré (2000). Evolving Automata Negotiate with a Variety of Opponents. Deliverable for the Trade Agents project.

D.D.B. van Bragt, W.B. Langdon, J.A. La Poutré, S. Bohté (2000). *Haalbaarheidsonderzoek voor de Ontwikkeling van een Risicovoorspellingsmodel voor Kruispunten met behulp van Genetisch Programmeren.* Onderzoek CWI in opdracht van ROVL, September 6.

MODELLING, ANALYSIS AND SIMULATION

General Overview

In 2000 cluster MAS consisted of two themes (MAS1 and MAS2) and one pilot theme (MAS3).

- MAS1 – Applied Analysis and Scientific Computing for PDEs
- MAS2 – Computational Fluid Dynamics
- MAS3 – Mathematics of Finance

MAS1 and MAS2 focus on advanced mathematical and computational research on partial differential equations (PDEs), including applied analysis, pattern formation, numerical analysis, scientific computing and computational fluid dynamics. Small sized activities are asymptotics and special functions and computational number theory.

Unfortunately, the assessment of MAS3 has led to the decision to terminate this pilot theme by the end of 2000. The two postdocs Drs. Hoogland and Neumann will continue their mathematics of finance research within the SEN4 theme 'Evolutionary Systems and Applied Algorithms'. The theme leader Prof. dr. M.S. Keane has returned to the theme PNA3.

The main objective of current MAS research is to make fundamental contributions to the theory and applications of PDEs. Applications are numerous and are found in physics, life-, geo- and environmental sciences, in engineering and in many industrial and technological fields. We are involved in a wide variety of projects and activities with universities, government laboratories and industry. A substantial part of the work is application driven and externally financed through special NWO programs, NCF, EU, FOM, etc. In 2000 we produced 60 research papers in journals and proceedings, 31 MAS reports and 1 MAS Note.

With respect to academia, the two theme leaders Profs. P.W. Hemker and J.G. Verwer hold a part time position as professor of numerical analysis at the UvA. Dr. ir. B. Koren holds a part time position as associate professor (UHD) at the Faculty of Aerospace Engineering of TU Delft. Dr. M.A. Peletier holds a part time position as associate professor (UHD) in applied analysis at the TUE. Profs. J. Hulshof (VU) and C.J. van Duijn (TUE) actively participate in two of our analysis projects as PhD supervisor. Profs. O. Diekmann (UU) and H.V. Westerhoff (VU) are advisor for life-science applications and Profs. P. Wesseling (TUD) and B. van Leer (University of Michigan) are advisor for computational fluid dynamics.

September 1st of 2000, two of our leading researchers left. Prof. dr. ir. C.J. van Duijn, cluster leader, took up the position of full professor of analysis at the TUE. Prof. dr. P.J. van der Houwen, CWI Fellow and former department head, went into retirement after 36 years of active research in numerical analysis.

Farewell Symposium Piet van der Houwen

On this occasion a one-day symposium was organized on October 20 jointly with the Korteweg-de Vries Institute of the University of Amsterdam. The following speakers delivered a contribution. Dr. ir. G. van Oortmerssen (Director CWI: Welcome and opening), Dr. B.P. Sommeijer (CWI: A survey of Piet van der Houwen's research), Prof. dr. K. Strehmel (Martin-Luther-University Halle-Wittenberg: Linear partial differential-algebraic equations, theory and numerics), Prof. dr. C.T.H. Baker (Manchester University: Propagation of discontinuities in Volterra evolutionary problems), Prof. dr. A.O.H. Axelsson (Catholic University Nijmegen: Iterative methods in function spaces), Prof. dr. M.N. Spijker (Leiden University: Aspects of stability in numerical initial value problems), Prof. dr. H. Brunner (Memorial University of Newfoundland: Volterra equations at CWI: 1976–2000) and Prof. dr. T.H. Koornwinder (Director KdV Institute: Closing remarks).

Staff

- Staff directly managed by cluster leader
  - N.M. Temme (0.2 fte); 0.8 at MAS1)
  - J. de Vries
  - P. de Zeeuw (0.1 fte; 0.9 at PNA4)
- Applied Analysis and Scientific Computing for PDEs – MAS1
  - J.G. Verwer
  - M. Arrayás
  - P.J.F. Berkvens
  - J.G. Blom
  - M.A. Botchev
  - C. Cuesta
  - O. Diekmann
  - C.J. van Duijn
  - U.M. Ebert
  - J.E. Frank
  - I.A. Guerra
  - P.J. van der Houwen
  - J. Hulshof
  - W.H. Hundsdorfer
  - J. Kok
  - D. Lanser
  - B. Lastdrager
  - M.A. Peletier
  - R. Planqué
  - I.S. Pop
  - P. Rodin
  - D. Sijacic
  - B.P. Sommeijer
  - N.M. Temme
  - R. Vidunas
  - H.V. Westerhoff
- Computational Fluid Dynamics – MAS2
  - P.W. Hemker
  - E.H. van Brummelen
  - S. Cavallar
  - J.L.M. van Dorsselaer
  - G.F. Duivesteijn
  - M. Genseberger
  - P.J. van der Houwen
  - J. Kok
  - B. Koren
  - B. Lastdrager
  - M.R. Lewis
  - P.L. Montgomery
  - M. Nool
  - M.H. van Raalte
  - H.J.J. te Riele
  - L. Voort
  - P. Wesseling
  - D. Wilschut
- Mathematics of Finance – MAS3
  - M.S. Keane
  - J.K. Hoogland
  - C.D.D. Neumann
- Secretary:
  - N. Mitrovic

CWI Reports and Notes

MAS-R0001. J.G. Verwer and B.P. Sommeijer. *A numerical study of mixed parabolic-gradient systems.*

MAS-R0002. C. Storm, W. Spruijt, U. Ebert and W. van Saarloos. *Universal algebraic relaxation of velocity and phase in pulled fronts generating periodic or chaotic states.*

MAS-R0003. U. Ebert and W. van Saarloos. *Breakdown of the standard perturbation theory and moving boundary approximation for 'pulled' fronts.*

MAS-R0004. A. Gil, J. Segura and N.M. Temme. *On non-oscillating integrals for computing inhomogeneous Airy functions.*

MAS-R0005. N.M. Temme and J.L. López. *The Askey scheme for hypergeometric orthogonal polynomials viewed from asymptotic analysis.*

MAS-R0006. J. de Vries. *Compactification of G-spaces revisited.*

MAS-R0007. S. Cavallar, W.M. Lioen, H.J.J. te Riele, B. Dodson, A.K. Lenstra, P.L. Montgomery and B. Murphy. *Factorization of a 512–bit RSA modulus.*

MAS-R0008. B.P. Sommeijer and P.J. van der Houwen. *Parallel solution of a coupled flow and transport model for shallow water.*

MAS-R0009. J.E. Frank and C. Vuik. *On the construction of deflation-based preconditioners.*

MAS-R0010. A. Rocco, U.M. Ebert and W. van Saarloos. *Subdiffusive fluctuations of 'pulled' fronts with multiplicative noise.*

MAS-R0011. U.M. Ebert, W. van Saarloos and L.A. Peletier. *Universal algebraic convergence in time of pulled fronts: the common mechanism for difference-differential and partial differential equations.*

MAS-R0012. S. Cavallar. *Strategies in filtering in the number field sieve.*

MAS-R0013. J. Lang and J.G. Verwer. *ROS3P - An accurate third-order Rosenbrock solver designed for parabolic problems.*

MAS-R0014. A. Gil, J. Segura and N.M. Temme. *Computing toroidal functions for wide ranges of the parameters.*

MAS-R0015. N.M. Temme. *Numerical and asymptotic aspects of parabolic cylinder functions.*

MAS-R0016. T. Lachand-Robert and M.A. Peletier. *The minimum of quadratic*

functionals of the gradient on the set of convex functions.

MAS-R0017. T. LACHAND-ROBERT and M.A. PELETIER. *Newton's problem of the body of minimal resistance in the class of convex developable functions.*

MAS-R0018. E.H. VAN BRUMMELEN. *Numerical solution of steady free-surface Navier-Stokes flow.*

MAS-R0019. J.K. HOOGLAND and C.D.D. NEUMANN. *Asians and cash-dividends: exploiting symmetries in pricing theory.*

MAS-R0020. J.G. BLOM and M.A. PELETIER. *Diffusive gradients in the PTS system.*

MAS-R0021. D. LANSER, J.G. BLOM and J.G. VERWER. *Time integration of the shallow water equations in spherical geometry.*

MAS-R0022. C.J. VAN DUIJN, I.A. GUERRA and M.A. PELETIER. *Asymptotic results for injection of reactive solutes from a three-dimensional well.*

MAS-R0023. P.J.F. BERKVENS, M.A. BOTCHEV, J.G. VERWER, M.C. KROL and W. PETERS. *Solving vertical transport and chemistry in air pollution models.*

MAS-R0024. J.K. HOOGLAND and C.D.D. NEUMANN. *Tradable schemes.*

MAS-R0025. B. LASTDRAGER, B. KOREN and J.G. VERWER. *Solution of time-dependent advection-diffusion problems with the sparse-grid combination technique and a Rosenbrock solver.*

MAS-R0026. A. GERISCH and J.G. VERWER. *Operator splitting and approximate factorization for taxis-diffusion-reaction models.*

MAS-R0027. M.A. PELETIER. *Generalized monotonicity from global minimization in fourth-order ODEs.*

MAS-R0028. U.M. EBERT and M. ARRAYÁS. *Pattern formation in electric discharges.*

MAS-R0029. M. GENSEBERGER, G.L.G. SLEIJPEN and H.A. VAN DER VORST. *Using domain decomposition in the Jacobi-Davidson method.* (Also appeared as Preprint No. 1164, Mathematical Institute, Utrecht University (October 2000).)

MAS-R0030. W.H. HUNDSDORFER and J. JAFFRÉ. *Implicit-explicit time stepping with spatial discontinuous finite elements.*

MAS-R0031. M.A. BOTCHEV and J.G. VERWER. *Improving approximate matrix factorizations for implicit time integration in air pollution modelling.*

MAS-N0001. D.E. WILSCHUT. *Digitale handtekeningen: een experimentele vergelijking.*

Applied Analysis and Scientific Computing for PDEs – MAS1

Staff

- Prof. dr. J.G. Verwer, cluster and theme leader
- Dr. M. Arrayás, postdoc (EU)
- Dr. P.J.F. Berkvens, postdoc (NWO)
- Drs. J.G. Blom, researcher
- Dr. M.A. Botchev, postdoc (NWO)
- C. Cuesta MSc, PhD student (NWO)
- Prof. dr. O. Diekmann, advisor (UU)
- Prof. dr. ir. C.J. van Duijn, cluster leader until August 31, PhD supervisor (TUE)
- Dr. U.M. Ebert, researcher, subtheme leader (NWO till August)
- Dr. J.E. Frank, postdoc (CWI/GMD)
- I.A. Guerra MSc, PhD student
- Prof. dr. P.J. van der Houwen, CWI Fellow, until August 31
- Prof. dr. J. Hulshof, advisor and PhD supervisor (VU)
- Dr. W.H. Hundsdorfer, researcher
- Drs. J. Kok, programmer and general support
- Ir. D. Lanser, PhD student (NWO)
- Drs. B. Lastdrager, PhD student (NWO)
- Dr. M.A. Peletier, researcher
- Drs. R. Planqué, PhD student from December 1
- Dr. I.S. Pop, until August 31, postdoc (NWO)
- Dr. P. Rodin, 4-month guest researcher (CWI/FOM)
- D. Sijacic MSc, PhD student from May 1 (FOM)
- Dr. B.P. Sommeijer, researcher
- Dr. N.M. Temme, researcher
- Dr. R. Vidunas, postdoc (NWO)
- Prof. dr. H.V. Westerhoff, advisor (VU)

Scientific Report

The mathematical research within this theme deals with partial differential equations, applied and numerical analysis, modelling and scientific computing. An activity of limited size is asymptotics for special functions. The nature of the projects ranges from fundamental to practical with the greater part application driven. In previous years the emphasis has been on geo-science

applications (environmental, surface water, atmospheric, porous media). The subtheme 'PDEs in Porous Media Research' has been terminated this year at the departure of the project leader Prof. Van Duijn to the University of Eindhoven. The porous media subject will remain in the form of two PhD projects until mid 2002. One will be supervised by Prof. Van Duijn and Dr. Peletier and the other by Prof. Hulshof. In 1999 more emphasis has been laid on PDE problems from biology (MAS1.3) and physics (MAS1.4). This trend has been continued in 2000.
In 2000 the MAS1 subthemes were

- Atmospheric Flow and Transport Problems – MAS1.1
- Analysis, Asymptotics and Computing – MAS1.2
- Applications from the Life Sciences – MAS1.3
- Pattern Formation and Low Temperature Plasmas – MAS1.4

Atmospheric flow and transport problems – MAS1.1

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 four projects.

(1) Transport modelling.
The first project is on TM3, a global atmospheric dispersion model in use by KNMI and IMAU and other European atmospheric institutes. The research on TM3 is supported by the NWO program 'Wiskunde Toegepast' and NCF. In report MAS-R0023, Berkvens, Botchev, Krol, Peters, and Verwer have improved an algorithm for the columnwise solution of vertical transport and chemistry. The improvement has been achieved by better splitting techniques and by approximate matrix factorization. In report MAS–R0031, Botchev and Verwer propose further improvements for approximate matrix factorization. Both reports have been submitted for publication. The TM3-code has been parallelized and a start has been made with the successor TM5 which implements a zoom method from CWI.

(2) Circulation modelling
The second project is the PhD project of 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. A report on the spatial discretization of the spherical shallow water equations was published in the *Journal of Computational Physics*. Furthermore, a companion article on time stepping issues was written by Lanser, Blom, and Verwer (MAS-R0021) and submitted to the same journal. A report handling similar issues for a more realistic 3D model is in preparation.

(3) Numerical atmospheric dynamics
In a joint project of CWI and GMD, Frank is carrying out numerical atmospheric dynamics research. A method which takes into consideration the important concepts of potential vorticity conservation and gravity wave interactions is being developed in cooperation with Imperial College London. A report on this work is in preparation. An efficient reversible integrator incorporating mean gravity wave effects is also being developed in cooperation with Blom.

(4) Sparse grid methods.
This subject concerns the PhD research of Lastdrager. With Koren and Verwer he considered time-dependent mixed advection-diffusion problems with grid-aligned solution layers. The applicability of sparse grids for such problems has been assessed by using the nonlinear Burgers' equations as a numerical test case. Theoretical error predictions for a linear test problem matched numerical observations. The overall conclusion is that sparse grids perform less well than the theory based on computational complexity considerations and a priori error estimates predict.

Analysis, Asymptotics and Computing – MAS1.2

This subtheme comprises a number of different activities including some from the terminated subtheme 'PDEs in Porous Media Research'.

(1) Nonlinear PDEs and free boundary problems.
Asymptotic results were obtained by Van Duijn, Guerra (PhD research) and Peletier for injection of reactive solutes from a three-dimensional well (MAS-R0022). It was shown that the solute profile evolves in a self-similar way towards a stationary distribution and an estimate for the rate of the convergence was obtained. Further, a model for non-static groundwater flow was studied, in which the saturation-pressure relation is extended by a dynamic term. This results in a non-

linear degenerate diffusion equation with mixed derivatives in space and time. Stability of traveling wave solutions has been studied. Reports on this topic by Cuesta (PhD research) and Hulshof are in preparation.

(2) A model for geological structures
In report MAS-R0027, Peletier has considered solutions of the stationary Extended Fisher-Kolmogorov equation with general potential that are global minimizers of an associated variational problem. Results have been presented that relate the global minimization property to a generalized concept of monotonicity of the solutions. The method can be directly extended to a wide class of fourth-order ordinary differential equations that derive from minimization problems.

(3) Minimization problems.
Lachand-Robert and Peletier have studied the minimum of quadratic functionals of the gradient on the set of convex functions (MAS-R0016), and Newton's problem of the body of minimal resistance in the class of convex developable functions (MAS-R0017). It was proved that the minimizer in this class has a minimal set in the form of a regular polygon with n sides centered in the disc, and numerical experiments indicate that the natural number $n \geq 2$ is a non-decreasing function of the maximal height M. The corresponding functions all achieve a lower value of the functional than the optimal radially symmetric function with the same height M. This project will be terminated in 2001.

(4) Asymptotics and special functions.
R. Vidunas and N.M. Temme developed algorithms for the coefficients in Airy-type uniform asymptotic expansions; the expansions were obtained by using integral representations. N.M. Temme wrote a paper with J.L. López (Pamplona, Spain) on expanding polynomials in terms of other polynomials in order to obtain asymptotic representations, with applications to the Askey scheme for hypergeometric orthogonal polynomials. With J. Segura and A. Gil (Alicante, Spain) he wrote a paper on the numerical aspects of the solutions of an inhomogeneous Airy differential equation and on computing toroidal functions (a special class of Legendre functions) for wide ranges of the parameters. Temme also wrote a paper on the numerical and asymptotic aspects of parabolic cylinder functions. N.M. Temme started writing revisions of three chapters for the new edition of the *Handbook of Mathematical Functions* (Abramowitz and Stegun), and signed a contract for writing the new chapters.

(5) Numerical integration
A new class of discontinuous finite element methods has been studied by Hundsdorfer and Jaffré (MAS-R0030). The effect of low order quadrature has been studied for 1D convection-reaction equations with stiff reaction terms. For such equations efficient algorithms were obtained by using appropriate time stepping techniques. As a new activity, Hundsdorfer and Verwer have started working on a book on 'Numerical Solution of Advection-Diffusion-Reaction Equations'. Completion is expected in 2003.

Applications from the life sciences – MAS1.3
This topic started in 1999 and has been continued and extended. The emphasis is on the analytical and numerical analysis of PDEs from biology. Co-operative contacts exists with the Netherlands Institute for Brain Research (NIH), with three different research groups of the two universities in Amsterdam (UvA and VU), and with the university in Halle (Germany).

(1) Modelling axon growth
In collaboration with NIH, Lastdrager, Verwer, Peletier and Sommeijer work on a mathematical model for outgrowth of axons from neurons in the nervous system and study numerical methods for this model. The model in use at this moment comprises a set of parabolic PDEs coupled with gradient equations. First numerical investigations have been published in Report MAS-R0001 (to appear in *J. Comput. Appl. Math.*). Lastdrager is furthering this numerical work and developed a robust preliminary code that much better mimics the experimentally observed behaviour of bundling and debundling in the growth of axons. An interesting complication in the numerical treatment of delta type source terms and gradients was observed and tackled. End of this year, a PhD project has been granted by NWO which will provide a long-standing co-operation with NIH.

(2) Modelling tumour growth
A related problem, modelling tumour growth by means of a taxis-diffusion-reaction system, has been studied numerically by Verwer and Gerisch (Halle). Their results on splitting methods in

combination with approximate matrix factorization has been published in MAS-R0026.

(3) Biofilm problems
Peletier and Sommeijer participate in an EU project, called BIOFILMS. This 3-year project, started in 2000 and co-ordinated by the Aquatic Ecology and Ecotoxicology-group of the UvA, aims at studying biofilms, the thin layers of micro-algae, bacteria and their mucus which occur in all natural rivers and lakes, but also in drinking water plants. Especially this last aspect is the main focus of the project. CWI gives model advice and assists with numerical algorithms.

(4) Phytoplankton models
In 2000, a joint research activity has been started with J. Huisman from the Institute of Biodiversity and Ecosystems Dynamics (UvA). This collaboration concerns the numerical study of phytoplankton models. In this application, research questions comprise the dynamics of phytoplankton species, the mutual competition for light and the role of mixing processes and vertical velocities (sinking or buoyant species). Several new and interesting results were obtained which have been described in four manuscripts; these will appear as CWI reports, early 2001. On a global scale, about 15% of the greenhouse gas CO_2 is transported by sinking phytoplankton species to the bottom of the oceans. One of our results has a direct relevance for the feedback between aquatic phytoplankton and the greenhouse effect.

People involved are B.P. Sommeijer (for the numerical aspects) and U. Ebert, M. Arrayás and N.M. Temme (for the analytical aspects). At the moment we are seeking external funding to continue this successful co-operation.

(5) Molecular crowding
In the framework of the ICES-KIS programme, M.A. Peletier and J.G. Blom study a mathematical model describing molecular crowding in a cell (in collaboration with theoretical and experimental cell-biologists from the UvA and VU). In most cell models the assumption is made that the concentrations of enzymes in a cell are homogeneous. This well-stirred approximation may very well be a too simplistic approach and the extent of inhomogeneity may even vary depending on the functioning of the system and be important for its mechanisms and regulations. Taking into account the spatial aspects leads to a system of PDEs of the reaction-diffusion type. Preliminary experiments with the PTS (phosphotransferase) system in *E-coli* have shown that macromolecular crowding can have strong implications on the glucose metabolism and transport (see MAS-R0020).

Pattern formation and low temperature plasmas – MAS1.4
In 2000, the new project group MAS1.4 headed by U. Ebert received funding from NWO (staff position Ebert till 8/00), EU–TMR (postdoc position Arrayás), FOM (PhD position Sijacic from 5/00, two months guest position Rodin, material budget) and CWI (two months guest position Rodin, staff position Ebert from 9/00). Collaborations with CWI staff (W. Hundsdorfer, N. Temme, B. Sommeijer), and with external colleagues (UL, UvA, Univ. Essen, Univ. Münster, Forschungszentrum Jülich, Ioffe–Inst. St. Petersburg, Univ. Barcelona) were extended.

(1) Basic research on nonlinear PDEs and pulled fronts
The Mathematics Classification Index does distinguish parabolic or higher order equations, since these are traditional concepts of linear PDE theory. However, it does not allow to distinguish pushed or pulled fronts as fundamentally different solutions of nonlinear PDEs. While pushed or bistable fronts are well-covered by textbooks on nonlinear dynamics, the different nature of so-called 'pulled' fronts, that always propagate into an unstable state, up to now has not received much attention beyond the analysis of planar solutions of the Fisher equation, though it causes characteristical new challenges both to analysis and to numerics. Since negative ionization fronts in electric discharges fall into the category of pulled fronts, the investigation of this basic issue is deeply related to the research described under (2).

The investigation has led to the following publications and results. The extended research paper by Ebert and Van Saarloos (UL) on the algebraic relaxation of monotonous pulled fronts (MAS-R9908) has appeared in *Physica D*. The results found recognition at the spring meeting of the American Physical Society, Minneapolis, 3/00 by an invited talk by Van Saarloos on pulled fronts and by Ebert on its implications for electric discharges and by a contribution by Van Saarloos and Ebert to the virtual press-room of the APS meeting (about 20 out of approx. 4000 contribu-

tions were selected for the press-room).

In 2000, U. Ebert has continued the publication of her basic analytical results on pulled fronts together with W. van Saarloos, C. Storm, W. Spruijt, L.A. Peletier (all UL) and A. Rocco (Univ. Barcelona). Report MAS-R0002 deals with the algebraic relaxation of pulled fronts that generate periodic or chaotic patterns, like in the extended Fisher-Kolmogorov-equation, in the Swift-Hohenberg-equation or in the complex Ginzburg-Landau-equation; the paper has been published as a Rapid Communication in *Phys. Rev. E.* Report MAS-R0003 describes the implications of pulled front propagation for perturbative schemes in higher spatial dimensions, in particular, it explains why moving boundary approximations for pulled fronts cannot be derived by Fredholm analysis; the paper has been published in *Phys. Rep.*

Report MAS-R0010 investigates a problem in stochastic PDEs, namely the mean square displacement of propagating fronts due to multiplicative noise – it is found that in contrast to the diffusive behaviour of pushed fronts, a different subdiffusive behaviour of pulled fronts could be predicted analytically and verified numerically; the paper has been published as a Rapid Communication in *Phys. Rev. E.*

Report MAS-R0011 discusses the algebraic relaxation (or convergence) of pulled fronts on a particular example, a difference-differential-equation, submitted to *Eur. J. Appl. Math.* In 2000, W. Hundsdorfer and U. Ebert found, that pulled fronts also require different numerical techniques and that adaptive grid codes fail. This problem, which has direct implications for the simulations of so-called streamers (see below), is presently under investigation.

(2) Pattern formation in electric discharges

This topic has found broad recognition by invited talks of U. Ebert at the spring meeting of the American Physical Society, at the Euroconference on 'Coherent Structures in Classical Systems' in Sitges, Spain, at the national Dutch annual meetings on 'Mathematical Physics' and on 'Plasma Physics', and at the NWO Symposium on nonlinear systems.

D. Sijacic as a qualified PhD student could be attracted for the new subject of spatio-temporal instabilities in barrier discharges. In the meantime, she has visited a number of schools, got into the problem and starts to get first results.

M. Arrayás and U. Ebert wrote the short review Report MAS-R0028 on streamer discharges, which will appear in *Lecture Notes in Physics* (Springer). A paper on transversal instabilities of streamer fronts is in preparation. The numerical solution of streamer ionization fingers in three dimensions with radial symmetry poses the challenges of pulled fronts that are discussed under (1) above. A preliminary solver is presently being developed by W. Hundsdorfer and M. Arrayás. It will be used later by M. Arrayás, P. Rodin and U. Ebert in their investigations. Funding for a more basic investigation and solution of the numerical problem is applied for.

During a 4 month's visit, P. Rodin together with W. Hundsdorfer and U. Ebert laid the base for a series of papers on streamer-like ionization fronts in layered semiconductor devices that are used in many power electronics applications. Rodin's homebase Ioffe-Institute St. Petersburg is world-leading in the production of these devices and has received the 2000 Nobel Prize in Physics for closely related research. In 2000, we modelled the problem, wrote numerical codes, and studied the solutions numerically as well as analytically in a planar approximation.

(3) Stochastic and deterministic analysis in biology and chemistry

U. Ebert and M. Arrayás have investigated analytically the phytoplankton problem that B. Sommeijer studies numerically for and with J. Huisman (Biology, UvA). It turned out that the conditions of long time survival of a phytoplankton species can be fully evaluated analytically. The problem could be reduced and transformed into a particular Bessel function problem that was analyzed together with N. Temme. Two articles are almost submitted.

M. Arrayás published three articles in statistical biophysics on the question how undirected chemical energy can be transformed into the directed motion of a biological motor by so-called Brownian ratchets. The investigations came forth from his PhD in Manchester and were partially written at CWI.

U. Ebert has continued her collaboration with L. Schäfer (Essen) and A. Baumgärtner (Jülich) on the diffusion of long flexible polymer chains. A paper in 2001 will deal with the structure function in the short time limit of chains reptating through a regular array of obstacles.

Organization of Conferences, Workshops, Courses, etc.

- M.A. Peletier organized the colloquium series 'Crossroads of Mathematics, Informatics, and the Life Sciences'.
- M.A. Peletier organized Crossroads Colloquium, 7 June, 'Modelling and Analysis in the Living Cell', CWI.
- N.M. Temme was organizer of the general monthly CWI seminar 'Scientific Meetings'.
- J.G. Verwer and J. Kok organized TASC Symposium 13, CWI, February 14 (final report on finished HPCN projects).
- W. Hundsdorfer and U. Ebert organized the MAS1-seminars.
- M. Arrayás organized the Capitán Araña–Sessions aimed to stimulate scientific discussions and exchange between oio's and postdocs at CWI.
- M.A. Botchev together with Prof. Jianping Zhu (Mississippi State University) organized the mini-session 'Advanced Methods for Reaction-Advection-Diffusion Problems at the 16th IMACS World Congress 2000, August 21–25, Lausanne, Switzerland.
- J.G. Verwer organized the mini-symposium Atmospheric Transport-Chemistry Problems at the NUMDIFF meeting, Halle, Germany, September 4–8.
- P.M. de Zeeuw organized the Symposium Numerieke Wiskunde as an integral part of the 36ste Nederlands Mathematisch Congres at Maastricht University, April 27–28.
- B.P. Sommeijer has given lectures in the course Parallel Scientific Computing & Simulation at the University of Amsterdam.
- W. Hundsdorfer has given a Stieltjes AIO course at Leiden University.

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

- EPF Lausanne, January 3–5, M.A. Peletier (*Sequential Buckling: A Variational Analysis*)
- Annual SIAM-UK Meeting, London, January 7, J.G. Verwer (*The numerical solution of air pollution models*).
- Conference USA-Chile workshop on Nonlinear Analysis. Valparaiso, Chile, January 10–14, I. Guerra (*Transport of reactive solutes induced by well injection in* $\mathbf{R}^3$*: constant flow rate*).
- International Symposium on Asymptotics and Applied Analysis, San Diego (USA), January 10–14, N.M. Temme (*Asymptotic expansions: Examples and recent problems* (invited talk)).
- Paris 6, January 15–31, M.A. Peletier (*New results for Newton's problem of the body of minimal resistance*).
- Wetenschappelijke vergadering statistische fysica, Lunteren, January 21–22, M. Arrayás and U. Ebert (poster: *Pattern Growth in Electric Discharges*).
- Oberwolfach meeting 'The Mathematics of Porous Media', Germany, January 23–29, C. Cuesta (*Infiltration of porous media with dynamic capillary pressure: travelling waves*), I. Guerra, W. Hundsdorfer (*Locally implicit time stepping for convection problems*)
- 'Onderwijsweek Eigenwaardeproblemen' held in February, in Leiden University. C. Cuesta, I. Guerra.
- TASC Symposium 13, February 14, CWI, B.P. Sommeijer (*Approximate factorization for time-dependent partial differential equations*).
- Leiden Univ., February 16, U. Ebert (*Breakdown of Moving Boundary Approximations for Pulled Fronts*).
- Spring meeting of the American Physical Society, Minneapolis, March 20–24, U. Ebert (*Streamers: Interfacial patterns in electric discharges* (invited talk)).
- Algemeen Wiskunde Colloquium, Univ. of A'dam, February 23, J.G. Verwer (*The numerical solution of partial differential equations used in air pollution modelling*).
- Workshop Scalable Solver Software, Sankt Augustin, Germany, February 28–March 1, P.J.F. Berkvens, J.E. Frank.
- IMA workshop Atmospheric Modelling, Minneapolis, March 15–19, J.G. Verwer (*Time integration issues, operator splitting and alternatives*).
- Numerical Analysis group of Prof. H.A. van der Vorst, Utrecht University, March 16, M.A. Botchev (*Numerical variations on the APM theme*).
- Wetenschappelijke vergadering plasmafysica, Lunteren, March 28–29, M. Arrayás and U. Ebert (poster: *Pattern Growth in Electric Discharges*).
- HPCN conferentie 'Simulatietechnologie', EUR Rotterdam, March 30, J. Kok, J.G. Verwer.
- Symposium 'Recent developments in Ordinary Differential Equations', April 14, TU Eind-

hoven, B.P. Sommeijer (*RKC: an explicit solver for parabolic PDEs*).

- Nederlands Mathematisch Congres, Maastricht, April 27 – 28, P.J.F. Berkvens (*On the Efficient Treatment of Vertical Mixing and Chemistry in Air Pollution Modelling*) (in *Symposium Wiskunde Toegepast*), D. Lanser (*Time Integration of the Shallow Water Equations in Spherical Geometry*).
- Visit to Scotland, May 8–19, Dundee Univ. (Dundee), Heriot-Watt Univ. (Edinburgh), Strathclyde Univ. (Glasgow), W. Hundsdorfer (*Second order splitting with internal consistency*), (*Locally implicit methods*).
- MAS1-seminar, CWI, May 11, D. Sijacic (*Green's functions methods in low–dimensional structures*).
- Kickoff meeting EU-BIOFILM project, May 23–24, UvA, Amsterdam, M.A. Peletier, B.P. Sommeijer (*Overview of CWI research activities in the life sciences*).
- NWO Symposium on nonlinear systems, Twente, May 25–26, M. Arrayás, U. Ebert (*Pattern Formation in Electric Discharges*), P. Rodin (poster: *Competing spatial and temporal instabilities in reaction-diffusion systems with subcritical spatial bifurcation*), D. Sijacic.
- Euroconference 'Coherent Structures in Classical Systems' in Sitges, Spain, June 5–9, U. Ebert (*Pattern Formation in Electric Discharges*), M. Arrayás and U. Ebert (poster: *Pattern Growth in Electric Discharges*).
- Working visit Surrey University, UK. Host: Sebastian Reich, 6–9 June, J.E. Frank.
- Working visit Univ. Münster, Germany, June 8–9, D. Sijacic.
- Jaarvergadering of the research school 'Centrum voor Plasmafysica en Stralingstechnologie' in Eindhoven, June 9, U. Ebert (*Pattern Formation in Electric Discharges*).
- Summer School UTwente 'Nonlinearities in Natural Sciences', June 13–16, C. Cuesta, I. Guerra, M.A. Peletier (lecturer, *A Variational Approach to Higher-order ODEs*), D. Sijacic.
- Cluj Academic Days, June 15–17, Cluj-Napoca, Romania, I.S. Pop (*Infiltrations in heterogeneous media*).
- Scientific Computing Group of Prof. R.M.M. Mattheij, Eindhoven University of Technology, June 14, M.A. Botchev (*Numerical Challenges in Air Pollution Modelling*).
- Working visit Univ. Münster, Germany, June 22–23, U. Ebert, D. Sijacic.
- Jaarvergadering Mathematische Fysica (FOM/NWO), Amersfoort, June 29, U. Ebert (*Pattern Formation in Electric Discharges*) (invited talk).
- 'Shaping the Future' Forum, Global Dialogue 3: 'Science and Technology – Thinking the Future', July 3–7, Expo 2000 Hannover, Germany, I.S. Pop (*Flow simulation in unsaturated, heterogeneous soils*).
- 'Intensive Course on Low Temperature Plasma Physics and Its Applications', Eindhoven, July 3–11, M. Arrayás, D. Sijacic.
- MAS1–seminar, CWI, July 11, B. Sommeijer and U. Ebert (*Phytoplankton Growth*).
- World Conference of Nonlinear Analysts Catania, July 18–22, M.A. Peletier (*Monotonicity Structure in Fourth-order ODEs*).
- Gordon Research Conference Oxford on Macromolecular Organisation and Cell Function, August 6–11, M.A. Peletier (Poster).
- 16th IMACS world congress, Lausanne, Switzerland, August 22, M.A. Botchev (*On the Efficient Treatment of Vertical Mixing and Chemistry in Air Pollution Modelling*) (joint work with P.J.F. Berkvens, and J.G. Verwer).
- Workshop of the EU-TMR network 'Patterns, Noise and Chaos' in Leiden, August 18–September, M. Arrayás (*Phytoplankton bloom development or playing with Bessel functions*), U. Ebert, D. Sijacic.
- International Workshop on Fluctuations and Superfluidity, Lancaster, UK, September 2–3, M. Arrayás (poster: *On the possibility of a Brownian ratchet on the ^{4}He surface*).
- Conference 'Multiscale problems in science and technology, challenges to mathematical perspectives', September 3–9, in Dubrovnik, Croatia, C. Cuesta, I. Guerra, M.A. Peletier.
- NUMDIFF conference, Halle, Germany, September 4–8, M. Botchev (*Improving Approximate Matrix Factorizations for implicit time integration in air pollution modelling*), J.E. Frank (*Parallel Extended Backward Difference Formulas*), W. Hundsdorfer (*Splitting with stabilizing corrections*), J.G. Verwer (*Numerical Time Integration of Air Pollution Models*).
- Summer school on 'Complex Fluids', Bayreuth (Germany), September 17–29, D. Sijacic.
- Conference Fises 2000, Santiago de Compostela, Spain, September 19–21, M. Arrayás (*Ratchets driven by quasimonochromatic noise*)
- Fourth GLOREAM Workshop, Cottbus, Germany, September 20–22, P.J.F. Berkvens (*Effi-*

cient Treatment of Vertical Mixing and Chemistry in Air Pollution Modelling).
- Universidad Rey Juan Carlos, Madrid, September 27, M. Arrayás (*Phytoplankton bloom development*)
- CWI in Bedrijf, October 6, CWI, B.P. Sommeijer (*Phytoplankton models: dynamics, competition and the struggle for light*).
- Trends in Nonlinear Analysis: Theory, Modelling and Computation, October 8–12, Heidelberg, Germany, I.S. Pop (*A numerical approach for Richards equation*).
- Seminar Selbstorganisation in komplexen nichtlinearen Systemen, TU Berlin, October 19, P. Rodin (*Avalanche-streamer transition and superfast ionization fronts in semiconductor devices*).
- ICAM-2, Second International Conference on Applied Mathematics, October 19–21, Baia Mare, Romania, I.S. Pop (*A linear semi-implicit discretization method for degenerate parabolic problems*).
- 3rd GMD-SCAI/DWD Workshop, October 19, D. Lanser (*Spatial Discretization and Time Integration of the Shallow Water Equations in Spherical Geometry*).
- Farewell symposium P.J. van der Houwen, October 20, CWI, B.P. Sommeijer (*A survey of Piet van der Houwen's research*).
- Visit to University of Torino (Italy), October 20–24, N.M. Temme (*Asymptotic expansions: Examples and recent problems*).
- KNMI, October 23, D. Lanser (*A Suitable Testcase to Evaluate a Numerical Solution Method for Solving the Primitive Equations*).
- University of Bologna (Italy), October 25–26, N.M. Temme (*Special Functions and Asymptotic Expansions: Examples and recent problems*).
- Nonlinear Dynamics Days, Dresden, Germany, November 5–8, P. Rodin (*Competing spatial and temporal instabilities in reaction-diffusion systems with subcritical spatial bifurcation*).
- Colloquium: Faculteit Toegepaste Wiskunde, Universiteit Twente, 9 November, J.E. Frank (*A potential vorticity conserving geometric integrator for rotating shallow water equations*).
- Visit to Valladolid, Spain, December 11–18, W. Hundsdorfer (*IMEX time stepping with spatial discontinuous finite elements*).
- MAS1-seminar, CWI, December 13, M. Arrayás (*On the streamer's flight: the bent and winding road*).
- Universidad de Sevilla, Spain, December 20, M. Arrayás (*On the streamer's flight: the bent and winding road*).
- Seminar of the Mathematical Modeling Department, Rostov State University, Rostov-on-Don, Russia, December 21, M.A. Botchev (*Iterative linear solvers: GMRES, BiCGSTAB and other Krylov subspace methods*).

Memberships of Committees and Other Professional Activities

J.G. Verwer:
- Professor of Numerical Analysis, Korteweg-de Vries Institute, University of Amsterdam.
- Senior Editor *APNUM* (*Applied Numerical Mathematics*).
- Member organizing committee 9th Seminar NUMDIFF – Numerical Solution of Differential and Differential-Algebraic Equations, Halle, Germany, September 4–8, 2000.
- Editor special APNUM issue devoted to proceedings of the 9th NUMDIFF Seminar.
- Member advisory committee of CMUC (The Centre for Mathematics of the University of Coimbra, Portugal).
- Member scientific committee APMS'2001 – 2nd International Conference on Air Pollution Modelling and Simulation, April 9–13, 2001, Paris, organized by ENPC and INRIA.
- Committee member PhD thesis J. Frank, April 17, Delft University of Technology (*Efficient algorithms for the numerical solution of differential equations*).
- CWI contact for the Flemish Research Network on Advanced Numerical Methods for Mathematical Modelling (WOG).

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'.

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*).

- 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. Ebert:
- Leader FOM-working group TF-CWI.
- Leader CWI-group of the research school 'Center for Plasma Physics and Radiation Technology'.

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

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

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

B.P. Sommeijer:
- Lecturer in the course Parallel Scientific Computing & Simulation (University of Amsterdam).
- Managing editor *Letter Section Journal Computational and Applied Mathematics (JCAM).*
- Member organizing committee 9th Seminar NUMDIFF – Numerical Solution of Differential and Differential-Algebraic Equations, Halle, Germany, September 4–8, 2000.
- Editor special *APNUM* issue devoted to proceedings of the 9th NUMDIFF Seminar.

N.M. Temme:
- Editor *ZAMP.*
- Editor *Mathematics of Computation.*
- Editor *SIAM Journal on Mathematical Analysis.*
- Editor *Update Handbook of Mathematical Functions* ('Abramowitz and Stegun').
- Member governing board of the Stieltjes Institute for Mathematics and CWI-coordinator for the Dutch research schools in mathematics and computer science.
- Organizer CWI general monthly seminar CWI Scientific Meetings.
- Co-advisor PhD thesis P.J. Oonincx, Mathematical Signal Analysis: *Wavelets, Wigner Distribution and a Seismic Application*, University of Amsterdam, February 2000.

P.M. de Zeeuw:
- Secretary Dutch-Flemish Numerical Analysis Society.
- Editor *Het Nummer*, the newsletter of the Dutch-Flemish Numerical Analysis Society.

Visitors

- H. Berestycki (C.J. van Duijn), Univ. Marie Currie, Paris, 7.12–8.12.
- R. Folch (U. Ebert), Paris, 8.11–11.11.
- P. Rodin (U. Ebert), St. Petersburg, 1.4–30.6.
- R. Beardmore (M.A. Peletier), Bath/Bristol, 21.4–27.4.
- J. Lang (J.G. Verwer), ZIB, Berlin, 27.1–29.1.
- J. Lang (J.G. Verwer), Konrad-Zuse-Center, Berlin, 26.01–28.01.
- P. Tupper (J.G. Verwer), Univ. of Warwick, UK, 25.02–28.02.
- A. Friedman (P.W. Hemker, C.J. van Duijn), Minneapolis, 15.05–16.05.
- J. Keener (M.A. Peletier), Utah, 01.06–01.07.
- A. Gerisch (J.G. Verwer), Univ. of Halle, 21.06–24.06.
- H. Levine (M.A. Peletier), Univ. of Iowa, 19.06–23.06.
- S. Reich (J.E. Frank), Imperial College, London, 25.08–29.08.
- R. Wong (N.M. Temme), Univ. of Hong Kong, 27.08–30.08.
- K. Strehmel (P.J. van der Houwen), Martin-Luther-University Halle-Wittenberg, 19.10–20.10.
- C.T.H. Baker (P.J. van der Houwen), Manchester University, 18.10–20.10.
- A.O.H. Axelsson (P.J. van der Houwen), Catholic University Nijmegen, 20.10.
- M.N. Spijker (P.J. van der Houwen), Leiden University, 20–10.
- H. Brunner, (P.J. van der Houwen), Memorial University of Newfoundland, 19.10–20.10.
- R. Folch (U. Ebert), Univ. Paris VI, 9.–11.11.
- M. Garbey (J.G. Verwer), Centre pour le Développement du Calcul Scientifique, Université Claude Bernard Lyon1, 22.11.
- B. Kholodenko (J.G. Blom, M. Peletier), Dept. of Pathology and Cell Biology, Thomas Jefferson University, Philadelphia, 27.11.
- B. Sportisse (J.G. Verwer), Centre d'Enseignement et de Recherche en Mathématiques, Informatique et Calcul Scientifique (CERMICS), Paris, 28.11–01.12.

Papers in Journals and Proceedings

C. VUIK, A. SEGAL and F.J. VERMOLEN (2000). A conserving discretisation for a Stefan problem with an interface reaction at the free boundary. *Computing and Visualisation in Science* **3**, 109–111.

S.P. CHEN, M.S. VOSSENBERG, F.J. VERMOLEN, J. VAN DE LANGKRUIS and 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.

H.W. ALT and C.J. VAN DUIJN (2000). A free boundary problem involving a cusp: breakthrough of salt water. *Interfaces and Free Boundaries* **1**, 21–72.

M. ARRAYÁS, M.I. DYKMAN, R. MANNELLA, P.V.E. MCCLINTOCK and N.D. STEIN (2000). Symmetry breaking of fluctuation dynamics by noise color. *Phys. Rev. Lett.* **24**, 5470–5473.

M. ARRAYÁS, I.KH. KAUFMAN, D.G. LUCHINSKY, P.V.E. MCCLINTOCK and S.M. SOSKIN (2000). Kramers problem for multiwell potential. *Phys. Rev. Lett.* **84**, 2556–2559.

M. ARRAYÁS, R. MANNELLA, P.V.E. MCCLINTOCK, A.J. MCKANE and N.D. STEIN (2000). Ratchet driven by quasimonochromatic noise. *Phys. Rev.* **E 61**, 139–146.

P.J.F. BERKVENS, M.A. BOTCHEV and J.G. VERWER (2000). On the Efficient Treatment of vertical mixing and chemistry in air pollution modelling. *Proceedings of the Symposium Wiskunde Toegepast*, Maastricht, The Netherlands.

P.J.F. BERKVENS, M.A. BOTCHEV and J.G. VERWER (2000). On the efficient treatment of vertical mixing and chemistry in air pollution modelling. CD-ROM Procs. *16th IMACS World Congress*, Lausanne, 2000.

J.G. BLOM and J.G. VERWER (2000). A comparison of integration methods for atmospheric transport-chemistry problems. *J. Comp. Appl. Math* **126**, 381–396.

S. BOSE, P. RODIN and E. SCHÖLL (2000). Competing spatial and temporal instabilities in a globally coupled bistable semiconductor systems near a codimension-two bifurcation. *Phys Rev.* **E 62**, 1778–1789.

J. BRUINING and C.J. VAN DUIJN (2000). Uniqueness conditions in a hyperbolic model for oil recovery by steamdrive. *Computational Geosciences* **4**, 65–98.

S. BRYANT, C.N. DAWSON and C.J. VAN DUIJN (2000). Dispersion induced chromatographic waves. *Industrial & Engineering Chemistry Research* **39**, 2682–2691.

V. CHEIANOV, P. RODIN and E. SCHÖLL (2000). Transverse coupling in bistable resonant-tunneling structures. *Phys. Rev.* **B 62**, 9996–9968.

R. CHELLURI, L.B. RICHMOND and N.M. TEMME (2000). Asymptotic estimates for generalized Stirling numbers. *Analysis* **20**, 1–13.

C.CUESTA, C.J. VAN DUIJN and J. HULSHOF (2000). Infiltration in porous media with dynamic capillary pressure: travelling waves. *European Journal of Applied Mathematics* **11**, 381–397.

U. EBERT and W. VAN SAARLOOS (2000). Front propagation into unstable states: Universal algebraic convergence towards uniformly translating pulled fronts. *Physica D* **146**, 1–99.

U. EBERT and W. VAN SAARLOOS (2000). Breakdown of the standard Perturbation Theory and Moving Boundary Approximation for 'Pulled' Fronts. *Phys. Rep.* **337**, 139–156.

J.E. FRANK and P.J. VAN DER HOUWEN (2000) Diagonalizable extended backward differentiation formulas. *BIT* **40:3**, 497–512.

G. GALIANO (2000). Spatial and time localization of solutions of the Boussinesq system with nonlinear thermal diffusion. *Nonlinear Analysis* **42**, 423–438.

A. GIL, J. SEGURA and N.M. TEMME (2000). Computing toroidal functions for wide ranges of the parameters. *J. Comput. Phys.* **161**, 204–217.

D. HILHORST and M.A. PELETIER (2000). Convergence to travelling waves in a reaction-diffusion system arising in contaminant transport. *Journal of Differential Equations* **163**, 89–112.

P.J. VAN DER HOUWEN (2000). Note on the time integration of 3D advection-reaction equations. *J. Comput. Appl. Math.* **116**, 275–278.

P.J. VAN DER HOUWEN, E. MESSINA and B.P. SOMMEIJER (2000). Oscillatory Störmer-Cowell methods. *J. Comput. Appl. Math.* **115**, 547–564.

P.J. VAN DER HOUWEN and B.P. SOMMEIJER (2000). Diagonally implicit Runge-Kutta methods for 3D shallow water applications. *Adv. Comput. Math.* **12**, 229–250.

G.W. HUNT, M.A. PELETIER, A.R. CHAMPNEYS, P.D. WOODS, M. AHMER WADEE,

C.J. Budd and G. Lord (2000). Cellular buckling in long structures. *Nonlinear Dynamics*, **21**, 3–29.

G.W. Hunt, M. Ahmer Wadee and M.A. Peletier (2000). The Maxwell Stability Criterion in pseudo-energy models of kink banding. *Journal of Structural Geology* **22**, 667–679.

D. Lanser, J.G Blom and J.G. Verwer (2000). Spatial discretization of the shallow water equations in spherical geometry using Osher's scheme. *J. Comput. Phys.* **165**, 522–541.

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R. van Liere, J. Mulder, J. Frank and J. de Swart (2000). Virtual Fekete point configurations: a case study in perturbing complex systems. S. Feiner and D. Thalmann, (eds.). *Proceedings of IEEE Virtual Reality 2000*, IEEE Computer Society Press, Los Alamitos, California, USA, 189–196.

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CWI Reports

The following CWI reports were published by members of theme MAS1. See page 78 for the complete titles of the reports.

MAS-R0001	MAS-R0002	MAS-R0003
MAS-R0004	MAS-R0005	MAS-R0006
MAS-R0008	MAS-R0009	MAS-R0010
MAS-R0011	MAS-R0012	MAS-R0013
MAS-R0014	MAS-R0015	MAS-R0016
MAS-R0017	MAS-R0018	MAS-R0020
MAS-R0021	MAS-R0022	MAS-R0023
MAS-R0025	MAS-R0026	MAS-R0027
MAS-R0028	MAS-R0029	MAS-R0030
MAS-R0031		

Computational Fluid Dynamics – MAS2

In 2000 the MAS2 subthemes were:

MAS2.1	Computational Fluid Dynamics (Koren)
MAS2.2	Computational Number Theory and Data Security (Te Riele)

Staff

- Prof. dr. P.W. Hemker, theme leader
- Ir. E.H. van Brummelen, PhD student
- Drs. S. Cavallar, PhD student
- Dr. J.L.M. van Dorsselaer, postdoc (until June 30)
- G.F. Duivesteijn, trainee (seconded by Faculty of Aerospace Engineering, Delft University of Technology, since June 26)

- Drs. M. Genseberger, PhD student (joint with Mathematical Institute, Utrecht University)
- Prof. dr. P.J. van der Houwen, CWI Fellow (until August 31)
- Drs. J. Kok, researcher
- Dr. ir. B. Koren, project leader
- Drs. B. Lastdrager, PhD student (joint with MAS1)
- Ir. M.R. Lewis, PhD student
- Dr. P.L. Montgomery (San Rafael, CA, USA), researcher (honorary advisor)
- Drs. M. Nool, scientific programmer
- Ir. M.H. van Raalte, PhD Student (since Dec. 1, seconded by University of Amsterdam)
- Dr. ir. H.J.J. te Riele, project leader
- L. Voort, trainee (seconded by Faculty of Aerospace Engineering, Delft University of Technology, since September 4)
- Prof. dr. ir. P. Wesseling, advisor (Delft University of Technology)
- D. Wilschut, trainee (Hogeschool Holland), from February 1 until June 30

Scientific Report

Computational Fluid Dynamics – MAS2.1

MARIN
In the framework of the joint CWI/MARIN project *Robustness Improvement and Extension of PARNASSOS*, Van Brummelen continued the development of an efficient solution method for steady free-surface Navier-Stokes flow problems. It was shown that the usual time-integration approach is necessarily inefficient at subcritical Froude numbers. An efficient iterative solution method was then proposed. By reformulating the free-surface flow problem into an equivalent optimal shape-design problem, it was shown that the new iterative method displays mesh-width independent convergence behaviour. This favourable convergence behaviour was confirmed by numerical experiments for a 2D test-case. Implementation of the method for actual 3D ship hydrodynamics computations has been initiated. Preliminary results indicate that the envisaged 3D ship hydrodynamics applications can indeed be solved efficiently with the new method. In a parallel development, an investigation of the suitability of adjoint shape optimization methods for solving steady free-surface flows has been initiated. Theoretical results indicate that such a method is indeed viable. The implementation of numerical experiments is currently in progress.

NCF
In the framework of the NCF-project *Parallel Adaptive Mesh Refinement for Computational Magneto-Fluid Dynamics*, Nool continued on the multi-dimensional adaptive mesh refinement code for problems in (magneto)hydrodynamics. The final step of this project was to convert the Fortran 90 software to LASY, a Loop Annotation SYntax, such that the grid adaption algorithm can be incorporated with the Versatile Advection Code (VAC), and can be used to time-advance sets of conservation laws with options for spatial discretization employed. First results with this code have been obtained in 1D, 2D and 3D simulations on a sequential platform. More effort is needed to adapt the software to distributed memory systems, to be able to perform large 3D simulations.

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 was incorporated to compute solutions of the correction equation, which causes most of the computational work in Jacobi-Davidson.

The construction of the preconditioner needed special care. For a two-dimensional advection-diffusion model problem, with fixed coefficients, an analysis of the error amplification was performed which makes it possible to determine optimal coupling parameters. It turned out that from this point of view also coupling parameters for variable coefficient problems can be estimated.

With the same preconditioner, even better performance is obtained by application on the eigenvalue problem level instead of the correction equation level. Numerical experiments showed that the differences between these two approaches become significantly larger when the number of subdomains increases.

NWO2
In the framework of the NWO-project *Sparse Grid Methods for Transport Problems*, Lastdrager, Koren and Verwer considered time-dependent mixed advection-diffusion problems with grid-aligned solution layers. In particular the Burgers' equation was considered to assess

the applicability of the method to a non-linear problem. For a linear problem, error predictions were computed that matched numerical observations. In addition, a gradient-diffusion problem from neuro-biology has been studied. For this problem a robust preliminary code has been developed that mimics experimentally observed behaviour of bundling and debundling in the growth of axons. During the development an interesting complication in the numerical treatment of source terms and gradients was observed and tackled.

NWO-MPR

In the framework of the NWO-MPR project *Parallel Computational Magneto-Fluid Dynamics*, Van Dorsselaer studied several tools to investigate strongly non-normal eigenvalue problems. For such problems an analysis based on eigenvalues and eigenvectors may lead to misleading results concerning, e.g., stability of equilibria. Both standard and generalized eigenvalue problems were dealt with. The tools considered were ε-pseudospectra, the condition number of an eigenvalue, the condition number of a set of eigenvectors, and angles between invariant subspaces. The (theoretical) properties of these concepts were compared, and attention was paid to the amount of computational work needed to apply these tools to large eigenvalue problems. It turned out that the computation of ε-pseudospectra is the most expensive, while the other tools can be applied without much effort once the relevant eigenvalues and eigenvectors have been computed. These tools were applied to a strongly non-normal generalized eigenvalue problem arising in magneto-hydrodynamics.

STW-MARIN

In the framework of the STW-MARIN-project *Development of a State-of-the-Art Navier-Stokes Solver for Water Flows around Moving Ships*, Lewis developed, in close cooperation with Van Brummelen, Koren and Van Leer a method for computing 1D, unsteady, inviscid and immiscible water-air flows. Furthermore, Lewis and Koren extended this method for flows with a gravitational field. The method has been tested on a model problem and shows promising results. This method will be the basis for the computation of 2D, steady, Navier-Stokes flows with free surfaces, for which a code is currently under development.

NWO-NL-RF

In this year the cooperation with our Russian colleagues in the field of Numerical Singular Perturbation Problems could be continued. A new NWO-project (nr.047.008.007) with the title: *Efficient and robust Numerical Methods for Differential Equations with Singularities* started in January 2000. The Dutch groups in this cooperation involve KUN (Prof. Dr. A.O.H. Axelsson, general coordinator) and CWI (Hemker). The cooperating Russian groups are: Moscow State University (Prof. G. Kobelkov and Prof. N.S. Bakhvalov, MSU), the Computing Center of the Russian Academy of Sciences, Moscow, (Dr. I.E. Kaporin and Dr. V. Konshin, RAS), the Institute of Mathematics and Mechanics, Ural branch RAS, Ekaterinburg, (Prof. G.I. Shishkin, IMM), the Institute of Computational Mathematics, Siberian branch RAS, Novosibirsk (Prof. V.P. Il'in, ICM), the Steklov Institute of Mathematics, RAS, St. Petersburg (Dr. L.Y. Kolotilina and Dr. A. Yeremin) and the Department of Applied Mathematics, Kuban State University, Krasnodar (Prof. E. Glushkov).

A start-up workshop for the NWO-NL-RF project was held in Novosibirsk on June 28, 2000 during the 4th Siberian Congress on Industrial and Applied Mathematics (Novosibirsk, June 26 - July 1, 2000). The purpose of the Workshop was general discussions between representatives of the participating groups about the cooperation and the recent progress in the project, forthcoming visits and directions for further research. Prof. V.P. Il'in was responsible for the local organization. Short scientific presentations were given by eight participants from Ekaterinburg and Novosibirsk groups. A second workshop was held at CWI (November 16–17) and KUN (November 21).

In the framework of this cooperation Prof. G.I. Shishkin, Dr. L.P. Shishkina and I.V. Tselisheva, from the Institute of Mathematics and Mechanics, Ural branch RAS, Ekaterinburg, visited CWI from 2 until 30 November. During the visit research was focused on special numerical methods that realize ε-uniform convergence for parabolic and elliptic equations. High-order accurate methods, based on defect correction were used to improve the time-accuracy of the methods studied. For this research several papers were prepared. A CWI report will appear in 2001.

number	$2,773+$	$10,211-$	RSA140	RSA155
algorithm	SNFS	SNFS	GNFS	GNFS
size of the number factored (in decimal digits)	227	211	140	155
size of the factors (in decimal digits)	55, 71, 102	93, 118	70, 70	78, 78
sieving time (in CPU years)	57.4	10.9	8.9	35.7
calendar time for sieving (in days)	150	64	30	110
# workstations and PCs used for sieving	250	125	125	300
matrix size	6.8M	4.8M	4.7M	6.7M
row weight	65	49	32	62
Cray CPU hours for matrix step	250	121	100	224

Table 1: Factorization results

UvA
The cooperation with the numerical analysis group of the University of Amsterdam was continued. In January, the PhD student Drs. E.D. Havik stopped his activities and found a new job in a bank. A paper on the subject of his research was published in Computing. In December, a new PhD student, Ir. M.H. van Raalte, restarted the work that now will be primarily directed towards the development of discontinuous Galerkin methods.

Gerken's yield formula
This was a minor activity with the purpose to answer a question arising from a food industry. The problem was to model the production process of cacao such that the efficiency of the total process could be expressed in terms of some available data.

Computational Number Theory and data security – MAS2.2

Introduction
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 enlarges 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. For example, some algorithms for factoring large numbers can be carried out on a grid of heterogeneous computers where the number of computers in the grid is allowed to vary in a dynamical way.

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 permit, problems are chosen for which CWI had prior experience. Examples are: 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 most of the workstations and PCs at CWI. The group also has a limited budget on the Cray C90 supercomputer and its successor, the 1024 processor SGI Origin 3800 (also called TERAS) at SARA.

Scientific collaboration exists with (the groups of) Prof. R.P. Brent (Oxford University Computing Laboratory, Oxford, England), Prof. J. Cannon (University of Sydney, Australia), Prof. M. García (New York, USA), Dr. A.K. Lenstra (Citibank, New York and Parsippany, USA), J.M. Pedersen (Vejle Business College, Vejle, Denmark), 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).
See table. In this project the number field sieve and its suitability to factor general numbers is being studied. A variant of NFS was studied in which three large primes are allowed in the rela-

tions which are collected during the sieve part. Theoretical expectations were derived and compared with experimental results with the purpose of facilitating the choice of certain parameters in NFS like the factor base bound.

Peter Montgomery, in cooperation with Paul Leyland of Microsoft Research (Cambridge, UK) continued to develop 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 (at CWI), and the new SGI Origin 3800 (at SARA, operational early 2001).

Stefania Cavallar visited the University of Sydney (host: Prof. dr. J. Cannon) during the month October in order to help with the implementation of the NFS algorithm in the software package MAGMA. In particular, she gave advice concerning the filter part of NFS, which discards and rearranges the relations collected earlier during the sieve part of NFS. The purpose of this step is to compress the huge matrix in the next step of NFS as much as possible.

One factoring world record was established, namely for the Special Number Field Sieve (SNFS): on November 14 the 233-digit Cunningham number $2^{773}+1$ was factored by 'The Cabal'[1] into the product of 3, 533371 and three primes of 55, 71, and 102 digits, respectively. For details, see `ftp://ftp.cwi.nl/pub/herman/SNFSrecords/SNFS-233` .

The previous SNFS record was the 211-digit repunit number $(10^{211}-1)/9$, factored on April 8, 1999, also by the Cabal (see: `ftp://ftp.cwi.nl/pub/herman/SNFSrecords/SNFS-211`).

The following table summarizes some technical information about the SNFS factoring world record in comparison with the previous SNFS world record, and the two GNFS world records RSA140 and RSA155.

(b) Extending the Cunningham table (P.L. Montgomery, S. Cavallar, W.M. Lioen, H.J.J. te Riele).
In this project numbers of the form $a^n \pm 1$, $13 \leq a < 100$, are factored with the help of the ECM, SNFS, and GNFS factoring methods. This is an extension of the original Cunningham table. An update report will appear early 2001.

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) The inequality $\phi(an+b) < \phi(an)$, $gcd(a,n) = 1$ (H.J.J. te Riele)
During a visit at the Mathematical Sciences Research Institute in Berkeley, CA, the size of solutions of the inequality $\phi(an+b) < \phi(an)$, $\gcd(a,n) = 1$ was studied. An analysis was made of a constructive method of D.J. Newman and G. Martin to find solutions of this inequality. As a result, a formula was derived which gives a reasonably accurate estimate of the size of a solution found with Newman and Martin's method. For example, for the case $a = 30, b = 1$ this formula predicts a size of 1126 digits whereas Martin found the *minimal* solution to be a number of 1116 digits. A preprint has been submitted for publication, and the report will appear early 2001.

(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 has exceeded 700,000 and the 1 million barrier is expected to be broken in 2001. A survey paper which documents the main developments leading to this explosion of known amicable pairs is (still) in preparation.

(e) Digital signatures (D. Wilschut, H.J.J. te Riele)
This was a trainee project carried out by D. Wilschut for completing her study 'Bedrijfskunde' at the Hogeschool Holland in Diemen. In this study two digital signature algorithms were compared: the Digital Signature Algorithm (DSA) based on the discrete logarithm problem in F_p^*, and Elliptic Curve DSA (ECDSA), the elliptic curve variant of DSA, based on the discrete logarithm problem in $E(F_p)$. A difficult problem in this comparison is to find a good *measure of security*, which is required for a fair comparison

[1] A worldwide 'grid' of number field sievers, namely: Stefania Cavallar, Bruce Dodson, Jim Fougeron, Jeff Gilchrist, Arjen Lenstra, Paul Leyland, Walter Lioen, Peter Montgomery, Alec Muffett, NFSNET2 (Matthias Bruestle, Scott Contini, Pete Dodson, Eddie C. Dost, Scott Edick, Tom Holroyd, and John Klos), and Herman te Riele.

of the two signature systems. The main result is that for the bit-lengths currently used, ECDSA is faster, but when the security requirements are increased (i.e., the bit-lengths are increased), DSA eventually beats ECDSA. A turn-over point always exists: DSA is less sensitive to increasing bit-lengths than ECDSA. The trainee report has also appeared as a CWI Report (MAS-N0001).

Knowledge Transfer

M. Genseberger:

- Instruction courses Infinitesimaalrekening 1A, 1B and 1C and Lineaire Algebra voor Natuurkunde A, Utrecht University.

P.W. Hemker:

- Capita course at University of Amsterdam 'Advanced Scientific Computing' (September 14–November 23).
- Course at University of Amsterdam 'Numerical Hydrodynamics' (February 10–March 23).

Organization of Conferences, Workshops, Courses, etc.

P.W. Hemker:

- WG Najaarssymposium, CWI, December 1. (Lecturers: E. van Damme, J. Hoogland (CWI), D. Neumann (CWI), L. Kuipers (UT), D. Lenstra (VU) , P. Groeneboom (TUD), R. Geskus (GGGD Amsterdam), C. Venner (UT-WB), H. Raven (MARIN), E. Fledderus (KPN)).
- NWO-Workshop Efficient and Robust Numerical Methods for Differential Equations with Singularities, November 16 and 17 (CWI) and November 21 (KUN). Lecturers: O. Axelsson (KUN), G.I. Shishkin (IMM), V.P. Il'in (Novosibirsk), B. Koren (CWI), I.V. Tselishcheva (IMM), G.M. Kobelkov (MSU), H.van Brummelen (CWI), Yu. M.Laevsky (RAS-Sib.br.), I. Kaporin (RAS Moscow), L. Vijfvinkel (Shell), L.Yu. Kolotilina (St. Petersburg), A. Yeremin (MSU), P. Hemker (CWI), R. Blaheta (ASCR Ostrawa), L.P. Shishkina (IMM), V.P. Il'in (Novosibirsk), B. Polman (KUN), M. Lewis (CWI), I. Konshin (RAS Moscow).
- NWO-MPR-meeting, CWI, November 15.

B. Koren:

- MAS-Colloquium Advanced Discretization Methods for Hyperbolic Problems, CWI, March 1. (Lecturers: B. van Leer (University of Michigan), J.J.W. van der Vegt (University of Twente), R. Schwane (ESA-ESTEC).)
- NWO-MPR-meeting, CWI, June 5.
- Meeting Users Committee STW-MARIN-project, CWI, October 24.
- CFD-meetings, CWI, January 10, February 7+28, March 20, April 10, May 22, June 19, September 19, October 17,31, November 14, 28, December 12. (Guest lecturers: R. Keppens (FOM Rijnhuizen), M.M.J. Proot (TU Delft), I. Wenneker (TU Delft), J.M.L. Maubach (TU Eindhoven), M.H. van Raalte (TU Delft), G.I. Shishkin (IMM Ekaterinburg), F. Sprengel (GMD).)

E.H. van Brummelen and M.R. Lewis:

- Organization of the PhDays 2000, Meeting for Dutch and Flemish PhD students in Numerical Mathematics, Heemskerk, May 19–21.

Visits to Conferences, Workshops, Courses, etc.

- Intercity Colloquium Getaltheorie, various places (Leiden, Utrecht) and dates, Cavallar, Te Riele.
- NWO-MPR-meeting, CWI, January 12: Van Dorsselaer, Genseberger, Hemker (*Exercises with a two-dimensional convection-diffusion model problem*), Nool.
- AMIF-ESF Workshop Computing Methods for Two-Phase Flow, Aussois, January 12–14: Koren (*A level-set method and an approximate Riemann solver for capturing free-surface water waves*).
- ACCS-Seminar Univ. Amsterdam, January 21: Hemker (*Exercises with a two-dimensional convection diffusion model problem*).
- J.M. Burgers Centre course *Computational Fluid Dynamics I (CFD I)*, January 24–28: Lewis.
- Working visit MARIN, Wageningen, January 25: Koren.
- CFX-Seminar Amsterdam, February 8: Hemker, Lewis.
- Working visit to Prof. U. Rüde, Erlangen, February 16–19: Lastdrager (*Multivariate extrapolation techniques*).
- International Workshop on Water Waves and Floating bodies, Caesarea, February 27–March 1: Van Brummelen (*Numerical solution of steady free-surface Navier-Stokes flow*).
- NWO-MPR-meeting, Utrecht University, March 7: Van Dorsselaer, Genseberger, Hemker,

Koren (*Solution-adaptive multigrid for compressible flows*), Nool.
- NVTI Theoriedag 2000, Utrecht, March 10, Te Riele (*Factoring algorithms and their complexity, with application to cryptography*).
- Teambuilding CWI Works Council, Zuiderduin, Egmond, March 13–14: Nool.
- Working visit Corus (Hoogovens), IJmuiden, March 28: Koren.
- Landelijke VGWM-dag, Jaarbeurs, Utrecht, March 30: Nool.
- NWO-MPR-meeting, FOM-Rijnhuizen, April 26: Genseberger, Hemker, Koren, Van Leer (*Computational physics: science or tool?*), Nool.
- Zesendertigste Nederlands Mathematisch Congres, Universiteit Maastricht, April 27–28: Lastdrager (*Advection and mixed advection-diffusion problems solved with the sparse-grid combination technique*), Lewis, Te Riele.
- MPR-symposium 2000, CWI, May 8: Van Dorsselaer, Genseberger, Hemker, Koren, Nool (*A parallel solution for generalized eigenvalue problems,* (poster)).
- HPCN Europe 2000, Amsterdam, May, 8–10: Genseberger (*Jacobi-Davidson QZ: an efficient tool for solving generalized eigenproblems,* (poster)), Nool (*Dynamic grid adaptation for computational magneto-hydrodynamics*).
- Eurocrypt 2000, Brugge (Belgium), May 14–18: Cavallar (*Factorization of a 512-bit RSA modulus*), Te Riele.
- Working visits MARIN, Wageningen, May 15, October 2: Lewis.
- ERCIM-meeting, CNR, Pisa, May 29–31: Koren.
- NWO-MPR-meeting, CWI, June 5: Van Dorsselaer (*Sensitivity of Alfvén spectra: pseudospectra and other tools*), Genseberger, Hemker, Koren, Nool.
- Second Conference on Numerical Analysis and Applications, Rousse, Bulgaria, June 11–15: Hemker (*Experience with the Solution of a Finite Difference Discretization on Sparse Grids*) invited paper.
- ANTS4 (Algorithmic Number Theory Symposium IV), Leiden, July 2–7: Cavallar (*Strategies in filtering in the number field sieve*), Montgomery, Te Riele.
- First International Conference on Computational Fluid Dynamics, July 9–14: Kyoto: Van Brummelen (*Numerical solution of steady free-surface Navier-Stokes flow*).
- SIAM Annual Meeting, Rio Grande, Puerto Rico, July 10–14: Lastdrager (*The sparse-grid combination technique applied to a time-dependent advection-diffusion equation with grid-aligned transition layers*).
- Working visits FOM-Rijnhuizen, July 19, October 9, December 18: Nool.
- Mathematical Sciences Research Institute (Algorithmic Number Theory Program), Berkeley, CA, USA, August 23–September 26: Te Riele (*On amicable numbers and values of multiplicative functions*).
- ERCIM-meeting, FORTH, Crete, September 11: Koren.
- NWO-MPR-meeting, FOM-Rijnhuizen, September 20: Van Dorsselaer, Genseberger.
- 25^{e} Conferentie van Numeriek Wiskundigen, Woudschoten, September 27–29: Van Brummelen, Genseberger, Koren, Lewis, Nool.
- Stieltjes courses 'Contemporary Numerical Analysis of Initial-Value Problems' and 'Numerical Methods for Advection-Diffusion-Reaction Equations', September–December (weekly): Lewis.
- University of Sydney, Australia, October 1–November 5: Cavallar.
- *The 4th Workshop on Elliptic Curve Cryptography*, Essen, Germany, October 4–6: Montgomery (*Parallel Block Lanczos*), Te Riele
- CWI in Bedrijf, CWI, October 6: Van Brummelen, Hemker, Koren (*Berekenen van watergolven rond scheepsrompen*), Lewis, Nool.
- Farewell Symposium P.J. van der Houwen, CWI, October 20: Hemker, Koren, Nool, Te Riele.
- Meeting Users Committee STW-MARIN-project, CWI, October 24: Van Brummelen, Hemker, Koren (*Berekening van Navier-Stokesstromingen rond scheepsrompen*), Lewis.
- Working visit Faculty of Aerospace Engineering, Delft University of Technology, November 3: Nool.
- ERCIM-meeting, Trinity College, Dublin, November 9–10: Koren.
- NWO-MPR-meeting, CWI, November 15: Genseberger, Nool.
- NWO Workshop Convection Dominated Problems in the NWO-NL-RF project *Efficient and Robust Numerical Methods for Differential Equations with Singularities*, CWI, November 16, 17: Van Brummelen (*Adjoint shape optimization for steady free-surface flows*), Hemker, Koren (*A fed back level-set method for moving material-void interfaces*), Lewis.

- NWO Workshop Convection Dominated Problems in the NWO-NL-RF project *Efficient and Robust Numerical Methods for Differential Equations with Singularities*, KU Nijmegen, November 21: Hemker (*Discontinuous Galerkin for elliptic problems*), Lewis (*Free-surface Navier-Stokes flow in ship hydrodynamics*).
- Working visit Shell, Rijswijk, December 4: Hemker, Koren (*Computation of two-phase flows with surface gravity waves*).

Memberships of Committees and Other Professional Activities

M. Genseberger:
- Coordinator instruction courses Infinitesimaalrekening 1A, 1B and 1C, Utrecht University.
- Representative of BAU (Union for PhD students of Utrecht University) in LAIOO (Union for PhD students in the Netherlands).
- Review of a journal paper.

P.W. Hemker:
- Professor of Industrial Mathematics, University of Amsterdam.
- Working Group 2.5 on Numerical Software, IFIP, vice-chair.
- Member NWO Programmacommissie Computational Science.
- Member steering group Amsterdam Centre for Computational Science (ACCS).
- Member Numerical Algorithms Group, NAG Inc.
- Associate editor *Computational Methods in Applied Mathematics.*
- Member project committee ISTC-project *Techniques and software development for the solution of 3-dimensional gasdynamics problems on irregular Lagrangian grids*
- Member Users Committee STW-project 'development of a state-of-the-art Navier-Stokes solver for water flows around moving ships'.
- Referee of papers for various scientific journals and projects.
- Reviewer for *Mathematical Reviews.*
- External examiner PhD thesis, H. MacMullen, Dublin City University (E. O'Riordan supervisor) May 24.

B. Koren:
- Associate professor of Aerodynamics, Faculty of Aerospace Engineering, Delft University of Technology.
- CWI-representative in Executive Committee ERCIM.
- Member STW-jury 164.
- Member Users Committee STW-project 'Smering van ruwe oppervlakken'.
- Member MSc-committee M.H. van Raalte, Delft University of Technology, Faculty of Aerospace Engineering.
- Review of project proposals, journal papers and conference proceedings.

M. Nool:
- Member CWI Works Council.

H.J.J. te Riele:
- Chairman of the Organizing Committee of the 37th Nederlands Mathematisch Congres (Free University, Amsterdam, April 19–20, 2001).
- Member of the Board of the *Mathematisch Research Instituut* onderzoekschool, on behalf of CWI
- Member of the Program Committee and of the Local Organizing Committee (treasurer) of ANTS4 (Algorithmic Number Theory Symposium IV, Leiden, July 2–7).
- Reviewer for *Mathematical Reviews* and the *Zentralblatt für Mathematik*
- Referee of papers for various scientific journals.
- Chairman of the CWI-Bibliotheekcommissie.

Visitors

- Prof. dr. B. van Leer (University of Michigan, Ann Arbor), January 31 – March 2 and April 4 – May 15 (*From the magic garden of numerical advection*).
- Dr. R. Keppens (FOM-Rijnhuizen), February 7 (*Massively parallel programming in computational magneto-fluid dynamics*), November 1.
- Prof. dr. ir. J.J.W. van der Vegt (University of Twente), March 1 (*Discontinuous Galerkin finite element methods for the Euler equations of gas dynamics*).
- Dr. R. Schwane (ESA-ESTEC), March 1 (*Multi-dimensional steady subcell reconstruction techniques for the Euler and Navier-Stokes equations*).
- Dr. ir. M.I. Gerritsma (Delft University of Technology, Faculty of Aerospace Engineering), April 10.
- Ir. M.M.J. Proot (Delft University of Technology, Faculty of Aerospace Engineering), April 10 (*Krylov subspace methods for saddle-point problems, with application to the incompressible Navier-Stokes equations*).
- Prof. dr. A. Friedman (Minnesota Center for Industrial Mathematics, USA) May 14–15 (Lecture: *Nonlinear stability of quasi-static Stefan problems with surface tension*).

- Dr. P. Boekholt (Technopolis, Innovation Policy Research Associates, Amsterdam), May 18.
- Ir. I. Wenneker (Delft University of Technology, Faculty of Information Technology and Systems), May 22 (*Computation of compressible flows on unstructured staggered grids*).
- Prof. I. Yavneh (Dept. of Computer Science, Technion, Haifa, Israel), June 14 (*Some generalized algebraic multigrid techniques*)
- Dr. P.L. Montgomery (Microsoft Research, USA), June 26–30.
- A. Schrauwers (science journalist for Technisch Weekblad), August 28.
- Dr. J.M.L. Maubach (Eindhoven University of Technology, Department of Mathematics), October 31 (*Rapid application design for scientific computing research: the NumLab workbench*).
- M.H. van Raalte (Delft University of Technology, Faculty of Aerospace Engineering), October 31 (*An analytical study of a supersonic base flow*).
- Prof. dr. G.I. Shishkin (IMM RAS Ural br, Ekaterinburg, Russia), November 2 – 30 (*On Reynolds-uniform numerical methods resolving model flow problems for Prandtl-like boundary layer equations.* 16 November) (*On adaptive numerical methods for singularly perturbed reaction–diffusion equations with a moving concentrated source.* 17 November).
- I.V. Tselishcheva (IMM RAS Ural br, Ekaterinburg, Russia), November 2–30 (*Domain decomposition methods for singularly perturbed parabolic problems in composed domains.* 16 November).
- Dr. L.P. Shishkina (IMM RAS Ural br, Ekaterinburg, Russia), November 2–30 (*Defect correction for convection-diffusion problems.* 21 November).
- Dr. F. Sprengel (SCAI, GMD), December 12 (*Multilevel algorithms on adaptive dyadic grids*).

Software Developed

M. Nool:

- AMRVAC: a multidimensional grid-adaptive magneto-fluid dynamics code

Papers in Journals and Proceedings

A.J.C. Beliën, B. van der Holst, M. Nool, A. van der Ploeg and J.P. Goedbloed (2000). Application of the Jacobi-Davidson Method to Spectral Calculations in Magneto-hydrodynamics. M. Bubak, H. Afsarmanesh, R. Williams and B. Hertzberger, (eds.). *Proceedings of High Performance Computing and Networking, Europe 2000*, Amsterdam, 2000, *LNCS* **1823**, 119–126, Springer, Berlin (2000). This paper won the 2nd prize in the category best presented paper.

H. van Brummelen, B. Koren (2000). A level-set method and an approximate Riemann solver for capturing free-surface water waves. H. Paillère (ed.). *Proceedings of the AMIF-ESF* Workshop *Computing Methods for Two-Phase Flow*, Aussois, 2000, Paper 23 from CD-ROM published by CEA, Saclay.

E.H. van Brummelen and H.C. Raven (2000). Numerical solution of steady free-surface Navier-Stokes flow. Miloh, T. and Zilman, G. (eds.). *Proceedings of the 15th International Workshop on Water Waves and Floating Bodies* 16–19, Caesarea. Tel-Aviv University, Faculty of Engineering.

S. Cavallar, B. Dodson, A. K. Lenstra, W.M. Lioen, P. L. Montgomery, B. Murphy, H.J.J. te Riele, K. Aardal, J. Gilchrist, G. Guillerm, P. Leyland, J. Marchand, F. Morain, A. Muffett, C. Putnam and P. Zimmermann (2000). Factorization of a 512-bit RSA Modulus. Bart Preneel (ed.). *Advances in Cryptology – EUROCRYPT 2000* (Brugge, May 14–18, 2000), 1–18. *LNCS* **1807**, Springer, Berlin etc., 2000 (also issued as Report MAS-R0007).

S. Cavallar (2000). Strategies in filtering in the number field sieve. Wieb Bosma (ed.). *Algorithmic Number Theory – 4th International Symposium, ANTS-IV* (Leiden, The Netherlands, July 2–7, 2000), *LNCS* **1838**, Springer, Berlin etc., 209–231 (also issued as Report MAS-R0012).

J-M. Deshouillers and H. te Riele (1999). On the probabilistic complexity of numerically checking the binary Goldbach conjecture in certain intervals. S. Kanemitsu and K. Győry (eds.). *Number Theory and its Applications*, Kluwer, 89–99.

J.L.M. van Dorsselaer, M.E. Hochstenbach and H.A. van der Vorst (2000). Computing probabilistic bounds for extreme eigenvalues of symmetric matrices with the Lanczos method. *SIAM J. Matrix Anal. Appl.* **22**, 837–852.

C.T.H. Everaars, B. Koren and F. Arbab (2000). Dynamic process composition

and communication patterns in irregularly structured applications. *Concurrency: Practice and Experience* **12**, 157–174.

E.D. HAVIK, P.W. HEMKER and W. HOFFMANN (2000). Application of the over-set grid technique to a model singular perturbation problem. *Computing* **65**, 339–356.

P.W. HEMKER, G.I. SHISHKIN and L.P. SHISHKINA (2000). Acceleration by parallel computations of solving high-order time-accurate difference schemes for singularly perturbed convection-diffusion problems. L. VULKOV, J. WASNIEWSKI and P. YALAMOV (eds.). *Numerical Analysis and Its Applications*, Berlin, Springer-Verlag.

P.W. HEMKER, G.I. SHISHKIN and L.P. SHISHKINA (2000). Distributing the numerical solution of parabolic singularly perturbed problems with defect correction over independent processes. *Siberian J. Numer. Mathematics* **3**, 229–258.

P.W. HEMKER, G.I. SHISHKIN and L.P. SHISHKINA (2000). ε-Uniform schemes with high-order time-accuracy for parabolic singular perturbation problems. *IMA Journal of Numerical Analysis* **20**, 99–121.

P.W. HEMKER, G.I. SHISHKIN and L.P. SHISHKINA (2000). Parallel methods based on a defect-correction technique for parabolic singularly perturbed problems. G.I. SHISHKIN J.J.H. MILLER and L. VULKOV (eds.). *Analytical and Numerical Methods for Convection-Dominated and Singularly Perturbed Problems*, New York, USA, Nova Science Publishers, Inc., 43–50.

P.W. HEMKER, G.I. SHISHKIN and I.V. TSELISHCHEVA (2000). Parallel methods for quasilinear singularly perturbed reaction-diffusion equations. I.I. EREMIN, L. LASIECKA and V. I. MAKSIMOV (eds.). *Proceedings of the International Conference on Distributed Systems: Optimization and Economic-Environmental Applications*, Ekaterinburg, Russia, Nauk, 348–351.

P.W. HEMKER and F. SPRENGEL (2000). Experience with the solution of a finite difference discretization on sparse grids. L. VULKOV, J. WASNIEWSKI and P. YALAMOV (eds.). *Numerical Analysis and Its Applications*, Berlin, Springer-Verlag.

R. KEPPENS, M. NOOL, P.A. ZEGELING and J.P. GOEDBLOED (2000). Dynamic grid adaptation for computational magnetohydrodynamics. *Proceedings of High Performance Computing and Networking, Europe 2000*, Amsterdam, 2000, *LNCS* **1823**, 61–70, M. BUBAK, H. AFSARMANESH, R. WILLIAMS and B. HERTZBERGER (eds.). Springer, Berlin.

B. LASTDRAGER, B. KOREN and J.G. VERWER (2000). The sparse-grid combination technique applied to time-dependent advection problems. E. DICK, K. RIEMSLAGH and J. VIERENDEELS (eds.). *Proceedings of the Sixth European Multigrid Conference*, Gent, 1999, *Lecture Notes in Computational Science and Engineering* **14**, Springer, Berlin, 143–149.

M. NOOL and A. VAN DER PLOEG (2000). A parallel Jacobi-Davidson-type method for solving large generalized Eigenvalue Problems in Magnetohydrodynamics. *SIAM J. Sci. Comput.* **22**, 95–112.

J. NOORDMANS and P.W. HEMKER (2000). Application of an adaptive sparse-grid technique to a model singular perturbation problem. *Computing* **65**, 357–378.

HERMAN TE RIELE (1999). Computational sieving applied to some classical number-theoretic problems. KÁLMÁN GŸORY, HENRYK IWANIEC and JERZY URBANOWICZ (eds.). *Number Theory in Progress, Proceedings of the International Conference on Number Theory* (Zakopane, Poland, June 30–July 9, 1997), Walter de Gruyter, Berlin etc., 1071–1080.

CWI Reports

The following CWI reports were published by members of theme MAS2. See page 78 for the complete titles of the reports.

MAS-R0007	MAS-R0012	MAS-R0018
MAS-R0025	MAS-R0029	MAS-N0001

Other Publications

M. ANTHONISSEN, E.H. VAN BRUMMELEN, W. DRENTH, S. GOOSSENS, S. HOUBEN, D. LANSER and M.R. LEWIS (eds.) (2000). *PhDays 2000.*

J.L.M. VAN DORSSELAER (2000). *Several concepts to investigate strongly non-normal eigenvalue problems.* Preprint # 1177, Mathematical Institute, Utrecht University.

M.I. GERRITSMA and B. KOREN (2000). Lecture Notes *Introduction to Computational Fluid Dynamics* (Delft University of Technology, Faculty of Aerospace Engineering). URL: www.hsa.lr.tudelft.nl/~ marc/ICFD.html

Mathematics of Finance – MAS 3

Staff

- Prof. dr. M.S. Keane, theme leader (see also PNA3)
- Dr. J.K. Hoogland, postdoc
- Dr. C.D.D. Neumann, postdoc

Scientific Report

The theme leader has devoted his research time to finding interesting mathematical problems and areas which could eventually be developed at CWI in the new discipline of mathematical finance. For this, a number of visitors were invited: M. Taksar (Stony Brook), R.M. Burton (Corvallis), P. Wilmott (Oxford) for short periods, and M. Smorodinsky (Tel Aviv) for a period of three months. Smorodinsky and Keane have developed a preliminary theory of deterministic Brownian motion applicable to prediction problems in stock prices and indices, based on previous work by Keane and Kamae, and have proved an interesting theorem showing the topological ergodicity of the Levy transformation, although the main conjecture concerning this transformation remains open. These results are now being prepared for publication. Keane has also given two lectures on mathematical finance, an invited lecture in the well-known Seminaire des Probabilités at Strasbourg on Japanese stock indices (Nikkei 225 and Topix), and a lecture on prediction and deterministic Brownian motion in the Financial Mathematics Seminar of the University of Amsterdam. In addition, Keane has visited the ETH at Zürich for interesting mathematical discussions with two of the leaders in this field, F. Delbaen and P. Embrechts. For related results of Keane and his activities see also the section PNA3.

Hoogland and Neumann have extended their work on models for pricing of derivatives. By making the numeraire-invariance explicit in the pricing of complex options, they have been able to derive, for example, prices for arithmetic asian options in a very intuitive and elegant manner. The formulation provides a better understanding of options on tradable accounts. In the literature these contracts are considered to be complex options. Hoogland and Neumann show that they are fundamentally not any different from other exotic contracts. Using this formulation they have computed arithmetic average strike options semi-analytically. Furthermore the symmetries allow one to relate this type of contract to arithmetic average price options. It has also been shown that vanilla options that pay cash-dividends are equivalent to arithmetic asian options. When one compute prices of options using a PDE-formulation boundary-layer problems can cause significant problems. Hoogland and Neumann have shown that it is possible to use so-called fitted schemes which do not have these problems. The trick is to adapt the finite-difference scheme to an exactly solvable solution of the PDE, that is closely related to the problem at hand. The simplicity of the scheme makes it a very interesting alternative to the more complex solutions proposed in the literature.

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 again been very successful. Many people from financial institutions visited these courses.

Organization of Conferences, Workshops, Courses, etc.

- Organization of FWA course Financial Engineering: J.K. Hoogland, C.D.D. Neumann
- Organization of FWA lecture by Paul Wilmott: J.K. Hoogland

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

- Invited lecture in Seminaire des Probabilités, Strasbourg, France, March 27: M.S. Keane
- Fourth meeting of EURANDOM project 'Financial Stochastics', EURANDOM, Twente, June 15: J.K. Hoogland, C.D.D. Neumann (Asian variations).
- Colloquium Financial Mathematics, University of Amsterdam, February 14: M.S. Keane.
- Colloquium Financial Mathematics, University of Amsterdam, May 22: C.D.D. Neumann (*Asian variations*).
- Visit Hungarian students CWI, April 26, J.K. Hoogland (*Tulips, options and financial risk*).
- Workshop on Model Calibration and Stochastic Volatility Models London, United Kingdom: J.K. Hoogland, C.D.D. Neumann.
- Workshop on mathematical physicists in finance and industry, June 11–15, University of Montréal, Canada: J.K. Hoogland (*Local scale*

invariance in contingent claim pricing), C.D.D. Neumann.
- Conference Applications of Physics in Financial Analysis II, July 13–15, University of Liège, Belgium: J.K. Hoogland (*Asians and cash-dividends: exploiting symmetries in pricing theory*), C.D.D. Neumann.
- Colloquium MRI-course Financiële Wiskunde, Univ. Twente, October 17: J.K. Hoogland (*Local scale invariance in contingent claim pricing*).
- Landelijk seminarium Statistische Fysica, TU Delft, November 24: J.K. Hoogland (*Applying physics principles to crack finance problems*), C.D.D. Neumann.
- Dutch stochasticians meeting, Lunteren, November 13–15: J.K. Hoogland, C.D.D. Neumann.
- ITW-symposium, CWI, December 1: J.K. Hoogland (*To win or not to lose*), C.D.D. Neumann (*The theory of relativity behind option prices*).
- PNA-colloquium CWI, December 5: J.K. Hoogland (*Asians, Cash Dividends and dualities in option pricing*).

Memberships of Committees and Other Professional Activities

J.K. Hoogland:

- Management team FWA

Visitors

- M. Taksar (Stony Brook), R.M. Burton (Corvallis), P. Wilmott (Oxford), M. Smorodinsky (Tel Aviv).

Papers in Journals and Proceedings

J.K. HOOGLAND and C.D.D. NEUMANN (2000). Local scale invariance in option pricing. *Proceedings Workshop on mathematical physicists in finance and industry*, June 11–15, University of Montréal, Canada.

J.K. HOOGLAND and C.D.D. NEUMANN (2000). Exploiting symmetries in pricing theory with applications to asians and cash dividends. *Proceedings Applications of Physics in Financial Analysis II*, July 13–15, University of Liège, Belgium.

CWI Reports

The following CWI reports were published by members of theme MAS3. See page 78 for the complete titles of the reports.

MAS-R0019 MAS-R0024

INFORMATION SYSTEMS

General Overview

Information Systems is a cluster of five related themes:

INS0	Applied Logic and Digital Libraries (renamed Standardization and Knowledge Transfer as of 1/1/2001)
INS1	Data Mining and Knowledge Discovery
INS2	Multimedia and Human-Computer Interaction
INS3	Interactive Information Engineering (renamed Visualization as of 1/1/2001)
INS4	Quantum Computing and Advanced Systems Research

The research activities are focused in this cluster on various aspects of information systems. The activities in Theme 1 are dominated by large-scale activities in the area of multimedia databases, while investments in data mining techniques are maintained. The focus on DBMS architectures has being reduced to exploitation of the existing platform, while long-term research in this area will be gradually started.

Much of the work in theme 2 and 3 was centred around multimedia applications. The former shifts towards challenges posed by automatic generated multimedia documents. In this context constraint-based methods are the leading technology basis. The latter primarily dealing with interactive scientific and information visualization.

The core of theoretical investigations into new computing paradigms and machines –Quantum Computing– is undertaken in theme 4.

The remaining activities within INS0 are cluster projects geared at knowledge transfer towards research institutions.

An important output of the work in this cluster is the development of prototypes for demonstrating and experimenting with 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. The close affiliation with Data Distilleries secures knowledge transfer and feedback on problems in the area of data mining. The relationship with Oratrix is organized in cooperative projects, thereby securing a channel of our research results into the market for multimedia authoring. In 2000 acceptance in the market of the facial animation software has led to the preparation of the spin-off EPICTOID, which as of Januari 2001 is operational.

Another important outlet of the knowledge acquired is through active participation in International Standardization committees such as those organized in the context of the World Wide Web Consortium (W3C). In 2000, researchers from INS2 were involved in e.g. XHTML and SMIL standardization activities of W3C.

INS has participated in several large national projects (ICES/KIS, ToKeN2000) Telematics Top Institute (DMW, Uwish), international projects (QAIP, NeuroColt) and projects aimed at knowledge transfer (W3C, STW-FACES). 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, OzsL, IPA), broadly disseminate their research results in the international scene, and hold faculty positions at the universities. Highlights are the nomination of Arno Siebes as full-professor at the University of Utrecht, and Harry Buhrman becoming a part-time professor at the University of Amsterdam.

Staff

- Applied Logic and Digital Libraries – INS0
  - S.M. van Dongen
  - D.J.N. van Eijck
  - M. Hazewinkel
  - M. Pauly
- Data Mining and Knowledge Discovery – INS1
  - M.L. Kersten
  - A.P.J.M. Siebes
  - A.R. van Ballegooij
  - M. Bertran
  - H.G.P. Bosch
  - C. Blokker
  - P.M.E. De Bra
  - J.R. Castelo
  - Dr. A. Eliëns (0.2)
  - D. Fernandez
  - Z. Huang
  - S. Karlsson
  - A.J. Knobbe
  - W.M. Lioen
  - J.A. List
  - N. Mamoulis
  - 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
  - F.J. Cornelissen
  - J.R. Davis
  - J. Geurts
  - M.W.J.H. Huijberts
  - C.A. Lindley
  - F.-M. Nack
  - J.R. van Ossenbruggen
  - S. Pemberton
- Interactive Information Engineering – INS3
  - P.J.W. ten Hagen
  - A.V. Groenink
  - J. Hendrix
  - I. Herman
  - A.P.C. Kiers
  - A.D.F. Lelièvre
  - M.S. Marshall
  - G. Melançon
  - H. Noot
  - M.M. de Ruiter
  - Zs.M. Ruttkay
- Quantum Computing and Advanced Research Systems – INS4
  - P.M.B. Vitányi
  - A.E. Brouwer
  - H.M. Buhrman
  - W. van Dam
  - J. Delgado Pin
  - P. Gács
  - P.D. Grünwald
  - H. Klauck
  - M. van Liempt
  - R. Manniesing
  - H.Röhrig
  - L. Torenvliet
  - J.T. Tromp
  - R.M. de Wolf
- Secretary:
  - M.W.A. Hegt

CWI Reports

INS-R0001. M.S. Marshall, I. Herman and G. Melançon. *An object-oriented design for graph visualization.*

INS-R0002. S. Manegold, J. Pellenkoft and M.L. Kersten. *A multi-query optimizer for Monet.*

INS-R0003. F. Waas and C.A. Galindo-Legaria. *The effect of cost distributions on evolutionary optimization algorithms.*

INS-R0004. H. Noot and Zs.M. Ruttkay. *CharToon 2.0 manual.*

INS-R0005. G. Melançon, I. Dutour and M. Bousquet-Melou. *Random generation of dags for graph drawing.*

INS-R0006. H.G.P. Bosch and S.J. Mullender. *Real-time disk scheduling in a mixed-media file system.*

INS-R0007. H.G.P. Bosch, N. Nes and M.L. Kersten . *Navigating through a forest of quad trees to spot images in a database.*

INS-R0008. Z.R. Struzik and A.P.J.M. Siebes. *Outlier detection and localisation with wavelet based multifractal formalism.*

INS-R0009. I. Herman and M.S. Marshall. *GraphXML – An XML based graph interchange format.*

INS-R0010. S. van Dongen. *A cluster algorithm for graphs.*

INS-R0011. S. van Dongen. *A stochastic uncoupling process for graphs.*

INS-R0012. S. van Dongen. *Performance criteria for graph clustering and Markov cluster experiments.*

INS-R0013. J. Hendrix, Zs.M. Ruttkay. *Exploring the space of emotional faces of subjects without acting experience.*

INS-R0014. M.S. Marshall, I. Herman and G. Melançon. *Automatic generation of interactive overview diagrams for the navigation of large graphs.*

INS-R0015. Z.R. Struzik. *Revealing local variability properties of human heartbeat intervals with the local effective Holder exponent.*

INS-R0016. Zs.M. Ruttkay and A.D.F. Lelièvre. *CharToon 2.1 extensions; Expression repertoire and lip sync.*

INS-R0017. M. Pauly. *Game logic for game theorists.*

INS-R0018. D.J.N. van Eijck. *On the proper treatment of context in NL.*

INS-R0019. A.M. Bleeker and D.J.N. van Eijck. *The epistemics of encryption.*

INS-R0020. D.J.N. van Eijck, J.M. Heguiabehere and B.O. Nuallain. *Theorem proving and programming with dynamic first order logic.*

INS-R0021. F. Waas and M.L. Kersten. *Memory aware query scheduling in a database cluster.*

INS-R0022. L.W. Rutledge, A.R. van Ballegooij and A. Eliëns. *Virtual context - relating media objects to their real world subjects.*

INS-R0023. Z.R. Struzik. *Wavelet methods in (financial) time-series processing.*

INS-R0024. J.R. van Ossenbruggen, H.L. Hardman and L.W. Rutledge. *Integrating multimedia characteristics in web-based document languages.*

INS-R0025. J.R. van Ossenbruggen, F.J. Cornelissen, J.P.T.M. Geurts, L.W. Rutledge and H.L. Hardman. *Cuypers: a semi-automatic hypermedia generation system.*

Applied Logic and Digital Libraries – INS0

As of January 2000 part of the research activities of the former group INS3 has been turned into cluster projects, pending future developments in terms of reallocation of resources or thematic focus in the institute.

Staff

- Dr. ir. S.M. van Dongen, PhD student (until May 31)
- Prof. dr. D.J.N. van Eijck, researcher
- Prof. dr. M. Hazewinkel, reseacher
- M. Pauly, M.Sc., PhD student

Scientific Report

Applied Logic

Van Eijck is working with colleagues from ILLC and from Uil-OTS (Utrecht) on a new format for Montague Grammar, IMG (Incremental Montague Grammar). He reported on this enterprise at CLIN (Tilburg), and lectured on it at Uil-OTS in Utrecht. A book on this topic is in preparation. Van Eijck co-authored a report and a conference paper with Annette Bleeker, on the logic of epistemic actions. Van Eijck is also involved in interactive information engineering, in a pilot project with Elsevier Science BV (in collaboration with ILLC), together with Johan van Benthem and Maarten de Rijke (ILLC). Together with his co-workers Juan Heguiabehere and Breanndán Ó Nualláin at ILLC, Van Eijck produced a number of papers that provide a foundation for programming and automated (tableau) reasoning with Dynamic First Order Logic. This provides a logical underpinning for Dynamo See `http://www.cwi.nl/~jve/dynamo`.

Pauly applied his research in the logic of games to the problem of coalition formation, an important topic in game theory. Game theory has developed a number of solution concepts to describe, given a particular game situation, which coalitions will form and what payoffs the members of the coalitions obtain. Part of Pauly's recent research was to develop a formal logical model for describing the coalitional power structure in a dynamic setting. For the social choice theorist and the game theorist, the study of this Coalition Logic can yield some interesting new insights which go beyond the standard game-theoretic analysis; among other things, it sheds light on the complexity of reasoning about coalitional effectivity.

Van Eijck and Pauly were involved in work done within the Spinoza project which aims to publish a Dutch high school level

book on machine models and logic with Amsterdam University Press. A draft has been written and is in the process of being tested at some high schools in The Netherlands. This material is electronically available from `http://www.cwi.nl/~jve/AUP/crr`.

Stijn van Dongen rounded off his work on graph clustering, and on May 29, 2000, he successfully defended his PhD thesis on *Graph Clustering by Flow Simulation*, at the faculty of computer science and mathematics of Utrecht University. Thesis advisors were M. Hazewinkel and D.J.N. van Eijck.

Digital Libraries

The Hopf algebras of noncommutative symmetric functions, NSymm, and of quasisymmetric functions, Qsymm

These are two (different, but dual) generalizations of the Hopf algebra of symmetric functions, *Symm*, that have become important in the last 30 years. It has become in particular important to investigate to what extent the very rich structure of Symm can be lifted to *NSymm* (c.q. extended to *QSymm*). Substantial progress has been made on this in 2000. In particular it has been completely sorted out what the situation is with respect to the important Frobenius and Verschiebungs endomorphisms of *Symm*.

Trial

The main CWI deliverable concerns the development of a software tool that takes an (IMS packaged) sliced book and a list of 'key phrases with identification clouds' and assigns automatically key phrases to the slices of the book. The output is to be twofold: an HTML file (for human use; for instance to compare the results of the tool with human assigned keyphrases) and an (IMS packaged) version of the original book file with key phrases inserted. A demo version is ready (for the HTML output part) and has been demonstrated in February 2001 in Luxembourg at the occasion of the first review meeting. (It remains to take care of the IMS packaged stuff, which cannot be done until IMS packaged input files are available (as well as a corresponding parser).)

PhD Thesis

S.M. van Dongen. *Graph clustering by Flow Simulation.*

Organization of Conferences, Workshops, Courses, etc.

D.J.N. van Eijck:

- Reasoning and Computation, first year course in mathematical thinking for computer science students, Amsterdam, Spring 2000,
- Compositional Semantics and Type Theory, Course for PhD Students and Graduate Students of Uil-OTS and LOT, Utrecht, Fall 2000,
- (organizer) ILLC Colloquium Afternoon With Hans Kamp, April 3, Amsterdam.
- (organizer) Dutch Graduate School in Logic School Week, October 23–27, Nunspeet.

M. Hazewinkel:

- Algebra 4 (Galois theory), second year course, University of Utrecht.
- Master class course: Knots, links, braids, and tangles, University Utrecht.
- KNAW colloquium Symbolic computation and systems/control theory (organizer together with B. Hanzon), November 1–3.

M. Pauly:

- 'Logic and Games', course given at the European Summer School in Logic, Language and Information (ESSLLI), together with Johan van Benthem, Birmingham, August 2000.

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

D.J.N. van Eijck:

- Incremental Montague Grammar, DIP Colloquium, Amsterdam, February 11.
- Tableaux Reasoning for Dynamic First Order Logic, Computational Logic Seminar, Amsterdam, March 31.
- Tuturial on Reasoning and Programming with Dynamic First Order Logic, EEF Foundations School Deduction and Theorem Proving (DTP'00), Edinburgh, April 8.
- Logic Dissemination with Functional Programming: Reasoning + Computation, Tools for Teaching Logic, Salamanca June 16.
- Epistemic action and change (with Annette Bleeker), LOFT-4, Torino, July 1.
- Reasoning and Computation with Dynamic First Order Logic, Festival Workshop in Foundations and Computations, Edinburgh, July 17.
- A Tableau Calculus for Dynamic First Order Logic with Applications in Natural Language Semantics (with Juan Heguiabehere and Breanndán Ó. Nualláin), ICOS-2, July 29.

- Reasoning and Programming with Dynamic First Order Logic (with Juan Heguiabehere and Breanndan O. Nuallain), WFLP-2000, Benicassim, September 28.
- Modality in Context, CLIN-2000, Tilburg, November 1.

M. Hazewinkel:

- Vilnius Inst. Mathematica, Statistics of thesauri, lecture *Automatic updating of evolving thesauri in science*; Working visit January 8–11.
- INTAS Council of Scientists meeting, Brussels, February 1–4.
- Steering committee of the ESF program on Noncommutative Geometry, Strassbourg, France, March 30–31.
- Mathematical Theory of Networks and Systems, Perpignan, June 16–23.
- Formal Power Series and Algebraic Combinatorics, Moscow, June 25–30.
- Conf. on Formal Power Series and Algebraic Combinatorics, Invited plenary lecture *Quasisymmetric functions*, Moscow, June 29.
- Working visit, Kiev, Automatic generation of thesauri, July 1–3.
- Working visit, Thesaurus theory, 5 lectures on *Semi-automatic updating of evolving thesauri*, Vilnius, Lithuania, July 12–26.
- Meeting Council of Scientists, Brussels, September 13–16.
- Steering group TRIAL, Nice, France, September 24–26.
- Conference Trends in Noncommutative Algebra and Geometry, Invited lecture *Noncommutative symmetric functions and quasisymmetric functions*, Max Planck Inst., Bonn, September 26–30.
- Meeting steering Committee Trial, Kaiserslautern, October 28–30.
- Karlsruhe. Working visit to D. Pallaschke and R.V. Gamkrelidze (Trial en Eretima), November 6–8.
- O. Schmidt memorial conference, Invited lecture *Noncommutative symmetric functions and quasisymmetric functions* Moscow State University, November 13–16.
- Colloquium lecture Math. Inst. University of Osnabrück, *Identification clouds in information retrieval*, November 17–18.
- Working visit to CIS, lecture *Missing information in information retrieval and identification cloud*, University of München (Prof. F. Guenthner) November 22–26.

M. Pauly:

- 25/3–23/4 New York, visit to Rohit Parikh (New York University & City University New York), 2 talks: *Coalition Logic* (6/4) and *The Complexity of Coalition Logic* (11/4).
- Aachen, visit to Erich Graedel (RWTH Aachen), 1 talk: *Game Logic and the Mu-Calculus.*
- 29/6–2/7 Turin, LOFT 4, talk *The Power of Coalitions in Dynamic Procedures.*
- 21/8–26/8 Fischbachau (Germany), CSL 2000, talk *From Programs to Games: Invariance and Safety for Bisimulation.*

Visitors

Guests of Van Eijck

- Joachim Niehren (University of the Saarland), March 20–23
- Michael Kohlhase (University of the Saarland), March 28–29
- Hans Kamp (University of Stuttgart), April 3
- Urszula Wybraniec (Univ. of Opole), March and April 2000

Guests of Hazewinkel

- Dr. Rimas Maliukevicius (Univ. Vilnius), February 22–25
- Dr. Alexandras Kazbaras (Univ. Vilnius), February 22–25
- Dr. D. Malyshev (Univ. Kiev), January 24–28, March 27–30, November 26–December 12.

Memberships of Committees and Other Professional Activities

D.J.N. van Eijck:

- Professor of Logical Aspects of Computational Linguistics, University of Utrecht (since December 1990).
- Member of the European Network in Computational Logic (initiated by the ESPRIT Basic Research Action 'Compulog'), since March 1997.
- Member of the SEMANTICS and PRAGMATICS subcommittee for COLING 2000.
- Scientific Director of the Dutch Graduate School in Logic (since Spring 1997)
- Member of the International User and Consultation Group for TRINDI.
- Member of the Thesis Defence Committee of Vera Stebletsova, UU, January 26, 2000.
- Thesis advisor of Stijn van Dongen, UU (together with Michiel Hazewinkel), May 29, 2000.

M. Hazewinkel:

- Ass. Editor journal: *Systems and Control Letters*, North Holland Publ. Co., 1981
- Co-managing Editor book series Mathematics and Geophysics, Reidel Publ. Co., 1981
- Managing Editor book series: *Mathematics and Its Applications*, Kluwer Academic Publishers, 1977
- Managing Editor journal: *Acta Applicandae Mathematicae*, Kluwer Academic Publishers, 1983
- Managing Editor *Encyclopaedia of Mathematics*; Vols 1–10, 1988–1994; first update volume, 1997; CDROM version, 1998; further update volumes 1999
- Managing Editor *Handbook of Algebra* in 9 volumes; first volume 1996. Editorial board Trends in Scientific Research, Unesco/Reidel, 1984
- Co-managing editor (with H. Neunzert, A.B. Tayler, H.J. Wacker), book series 'European Consortium for Mathematics in Industry', Reidel/Kluwer Academic, 1988
- Associate editor journal *Chaos, Solitons, and Fractals*, Pergamon, 1991
- Associate editor journal *Multi-dimensional System Theory*, Kluwer Boston, 1994
- Member Taskforce ERCIM-INTAS (now called Network Coordinating Committee), 1993
- Chairman Scientific Steering Group ERCIM-INTAS FSU, 1995
- Manager (coordinator) INTAS projects 96-0793 (1997-2000), 96-0741 (1997–2000), 97-0808 (1998-2001), 97-0804 (1999-2001).
- Member Council of Scientists INTAS, September 1999
- Member Steering committee ESF program on Noncommutative Geometry, 2000-2004

Books edited

M. HAZEWINKEL (2000). *Encyclopaedia of Mathematics*, 2nd supplement **12**, KAP, 631 pp.

M. HAZEWINKEL (2000). *Handbook of Algebra* **2**, Elsevier, 878 pp.

M. PAULY (2000). *Formalizing the Dynamics of Information*, MARTINA FALLER, STEFAN KAUFMANN & MARC PAULY (eds.), CSLI Publications.

Papers in Journals and Proceedings

J. VAN EIJCK (2000). Making Things Happen. *Studia Logica* **66**, 41–58.

J. VAN EIJCK (2000). The Proper Treatment of Context in NL. PAOLA MONACHESI (ed.). *Epistemic Action and Computational Linguistics in the Netherlands 1999; Selected Papers from the Tenth CLIN Meeting*, Uil-OTS, Utrecht, 41–51.

J. VAN EIJCK, J. HEGUIABEHERE, B. Ó NUALLÁIN (2000). A Tableau Calculus for Dynamic First Order Logic with Applications in Natural Language Semantics. JOHAN BOS and MICHAEL KOHLHASE (eds.), *ICOS-2 Proceedings*, 25–40 (published by the University of Saarland, Saarbrücken).

J. VAN EIJCK (2000). Theorem Proving and Programming with Dynamic First Order Logic. MARÍA ALPUENTE (ed.). *Functional and Logic Programming: Ninth International Workshop*, WFLP'2000, Benicàssim, Spain, September 28–30, 56–71. Published by Universidad Politéchnica de Valencia.

J. VAN EIJCK (2000). The Tbilisi Symposium on Logic, Language and Computation (Book Review). *Science of Computer Programming*, **38**, 147–149.

J. VAN EIJCK, A. BLEEKER (2000). Epistemic Action and Change. G. BONANNO, E. COLOBATTO, W. VAN DER HOEK (eds.). *LOFT-4 Proceedings* Torino, 24 pp.

M. HAZEWINKEL (2000). Key words and key phrases in scientific databases. Aspects of guaranteeing output quality for databases of information. *Statistical publishing, Proceedings of the August 1999 Warsaw conference* ISI, 44–48.

M. HAZEWINKEL (2000). Quasi-symmetric functions. D. KROB, A.A. MIKHALEV, A.V. MIKHALEV (eds.). *Formal Power Series and Algebraic Combinatorics*, 12-th international conference, Moscow 2000, Springer-Verlag, 30–44.

M. HAZEWINKEL (1999). Oboshchennye perkryvayushchie tacobochnye algebry (Generalized overlapping shuffle algebras). *Sovremennaya Matematika i ee prilozheniya* **69**, 193–222.

M. PAULY (2000). The Power of Coalitions in Dynamic Procedures. BONANNO, E. COLOBATTO, W. VAN DER HOEK (eds.). *LOFT-4 Proceedings* Torino.

M. PAULY (2000). From Programs to Games: Invariance and Safety for Bisimulation. PETER CLOTE and HELMUT SCHWICHTENBERG (ed.). *Proceedings Computer Science Logic*, Springer-Verlag, *LNCS* **1862**.

CWI Reports

See page 91 for complete titles.

INS-R0018 INS-R0019 INS-R0020

Other Publications

M. HAZEWINKEL (2000). Index Discrete Applied Mathematics Volumes 1–92. *Discrete Applied Mathematics* **106**, 106–261.

Data Mining and Knowledge Discovery – INS1

Staff

- Prof. dr. A.P.J.M. Siebes, theme leader, until September 1, advisor, from September 1
- Prof. dr. M.L. Kersten, senior researcher, theme leader as of October 1, cluster leader
- Drs. A.R. van Ballegooij, PhD student
- M. Bertran, trainee, until July 1
- Dr. ir. H.G.P. Bosch, postdoc
- C. Blokker, trainee from October 1
- Prof. dr. P.M.E. De Bra, senior researcher, seconded by TUE (0.2)
- J.R. Castelo Comp.Eng., PhD student until September 1
- Dr. A. Eliëns, senior researcher, seconded by VU (0.2)
- D. Fernandez, B.A, trainee, from February 10–July 10
- Dr. Z. Huang, postdoc from March 1, seconded by VU (0.2)
- S. Karlsson M.Sc., researcher, until March 1
- Drs. A.J. Knobbe, researcher, seconded by Perot Sytems. (0.2)
- Drs. W.M. Lioen, programmer, from January 1
- Drs. J.A. List, PhD student, from November 1
- Dr. N. Mamoulis, postdoc, from September 1
- Dipl.-Inform. S. Manegold, PhD student
- Dr. H. Naacke, postdoc, until September 1
- Dr. N. Nes, postdoc
- Dr. ir. J. Pellenkoft, postdoc, until September 1
- Dipl.-Inform. A.R. Schmidt, PhD student
- Dr. ir. Z.R. Struzik, postdoc
- Dr. ir. A.P. de Vries, postdoc (0.6)
- Dipl. Inform. F. Waas, PhD student until August 1
- Drs. M.A. Windhouwer, PhD student

Scientific Report

Data Mining – INS1.1

Struzik concentrated his activities on two aspects of wavelet theory: heartbeat time series analysis and methodology of feature representations.

Work on heartbeat analysis has mainly been centred around the issue of characterization of fetus heartbeat with wavelet transform based local Hoelder exponent. This has been done in (informal) collaboration with Dr. Wim Wijngaarden (AMC). The local Hoelder exponent has been used to characterize the variability of the heart rate. Filtering the decelerations and accelerations has proven to be crucial for obtaining a good estimate of variability, as the magnitude of these events exceeds that of the variability by roughly one order of magnitude. A multiscale technique – the wavelet transform – proved well suited to the task of separating the two characteristics of the fetus heartbeat time series (variability, accelerations/decelerations). It has been concluded that local Hoelder exponent alone may not be enough to provide reliable information for fetus monitoring and prediction of birth outcome. Therefore a data mining experiment is currently being set up in order to look for a wider based theory.

In the area of methodologies of feature representation the main activity in the first half of the year was focused on the design of an efficient Haar incremental update scheme. Translation invariant representations based on the Haar decomposition were suggested and released for implementation for use with the Monet database system. A model application of the routines was designed as the real time decomposition of the fetus heartbeat. Three orthogonal components of the fetal heartbeat, baseline, acceleration/deceleration and variability will serve as an input to data mining algorithms.

Castelo worked on the formalization of the tree conditional independence Markov models, as well as concepts related to this class as: marginalization and collapsability and enumeration of such graphical Markov models. A lecture was given about this subject at the Workshop on Data Analysis with Graphical Models at the University of Munich in March 2000. The EU research program on Highly Structured Stochastic Systems (HSSS) granted a research visit to Ass. Prof. Dr. Paolo Giudici at University of Pavia during the second and third weeks of June where research relating MCMC methods for Graphical Models was

carried out.

Together with Manuel Bertran Ibarz (an intern from UPC Barcelona) he worked on a new implementation for a system to discover Bayesian Networks on top of Monet.

Siebes worked with Heike Hoffman (Augsburg University) on visualization problems for association rules. The results were published at the KDD. Together with Daniel Fernandez (an intern from UPC Barcelona) he worked on an algorithm for the reject inference problem. Together with Arno Knobbe he worked on algorithms and a methodology for multi-relational data mining; results were published at the PKDD. Finally he worked on the design of a database and data mining system for bioinformatics.

Lioen joined the group as a programmer and spent most of his time getting acquainted with database technology as a basis for his task to prepare a time-series extension for Monet.

Multimedia Databases – INS1.2

The activities in the Digital Media Warehouse project, a cooperation with Telematics Institute, University of Twente, KPN Research and Perot Systems focus on two aspects: XML handling in a database context and Feature grammars for multimedia indexing.

Schmidt, Kersten and Windhouwer continued their studies of the implications that the advent of XML has on database technology. As a first step, several ways to map documents to relational database tables were examined and resulted in the finding of an innovative mapping, named Monet XML, that exploits all hierarchical information present in the source documents. The schema performs a semantic clustering of XML data. Based on the notion of lowest common ancestor, a new XML aggregation operator was defined: the *meet* operator. The input to the operator is a set of arbitrary nodes in an XML syntax tree, such as the results of a full-text search or footprints of a user's browsing session. The meet operator fragments the input set in such a way that for each fragment the lowest common node in the tree is returned, thereby revealing the semantic context of a query result. With this step, we improve the expressiveness of an XML query engine in a direction where users do not need to know a priori the database schema.

A third line of research was established to gain insights into the implications of architectural choices inside the storage engine with respect to query performance. Little work has been done so far to find out what patterns are typical to XML queries and whether they translate to efficient and natural query evaluation plans. Our approach is to define a set of queries and investigate their behaviour on different systems. Under the URL `www.xml-benchmark.org` the interested reader will find more information on this international project involving GMD-IPSI, INRIA, Microsoft, and Propel.

Menzo Windhouwer worked on the Acoi system architecture, which is geared towards support of multimedia searching. A prototype had already been constructed and presented at many places. In 2000 the feature grammar language formalism was not extended any further. Experiences gained in the ongoing projects (Digital Media Warehousing, Multimedia Information Analysis, and ToKeN2000) proved validity of the approach in concrete problem settings. Instead, the toolset has been more tightly integrated with XML standards, and made easily adaptable for different requirements from both developers and underlying DBMS technology.

The Acoi software-robot case study has been extended with multimedia feature extractors, and has been demonstrated at WWW9. More collaborations, in the domain of full text retrieval (University of Twente) and multimedia metadata extraction for hypermedia presentation generation (INS2), are underway. These experiments use as their basis the setup for the robot case study, which has already been extended to become generally applicable both in speed and functionality.

De Vries has taken over project management from Pellenkoft on the WTCW Multimedia Image Analysis project, and the Telematica Institute DMW project management from Kersten. His research activities has been focused mainly on information retrieval, participating in both CLEF, the European cross-language retrieval initiative, and TREC, the international text retrieval evaluation. The Monet layer of the software used in these experiments has been improved for efficiency. Other activities included two papers on his (previous) PhD work.

In the context of the Multimedia Image Analysis, Mamoulis, De Vries, Bosch, and Nes started work on *query articulation* in image databases, based on assumption that only through confronting the user with feedback on the high-dimensional space spanned by feature vectors we might be able to improve effectiveness of search-

ing a large databases.

Bosch has worked on the ImageSpotter, which uses local-spatial based image regions, i.e. subimages, as input for a query-by-example search system. The reason for using subimages instead of complete image feature vectors is straightforward: often users are not interested in the whole image when they are searching a database – we believe users find local, discriminative regions more important. Subimages are formulated in 'spots' and a multispot vector. A spot describes precisely the required colour content of the subimage. A multispot vector describes the spatial interrelationship between the individual spots.

The multi-spot is matched in an exact manner to the database. The database describes for each image the spatial-based dominant colours. These colours are combined during searching to retrieve images that satisfy the multispot constraints. The search operation is performed in several phases to allow for local performance optimizations.

A prototype system has been built and is available for experimentation. A number of initial experiments showed a number of strengths and weaknesses. Strong points are the ability to precisely describe the user's need, and the ability to find images and subregions, which could not have been found with traditional approaches. However, we also noted a number of weaknesses: the system has difficulty in finding occluded image objects and we can only search for similarly coloured objects. We are working on these weaknesses to improve our system and to locate and to improve database support for multimedia retrieval.

Mamoulis worked on bitmap-index technology, that is meant for content-based retrieval for images. A user often poses queries to a multimedia database system that ask for images containing a specific configuration of objects (e.g., find images containing a car which is close to a burning forest). The aim of the index is to filter out images that do *not* contain information relative to the query, in order to avoid applying an expensive, detailed algorithm. This index is to be embedded as a module of ImageSpotter, a tool that answers queries based on spatial arrangements of interesting areas (spots).

Together with Eliëns and Huang, Ballegooij started working on the NWO-RIF project. This project centres around 'Navigation By Query' in online virtual (VRML) worlds by allowing users to search the space using database queries. Initial ideas on this research route were presented early 2001 at the Web3D conference. Additionally collaboration with other themes in CWI has resulted in several small demonstrators and publications, amongst which an exploration in using VR technology for cultural heritage applications (INS-R0022) and a VRML application of the facial animation technology developed in the 'CharToon' project. Finally virtual community expertise contributed to the WASP project (VU) and resulted in a paper on the application of WASP agent technology in virtual worlds. End of 2000, it was decided to relocate the RIF project to the Vrije University, because its focus was too much offcentred from the groups activities. Ballegooij joined the MIA project to concentrate on video retrieval in a multimedia database context.

Database Architectures – INS1.3

The multi-year activity on the Monet database system has lead to publication of our VLDB best-paper award in the VLBJ journal in 2000 and coverage of our results in the leading conferences.

Manegold, Boncz and Kersten extended their work on the impact of modern hardware features – especially hierarchical cache-memory systems and super-scaler CPUs – on the performance of databases. Exhaustive experiments on various hardware platforms confirmed that – unless special care is taken – main-memory access forms a severe performance bottleneck on virtually any contemporary computer architecture. Our memory-conscious algorithms proved to minimize the main-memory access costs on all systems. We confirmed that once main-memory access is optimized, efficient CPU utilization becomes vital for achieving good performance in database query execution. We improved the implementation techniques already used in our Monet system to exploit CPU resources as efficiently as possible.

Our work proved that the Decomposed Storage Model – combined with memory-conscious query algorithms and proper main-memory implementation techniques –, as used in Monet, improves database query performance on modern hardware significantly by minimizing memory access costs. Compared to the traditional (wide) relational approach, however, vertical decomposition requires some additional work to create the final multi-column query result. Further pursuing our work on memory-conscious query algo-

rithms, we designed and implemented proper algorithms for creating multi-column query results and analyzed their impact on the overall query execution costs. For simple (single-join) queries, where query result creation is supposed to have the largest impact on the total query execution time, we compared our approach with a traditional (wide) relational approach. The results clearly indicate, that with relatively narrow query results, Monet performs up to 4 times faster than the relational approach. With increasing result width, the gap narrows down, but Monet never gets worse than the relational approach. We expect the differences to be even more significant with more complex queries, where the relative impact of result creation becomes less.

Along with our work on database algorithms and implementation techniques, we developed analytical cost functions for main-memory database algorithms. Besides being used for query optimization purposes, the cost functions proved their vital services for designing memory-conscious query algorithms.

However, specifying accurate cost functions for various database algorithms on arbitrary hardware platform turned out to be a complicated and especially time-consuming task. In order to simplify and speed-up this process, we investigated whether and to which extent such cost functions might be generated (semi-) automatically. We found that the memory access behaviour of most database algorithms can be made-up as a combination of very few rather basic patterns, like sequential access or random access to a memory area of a given size. The cost functions for these basic patterns are rather simple mathematical terms and need to be specified only once. Then, given the description of an algorithms memory access pattern in terms of these 'building blocks', the complete cost functions can be derived automatically.

In order to estimate absolute execution times, we need to feed our cost function specific hardware parameters, such as cache sizes, cache line sizes and especially cache miss latencies. We designed and implemented a hardware calibration tool that automatically extracts these hardware-specific parameters on arbitrary hardware platform. Once publically available on the web, numerous users confirmed not only the portability and reliability of our Calibrator, but also its benefit when analyzing hardware and algorithms in various areas.

While extending our multi-query optimizer for Monet to exploit pattern rewriting techniques to optimize the execution time of database queries formulated in MIL, Pellenkoft, Manegold and Kersten discovered that the current architecture of Monet is not really suitable for this purpose. Especially, MIL turned out to be too complex to do efficient query rewriting. Hence, we decided to re-think the query execution mechanisms in Monet. As a first result, we designed and introduced a new assembler-like intermediate language called MAL that allows more efficient query rewriting and query execution. Finalizing the design of MAL and implementing a MAL compiler as well as compilers to translate SQL and/or MIL to MAL are the tasks to be done in the near future.

Waas finished his PhD work on probabilistic analysis of the query optimization space. He contributed to the MIA projects with studies on query scheduling in a database cluster, visualization of feature spaces (with Van Liere) and wavelet transforms for user feedback modelling. Research cooperation continued after his joining Microsoft (Redmond, USA). Together with Schmidt he organizes the global activities on measuring performance of xml-server technology.

Karlson finished his PhD work on Scalable Distributed Datastructures and accepted a job at IBM San Jose to work on the DB2 database kernel on handheld computers.

Kersten spent part of the summer (June–August) at Stanford University to continue work with with P. Mitra and G. Wiederhold on ontology integration, an essential ingredient to enable XML-based information systems to cooperate in a meaningful way.

PhD Theses

N. Mamoulis. *Processing and Optimization of Complex Spatial Queries,* July 2000, Hong Kong University of Science and Technology.

Florian Waas. *Principles of Probabilistic Query Optimization.* 3 November 2000, Univ. van Amsterdam. Thesis advisor: Prof. dr. M.L. Kersten.

Jonas S. Karlsson. *Scalable Distributed Data Structures for Database Management.* 14 December 2000, Univ. van Amsterdam. Thesis advisor: Prof. dr. M.L. Kersten.

Niels Nes. *Image Database Management Systems Design Considerations, Algorithms and*

Architecture. 14 December 2000, Univ. van Amsterdam. Thesis advisor: Prof. dr. M.L. Kersten.

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

Ballegooij:
- Workshop Web-Agent Systems and Applications WASA200, *A Taxonomy of Web Agents*, September 6–8, London (UK)
- VRML/Web 3D-2000 conference, *3D Gadgets for Business Process 20 Visualization: a case study*, February 21–24, Monterey (USA)

Bosch:
- Conference RTAS, *Real-time disk scheduling for mixed-media file systems*, May 31–June 2, Washington (USA)
- MIA seminar series, *Finding a needle in the haystack*, April 21, UvA (MIA), Amsterdam.
- IBM Watson Research Center, *Clockwise – a mixed-media storage system*, July 11 Hawthorne, NY (USA)
- Lucent Bell-Labs, *Clockwise – a mixed-media storage system*, July 13, Murray Hill, NJ (USA)

Castelo:
- Workshop on Data Analysis with Graphical Models: *TCI models: the bijection between DEC through LCI and labeled trees*, March 13–15, University of Munich (Germany)
- Workshop Uncertainty on Artificial Intelligence June 30–July 3, Stanford University (USA)
- Workshop on Causal Networks (within the ECAI2000) *Marginalization and Collapsability in Decomposable TDAGs*, August 20–25, Humboldt University, Berlin (Germany)
- September 5–10, Edinburgh, UK, VLDB00.

Karlsson:
- Australasian Database Conference ADC2000, *Omega-storage: A Self Organizing Multi-attribute Storage Technique for Large Main Memories*, January 31 – February 3, Canberra (Australia)

Kersten:
- MIA seminar series, *The ImageSpotter*, January 14, UvA, Amsterdam
- NSF Evaluation committee, February 7–9, Washington (USA)
- GDM Darmstadt advisory board meeting, March 27–28, Darmstadt (Germany)
- EDBT Conference, March 28–31, Konstanz (Germany)
- VLDB PC-meeting, May 2, Düsseldorf (Germany)
- IFIP WG2.6 meeting, May 8–9, Fukuyoka (Japan)
- Conference on Visual Database System VDB5, May 10–12, Fukuoka (Japan) *Panel chair: Lost in feature space*
- ToKeN2000 workshop, June 27, Maastricht
- Visit Stanford University, July 8–20, August 19–24, Palo Alto (USA)
- Working visit HP-Lab (U. Dayal), July 18, *Acoi, a digital media warehouse*
- Working visit HP-Lab (U. Dayal), Augustus 22, *An Impressionist Monet Exhibit*
- VLDB conference, September 11–15 , Cairo (Egypt)
- Ericsson Innovation Center, September 25, Stockholm (Sweden)
- TI Mindshare, September 29, Enschede, *Acoi, a digital media warehouse*
- ICDE PC meeting, October 14–17, Morristown (USA)
- Univ. de Milan W3I3 project meeting, October 12–13, Milan (Italy)

Manegold:
- *What happens during a join? - Dissecting CPU and Memory Optimization Effects*, VLDB conference, September 11–15, Cairo (Egypt)
- September 5–10, Edinburgh, UK, VLDB00. *Database Architecture for the new Bottleneck: Memory Access.*

Nes:
- British National Conference on Databases (BNCOD), *A multi-query optimizer for Monet*, July 2–5, Exeter(UK).
- VLDB conference, *What happens during a Join? - Dissecting CPU and Memory Optimization Effects*, September 11–15 , Cairo (Egypt)

Schmidt:
- International Workshop on the Web and Databases (In conjunction with ACM SIGMOD), *Efficient Relational Storage and Retrieval of XML Documents*, May 14–19, Dallas (USA)

Siebes:
- Working visit to DRAL, UK, March 18–21
- Dagstuhl Meeting: Intelligent Data Analysis, *Developing Data Mining Systems*, August 13–19 (Dagstuhl, Germany)
- KDD200, *Visualizing Association Rules with Interactive Mosaic Plots*, August 20–23, Boston (USA)
- PKDD2000, *Developing Data Mining Systems*, September 13–16, Lyon, France

Struzik:

- Fractals 2000, April 16–19, Singapore
- *Multifractility in Heart Beat Dynamics*, Working visit (T.G. Dewey) Applied Math. Institute, Claremont Colleges, April 27
- *Determining Local Singularity Strengths and their Spectra with Wavelet Transform*, Working visit (H.E. Stanley) Physics Department, Boston University, May 2
- *De-mystifying Multifractals: Can wavelets help to better understand multifractals?* Physics Department, Boston University, May 4
- *Wavelets Methods in (financial) Time Series Processing, - Quantitative Methods in Economical Studies,* Invited talk, SGGW, Warszawa, September
- *Beyond Morphology - Uncovering Structure with the Wavelet Transform*, Year 2000 Symposium on Statistical Physics, Zakopane, September
- *Quantitative Methods in Economical Studies*, SGGW, Warszawa, September

Waas:

- Australasian Database Conference ADC2000, *Extending Iterators for Advanced Query Execution* January 31 – February 3, Canberra (Australia)
- ACM SIGMOD Conference, *Counting, Enumerating and Sampling of Execution Plans in a Cost-Based Query Optimizer*, May 14–19, Dallas (USA)
- British National Conference on Databases (BNCOD), *Join Order Selection - Good Enough is Easy*, July 2–5, Exeter (UK)

Windhouwer:

- World-wide-web conference 2000, poster *The Acoi search engine*, May 15–19, Amsterdam

Visitors

- N. Mamoulis (Kersten), Univ. Hongkong, 13/03
- Robert Fenk & Volker Markl (Kersten), 06/04
- Valduriez (Kersten), INRIA, 02/11
- Galindo Legaria (Kersten), Microsoft, 02/11
- T. Risch (Kersten),Univ. Upsula, 14/12
- Florian Waas (Kersten), Microsoft, 16/08
- Daniela Florescu (Schmidt), INRIA, 16/08
- Manuel Bertran Ibarz (Siebes), Univ. Barcelona, February
- Daniel Fernandez (Siebes), Univ. Barcelona, February
- H.E. Stanley (Struzik), Boston University, 25/05.

Memberships of Committees and Other Professional Activities

Kersten:

- Editor *The VLDB Journal*
- Editor Kluwer *Distributed and Parallel Databases*
- Invited Speaker:
  - Lost in Feature Space, Visual Databases VDB 5, May 8, Fukuyoka (Japan)
  - An Impressionist Monet Exhibit, HP Research, August 17, Palo Alto (USA)
  - The ACOI project: building a Multi-media Index Server TI Mindshare, September, Enschede
- Member program committee WebNet 2000 World Conference on the WWW, Internet & Intranet, October 30–November 4, Austin, Texas (USA)
- Member program committee conference on Extending Database Technology 2000, March, Konstanz (Germany)
- Member program committee conference on Visual Databases, VDB5, May, Fukuyoka (Japan)
- Member program committee conference on Very Large Databases September, Cairo (Egypt)
- Member program committee ACM Sigmod 2001, May 2001, Santa Barbara (USA)
- Member program committee International Data Engineering Conference April 2001, Heidelberg (Germany)
- Member program committee RIDE workshop April 2001, Heidelberg (Germany)
- Member steering committee ToKeN2000 (NWO)
- Member review committee National Science Foundation (USA)
- Member of the VLDB Endowment Executive Board
- Member of the IFIP WG-2 Databases working group
- CEC Reviewer for the ESPRIT IV projects and W3I3
- Member scientific advisory board GMD Darmstadt
- Chairman of the non-executive board Data Distilleries

Siebes:

- Member program committee PKDD, Lyon, France
- Chair PKDD Challenge, Lyon, France
- Member of the editorial board of the *Journal of Knowledge Discovery and Data Mining.*

- Member of the editorial board of the *IDA journal*
- Member of the IDA Council
- Member of the Board of SIKS

Mamoulis:

- Served as a reviewer for *IEEE TKDE Journal and Int. Conference on Data Engineering '01.*

Papers in Journals and Proceedings

BALLEGOOIJ, A.E. (2000). 3d gadgets for business process visualization: a case study. *Proceedings of VRML/Web 3D* (Monterey, California, 2000).

BARTOLINI, I., CIACCIA, P., WAAS, F. (2000). Using the Wavelet Transform to Learn from User Feedback. *Workshop of the ERCIM Network of Excellence on Digital Libraries* (December 2000).

BOSCH, H.G.P., MULLENDER, S.J. (2000). Real-time Disk Scheduling in a Mixed-media File System. *Proceedings Conference RTAS*, May 31–June 2, Washington (USA), 2000.

CASTELO, R., SIEBES, A.P.J.M. (2000). Priors on network structures. Biasing the search for Bayesian networks. *International Journal of Approximate Reasoning* **24** (1), 39–57.

HOFMANN, H, SIEBES, A., WILHELM, F. (2000). Visualizing Association Rules with Interactive Mosaic Plots. *Proceedings of the 6th ACM SIGKDD Conference on Knowledge Discovery and Data Mining*, 227–235

KNOBBE, A., SIEBES, A., BLOCKEEL H., VAN DER WALLEN, D. (2000). Multi Relational Data Mining: Using UML for ILP. *Proceedings of the fourth European Conference PKDD2000, LNCS 1910*, 1–12.

DE VRIES, A. (2000). Challenging ubiquitous inverted files. *Proceedings of the First DELOS Network of Excellence Workshop on 'Inf ormation Seeking, Searching and Querying in Digital Libraries'* (Zürich, Switzerland, December 11–12 2000), 01/W001 in ERCIM Workshop Reports, pp. 71–75.

DE VRIES, A. (2000). The Mirror DBMS at TREC-9. *Proceedings of the Nineth Text Retrieval Conference TREC-9* (Gaithersburg, Maryland, November 2000).

DE VRIES, A. (2000). A poor man's approach to CLEF. *CLEF 2000: Workshop on cross-language information retrieval and evaluation* (Lisbon, Portugal, September 2000).

DE VRIES, A.P., WINDHOUWER, M.A., APERS, P.M.G., KERSTEN, M.L. (2000). Information Access in Multimedia Databases based on Feature Models. *New Generation Computing* **18**, October 4, 323–339.

IVANOV, P.C., AMARAL, L.A.N., GOLDBERGER, A.L., HAVLIN, S., ROSENBLUM, M.G., STRUZIK, Z.R., STANLEY, H.E. (2000). Beyond 1/f: Multifractality in Human Hearbeat Dynamics. D. ABBOTT and L.B. KISH (eds.) *International Conference on Unsolved Problems of Noise* (Adelaide, Australia, April 2000), **511**, American Institute of Physics, Melville, NY, USA, 273–281.

KARLSSON, J.S., KERSTEN, M.L. (2000). Omega-storage: A Self Organizing Muli-attribute Storage Technique for Large Main Memories. *Australasian Database Conference* (Canberra, Australia, January 2000), IEEE Computer Society Press, 57–64.

MANEGOLD, S., BONCZ, P. A., KERSTEN, M.L. (2000). Optimizing Database Architecture for the New Bottleneck: Memory Access. *The VLDB Journal* **9**, December 3, 231–246.

MANEGOLD, S., BONCZ, P.A., KERSTEN, M.L. (2000). What happens during a Join? – Dissecting CPU and Memory Optimization Effects. *Proceedings of the International Conference on Very Large Data Bases (VLDB)* (Cairo, Egypt, September), 339–350.

MANEGOLD, S., PELLENKOFT, A., KERSTEN, M. L. (2000). A Multi-Query Optimizer for Monet. *Proceedings of the British National Conference on Databases (BNCOD)* (Exeter, UK, July), *LNCS* **1832**, Springer-Verlag, 36–51.

MITRA, P., WIEDERHOLD, G., KERSTEN, M.L. (2000). A Graph-Oriented Model for Articulation of Ontology Interdependencies. *Proceedings of the International Conference on Extending Database Technology (EDBT)* (Konstanz, Germany, April 2000), *LNCS* **1777**, A9 Springer-Verlag, 86–100.

SCHMIDT, A.R., KERSTEN, M.L., WINDHOUWER, M.A., WAAS, F. (2000). Efficient Relational Storage and Retrieval of XML Documents. *International Workshop on the Web and Databases* (In conjunction with ACM SIGMOD) (Dallas, TX, USA, May 2000), 47–52.

STRUZIK, Z.R. (2000). Determining Local Singularity Strengths and their Spectra with the Wavelet Transform. *Fractals* **8**, 2 (June 2000).

VAN DOORN, M., DE VRIES, A. (2000). The psychology of multimedia databases. *Proceedings of the 5th ACM Digital Libraries Conference*

(DL'00) (San Antonio, Texas, USA, June 2000), 1–9.

VAN LIERE, R., DE LEEUW, W., WAAS, F. (2000). Interactive Visualization of Multidimensional Feature Spaces. *New Paradigms for Information Visualization* (Washington, DC, USA, November 2000).

WAAS, F. (2000). Extending Iterators for Advanced Query Execution. *Australasian Database Conference* (Canberra, Australia, January 2000), IEEE Computer Society Press, 135–139.

WAAS, F., GALINDO-LEGARIA, C.A. (2000). Counting, Enumerating and Sampling of Execution Plans in a Cost-Based Query Optimizer. *Proceedings of the ACM SIGMOD International Conference on Management of Data* (Dallas, TX, USA, May 2000), 499–509.

WAAS, F., PELLENKOFT, A. (2000). Join Order Selection - Good Enough is Easy. *Proceedings of the British National Conference on Databases (BNCOD)* (Exeter, UK, July 2000), *LNCS* **A9**, Springer-Verlag, 51–67.

WINDHOUWER, M.A., SCHMIDT, A.R., KERSTEN, M. L. (2000). Acoi: A System for Indexing Multimedia Objects. *Proceedings of the International World Wide Web Conference* (Amsterdam, The Netherlands, May 2000). Poster.

DE BRA, P., AERTS, A., HOUBEN, G.J., WU, H. (2000). Making General-Purpose Adaptive Hypermedia Work. *Proceedings of the WebNet Conference*, 117–123.

WU, H., DE BRA, P., AERTS, A., HOUBEN, G.J. (2000). Adaptation Control in Adaptive Hypermedia Systems. *Proceedings of the AH2000 Conference* 250–259. *LNCS* **1892**, Springer.

DE BRA, P. (2000). Pros and Cons of Adaptive Hypermedia in Web-Based Education. *Journal on CyberPsy chology and Behavior*, **3** (1), 71–77, Mary Ann Lievert Inc.

DE BRA, P. (2000). Using hypertext metrics to measure research output levels. *Scientometrics* **47** (2), 227–236, Kluwer Academic Publishers. (URL of a draft version in Postscript: `http://wwwis.win.tue.nl/~debra/scientometrics/paper.ps`)

CWI Reports

The following CWI reports were written by members of INS1. See page 91 for the complete titles.

INS-R0002	INS-R0003	INS-R0006
INS-R0007	INS-R0008	INS-R0015
INS-R0021	INS-R0022	INS-R0025

Other Publications

M.L. KERSTEN, M. HEGT, P.M.G. APERS (2000). *Liber Amicorum Reind P. van de Riet*, Stichting Mathematisch Centrum, Amsterdam.

ARNO SIEBES (2000), Data Mining and Statistics: a Systems point of View in *Computational Intelligence in Data Mining*, edited by GIACOMO DELLA RICCIA, RUDOLF KRUSE and HANS-J. LENZ. CISM Courses and Lectures No 408, Springer Verlag, 1–38

ALEX VAN BALLEGOOIJ, ANTON ELIËNS (2000). *Avatars in RIF*, Presented at the FASE2FASE 2000 Symposium, Delft, The Netherlands.

D. HIEMSTRA, A. DE VRIES (2000). *Relating the New Language Models of Information Retrieval to the Traditional Retrieval Models.* Tech. Rep. TR–CTIT–00–09, Centre for Telematics and Information Technology, May 2000.

Z.R. STRUZIK (2000). Beyond Morphology: Uncovering Structure with the Wavelet Transform. *Year 2000 Marian Smoluchowski Symposium on Statistical Physics.* Zakopane, Poland, September. Transparencies from the lecture.

A.P. DE VRIES (2000). *The Role of Evaluation in the Development of Content-Based Retrieval Techniques.* Tech. Rep. TR–CTIT–00–19, Centre for Telematics and Information Technology, November 2000.

Software

The Monet database system forms the core of the research experimentation platform of INS1 (`www.cwi.nl/~monet`). The code base is maintained and enhanced in close cooperation with P. Boncz of Data Distilleries. Nes developed a prototype version of the SQL-92 to MIL compiler and realized the port of the Monet software base to the Windows NT platform. Manegold maintained the quality control system for the Monet code base. Manegold developed the Calibrator package, which is widely used to obtain hardware characteristics for performance studies.

Windhouwer developed and maintained the Acoi search engine; an extensive code base to collect, analyze, and index multimedia information on the web (`www.cwi.nl/~acoi`).

Kersten developed a Java prototype front-end, called the ImageSpotter, to steer the research lines in image storage, indexing and retrieval in the MIA project. This prototype was

taken up by Bosch to develop a series of improved prototypes for image retrieval on the Monet database.

Multimedia and Human-Computer Interaction – INS2

Staff

- Dr. H.L. Hardman, theme leader
- Dr. D.C.A. Bulterman, external advisor
- Drs. F.J. Cornelissen, PhD student
- Dr. J.R. Davis, researcher
- Ir. J. Geurts, PhD student
- Ir. M.W.J.H. Huijberts, researcher
- Dr. C.A. Lindley, guest
- Dr. F.-M. Nack, researcher
- Drs. J.R. van Ossenbruggen, PhD student
- S. Pemberton, researcher
- Dr. L.W. Rutledge, researcher

Scientific Report

The research line on the automated generation of hypermedia presentations, initiated in 1999, has been consolidated in 2000. This research builds on the expertises of the existing group, in particular the hypermedia document modelling and authoring activities and the close associations with W3C – in particular the SYMM and XHTML working groups. Through the additional expertise from new members of the group (Cornelissen and Nack, and, towards the end of the year, Huijberts) and experienced visiting researchers (Davis and Lindley), ground has been made on both the theoretical aspects of the research as well as being able to construct an initial demonstrator of our ideas. In 2001 we plan to work on different aspects of the problem, such as the role of user profiles, network characteristics and graphical design information in the overall process. Running projects were DYNAMO, RTIPA and ToKeN2000. These will continue in 2001.

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 organizations 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 and available network bandwidth. We are cooperating with the Dutch project partners Philips Research, TU Eindhoven and Oratrix Development B.V. and with LIP6, Thales and INRIA in France.

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. The work is being 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 cognitive science 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 first phase of the project has resulted in a prototype system for accessing multimedia information in the Rijksmuseum database. This allows the generation of hypermedia presentations tailored to the display device and the characteristics (currently expertise level) of an individual user.

Other Activities

In addition to these projects Van Ossenbruggen and Rutledge contributed actively to the development of W3C's SMIL 2.0 (Synchronized Multimedia Integration Language).

In 2001 we plan to capitalize on the growing interest in the Semantic Web, where our strengths lie in its integration with multimedia and hypermedia.

Lynda Hardman. Successful recruitment, based on fund-raising in 1999, led to a significant broadening and strengthening of the group's expertise in 2000. High priority was given to developing dialog between old and new members of the group – with excellent results. At the beginning of the year, Hardman was still on maternity leave and then worked a number of months parttime, leaving the theme in the competent hands of Van Ossenbruggen and Rutledge. In November she was an invited speaker at an EU IST workshop on Semantic Web Technologies.

Dick Bulterman 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. Cooperation on the RTIPA project will also strengthen ties in 2001.

Frank Cornelissen joined the group in February from the AI department at the Vrije Universiteit. He contributed his considerable theoretical and programming experience to the development of the group's presentation generator demonstrator (Cuypers), ToKeN2000, and conceptual work around network issues, RTIPA.

Jim Davis spent in total 6 months working in the group and contributed significantly to the understanding of discourse issues, in particular in the established text-based field, and how these can, and cannot, be applied to multimedia.

Joost Geurts continued work on constraint-programming as part of the presentation generation process, and contributed to the implementation of the ToKeN2000 demonstrator.

Michel Huijberts joined the group in November from the Amsterdam Medical Centre. His expertise lies in the area of integrating hetergeneous (multimedia) data types in a distributed database environment.

Craig Lindley visited the group from the Australian CSIRO research centre for a total of three months. He brought expertise from the area of automatically generating video presentations from a database of annotated videos. Close work with Frank Nack led to a shower of papers.

Frank Nack joined the group in February from GMD-IPSI. His expertise lies in the fields of AI and multimedia, both of which we required for his PhD thesis on generating film sequences from a database of film clips. Frank was the chair of the ISO MPEG-7 working group on DDL (Description Definition Language) and has already contributed extensively to the conceptual work on rhetorics for multimedia. He was also the main author of a European IST proposal including partners directly involved in media archives.

Jacco van Ossenbruggen completed his PhD thesis *Processing Hypermedia: A Matter of Style.* In addition to continuing his own research on generating hypermedia presentations he also initiated work on integrating existing technologies for bringing multimedia towards the Semantic Web. He coordinated the software development efforts for the Cuypers hypermedia presentation generation demonstrator and continued to supervise Geurts. He continued to play a key role in the running of the RTIPA, DYNAMO and ToKeN2000 projects.

Steven Pemberton continued to chair the W3C HTML Working Group and initiated chairing the W3C Forms 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.

Lloyd Rutledge contributed significantly to the research carried out within the group, in particular for the MIA project, producing numerous papers and giving a number of tutorials. He performed joint work with our two visitors. He continues to play a significant role in the W3C SYMM working group.

Knowledge Transfer

Frank Cornelissen:

- *Hypermedia Presentation Generation*, ToKeN2000 workshop, Universiteit Maastricht, June 27.
- *Hypermedia Presentation Generation*, DFKI, Saarbrücken, Germany, August 1.

Lynda Hardman:

- *SMIL: The Synchronized Multimedia Integration Language* (Tutorial) given at ACM Hypertext 00, San Antonio, Texas, June 2.
- Invited talk *Multimedia and the Semantic Web*

at EU IST *Semantic Web workshop*, Luxemburg, November 23.

Frank Nack:

- Invited talk *A New Paradigm for Video Media*, University of Surrey, Guildford, UK, June 28.
- Invited talk *Whereof One Cannot Speak Thereof One Must Remain Silent*, IBM T. J. Watson Research Center, Hawthorne, NY, USA, November 6.
- *MPEG-7: Semantics for Audio-Visual Media on the Web*, Semantics for the WEB, Dagstuhl, Germany, March 19–24.
- *Streaming Meta-Data*, WWW9 Workshop *Multimedia on the Web*, Amsterdam, May 15.
- *Arbeitsumgebungen für die Entwicklung interaktiver Geschichten*, Workshop on Digital Storytelling, DISTEL 2000, Darmstadt, Germany, June 15–16.
- *About the influence of computer semiotics on communal Intelligence*, Workshop on Computational Semiotics for New Media, University of Surrey, UK, June 19–20.
- *Catch me, said the meaning, and turned out to be a hydra*, Narrative and Interactive Learning Environments, University of Edinburgh, UK, August 30–September 1.
- *Production and maintenance environments for interactive audiovisual stories*, ACM Multimedia workshop *Bridging the Gap: Bringing Together New Media Artists and Multimedia Technologists*, Los Angeles, CA, USA, November 4.

Jacco van Ossenbruggen:

- Panel participant *Graphics Shootout on the Web*, WWW9, Amsterdam, May 17.
- *Device Independent Multimedia Authoring*, W3C Workshop *Web Device Independent Authoring*, Bristol, UK, October 3.
- Structured Documents on the Web, Vrije Universiteit Amsterdam, December 13.

Steven Pemberton:

- Tutorial: *Styling the new web*, CWI March 10; CHI 2000 April 3.
- Tutorial: *Usability techniques for web-based services: diversity and technology*, CWI March 3, April 3.
- Tutorial: *XHTML: The new HTML*, CWI, November 23.
- Lecture: *Internationalisation of Websites*, SIGCHI.NL, Utrecht, Jun 6.
- Lecture: *Internationalisation*, University of Leiden, September 29

Lloyd Rutledge:

- *SMIL: The Synchronized Multimedia Integration Language* (Tutorial) given at:
  WWW9, Amsterdam, May 15,
  Dutch W3C office, Amsterdam, October 17,
  MMM00, Nagano, Japan, November 13,
  ATR-MIC, Kyoto, Japan, November 18.
- *Relating Museum Paintings with their Subject* Culture Track of WWW9, Amsterdam, May 16.
- *Inter-dimensional Hypermedia Communicative Devices for Rhetorical Structure*, Tokyo, Japan, November 17.

Organization of Conferences, Workshops, Courses, etc.

Lynda Hardman:

- WWW9 workshop on Multimedia and the Web (with Jacco van Ossenbruggen), Amsterdam, May 15

Frank Nack:

- Co-organizer of NILE 2000, Edinburgh, UK, August 30–September 1.

Jacco van Ossenbruggen:

- WWW9 workshop on Multimedia and the Web (with Lynda Hardman), Amsterdam, May 15.

Lloyd Rutledge:

- W3C SYMM Working Group face-to-face meeting, January 11–12.

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

Frank Cornelissen:

- DYNAMO: TU Eindhoven, February 15; CWI, March 16; Philips Research, Eindhoven, April 26; TU Eindhoven June 14; CWI, September 4; Philips Research, Eindhoven, October 16; TU Eindhoven, November 14; CWI, December 14.
- ToKeN2000 workshop, Universiteit Maastricht, June 27.
- Elisabeth André, DFKI Saarbrücken, Germany, August 1–5.
- David Ros, INRIA Rennes, France, October 30.
- RTIPA, Amsterdam, November 23–24.

Lynda Hardman:

- WWW9, Amsterdam, May 15–19.
- ACM Hypertext 00, San Antonio, Texas, USA, May 31–June 3.
- RTIPA: Copenhagen, Denmark, June 22–23; Toulouse, France, September 14.
- EU IST Semantic Web workshop, Luxemburg, November 22–23.
- Semantic Web workshop, Vrije Universiteit, Amsterdam, December 8.

- Korber panel presentation, University of Southampton, UK, December 11–12.

Frank Nack:
- Dagstuhl Seminar 00121 *Semantics for the Web*, Wadern, Germany, March 19–24.
- RIAO 2000, Content-Based Multimedia Information Access, Paris, France, April 12–14.
- 52nd ISO WG11 MPEG-Meeting, Genéve, Switzerland, May 31–June 2.
- NILE 2000 Narrative and Interactive Learning Environments, Edinburgh, UK, August 30 – September 1.
- ACM Multimedia 2000, Los Angeles, CA, USA, October 31–November 4.
- IBM Watson, New York, USA, November 6.
- EU IST Semantic Web workshop, Luxemburg, November 22–23.

Jacco van Ossenbruggen:
- W3C SYMM/WG Face to face meeting, CWI, January 10–11.
- ToKeN2000: NICI, Nijmegen, January 21; Rijksmuseum, Amsterdam, April 6; Koninklijke Bibliotheek, Den Haag, April 28; NWO, Den Haag, September 29.
- DYNAMO: TU Eindhoven, February 15; CWI, March 16; Philips Research, Eindhoven, April 26; TU Eindhoven June 14; CWI, September 4; Philips Research, Eindhoven, October 16; TU Eindhoven, November 14; CWI, December 14.
- Dagstuhl Seminar 00121 Semantics for the Web, Wadern, Germany, March 19–24.
- WWW9, Amsterdam, May 15–19.
- W3C Workshop Web Device Independent Authoring, Bristol, UK, October 3–4.
- RTIPA, Amsterdam, November 23–24.
- Semantic Web, Vrije Universiteit, Amsterdam, December 8.

Steven Pemberton:
- W3C HTML Working Group:
  Cupertino, California, USA, January 27–28,
  Fort Myers, Florida, USA, April 13–14,
  Malmö, Sweden, July 19–20,
  Tokyo, Japan, October 12–13.
- W3C Forms WG:
  Punta Gorda, Florida, USA, April 11–12, Munich, Germany, October 24–26.
- ACM SIGCHI EC:
  The Hague, April 7–9,
  Monterey, USA, August 10–12,
  Paris, France, December 14–17.
- ACM CHI 2000, The Hague, April 1–6.
- WWW9, Amsterdam, May 15–19.

Lloyd Rutledge:
- W3C SYMM/WG Face to face meeting, CWI, January 10–11.
- Digital Talking Books application of SMIL meeting, United States Library of Congress, Washington DC, January 31–February 1.
- W3C SYMM/WG Face to face meeting, San Francisco, USA, March 13–15.
- Dagstuhl Seminar 00121 *Semantics for the Web*, Wadern, Germany, March 19–24.
- WWW9, Amsterdam, May 15–19.
- ACM Hypertext 00, San Antonio, Texas, USA, May 31–June 3.
- W3C SYMM/WG Face to face meeting, Grenoble, France, June 25–27.
- International conference on MultiMedia Modeling, Nagano, Japan, November 13–15.
- ACM Multimedia 2000

Memberships of Committees and Other Professional Activities

- Members of W3C SYMM Working Group: Dick C.A. Bulterman, Lloyd Rutledge, Jacco van Ossenbruggen.

Dick Bulterman:
- Program committee chair WWW9.
- Member IW3C2 (WWW conference committee).

Lynda Hardman:
- Hypermedia Track chair of WWW9
- Editorial board *New Review of Hypermedia and Multimedia* (NRHM).
- Special issue editor of *Spatial and Time-Based Hypermedia of NRHM.*
- Committee Vereniging Werkgemeenschap Informatiewetenschap (Information Science).
- Reviewer for *ACM Computing Reviews.*
- Reviewer for conference papers: ICME 2000, WWW10.
- Reviewer for journal papers ACM *Computing Surveys*; *New Review of Hypermedia and Multimedia*; IEEE *Multimedia* special issue on Web Engineering.
- Reviewer for FWF (Austrian Science Foundation) proposal.

Frank Nack:
- Program committe member, DISTEL 2000.
- Program committee member and session chair RIAO 2000.
- Reviewing activities:
  ACM Multimedia 2000, CMB 2000,
  Information Retrieval Journal,
  MPEG-7 standard, Chapter 12.
- Chair of the MPEG-7 DDL group.

- Editor of the Media Impact Column of *IEEE MM journal*
- Member ACM-SIGMM
- Submitted EU IST proposal *DEMUS - Dynamic WWW-publishing Environments for Large Multimedia Information Spaces*, Proposal No: IST-2000-28153.

Jacco van Ossenbruggen:

- Reviewing activities: WWW9, ACM Hypertext 2000, ACM Multimedia 2000, WWW10.

Steven Pemberton:

- Member Program Committee, Designing Interactive Systems conference, DIS 2000, NY, August 17–19.
- Member Organising Committee, Designing Interactive Systems conference, DIS 2000, NY, August 17–19.
- Chair of Conferences, SIGCHI.NL.
- Member of the advisory board on the Executive Committee of SIGCHI.
- Editor-in-chief *ACM/interactions*.
- Chair W3C HTML Working Group.
- Chair W3C Forms Working Group.

Lloyd Rutledge:

- Member, ACM SIGWeb, SIGMM.
- Reviewing activities: WWW9, ACM Hypertext 00, ACM Multimedia 00, WWW10.

Visitors

- Jim Davis, CourseNet Systems, February – April.
- Craig Lindley, CSIRO, February – May.
- Alain Uginet, INRIA, February 10.
- Helma Töepper, Intelligent Views, Germany, March 2–3.
- Seongbin Park, May 6.
- Jane Hunter, DSTC, May 16.
- Elisabeth Andrè, DFKI, May 25–26.
- Tat-Seng Chua, National University of Singapore, June 24–25.
- Wolfgang Putz, GMD-IPSI, July 13.
- Jean-Claude Dufourd, ENST, July 13.
- Camino Fernandez, Universidad Carlos III de Madrid, Spain, September 8.
- Vincente Matellan, Universidad Rey Juan Carlos, Spain, September 8.
- Simon Buckingham-Shum, Open University, UK, October 17.
- David Ros, INRIA Rennes, November 22.

Software Developed

Frank Cornelissen/Joost Geurts/Jacco van Ossenbruggen:

- Cuypers ToKeN2000 demonstrator (see CWI Report INS-R0025).

Papers in Journals and Proceedings

LYNDA HARDMAN, JACCO VAN OSSENBRUGGEN, LLOYD RUTLEDGE and DICK C.A. BULTERMAN (2000). Hypermedia: The Link with Time. *ACM Computing Surveys*, December 1999.

LYNDA HARDMAN, PATRICK SCHMITZ, JACCO VAN OSSENBRUGGEN, WARNER TEN KATE and LLOYD RUTLEDGE (2000). The link vs. the event: Activating and deactivating elements in time-based hypermedia. *New Review of Hypermedia and Multimedia 2000* **6**, 89–109.

C. LINDLEY and F. NACK (2000). Hybrid narrative and associative/categorical strategies for interactive and dynamic video presentation generation. *New Review of Hypermedia and Multimedia 2000* **6**, 111–145.

LLOYD RUTLEDGE, JIM DAVIS, JACCO VAN OSSENBRUGGEN, and LYNDA HARDMAN (2000). Inter-dimensional hypermedia communicative devices for rhetorical structure. *Proceedings of International Conference on Multimedia Modeling 2000* (MMM00), November 13–15, Nagano, Japan.

LLOYD RUTLEDGE, BRIAN BAILEY, JACCO VAN OSSENBRUGGEN, LYNDA HARDMAN and JOOST GEURTS (2000). Generating presentation constraints from rhetorical structure. *Proceedings of the 11th ACM conference on Hypertext and Hypermedia*, May 30–June 3, San Antonio, Texas, USA.

NACK, F. (2000). Catch me, said the meaning, and turned out to be a hydra. *Workshop on Narrative and Interactive Learning Environments*, 30th August–1st September 2000, Edinburgh, Scotland.

NACK, F. (2000). About the influence of computer semiotics on communal Intelligence. *Workshop on Computational Semiotics for New Media*, 29–30 June, University of Surrey, Guildford, UK.

NACK, F., LINDLEY, C. (2000). Production and maintenance environments for interactive audio-visual stories. *Proceedings ACM MM 2000 Workshops – Bridging the Gap: Bringing To-*

gether New Media Artists and Multimedia Technologists, 21–24, October 31, Los Angeles, CA.

NACK, F., LINDLEY, C. (2000). Arbeitsumgebungen für die Entwicklung interaktiver Geschichten. *Computer Graphik Edition - Band 2*; Digital Storytelling (Tagungsband). Hrsg: Ulrike Spierling. 113–125. Frauenhofer IRB Verlag.

NACK, F. (2000). All content counts – the future in digital media computing is meta. *IEEE MultiMedia* **7** (3), 10–13.

DITTMANN J., NACK F. (2000). Copyright - *IEEE MultiMedia* **7**(4), 14–17.

STEVEN PEMBERTON (et al), XHTML 1.0: The Extensible HyperText Markup Language, W3C Recommendation 26 January, `http://www.w3.org/TR/xhtml1`
Proceedings CHI 2000, ACM Press, *CHI 2000 Extended Abstracts*, ACM Press. Support concepts for Web navigation: a cognitive engineering approach.

CWI Reports

The following CWI reports were published by members of theme INS2. See page 91 for the complete titles.

INS-R0002 INS-R0024 INS-R0025

Other Publications

LYNDA HARDMAN and JACCO VAN OSSENBRUGGEN (2000). Device independent multimedia authoring, *W3C Workshop on Web Device Independent Authoring*, October 3–4, Bristol, UK.

STEVEN PEMBERTON. The demise of the book. *Interactions* **7** (1), 92.

STEVEN PEMBERTON *It rings for thee interactions* **7**(3), 72.

STEVEN PEMBERTON. *The accidental death of reviewing interactions* **7** (4), 56.

STEVEN PEMBERTON. *So much for WYSIWYG interactions* **7** (5), 60.

STEVEN PEMBERTON *Abusus non tollit usum interactions* **7** (6), 56.

DICK C.A. BULTERMAN, JACCO VAN OSSENBRUGGEN and LLOYD RUTLEDGE (2000). *W3C. Synchronized Multimedia Integration Language (SMIL) 2.0.* Specification 21 September 2000 Note: Edited by AARON COHEN. `http://www.w3.org/TR/2000/WD-sunil20-2000`

Awards

Lynda Hardman:

- The research group formed part of a nominated proposal for the Korber Science award.

Interactive Information Engineering – INS3

Staff

- Drs. P.J.W. ten Hagen, theme leader
- Dr. A.V. Groenink, researcher, seconded by Eidetica b.v.
- Drs. J. Hendrix, project member
- Dr. I. Herman, researcher
- Ms. ir. A.P.C. Kiers, project member
- A.D.F. Lelièvre, project member till August 1
- M.S. Marshall, BSc., project member
- G. Melançon, researcher, till September 1
- Drs. H. Noot, programmer
- Drs. M.M. de Ruiter, programmer
- Ms. Dr. Zs.M. Ruttkay, researcher (STW)

Scientific Report

Information Visualization – INS3.1

The year 2000 saw the completion of the Royere software, an extensible Java-based system for Graph Visualization and also the testbed for the various scientific results the group had. The software architecture includes a number of novel approaches to graph visualization systems; an overview of the system has also been accepted for publication. Royere is also available for the public (`http://www.cwi.nl/InfoVisu`) and is used at the universities of Bath, Bordeaux, Monpellier, is experimented with by W3C and several students at various universities (the software is freely downloadable, and there is no exact track on who accessed).

The development of the software was at the basis of several interesting scientific work, too. The issue of DAG drawing has been addressed separately (and has resulted in the publication *DAG drawing from an information visualization perspective*; see Publications in Journals and Proceedings). Indeed, the special emphasis of information visualization has cast another view on the traditional approaches. More importantly, the recognition of the importance in the statistical distribution of metrics on graphs have led to novel

approaches in metric-based visual cue generation; this work has been fully carried out in the year 2000, and has also led to a separate publication (*Density Functions for Visual Attributes and Effective Partitioning in Graph*; see Publications in Journals and Proceeding) and reports. As a separate activity, an XML-based file format has been defined for the description of graphs, again with a special attention on the requirements of information visualization; this activity not only led to a publication (*GraphXML – a graph description language*; see Publications in Journals and Proceedings), but to the creation of an international group, under the co-leadership of Scott Marshall (and Prof. Ulrkik Brandes, University of Konstanz), whose goal is to define a general 'standard' for graph description based on XML and which should be reported at the next Graph Drawing conference in 2001. Finally, the State of the Art Report, which was originally prepared for the Eurographics'99 conference, was turned into a general written survey. (*Graph Visualization in Information Visualization*; see Publications in Journals and Proceedings).

Guy Melançon left the group in June 2000 and joined the University of Monpellier as a full-time professor. The group has ceased its existence on the 1st of January 2001, but the graph visualization activity is carried on by Scott Marshall in his position at the new pilot theme *Scientific Visualization.*

Independently of the information visualization activities, Ivan Herman was also co-chair of the 9th World Wide Web conference, which took place in Amsterdam, in May 2000. He also took over (in February 2000) the management of the Dutch W3C Office and served as an Advisory Committee member for CWI at W3C.

Facial Animation – INS3.2

The FASE project was completed this year, with the following results

Extensions to CharToon

1. The CharToon software was improved. The version 2.0 has new facilities which allow more flexible re-use of pieces of animation and the building of complex faces. The idea of facial feature and animation repertoire was developed, demonstrated and tested.
2. In order to support lip-sync and talking heads, a generic set of vizemes have been designed and the Animation Editor has been extended with facility to generate lip-sync automatically from phoneme or vizemes scripts.
3. The early prototype of Emotion Disc has been further developed, to be used for any face.
4. Conversion modules have been built to produce ShockWave and WAP WML format movies. The possibility of converting to/from SVG has been investigated.
5. Prototype of a constraint-based animation system has been implemented, by using the Opac Solver developed at the University of Nantes.

3D Facial Model

Confirmation of a generic 3D head has been made possible, concerning texture, thickness and elasticity. We can produce personalized 3D heads.

Analysis of facial expression data

The data of snapshots of 18 performers, provided by our partners at TUD, has been analysed. 86 facial expressions made by an artist designer were analysed and compared to real expressions. Time-curves of the 18 recordings of facial expressions have been analysed (still ongoing work).

Applications/demonstrators

1. In co-operation with the group of Eliëns (INS1.3), avatars in a VR system have been endowed with facial expressions, which could be controlled via an Emotion Disc.
2. In co-operation with IPO, a try-out demonstrator has been made for talking heads.
3. PhilipsNatLab has chosen CharToon as animation tool to make humanoid interfaces. Try-out demonstrator has been made.

Organization of Conferences, Workshops, Courses, etc.

- Face2Face Workshop at TUD: Zs. M. Ruttkay
- Animation Afternoons at CWI: Zs. M. Ruttkay

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

- *NPAR'2000*, Annecy, June 6: Noot, Ruttkay.
- *ERCIM Workshop on Constraints*, Padova, June 19–23: Ruttkay.
- *WWW'9*, Amsterdam, May 15–19: Ten Hagen, Hendrix, Noot, De Ruiter, Ruttkay; award for poster.

- *ERCIM E-Learning Workshop*, Bonn, November 23: Ruttkay.
- *Eurographics'2000*, Interlaken: August 22–26: Ten Hagen, Hendrix, Lelièvre, De Ruiter, Herman.
- *Learning to Behave*, Twente: Ten Hagen, Hendrix, Noot, De Ruiter, Ruttkay.
- *Fraunhofer IGD Darmstadt*, January 25: Ten Hagen, Hendrix, Kiers, Noot, Lelièvre, De Ruiter, Ruttkay.
- *IEEE Information Visualization Symposium 2000*, IEEE Visualization 2000, Virginia, USA, September 19: M.S. Marshall.
- *Euler project*, Göttingen, Germany, January 22: A.V. Groenink.
- *Euler project*, Zürich, September 2: A.V. Groenink, F.A. Roos.
- *Euler project*, Copenhagen, August 9: A.V. Groenink.
- *Euler project*, Berlin, March 15: F.A. Roos.
- *Euler project*, Luxemburg, September 25: F.A. Roos.
- *Anima 2000*, animation film festival, Brussels, Belgium, March 8: Lelièvre, Hendrix.
- *Eurographics 2000 IPC meeting*, Zürich, February 10: I. Herman
- *EU workshop on information visualization*, Luxemburg, April 11.
- *EU KePT project meeting*, Paris, France, July 6.
- *IW3C2 meeting*, Hong Kong, China, October 21.
- W3C Office meeting, Nice, France, September 9.
- *EU W3C project meeting*, Brussels, Belgium, October 13.
- *Eurographics Executive Board meeting*, Darmstadt, Germany, November 16.
- W3C AC Meeting, Boston, USA, November 26.

Visitors

- A. Paradiso (GMD)
- L. Gulyás (SZTAKI)
- Mel Slater, Maia Garau (University College London)

Memberships of Committees and Other Professional Activities

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 Enironments
  - 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 mathematics and computer science of the Dutch Aerospace Laboratory
  - Member of the editorial board of the Journal Research in Engineering Design
  - Editor of the Springer book series *Symbolic Computation/Computer Graphics*
- Ruttkay:
  - Member of the Constraints ERCIM Working Group
  - Member of the E-Learning ERCIM Working Group
  - Member of SIGGRAPH, EUROGRAPHICS, NAIC

Software/knowledge transfer

The spin-off company EPICTOID is going to sell CharToon from 2001.

Papers in Journals and Proceedings

P. ten Hagen (2000). A Facial Repertoire for Animation. *EUROGRAPHICS'2000 Short Presentations*, 79–84.

J. Hendrix, Zs. Ruttkay, P. ten Hagen, H. Noot, A. Lelièvre, M.M. de Ruiter (2000). A facial repertoire for avatars. *Proceedings of the Workshop Interacting Agents*, Enschede, The Netherlands, 2000.

Zs. Ruttkay, H. Noot (2000). Solution Strategies to Produce Facial Animations. *Proceedings of the ERCIM/Compulog Workshop on Constraints*, Padova, Italy, June 2000.

Zs. Ruttkay, H. Noot, Behr de Ruiter, Paul ten Hagen (2000). CharToon Faces for the Web, Poster. *Proceedings of the 9th Int.*

WWW conference, 28–31, Amsterdam, The Netherlands, May 2000.

Zs. RUTTKAY, H. NOOT (2000). Animated CharToon Faces. *NPAR 2000 : First International Symposium on Non Photorealistic Animation and Rendering*, 91–100.

I. HERMAN, G. MELANÇON, M.S. MARSHALL (2000). Graph Visualization in Information Visualization: a Survey. *IEEE Transactions on Visualization and Computer Graphics* **6** (1), 24–44.

G. MELANÇON, I. HERMAN (2000). DAG drawing from an information visualization perspective. R. VAN LIERE, W. DE LEEUW (eds.). *Data Visualization '00, Proceedings of the Joint Eurographics IEEE TCVG Symposium on Visualization*, Amsterdam, Springer-Verlag.

I. HERMAN, M.S. MARSHALL, G. MELANÇON (2000). Density Functions for Visual Attributes and Effective Partitioning in Graph Visualization. S.F. ROTH and D.A. KEIM (eds.). *Proceedings of the IEEE Information Visualization Symposium 2000* IEEE CS Press, 49–56.

I. HERMAN and M.S. MARSHALL (2000). GraphXML – a graph description language. *Proceedings of the Symposium on Graph Drawing GD'00*, Springer-Verlag.

CWI Reports

The following CWI reports were published by members of theme of INS3. See page 91 for the complete titles of the reports.

INS-R0001	INS-R0004	INS-R0005
INS-R0009	INS-R0013	INS-R0014
INS-R0016		

Other Publications

FaceTricks CD animations made with CharToon.

Quantum Computing and Advanced Research Systems – INS4

Staff

- Prof. dr. ir. P.M.B. Vitányi, group leader
- Prof. dr. A.E. Brouwer (seconded Univ. Eindhoven)
- Dr. H. M. Buhrman, senior researcher
- Drs. W. van Dam, PhD student UvA
- Dr. J. Delgado Pin, visting researcher
- Prof. dr. P. Gács (visiting scientist, Boston University)
- M. de Graaf, assistant researcher (undergrad) UvA
- Dr. P.D. Grünwald, postdoc (partially EURANDOM.
- Dr. H. Klauck, postdoc
- M. van Liempt, assistant researcher (undergrad) UvA
- Drs. R. Manniesing, PhD student NWO
- Drs. H. Röhrig, PhD student NWO-SION
- Dr. L. Torenvliet (seconded University of Amsterdam)
- Dr. J.T. Tromp, postdoc
- Drs. R.M. de Wolf, 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 physically 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 10 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 collaborates with the Theoretical Physics Department and the Computer Science and Logic Department of the University of Amsterdam and various major centers abroad: among others the Quantum Information Group at IBM T.J. Watson Research (C. Bennett), Quantum Computation Group at University of California, Berkeley (U. Vazirani), Quantum Computation Group at National Security Agency (M. Heiligman), 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), NEC Research, Princeton, USA (L. Fortnow), and the Computer Science group at Université Paris-Sud Orsay (M. Santha).

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 appeared in the *17th Annual Symposium on Theoretical Aspects of Computer Science* (STACS'2000).

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. Their results can be found in the paper 'Communication Complexity Lower Bounds by Polynomials'. which has been submitted.

Buhrman wrote an overview paper 'Quantum Computing and Communication Complexity' for the EATCS bulletin. The paper appeared in the March 2000 issue.

Buhrman and *De Wolf* finished their survey paper about the connections between various complexity measures (block sensitivity, certificate complexity, polynomial degrees) and classical or quantum decision tree complexity. The survey will appear in *Theoretical Computer Science.*

De Wolf gave mathematical characterizations of the non-deterministic complexity of quantum computers in various settings. The non-deterministic query complexity of a function equals the degree of its non-deterministic polynomial, and the non-deterministic communication complexity equals the logarithm of the rank of its non-deterministic communication matrix. He also gave examples for both settings where quantum computers are exponentially faster than classical computers. The paper appeared in the *15th IEEE Conference on Computational Complexity* (CCC2000).

De Wolf, together with A. Ambainis (Berkeley), M. Mosca, and A. Tapp, generalized Shannon's theorem about secure communication to the quantum case. Shannon's theorem says that n classical bits of shared random key are necessary and sufficient for Alice to send Bob any n-bit message in an information-theoretically secure way. In the quantum case, the result is that $2n$ classical bits of key are necessary and sufficient for sending any n-*qu*bit message The paper appeared in the *Proceedings of the 41th IEEE Conference on Foundations of Computer Science* (FOCS'2000).

Buhrman and *De Wolf*, together with C. Dürr (Paris), M. Heiligman (NSA), P. Hoyer (Aarhus), F. Magniez (Paris), and M. Santha (Paris), discovered a new quantum algorithm for the Element Distinctness problem. Give a list of n numbers, the problem is to find out whether they are all distinct (equivalently, whether any element occurs more than once on the list). For classical algorithms, the time complexity of the problem is the same as that of sorting the list: about $n \log n$ steps. The new quantum algorithm solves the element distinctness problem in about $n^{3/4}$ steps, which is polynomially better. A preprint is available at the Los Alamos preprint server `http://xxx.lanl.gov/abs/quant-ph/0007016` and has been submitted for publication.

Buhrman and *De Wolf* together with Cleve and Watrous (Calgary) developed a quantum analog of the classical finger printing and hashing

scheme. One of the applications of this technique is that the equality function can be computed with exponentially fewer qubits than bits. Their results can be found in the paper 'Quantum Finger Printing' which has been submitted.

Buhrman and *De Wolf*, together with C. Dürr (Paris), M. Heiligman (NSA), P. Hoyer (Aarhus), F. Magniez (Paris), and M. Santha (Paris), discovered a new quantum algorithm for the Element Distinctness problem. Give a list of n numbers, the problem is to find out whether they are all distinct (equivalently, whether any element occurs more than once on the list). For classical algorithms, the time complexity of the problem is the same as that of sorting the list: about $n \log n$ steps. The new quantum algorithm solves the element distinctness problem in about $n^{3/4}$ steps, which is polynomially better. A preprint is available at the Los Alamos preprint server `http://xxx.lanl.gov/abs/quant-ph/0007016` and has been submitted for publication.

Buhrman was an invited speaker of the main conference in quantum computing: Algorithms in Quantum Information Processing 2000 held in Montréal. He was also the main organizer of the 2001 edition held in Amsterdam from January 9 till 12. The conference was a great success. We get around 150 participants, 50 more than previous years. The conference received press coverage in The Netherlands, *NRC Handelsblad* (interview with Buhrman), *Automatisering Gids* (interview with Buhrman) as well as outside The Netherlands, *Deutschlandfunk* (German national radio, interview with Buhrman), *Financieel-Economische Tijd* (Belgium, interview with Buhrman), wired (USA, two articles about QIP)

Buhrman initiated and chaired the first steering committee meeting for the QIP conference. It was established that the conference is growing and very successful. The conference is alread booked for the coming five years: 2002 IBM Yorktown Hights (USA, Bennett and Divincenzo), 2003 Berkeley (USA, Vazirani), 2004 Paris (France, Santha), 2005 Waterloo (Canada, Mosca), 2006 MIT (USA, Chuang and Fahri).

Buhrman gave a short course quantum communication complexity and complexity theory for the 'International Center for Mathematical Sciences' in Edinburgh in March 2000.

Buhrman gave a course Quantum Computing at the University of Amsterdam during the first trimester of the year 2000/2001.

The fifth framework project Quantum Algorithms and Information Processing (QAIP) started officially on January 3$^{\text{rd}}$. *Buhrman* is coordinator of this EU project. The kickoff meeting of the project was held in Amsterdam, April 6–7.

Van Dam investigated how combinatorial objects like Hadamard matrices and weighing matrices can be used to define problems that have a lower query complexity in the quantum mechanical setting, than they have in the classical or probabilistic model of computation.

Together with Sean Hallgren, *Van Dam* used his results on quantum computation with Hadamard matrices to define the 'shifted character problem', which relies on the theory of quadratic characters over finite fields and rings. They devised a quantum algorithm that solves this problem efficiently, whereas it is unclear how to do so by classical means.

Klauck published results on quantum communication complexity concerning the power of quantum Las Vegas communication and of quantum one-way communication. He exhibited a total Boolean function, for which the quantum Las Vegas communication complexity is polynomially smaller than the classical probabilistic communication complexity. Furthermore he showed that for total functions quantum Las Vegas protocols using only one round of communication (one-way protocols) are at most a constant factor more efficient than deterministic one-way protocols, thus proving that interaction is crucial for the aforementioned speedup. Furthermore he gave lower bounds on quantum one-way communication complexity with bounded error, and used the communication complexity results to show lower bounds on the size of quantum automata and quantum formulae. The paper appeared in the proceedings of the *32nd Annual ACM Symposium on Theory of Computing* (STOC 2000).

Klauck published a survey paper about quantum communication complexity in the proceedings of the *Workshop on Boolean Functions and Applications*, which was held as a satellite workshop with ICALP 2000. The paper also proposed a new lower bound method for quantum one-way communication complexity.

Klauck established a linear lower bound on the quantum communication complexity of the pointer jumping function f_k for protocols, in which only some fixed number k of communication rounds is allowed. It is trivial that a deterministic protocol can compute f_k with logarith-

mic communication in $k+1$ rounds. This result shows that restrictions on the allowed interaction may lead to exponentially increased communication even if quantum communication is allowed. He also inferred lower bounds on the quantum communication complexity with bounded interaction for the disjointness problem, thus showing that quantum speedups for this problem require nontrivial interaction. A preprint is available at the Los Alamos preprint server `http://xxx.lanl.gov/abs/quant-ph/0004100` and has been accepted for STOC 2001.

Röhrig worked with Lov Grover (Bell Labs) on quantum search in the presence of noise, quantum string matching, convolution products, and quantum communication strategies based on Grover's quantum search algorithm.

Röhrig and *Gács* investigated 'bidirectional' communication and how to simulate non-oblivious quantum Turing machines by oblivious quantum Turing machines.

Röhrig and *de Wolf* worked on a lower bound on sorting on a quantum Turing machine (but the anticipated result turned out to be published already by Yaoyun Shi (Princeton)). They also looked into lower bounds for the element-distinctness problem and how to obtain time-space tradeoffs for quantum computers.

Vitányi developed the first theory of quantum Kolmogorov complexity. His approach chooses to quantify the algorithmic information in bits contained in an individual pure quantum state. This extends classical Kolmogorov complexity to the quantum domain retaining classical descriptions. Quantum Kolmogorov complexity coincides with the classical Kolmogorov complexity on the classical domain. Quantum Kolmogorov complexity is upper bounded and can be effectively approximated from above under certain conditions. With high probability a quantum object is incompressible. Upper and lower bounds of the quantum complexity of multiple copies of individual pure quantum states are derived and may shed some light on the no-cloning properties of quantum states. In the quantum situation complexity is not sub-additive. A preliminary version was published in the *IEEE 15th Conference on Computational Complexity* in Florence, 2000, at the *Quantum Computation and Communication Meeting* at the Benasque Science Center, Benasque, Spain, July 2000, and will appear in *IEEE Trans. Information Theory*. This work was successful in that it inspired *Van Dam* and co-authors Berthiaume and LaPlante for a second approach to the description complexity, and *Gács* to a third approach, partially connecting the previous approaches, see below.

Van Dam worked, together with André Berthiaume and Sophie Laplante, on the descriptive complexity of quantum information ('quantum Kolmogorov complexity') taking an alternative approach to the initial work of Vitányi described in this section. Their approach considers the quantum input (in so-called 'qubits') that enables a universal quantum Turing machine to reproduce the target string with arbitrary high precision. The size of the smallest of such input strings is then defined to be the intrinsic complexity of the target state. The result of this work was presented at the *15th Annual IEEE Conference on Computational Complexity*, and has been selected for a special conference issue of the *Journal of Computer and System Sciences*.

Gács developed an approach to quantum algorithmic information theory that works as follows: In classical algorithmic information theory it turns out that the negative logarithm of the 'largest' probability distribution effectively approximable from below – the universal distribution – coincides with the self-delimiting Kolmogorov complexity. Gács defines two notions of complexities based on the negative logarithm of the 'largest' density matrix effectively approximable from below. There arise two different complexities of pure quantum states, based on whether we take the logarithm inside or outside. It then turns out that this work glues and connects the Vitányi approach and the Van Dam et al approach. It was presented as invited talk at the TAI Conference in Lille, France, April 2000, the *Conference on Information Theory* at Balatonlele, Hungary, June 2000, the *Workshop on quantum information theory*, Bielefeld, Germany, and the Quantum Information Processing Workshop in Amsterdam, 2000. This work was accepted for the *IEEE 16th Conf. Computational Complexity* in Chicago, 2001.

Vitányi wrote and presented a survey on quantum computing as invited plenary speaker at the 10 years jubilee of the International Dagstuhl Computer Science Seminar Center 'Dagstuhl Informatics – 10 Years Back, 10 Years Ahead,' published in the memorial vol. 2000 of Springer LNCS. `http://www.dagstuhl.de/10Years/`

Vitányi wrote a survey on quantum comput-

ing for the *Encyclopedia of Life Support Systems (EOLSS).*

Machine Learning – INS4.2

Grünwald worked intensively on the Maximum Entropy (ME) Principle. First, he extended his joint work with Professor A.P. Dawid (University College London). This work concerns a general game-theoretic re-interpretation of the Maximum Entropy Principle (as a game a 'Statistician' plays against 'Nature'). It leads to 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. Grünwald and Dawid have met three times in 2000 to finalize and refine their results. They have written a raw paper containing all theorems and proofs; it remains to organize the paper and write a clear introduction and discussion. They also extended their work in several ways. The most important new development concerned the so-called *Pythagorean Property* of the Maximum Entropy (Minimum Relative Entropy) Principle. As was first remarked by Csiszar in 1975, the Kullback-Leibler (relative entropy) divergence to a 'prior' distribution Q behaves like a quared Euclidean distance in the sense that it satisfies an analogue to Pythagoras' theorem, under some regularity conditions. It turns out that these regularity conditions are exactly those under which the 'Maximum Entropy Game' has a value. Similarly, the generalized entropies as defined by Grünwald and Dawid also satisfy analogues to Pythagoras' theorem if and only if their associated game has a value. This fact has a practical application: it can be used to generalize iterative scaling algorithms to optimize just about any loss function one is interested in.

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 further refined, and it was shown that many of the perceived problems of ME disappear if its application is restricted to 'safe' cases. This led to a paper at *UAI 2000* (see below) which was very well received. The paper shows that one can *formally* distinguish between (at least) four qualitatively different applications of MaxEnt, ranging from 'completely safe' via 'a reasonable inductive principle, but not guaranteed to yield good results' through 'completely silly'.

Grünwald also started to work on *the MDL (Minimum Description Length) Principle in non-parametric settings.* To this end he visited *V. Balasubramanian*, a phycisist at Harvard University. In previous work, Balasubramanian used techniques from differential geometry to obtain sharp asymptotic expansions of the 'stochastic complexity', the main ingredient in modern MDL-based research. Balasubramanian's previous work was on the parametric case, where the model class at hand is a countable collection of finitely parameterizable models. Grünwald and Balasubramanian now plan to work together to address the more general non-parametric case. Here 'models' are defined not directly in terms of parameter values. For example, one may formulate MDL and investigate its behaviour on the model class of 'all densities that are bounded away from zero and are twice continuously differentiable'. By now (December 2000) we have succeeded in doing some preliminary work: we developed a non-parametric generalization of the *Fisher information matrix.* This matrix plays the role of a Riemannian metric in the parametric case and leads to *Jeffrey's prior*, a prior distribution that plays a fundamental rôle in both MDL and Bayesian statistics. The goal is now to find an analogue of Jeffrey's prior to the non-parametric case.

Grünwald has reached an agreement with *Kluwer Academic Publishers.* A revised version of the first two parths (Chapters 1–7) of Grünwald's thesis will appear as a book. The manuscript should be ready by July 2001; the book will appear a few months later.

Vitányi worked (partially with M. Li) treating the mathematical relation between data compression and learning. The relationship between the Bayesian approach, Kolmogorov complexity, and the minimum description length (MDL) approach was established. 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. In general it was shown that data compression is almost always the best strategy, both in hypothesis identification and prediction. This work was reported in the *Rank Prize Fund*

Meeting on Model Selection and Learning in Computer Vision, Grasmere, Lake District, UK, April 2000, and will appear in *IEEE Trans. Information Theory.*

Vitányi (together with Ming Li and Qiong Gao) applied the theoretical work on MDL to concrete problems: they tested how the theory behaves in practice on a general problem in model selection: that of learning the best model granularity. The performance of a model depends critically on the granularity, for example the choice of precision of the parameters. Too high precision generally involves modelling of accidental noise and too low precision may lead to confusion of models that should be distinguished. This precision is often determined ad hoc. In MDL the best model is the one that most compresses a two-part code of the data set: this embodies 'Occam's Razor.' In two quite different experimental settings the theoretical lue determined using MDL coincides with the best value found experimentally. In the first experiment the task is to recognize isolated handwritten characters in one subject's handwriting, irrespective of size and orientation. In the second experiment the task is to model a robot arm with two degrees of freedom using a three layer feed-forward neural network where we need to determine the number of nodes in the hidden layer giving best modelling performance. This work was published in *Artificial Intelligence.*

Vitányi, Tromp, and *Gács* thoroughly investigated the so-called 'Kolmogorov's minimal sufficient statistic. Based on Kolmogorov complexity, this is an intuitively appealing absolute notion for the relation between an individual data sample and an individual model summarizing the information in the data, for example, a finite set (or probability distribution) where the data sample typically came from. The statistical theory based on such relations between individual objects can be called algorithmic statistics, in contrast to ordinary statistical theory that deals with relations between probabilistic ensembles. They give characterizations of algorithmic (a.k.a. Kolmogorov) minimal sufficient statistic for all data samples for two description modes of the model classes–in the more difficult 'explicit' mode under some constraints. They also strengthen and elaborate some earlier results by Shen on the 'Kolmogorov structure function' and 'absolutely non-stochastic objects'–objects that have no simpler algorithmic (explicit) sufficient statistic and are literally their own algorithmic (explicit) minimal sufficient statistic. This work was presented at the 'Theory of Algorithmic Information' 2000 meeting in Lille, France, at the 'Algorithmic Learning Theory' 2000 Conference in Sidney, Australia, and will be published in *IEEE Trans. Inform. Theory.*

Vitányi and N. Chater (Warwick Univ., UK) started work in cognitive psychology based on algorithmic information theory. One direction is as follows: It has been argued by Shepard that there is a robust psychological law that relates the distance between a pair of items in psychological space and the probability that they will be confused with each other. Specifically, the probability of confusion is a negative exponential function of the distance between the pair of items. In experimental contexts, distance is typically defined in terms of a multidimensional Euclidean space –but this assumption seems unlikely to hold for complex stimuli. We show that, nonetheless, the Universal Law of Generalization can be derived in the more complex setting of arbitrary stimuli, using a much more universal measure of distance. This universal distance is defined as the length of the shortest program that transforms the representations of the two items of interest into one another: the algorithmic information distance. It is universal in the sense that it minorizes every computable distance: it is the smallest computable distance. We show that the universal law of generalization holds with probability going to one–provided the confusion probabilities are computable. We also give a mathematically more appealing form of the universal law. The work was reported on the Los Alamos Archives, cs.CV/0101036, and submitted to *Journal of Mathematical Psychology.*

Vitányi served in several program committees on learning in 2000: European Conference on Machine Learning (ECML), 2001, Ninth International Conference on Intelligent Systems: Artificial Intelligence Applications for the New Millennium, Louisville, KY, USA, 2000, Organizing/Program Committee 'Workshop on Complexity and Inference' for the 'Computational Information Theory and Coding Year' (2001-2002) at DIMACS at Rutgers University. He also served as member of IFIP WG 1.2 on data-compression and 1.4 (co-chair) on computational learning.)

Grünwald and *Vitányi* are the Conference Co-chairs of the international *ACM Conference on Computational Learning Theory*, 2001, to be held in Amsterdam, organized by CWI.

Algorithms and Complexity, Advanced Systems Research – INS4.3

Distributed and Network Computing
Buhrman, Vitányi worked with A. Panconesi (Bologna) and R. Silvestri (Aquila) 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. The paper *On the importance of having an identity or, is consensus really Universal* was presented at the *Distributed Computing Conference* (DISC'00) 2000 in Toledo, Spain.

Algorithms and Complexity
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 exists 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* was presented at the *2000 STOC* conference in Portland, Oregon on May.

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 statemnt 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* which was presented at the *Computational Complexity Conference (CCC'2000)* in July in Florence.

Buhrman, together with *Fenner, Fortnow* and *Van Melkebeek* studied the complexity class NP *cap* SPARSE. They exhibit a relativized world where this class does not have complete sets. It follows immideately 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* was presented at the *17th Annual Symposium on Theoretical Aspects of Computer Science (STACS'2000)* in February Lille France.

Buhrman together with Ambainis (Berkeley), Torenvliet (UvA), Gasarch (Maryland), and Kalyanasundaram (Georgetown) worked on a variant of the direct sum conjecture in communication complexity. This conjecture if proven to be true implies new important lower bounds in circuit complexity. They considered three new variants: enumeration, elimination, and selection. Their paper 'The Communication Complexity of Enumeration, Elimination, and Selection' was presented at the Computational Complexity Conference (CCC'2000) in Florence. The paper was selected and invited for the special issue of that conference.

Buhrman together with Fortnow (NEC), Beigel (Temple), and Torenvliet (UvA) studied the computation complexity of approximations and enumerations of the Kolmogorov function. We showed that in most cases approximation of the Kolmogorov function is still hard. The paper *Enumerations of the Kolmogorov Function* has been submitted.

Buhrman and Lutz (Iowa) studied a new notion of resource bounded dimension. We showed that a natural class of problems, the local selective sets, have resource bounded dimension log of the golden ratio. A paper is forthcoming.

Buhrman was member of the program committee of ICALP'2000, and also member of the steering committee of computational complexity (CCC conference) (2nd year of a 3 year period).

Vitányi together with Jiang (UCR) and Li (UCSB) established a first nontrivial general lower bound on the average complexity of Shellsort, a well-known sorting algorithm. This is the first advance in this problem for over forty years. The result was presented at the *Theory of Algorithmic Information Meeting* in Lille (France) in June 2000, and published in *J. Assoc. Comp. Mach.* 2000.

Vitányi together with Jiang (UCR) and Li (UCSB) continued work on a half-century old problem by Heilbronn, in combinatorical ge-

ometry, concerning the largest possible area of the smallest triangle in a configuration of n points in the unit square. They established the precise expected order of magnitude, $1/n^3$, if the points are distributed uniformly at random. This answers Heilbronn's question in the expected sense. See the problem web page at `http://www.mathsoft.com/asolve/constant/hlb/hlb.html`

The technique used was the well-known 'incompressibility method', based on Kolmogorov complexity and partially due to the authors. An invited talk on this work was held at the *27th SOFSEM'2000* conference held November 25 (Saturday) – December 1, 2000, in Milovy, Czech Republic. The November 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*, Dec 23, 1999–January 5, 2000, No. 477–478); the German magazine *Die Zeit* of April 13, 2000 (#16), ran an article about this work on p. 40: 'Geometrisch Eingekreist' by Wolfgang Blum.

Tromp, Vitányi, Buhrman obtained a general upper bound on the tradeoff between time and space that suffices for the reversible simulation of irreversible computation. Previously, only simulations using exponential time or quadratic space were known. The tradeoff shows for the first time that we can simultaneously achieve subexponential time and subquadratic space. They also give the first general lower bound on the extra storage space required by general reversible simulation. This lower bound is optimal in that it is achieved by some reversible simulations. The work was reported preliminary as *quant-ph/0101133* on the Los Alamos Archives.

Vitányi, *Tromp*, and O. Watanabe (Tokyo Inst. of Technology) continued the study of certain ruin problems associated with monopoly games. This work is inspired by a neural network updating rule due to von der Malsburg. This updating rule plays a key role in explaining orientation selectivity in the brain.

Buhrman and *Fortnow* vastly simplify the proof of Andreev, Clementi and Rolim and Andreev, Clementi, Rolim and Trevisan that if there exists 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.

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 Chevalley groups and buildings of spherical type, on knot theory and related topology, and on cryptographic protocols. He proved an NP-completeness result for a combinatorial problem. Ongoing research in computer algebra, and computer topics, and Linux.

Gács analyzed a problem in probabilistic algorithmics: an open problem by Peter Winkler that had been open for some time. If one generates two infinite binary sequences with a random coin of bias p, then can you make the sequences 'complementary bitwise' by casting out 0's in both sequences. The question is if there is a positive probability of being able to do it. Peter Winkler proved that it can only be done if $p < 1/2$. Gács showed that there exists an upper bound such that for positive p below this bound there is always positive probability that the two (infinite sequences) can be made complementary by casting out 0's only in both sequences. This fundamental result was accepted for presentation in the *ACM Symposium Theory of Computation*, to be held in Crete, 2001.

Tromp assisted *Gacs* in analyzing a percolation problem where (to formulate the above problem more plastic) each of two parties at any time step either talks (with probability p), or listens (with probability $1 - p$). The question of interest is whether both parties can be delayed in such a manner that whenever one talks, the other listens. Tromp's simulations suggest that this is possible only if p is less than some critical value which is very close to 0.3.

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 behavior 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 will appear in *Parallel Processing Letters*.

Tromp continued work with *Marcel Crâşmaru* of the Tokyo Institute of Technology on the complexity of Ladders in the game of Go, establishing their PSPACE-completeness. Their paper was accepted for the *2nd International Conference on Computers and Games* in Japan. Together with Mike Robson of Bordeaux, they now investigate the complexity of Go with the superko rule, which can be considered the standard version of the game. This work was presented at *2nd International Conference on Computers and Games*, October 26–28, 2000, Hamamatsu, Japan.

Organization of Conferences, Workshops, Courses, etc.

- *Buhrman* organized the kickoff meeting of the fifth framwork project QAIP in Amsterdam the 6th and the 7th of Amsterdam.
- *Buhrman*, *Röhrig*, and *De Wolf* organized the 4th Workshop on Quantum Information Processing (QIP 2001), January 9 to January 12, 2001, in Amsterdam. There were about 150 participants, 20 invited talks, and various other scientific events.
- *Buhrman* is coordinator of the fifth framework project Quantum Algorithms and Information Processing (QAIP). This project coinsists out of 13 European and North American sites. It runs for three years and started the 3rd of Januari 2000.
- *Buhrman* was member of the program committee of ICALP'2000. The PC met in Geneva in March. The number of submitted papers was unusually high possibly due to the new format of the Program Committee.
- *Buhrman* was member of the steering committee of Annual Computational Complexity Conference (2nd year of a 3 year period).
- COLORET. European HCM project in the area of Computation, Logic and recursion theory.
- *Grünwald* is program committee member of UAI-2001, the Seventeenth Conference on Uncertainty in Artificial Intelligence.
- *Grünwald* and *Vitányi* are conference co-chairs of COLT 2001, the *Fourteenth Annual Conference on Computational Learning Theory* in Amsterdam.
- *Vitányi* is site coordinator of the EU fourth framework BRA IV NeuroCOLT II Working Group EP 27150 on fundamental understanding of learning and of when and how it can be implemented algorithmically. Vitányi is work area manager of two out of three work areas. There are 11 European institutes in the working group. (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.)
- *Vitányi* is program committee member, International Conference on Algorithms, Languages, and Programming, (ICALP), Malaga (Spain), 2002.
- *Vitányi* is program committee member, European Conference on Machine Learning (ECML), 2001.
- *Vitányi* is program committee member of: Ninth International Conference on Intelligent Systems: Artificial Intelligence Applications for the New Millennium, June 14–17, 2000, Galt House Hotel Louisville, KY USA.
- *Vitányi* is program committee member of the IFIP International Conference on Theoretical Computer Science (IFIP TCS2000) Exploring New Frontiers of Theoretical Informatics August 17–19, 2000, Tohoku University, Sendai, Japan.
- *Vitányi* is member of organizing/program committee 'Workshop on Complexity and Inference' for the 'Computational Information Theory and Coding Year' (2001–2002) at DIMACS at Rutgers University.
- *Vitányi* is 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.
- *Grünwald* and *Vitányi* organize the 2001 *Computational Learning Theory Conference* in Amsterdam.
- *Vitányi* is 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.

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

A.E. Brouwer:

- Conference on Association Schemes, Codes and Designs, July 3–7, Postech, Pohang, Korea (invited speaker).
- Conference on Finite Geometries, July 16–21, Isle of Thorns, Sussex, UK. Contributed talk.

H. Buhrman:

- January 26–30, Visit Miklos Santha and member of thesis defense committee of Magniez, LRI Paris, France.
- February 16–19, Symposium on Theoretical Aspacts of Computer Science, Lille, France.
- March 16–19, Program COmmittee meeting ICALP, Geneva, Switzerland.
- March 29 – April 2, Short Course Quantum Computing, International Center for Mathematical Sciences, Edinburgh, Scotland. Series of three 45 minute talks on quantum computing and communication complexity.
- April 28, working visit Theory group in Würzburg (Klaus Wagner), Würzburg, Germany. Talk: *Quantum Communication Complexity.*
- May 10–12, work visit Juraj Hromkovic, Aachen, Germany. Talk: *Quantum Communication Complexity.*
- May 19–26, Symposium on Theory of Computing (STOC'2000), Portland OR, USA. work visit Chris Wilson, university of Oregon Eugene, OR, USA. Talk: *Are bitvectors optimal?*
- June 19, QAIP meeting for preparation Potsdam meeting, Brussels, Belgium.
- June 30–July 3, Conference on Search and Communication Complexity, Balatonlelle, Hungary. Talk: *Quantum Communcation Complexity.*
- July 3–9, Conference on Computational Complexity (CCC'2000), Florence, Italy. Meeting steering committee of CCC.
- July 14–28, workshop on quantum computing, Benasque, Spain. Talk: *Quantum Algorithms for the Element Uniqueness Problem.*
- September 27–29, meeting for QAIP project, Potsdam, Germany. Talk: *Overview of QAIP project.*
- October 6, CWI in Bedrijf, Amsterdam, The Netherlands. Talk: *Quantum Mechanics and Computer Science: Quantum Computing.*
- November 22–December 3, Work visit Caltech John Preskill, Padadena CA, USA Talk: *Quantum Communication Complexity.*
- December 7, visit of Busquin, Euro Commissioner of research to CWI, Amsterdam, The Netherlands. Talk: *Quantum Computing.*

P. Vitányi:

- April 10–13, Rank Prize Fund Meeting on Model Selection and Learning in Computer Vision, Grasmere, Lake District, UK. Talk: *MDL Induction, Bayesianism, and Kolmogorov Complexity.*
- June 9–8, Workshop on Algorithmic Information Theory, Lille, France. Talk: *Quantum Kolmogorov Complexity.*
- July 2–7, 15th IEEE Computational Complexity Conference, Florence, Italy. Talk: *Three Approaches to the Quantitative Definition of the Information in a Pure Quantum State.*
- July 8–18, Quantum Computation and Communication Meeting, Science Center, Benasque, Spain. Talk: *Classical and Quantum Kolmogorov Complexity.*
- Augustus 24–September 2, Visit Saarbrücken University and 10 years jubilee of the International Dagstuhl Computer Science Seminar Center 'Dagstuhl Informatics—10 Years Back, 10 Years Ahead,' Talk: *The Quantum Computing Challenge.*
- November 15–December 5, Visit Charles University, Prague, and 27th annual SOFSEM, Milovy, Czech Republic. Talk: *The Incompressibility Method with Applications.*
- December 6–December 23, Visit University of New-South Wales, Sidney, Australia, and Algorithmic Learning Theory Conference, Sydney Australia. *Talk: Algorithmic Statistics.*

J. Tromp:

- Fourth Workshop on Algorithmic Information Theory (TAI'00), June 8–9, Université de Lille, France. Talk: *Algorithmic Statistics.*
- 2nd International Conference on Computers and Games, October 26–28, Hamamatsu, Japan. Talk: *Ladders are PSPACE-complete.*

P. Grünwald:

- *EURANDOM*, Eindhoven. February 24th. Talk: *The Minimum Description Length Principle.* (this was not really a 'visit' since Grünwald spends two days there each week).
- *University College London, Department of Statistics* (host: A.P. Dawid). London, UK. February 26–March 3. Talk: *The Minimum Description Length Principle.*
- *University College London, Department of Statistics* (host: A.P. Dawid). London, UK. April 4–10.

- *Mini-Symposium on Model Selection in Computer Vision*, Windermere (Lake District), UK. April 10–13. Talk: *Maximum Entropy and Minimum Description Length.*
- *Harvard University, Dept. of Theoretical Physics* (host: V. Balasubramanian). Cambridge, Massachusets, USA. May 22–27. Talk (at the Dept. of Biostatistics): *Safe Statistics.*
- *UAI-2000, COLT-2000, ICML-2000*, (the annual conferences on Uncertainty in Artificial Intelligence, Computational Learning Theory and the International Conference on Machine Learning were held jointly this year), Stanford University, Stanford, CA. June 27–July 3. Talks: (1) at the Department of Statistics, Stanford University: *Safe Statistics.* (2) at the UAI Conference: *Maximum Entropy and the Glasses You are Looking Through.*
- *Stieltjesweek* (school on advanced topics in mathematical statistics), Leiden. December 4–December 8.
- *Foundations of Statistical Inference*, Shoresh Holiday Resort, Shoresh, Israel. December 17–21. Talk: *Robust Bayes and Maximum Generalized Entropy.*

H. Klauck:

- 32nd ACM Symposium on Theory of Computing (STOC 2000), Portland, Oregon, USA, May. Talk: *On Quantum and Probabilistic Communication: Las Vegas and One-Way Protocols.*
- 27th International Colloquium on Automata, Languages, and Programming (ICALP 2000), Geneva, Switzerland, July. Talk: *Measures of Nondeterminism in Finite Automata.*
- Workshop on Boolean Functions and Applications at ICALP 2000. Talk: *Quantum Communication Complexity.*
- Oberwolfach Meeting on Complexity Theory, November. Talk: *On Rounds in Quantum Communication.*

W. van Dam

- Centre for Quantum Computation at the University of Oxford (A. Ekert), Oxford, UK, January 20–25; working visit.
- Element 2000 PAC symposium, University of Utrecht, March 2; invited speaker: *NMR Quantum Computing.*
- Computer Science Division at the University of California (U. Vazirani), Berkeley, USA, May 7–June 8; working visit.
- 32nd Annual ACM Symposium on Theory of Computing, Portland, USA, May 21–23; presentation: *Self-testing of universal and fault-tolerant sets of quantum gates.*
- Centre for Quantum Computation at the University of Oxford (A. Ekert), Oxford, UK, June 13–24. Talk: *Quantum Kolmogorov Complexity.*
- 15th Annual IEEE Conference on Computational Complexity, Florence, Italy, July 4–7; presentation: *Quantum Kolmogorov Complexity.*
- Department of Combinatorics & Optimization at the University of Waterloo (M. Mosca), Waterloo, Canada, August 20–26. Talk: *Quantum Kolmogorov Complexity.*
- Department of Mathematics of the City University of Hong Kong (M. Rojas), Hong Kong, September 16–October 2; mini-course: *Quantum Computing.*
- Computer Science Division at the University of California (U. Vazirani), Berkeley, USA, October 9–December 20; Talk: *Quantum queries to oracles in the polynomial hierarchy and beyond.*

R. de Wolf:

- STACS'2000, Lille, France, February. Talk: *Average-case quantum query complexity.*
- IEEE Computational Complexity 2000, Florence, Italy, July 7. Talk: *Characterization of non-deterministic quantum query and quantum communication complexity.*
- July–August 7, Working visit Miklos Santha, LRI Paris, France.

P. Gács:

- Invited talk, Workshop on Kolmogorov Complexity, Lille, France, April. Talk: *Quantum algorithmic entropy.*
- Invited talk, Conference on Information Theory, Balatonlele, Hungary, June. Talk: *Quantum algorithmic entropy.*
- Invited talk, Workshop on Quantum Information Theory, Bielefeld, Germany, October; Talk: *Quantum algorithmic entropy.*
- Spatial Stochastics theory seminar, CWI, September 2000. Talk:*Compatible Sequences and a Slow Winkler Percolation.*
- Statistical Physics seminar, University of Rome, November 3. Talk: *Compatible Sequences and a Slow Winkler Percolation.*

Memberships of Committees and Other Professional Activities

P.M.B. Vitányi:

- Professor of Computer Science, Universiteit van Amsterdam

- 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 Scientific Board, 'Encyclopaedia of Mathematics', Reidel (updated and annotated translation of the Soviet 'Mathematical Encyclopaedia'.), since 1987.
- Program Committee, *International Conference on Algorithms, Languages, and Programming*, (ICALP), Malaga (Spain), 2002.
- Program Committee, *European Conference on Machine Learning (ECML)*, 2001.
- Program Committee, *Ninth International Conference on Intelligent Systems: Artificial Intelligence Applications for the New Millennium*, June 14–17, 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, 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.
- 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 in 2000 of W. van Dam, R. de Wolf, H. Röhrig, R. Manniesing, University of Amsterdam.
- 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 of the Society for Theoretical Computer Science in The Netherlands (Nederlandse Vereniging voor Theoretische Informatica (NVTI)) member.
- Dutch Institute for Logic, Language, and Computation (ILLC) (member of the board).
- Dutch Institute for Programming and Algorithmics (IPA) (member).
- Onderzoeksschool Logica (OzL) (member).
- Project leader various NWO projects in Machine Learning, Multiple Computing Agents, Cryptography and Randomness, Quantum Computing.

H.M. Buhrman:

- Professor of Computer Science, University of Amsterdam, since December.
- Coordinator of fifth framework project QAIP.
- Coordinator of NWO project 'Extenting Feasible Computation: Quantum Computing'.
- Dutch Institute for Logic, Language, and Computation (ILLC) (member).
- Dutch Institute for Programming and Algorithmics (IPA) (member).
- Promotor (PhD advisor) Ronald de Wolf.
- Member of PhD committee of: Barbara Terhal, Wim van Dam, Frederic Magniez.
- Member of Steering Committee for Anual Conference on Quantum Information Processing.
- Member of the Steering Committee for the Annual Conference on Computational Complexity, since 1998.
- Member of Program committee of QIP'2000
- Member of Program committee of ICALP'2000
- Member of Program Committee of MFCS'2001

P.D. Grünwald:

- EU fourth framework BRA VI NeuroCOLT II Working Group EP 27150: on Fundamental Understanding of Learning and Algorithmic Implementations.

- P. Grünwald works part-time (0.5 fte) at EURANDOM in the Complex Statistical Models Group. EURANDOM is a European research institute for the study of stochastic phenomena, located at the campus of Eindhoven Technical University of Technology.
- ESPRIT BRA VI NeuroCOLT II Working Group EP 27150: on Fundamental Understanding of Learning and Algorithmic Implementations.
- FoLLI (The European Association for Logic, Language and Information) (member).

A.E. Brouwer:
- Promotor (PhD Advisor) of Rieuwert Blok.
- Editor of *European J. Combinatorics.*
- Editor of *J. Algebraic Combinatorics.*

L. Torenvliet: Member of the Board of the NVTI–Dutch Society for Theorical Computer Science.

Awards

H.M. Buhrman:
- NWO project: Extending Feasible Computing: Quantum Computing. Grant for 1 OIO 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 Americca. Budget: 850K Euro.

P. Vitányi:
- NWO project: Universal Learning, Grant for 1 OIO and 1 Postdoc for 4 years and 4 times 0.25 fte for visitors.

W. van Dam:
- NWO-TALENT Award to continue his research during the academic year 2000/01 at the University of California, Berkeley.

Visitors

- January 2–9, Dr. Th. Korimort, University Graz.
- January 31–February 11, Dr. Peter Høyer, BRICS, Aarhus, Denmark.
- February 13–15, Dr. Lance Fortnow, NEC research, Princeton, NJ, USA.
- February 22–23, Prof. dr. Jack Lutz, Iowa state University, Ames IA, USA.
- April 26–28, Prof. dr. Alessandro Panconesi, University of Bolonga, Bolonga, Italy.
- May 12–14, Dr. Juan Garay, Lucent Research, NJ, USA.
- May 12–14, Dr. M. Jacobsson, Lucent Research, NJ, USA.
- May 22–29, Dr. L. Lamport, Compaq Researc, Palo Alto, CA, USA.
- June 19–23, Prof. M. Szegedy, Rutgers University, USA.
- September 10–30, Prof. R. Cleve, Computer Science Dept, University of Calgary, Canada.
- September 11–December 1, Dr. J. Delgado, Universitat Politecnica de Catalunya, Barcelona, Spain.
- September 29–30, Dr. F. Gruau, Université de Monpellier, Monpellier, France.

Papers in Journals and Proceedings

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APPENDIX
SURVEY OF FTP DOWNLOADS OF CWI REPORTS

Annual downloads

Year	# of reports downloaded	Total # of hits
2000	853	149416
1999	740	64607
1998	623	38623
1997	536	28332
1996	441	19857

25 most frequently downloaded reports in 2000

# of hits	Department / cluster	Report
2341	AA	CS-R9406. *Data Mining: the search for knowledge in databases.* MARCEL HOLSHEIMER and ARNO P.J.M. SIEBES
943	AP	CS-R9567. *A survey of automated timetabling* ANDREA SCHAERF
852	AA	CS-R9429. *Architectural Support for Data Mining.* MARCEL HOLSHEIMER and MARTIN L. KERSTEN
790	AP	CS-R9611. *Tabu search techniques for large high-school timetabling problems.* ANDREA SCHAERF
680	AA	CS-R9531. *A perspective on databases and data mining.* MARCEL HOLSHEIMER, MARTIN L. KERSTEN, HEIKKI MANNILA and HANNU TOIVONEN
638	AA	CS-R9455. *Off-line cash transfer by smart dards.* STEFAN A. BRANDS
628	SEN	SEN-R9921. *Coalgebra, concurrency, and control.* J.J.M.M. RUTTEN
555	PNA	PNA-R9707. *Scheduling sport tournaments using constraint logic programming.* ANDREA SCHAERF
536	INS	INS-R9908. *Multi-relational data mining.* ARNO J. KNOBBE, H. BLOCKEEL, ARNO P.J.M. SIEBES and D.M.G. van der Wallen
486	AA	CS-R9529. *Efficient and provable security amplifications.* RONALD J.F. CRAMER and TORBEN P. PEDERSEN
469	NW	NM-R9513. *Factoring integers with large prime variations of the quadratic sieve* HENK BOENDER and HERMAN J.J. TE RIELE
465	INS	INS-R9912. *Optimizing main-memory join on modern hardware.* STEFAN MANEGOLD, PETER A. BONCZ and MARTIN L. KERSTEN
461	AA	CS-R9530. *On shared randomness and the size of secure signatures.* RONALD J.F. CRAMER
458	AA	CS-R9413. *Proofs of partial knowledge and simplified design of witness hiding protocols.* RONALD J.F. CRAMER, IVAN B. DAMGÅRD and L.A.M. SCHOENMAKERS

# of hits	Department / cluster	Report
454	SEN	SEN-R9901. *Automata, power series, and coinduction: taking input derivatives seriously.* (extended abstract) J.J.M.M. Rutten
426	NW	NM-R9511. *An implementation of the number field sieve.* R. Marije Huizing.
411	INS	INS-R9914. *Direct multifractal spectrum calculation from the wavelet transform.* Zbigniew R. Struzik
409	INS	INS-R9815. *Wavelet transform in similarity paradigm II.* Zbigniew R. Struzik and Arno P.J.M. Siebes
402	INS	INS-R9802. *Wavelet transform in similarity paradigm I.* Zbigniew R. Struzik and Arno P.J.M. Siebes
386	AP	CS-R9457. *A trying C++ experience (why compare dropped C++).* T.B. Dinesh
385	MAS	MAS-R0007. *Factorization of a 512–bit RSA modulus* S. Cavallar, Walter M. Lioen, Herman J.J. te Riele, B. Dodson, Arjen K. Lenstra, Peter L. Montgomery and B. Murphy
382	INS	INS-R9807. *A feature database for multimedia objects* Martin L. Kersten, Niels Nes and Menzo A. Windhouwer
378	INS	INS-R9902. *Indexing real-world data using semi-structured documents.* A.R. Schmidt, Menzo A. Windhouwer and Martin L. Kersten
374	AP	CS-R9652 *Universal coalgebra: a theory of systems.* J.J.M.M. Rutten
360	MAS	MAS-R9825. *Numerical time integration for air pollution models.* Jan G. Verwer, Willem H. Hundsdorfer and Joke G. Blom

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723	AP	CS-R9567. *A survey of automated timetabling.* Andrea Schaerf
662	AP	CS-R9611. *Tabu search techniques for large high-school. Timetabling problems.* Andrea Schaerf
651	AA	CS-R9531. *A perspective on databases and data mining.* Marcel Holsheimer, Martin L. Kersten, Heikki Mannila and Hannu Toivonen
546	PNA	PNA-R9810. *Multiresolution signal decomposition schemes. Part 1: Linear and morphological pyramids.* John Goutsias and Henk J.A.M. Heijmans
451	AA	CS-R9455. *Off-Line Cash Transfer by Smart Cards.* Stefan A. Brands
367	PNA	PNA-R9905. *Multiresolution signal decomposition schemes. Part 2: Morphological wavelets.* Henk J.A.M. Heijmans and John Goutsias
318	AA	CS-R9413. *Proofs of Partial Knowledge and Simplified Design of Witness Hiding Protocols.* Ronald J.F. Cramer, Ivan B. Damgård and L.A.M. Schoenmakers
300	AA	CS-R9529. *Efficient and provable security amplifications.* Ronald J.F. Cramer and Torben P. Pedersen
296	AA	CS-R9530. *Dynamic server assignment in a two-queue model.* Onno J. Boxma and Douglas G. Down
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247	PNA	PNA-R9707. *Scheduling sport tournaments using constraint logic programming.* Andrea Schaerf
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221	PNA	PNA-R9715. *Size distributions in stochastic geometry.* Marie-Colette N.M. van Lieshout
219	PNA	PNA-R9811. *Automatic phase detection in seismic data using the discrete wavelet transform.* Patrick J. Ooninckx
216	AA	CS-R9556. *(Un)decidability results for trigger design theories* A.P.J.M. Siebes, J.F.P. van den Akker, M.H. van der Voort
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189	AP	CS-R9438. *A Survey of Program Slicing Techniques.* Frank Tip
189	PNA	PNA-R9701. *Frames, Riesz systems and MRA in Hilbert spaces.* Stephanus J.L. van Eijndhoven and Patrick J. Ooninckx.
183	AA	CS-R9354. *Schema refinement and schema integration in object-oriented databases.* Chris J.E. Thieme and Arno P.J.M. Siebes
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95	AA	CS-R9323. *An Efficient Off-line Electronic Cash System Based On The Representation Problem.* Stefan A. Brands
92	AA	CS-R9555. *Secret-key certificates (Continued).* Stefan A. Brands