PREFACE

This Overview is an extensive survey of the activities performed by the scientific departments of CWI in 1996. It serves as a supplement to the CWI Annual Report 1996, which highlights the CWI research in 1996.

For each department the following items are addressed.

- Staff survey.
- Scientific Report.
- Organization of Conferences, Workshops, Courses, etc.
- Visits to Conferences, Workshops, Colloquia, etc., Working Visits.
- Memberships of Committees and Other Professional Activities.
- Visitors.
- Consultancy, contract research, and relations with industry.
- Publications (papers in journals and proceedings; CWI publications; books; other publications).
- Lectures and colloquia given.
- Other relevant activities and achievements.

DEPARTMENT OF OPERATIONS RESEARCH, STATISTICS, AND SYSTEM THEORY

Staff 1996

- Combinatorial Optimization and Algorithmics – BS1

  CWI funded

  - A.M.H. Gerards
  - H. van der Holst
  - J.K. Lenstra
  - A. Schrijver
  - A.G. Steenbeek

  Externally funded

  - T. Fleiner
  - M. Laurent

- Analysis and Control of Information Flows in Networks – BS2

  - O.J. Boxma
  - J. van den Berg
  - R.J. Boucherie
  - J.W. Cohen
  - V. Dumas
  - F.A. van der Duyn Schouten
  - A. Ermakov
  - R. Núñez Queija

- System and Control Theory – BS3

  CWI funded

  - J.M. van den Hof
  - A.A.F. Overkamp
  - A.J. van der Schaft
  - J.M. Schumacher
  - J.H. van Schuppen

  Externally funded

  - U. Başer
  - J.J.F. Fey
  - K. Karamazen
  - A.A. Stoorvogel
  - P.R. de Waal
  - K.C. Wong

- Image Analysis and Spatial Stochastics – BS4

  - K. Dzhaparidze
  - H.J.A.M. Heijmans
  - R. Helmers
  - R. van der Horst
  - M.S. Keane
  - A. Mancham
  - F.K. Potjer
  - A.G. Steenbeek
  - S.J. van Strien
  - I.W. Mangku
  - B.A.M. Schouten

- Secretary: L.M. Schultze

Combinatorial Optimization and Algorithmics – BS1

Staff

- Prof. dr. A. Schrijver, group leader
- Dr. ir. A.M.H. Gerards, senior researcher
- Prof. dr. J.K. Lenstra, senior researcher
- A.G. Steenbeek, programmer
- Dr. M. Laurent, visiting researcher (ENS Paris)
- Drs. H. van der Holst, Ph.D. student
- T. Fleiner, M.Sc., Ph.D. student

Scientific Report

GF(4)-representable matroids. At the end of 1995 J. Geelen (Australia), A.M.H. Gerards and A. Kapoor (India) characterized the GF(4)-representable matroids in terms of forbidden minors. In 1996, main drafts for the report have been prepared.

Graphs and polyhedra. Together with M. Conforti (Italy), A.M.H. Gerards studied the structure of graphs with no 'odd-K_5'. A conjecture says that the MAX CUT problem in those graphs is just a simple linear program. A preliminary report confirming that conjecture for a subclass of the class of graphs with no 'odd-K_5' (through a constructive characterization of this subclass) has been prepared. The research will be continued. With M. Conforti (Italy) and M. Burlet (Grenoble) the investigation of the stable set polytope for 'cap free graphs' has been started.

Completion problems for matrices. M. Laurent investigated questions related to completion problems for positive semidefinite and Euclidean distance matrices. In particular, she showed how some functional transformations introduced long ago by Schoenberg permit to solve the problem for Euclidean distance matrices using information about the problem for positive semidefinite matrices. She also showed how tools and techniques from combinatorial optimization provide a unified and simpler setting for these completion problems. She wrote a survey paper on these questions emphasizing the interplay between combinatorial optimization and combinatorial matrix theory. ('A tour d'horizon on positive semidefinite and Euclidean distance matrix completion problems.' In P. PARDALOS AND H. WOLKOWICZ, editors, *Topics in Semidefinite and Interior-Point Methods, The Fields Institute for Research in Mathematical Science, Communications Series.* Providence, Rhode Island, 1997 (to appear).)

Optimization over cuts. M. Laurent continued research on max-cut problem and related questions, in particular, within the framework of semidefinite programming. Moreover, she completed with M. Deza a book project on this topic ('Geometry of Cuts and Metrics', to appear as volume 15 in the series 'Algorithms and Combinatorics', Springer-Verlag) and an annotated bibliography ('Max-cut problem'. In M. Dell'Amico, F. Maffioli, and S. Martello, editors, chapter in *Annotated Bibliographies in Combinatorial Optimization*. John Wiley & Sons, 1997 (to appear).)

Cycles in binary matroids. The lattice generated by the cycles of a binary matroid has been recently much studied. In particular, Lovász and Seress found a characterization of it for the class of Eulerian matroids (containing matroids with no dual Fano minor). M. Laurent considered the question of existence of a basis for this lattice consisting only of cycles (i.e., (0,1)-vectors of the lattice). Together with W. Hochstättler and M. Loebl she showed that a basis of cycles exists for matroids with no dual Fano minor and their one-element extensions. (cf. Cycle Bases for lattices of matroids without Fano dual minor and their one-element extensions. Preprint, 1996.) It is an open question whether the result extends to Eulerian matroids.

The CdV- and related invariants.
Together with L. Lovász (Yale University), H. van der Holst and A. Schrijver extended their research on the μ-invariant for graphs designed by Y. Colin de Verdière. In particular, L. Lovász and A. Schrijver proved the conjecture of Robertson, Seymour, and Thomas on the μ-value of linklessly embedded graphs, by developing a link version of Borsuk's antipodal theorem.
H. van der Holst continued his research on minor-monotone graph invariants and completed his thesis called 'Topological and Spectral Graph Invariants', which he defended successfully at the University of Amsterdam on 24 September 1996.

Bipartite edge colouring and timetabling.
A. Schrijver sharpened and extended the new algorithm for finding a minimum edge colouring for bipartite graphs found in 1995. In particular, the running time was improved to $O((p_{\max}(k) + \log k)m)$ for bipartite graphs of maximum degree k, with m edges, where $p_{\max}(k)$ denotes the maximum prime factor of k. This applies to scheduling classes (the 'timetabling problem').

Routing, scheduling, and timetabling.
A. Schrijver and A.G. Steenbeek continued the development of new methods for two problems coming from the Dutch Railways: 1. determining the minimum railway stock necessary to run a given timetable with lower bounds on the number of seats in

each of the train-stages; 2. determining a periodic timetable, given the running and waiting times, the desired connections, and the safety distance between trains. In particular, together with R. Groot (University of Amsterdam and LCN), a new algorithm was developed to find the minimum circulation of mixed rolling stock on one line, based on CPLEX. Moreover, new tools were developed to use the insight of the planner in designing a timetable, for fixing the order of trains on lines of the network, for fixing parts of the solution, and for recognizing and using clusters of constraints.

For the Rijksuniversiteit Limburg a system was built to plan the 'stages' (practical training) for 5th and 6th year medical students, including hospital assignment.

Books

J.K. Lenstra and A. Schrijver continued their preparations on the books *Polyhedral Combinatorics* (A. Schrijver), *Scheduling* (E.L. Lawler, J.K. Lenstra, A.H.G. Rinnooy Kan, and D.B. Shmoys) and *Local search* (E.H.L. Aarts and J.K. Lenstra). M. Laurent has completed (with M. Deza) the book *Geometry of Cuts and Metrics*, to appear as volume **15** in the series *Algorithms and Combinatorics* of Springer-Verlag.

Organization of Conferences, Workshops, Courses, etc.

- 'Twenty-first Conference on the Mathematics of Operations Research/Seventh International Workshop Landelijk Netwerk Mathematische Besliskunde', Lunteren, The Netherlands, January 9–11 A.M.H. Gerards, member Organizing Committee.
- 'Twenty-Second Conference on the Mathematics of Operations Research/Seventh International Workshop Landelijk Netwerk Mathematische Besliskunde', Lunteren, The Netherlands, January 14–16, 1997.
  A.M.H. Gerards, member Organizing Committee.
- Fifth MPS Conference on Integer Programming and Combinatorial Optimization: J.K. Lenstra, member programmacomité
- 17th International Symposium on Mathematical Programming J.K. Lenstra, member International Advisory Committee, A. Schrijver, member International Advisory Committee.

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

- Workshop 'Combinatorial Optimization', Aussois, 8–12 January; M. Laurent, A. Schrijver.
- 'Twenty-first Conference on the Mathematics of Operations Research/Seventh International Workshop Landelijk Netwerk Mathematische Besliskunde', Lunteren, The Netherlands, January 9–11; A.M.H. Gerards, M. Laurent, J.K. Lenstra, A. Schrijver.
- COSOR Jubileum Symposium Technische Universiteit Eindhoven 18 January; J.K. Lenstra.
- ORBEL 10: Tenth Conference of the Belgian Operations Research Society Brussel, Belgium 18–19 January; J.K. Lenstra.
- Program Committee Meeting Fifth MPS Conference on Integer Programming and Combinatorial Optimization Atlanta, USA 26–28 January; J.K. Lenstra.
- École Polytechnique, Paris, 1 February; A. Schrijver.
- Wiskundecongres 'SMC50' CWI, Amsterdam 6–7 February; M. Laurent, J.K. Lenstra, A. Schrijver.
- Symposium 'De waarde van de wetenschap' CWI, Amsterdam 8 February; J.K. Lenstra.
- Universidad de La Laguna, Tenerife, Spain 13–18 February; J.K. Lenstra.
- Soiree 'Wiskunde & informatica: een gouden bruiloft' Amsterdam 12 March; A.M.H. Gerards, H. van der Holst, J.K. Lenstra, A. Schrijver, A. Steenbeek.
- Symposium on Combinatorial Optimization CO96 London, England 27–29 March; J.K. Lenstra.
- University of Padova (Italy) 22 April–3 May; A.M.H. Gerards.
- EIDMA Minicourse on Approximation Algorithms by David P. Williamson Technische Universiteit Eindhoven 6–10 May; J.K. Lenstra.
- Semidefinite programming and interior-point approaches for combinatorial optimization problems, Toronto, 14–17 May; M. Laurent.
- London School of Economics 13–14 May; A.M.H. Gerards.
- 'The Reading Combinatorial Days', Reading, United Kingdom, May 15–16; A.M.H. Gerards.
- 'DONET Combinatorial Optimization, third annual meeting', Prague, Czech Republic, May 18–24; A.M.H. Gerards, H. van der Holst, M. Laurent.
- AMS-Benelux Meeting on Mathematics Antwerpen, Belgium 22–24 May; J.K. Lenstra, A. Schrijver.
- Summer School on Approximation Algorithms in Combinatorial Optimization Nakenstorf, Germany 17–19 June; J.K. Lenstra.
- University of Grenoble (France) 20–24 June; A.M.H. Gerards.

- Joint 1996 National Conference of the Canadian Operational Research Society/ 14th IFORS Triennial Conference Vancouver, Canada 8–12 July; J.K. Lenstra.
- International Colloquium on Combinatorics and Graph Theory, Balatonlelle, Hungary 15–20 July; A. Schrijver.
- School of Operations Research and Industrial Engineering Cornell University, Ithaca, USA 22 July–20 August; J.K. Lenstra.
- Algorithms: International Seminar on the Teaching of Computing Science University of Newcastle upon Tyne, Newcastle upon Tyne, UK 2–6 September; J.K. Lenstra.
- Stieltjes Workshop on High Performance Optimization Techniques TUD, Delft 19–20 September; M. Laurent, J.K. Lenstra.
- University of Sao Paulo 28 September–1 October; A.M.H. Gerards.
- 'Workshop Internacional de Combinatórica', UFRJ, Rio de Janeiro, Brazil, 2–4 October; A.M.H. Gerards.
- Tagung ' Combinatorial Optimization' Oberwolfach, Germany 13–19 October; J.K. Lenstra, A. Schrijver.
- Workshop on Network Design, Budapest, from 20–25 October; T. Fleiner.
- Praktische toepassingen van de combinatorische optimalisering: Najaars-symposium van het Wiskundig Genootschap, Technische Universiteit Eindhoven 25 October; J.K. Lenstra, A. Schrijver.
- Werkbezoek Politecnico di Milano, Milaan, Italy 26 October–1 November; J.K. Lenstra.
- Meeting on Control of Search in AI Planning, Dagstuhl, Germany 18–22 November; J.K. Lenstra.
- Fachbereich 3 - Mathematik, Technische Universität Berlin, Germany 22 November; J.K. Lenstra.
- Laboratoire LAFORIA Université P. et M. Curie, Paris, France 6 December; J.K. Lenstra.

Memberships of Committees and Other Professional Activities

Ph.D. Committees

- J.P. van den Berg (Universiteit Twente): J.K. Lenstra, E. van Dam (Katholieke Universiteit Brabant, Tilburg): A. Schrijver, M. van Eupen (Technische Universiteit Eindhoven): A. Schrijver, C.A. van Eijl (Technische Universiteit Eindhoven): J.K. Lenstra, H. van der Holst (University of Amsterdam): A.M.H. Gerards, A. Schrijver, B. Jansen (Technische Universiteit Delft) J.K. Lenstra, J.J. van de Klundert (Rijksuniversiteit Limburg) J.K. Lenstra, A. Munier (Université P. et M. Curie, Parijs) J.K. Lenstra, M. Schäffter (Technische Universität Berlin) J.K. Lenstra, H.J. Vaes (Technische Universiteit Eindhoven): J.K. Lenstra, M.G.A. Verhoeven (Technische Universiteit Eindhoven): J.K. Lenstra, Wenci Yu (Technische Universiteit Eindhoven): J.K. Lenstra

Habilitation Committees

- M. Laurent (Université Paris VI, Jury Thèse d'Habilitation à Diriger des Recherches): A.M.H. Gerards.

Organizational Activities

- EIDMA – Euler Institute for Discrete Mathematics and Its Applications: A. Schrijver, member Board.
- KNAW Akademie Raad voor de Wiskunde: J.K. Lenstra, member Board A. Schrijver, member.
- Koninklijke Nederlandse Akademie van Wetenschappen: A. Schrijver, member Dept. Science.
- Landelijk Netwerk Mathematische Besliskunde: A.M.H. Gerards, J.K. Lenstra, A. Schrijver, member Governing Board.
- Mathematical Programming Society: J.K. Lenstra, vice-chairman; A. Schrijver, member Symposium Advisory Committee.
- Stichting Wiskunde Onderzoek Nederland: A. Schrijver, member Board (treasury)
- Stieltjes Instituut voor Wiskunde: A. Schrijver, member Science Council.
- Werkgemeenschap Mathematische Besliskunde en Systeemtheorie: A.M.H. Gerards, ondervoorzitter A. Schrijver, member Science Council.
- Werkgemeenschap Discrete Wiskunde: A. Schrijver, member Science Council.
- Wiskundig Genootschap: J.K. Lenstra, member Board (till May 1996)

Editorial Activities

- ACM Journal of Experimental Algorithmics, J.K. Lenstra, member Advisory Board.
- Combinatorica, A. Schrijver, editor-in-chief.
- CWI Monographs, CWI Tracts, CWI Syllabi, J.K. Lenstra, editor.
- CWI Quarterly, A.M.H. Gerards, editor.
- Discrete Applied Mathematics, A. Schrijver, editor.
- Excerpta Informatica, J.K. Lenstra, member Advisory Board.
- INFORMS Journal on Computing, J.K. Lenstra, Area Editor for Design & Analysis of Algorithms.
- International Journal of Foundations of Computer Science, J.K. Lenstra, associate editor.
- Journal of Combinatorial Optimization, A. Schrijver, advisory editor.
- Journal of Combinatorial Theory, Series B, A. Schrijver, editor.

- Journal of Combinatorics, Information and System Sciences, A. Schrijver, editor.
- Kluwer Series in Operations Research/Computer Science Interface, J.K. Lenstra, member editorial Advisory Board.
- Mathematical Programming Series B, J.K. Lenstra, Guest Editor of issues in memory of E.L. Lawler.
- Mathematics of Operations Research, J.K. Lenstra, editor-in-chief, A. Schrijver, associate editor.
- North-Holland Mathematical Library, A. Schrijver, advisory editor.
- SCIMA Special Series, J.K. Lenstra, member Advisory Board.
- SIAM Journal on Discrete Mathematics, A. Schrijver, editor.
- SIAM Journal on Optimization, A. Schrijver, editor.
- Wiley/Interscience Series in Discrete Mathematics and Optimization, J.K. Lenstra, advisory editor.

Visitors

- Y. Colin de Verdière (Université Grenoble).
- L. Lovász (Yale University and Budapest).
- F.B. Shepherd (London School of Economics).

Miscellaneous (Consultancy, contract research, and relations with industry)

External orders:
- Timetable development Nederlandse Spoorwegen/Railned.
- Stageplanning medical students Rijksuniversiteit Limburg.

Graduate courses:
- Combinatorial Optimization, Combinatorial Algorithms and Graph Theory 1, EIDMA, January–March: A.M.H. Gerards, J.K. Lenstra, A. Schrijver.
- ECMI Course in Combinatorial Optimization, Göteborg, June 6–9: J.K. Lenstra.
- Combinatorial Optimization 1, Landelijk Netwerk Mathematische Besliskunde, November–December: A.M.H. Gerards.
- Matroid Decomposition, IASI, Roma, Italy, May 8–19: A.M.H. Gerards.

Papers in Journals and Proceedings

K.I. AARDAL, C.A.J. HURKENS, J.K. LENSTRA, S.R. TIOURINE (1996). Algorithms for frequency assignment problems. *CWI Quarterly* **9**, 1–8.

J.K. LENSTRA, M. VELDHORST, B. VELTMAN (1996). The complexity of scheduling trees with communication delays. *Journal of Algorithms* **20**, 157–173.

J.A. HOOGEVEEN, J.K. LENSTRA, B. VELTMAN (1996). Preemptive scheduling in a two-stage multiprocessor flow shop is NP-hard. *European Journal of Operational Research* **89**, 172–175.

J.H.M. KORST, E.H.L. AARTS, J.K. LENSTRA (1996). Scheduling periodic tasks. *INFORMS Journal on Computing* **8**, 428–435.

M. LAURENT (1996). Delaunay transformations of Delaunay polytopes. *Journal of Algebraic Combinatorics* **5**, 37–46.

M. LAURENT (1996). Hilbert bases of cuts. *Discrete Mathematics* **150**, 257–279.

M. LAURENT (1996). Graphic vertices of the metric polytope. *Discrete Mathematics* **151**, 131–153.

M. LAURENT AND S. POLJAK (1996). On the facial structure of the set of correlation matrices. *SIAM Journal on Matrix Analysis and Applications* **17**, 530–547.

M. LAURENT AND S. POLJAK (1996). Gap inequalities for the cut polytope. *European Journal of Combinatorics*, 17: 233–254.

R.J.M. VAESSENS, E.H.L. AARTS, J.K. LENSTRA (1996). Job shop scheduling by local search. *INFORMS Journal on Computing* **8**, 302–317.

Other Publications

A.M.H. GERARDS, F.B. SHEPHERD (1996). *The graphs with all subgraphs t-perfect*, Centre for Discrete and Applicable Mathematics, London School of Economics and Political Science, Research Report LSE-CDAM-96-09.

A.M.H. GERARDS, M. CONFORTI (1996). *A class of weakly bipartite graphs* (preliminary report).

W. HOCHSTÄTTLER, M. LAURENT, M. LOEBL (1996). *Cycle bases for lattices of matroids without Fano dual minor and their one-element extensions*. Preprint.

Analysis and Control of Information Flows in Networks – BS2

Staff

- Prof. dr. ir. O.J. Boxma, department head and group leader
- Dr. J. van den Berg, researcher
- Dr. R.J. Boucherie, postdoc, KNAW (0.2)
- Prof. dr. ir. J.W. Cohen, advisor
- Dr. V. Dumas, postdoc, INRIA/France; since October 1

- Prof. dr. F.A. van der Duyn Schouten, researcher (0.2 appointment), KUB
- Mr. A. Ermakov, Ph.D. student (OIO), NWO
- Mr. R. Núñez Queija, Ph.D. student (OIO)

Note 1: Only those activities, publications etc. of R.J. Boucherie (0.2 appointment), J.W. Cohen (advisor), V. Dumas, and F.A. van der Duyn Schouten (0.2 appointment) have been mentioned, that have a direct relation with BS2.

Note 2: the positions of R.J. Boucherie, V. Dumas and A. Ermakov are externally funded.

Scientific Report

BS2.1. Analysis of mathematical queueing models (Boucherie, Boxma, Cohen)

Complex variable techniques. In report BS-R9602, J.W. Cohen has compared the so-called compensation approach and an analytical approach for the symmetrical shortest queueing system. He has related the steps in the iterative algorithm of the compensation approach to the successive determination of the poles and their residues in the analytical approach. In BS-R9605 Cohen analyzes a nearest-neighbour random walk in the first quadrant, with transitions in the directions NE, SE, SW and NW. The compensation approach is not applicable to such a random walk. Cohen calculates the distribution of the first hitting point with the axes. In BS-R9612 the distribution of another 2-dimensional random walk in the first quadrant is determined. This random walk concerns the so-called asymmetric 2×2 clocked buffered switch. This switch had previously been analyzed via the compensation approach.

Negative customers and the Wiener-Hopf technique. Boucherie and Boxma have analyzed the workload process in an M/G/1 queue in which stochastic amounts of work are removed at random points in time. The key to their solution is a transformation of the M/G/1 queue with work removal into a GI/G/1 queue *without* work removal. In a second study they have, jointly with K. Sigman, used this transformation idea to (i) explain the occurrence of a Pollaczek-Khintchine form in the queue with work removal (that was derived by Jain and Sigman), and (ii) obtain new results for risk processes. The first study has been published in 1996, and the second one has been accepted for publication. Related research has concerned queues with removal of *customers*. This has led to three papers concerning Wiener-Hopf methods in one-dimensional random walks; these have all been published in 1996.

BS2.2. Stochastic processes on networks (Van den Berg, Ermakov)

Cellular automata. Van den Berg and Ermakov, motivated by a problem of stabilisation of a cellular automaton introduced by Coffman, Courtois, Gilbert and Piret, have refined a technique (due to Kesten) for the analysis of finitely dependent percolation systems. It is based on bounding crossing probabilities of annuli by crossing probabilities of rectangular blocks, and yields sharper lower bounds on percolation threshold (in terms of block crossing probabilities), than the alternative approach of J.T. Chayes and L. Chayes. The advantage of our approach increases with the dimension of the model. A short paper about this study has been submitted for publication (J. VAN DEN BERG AND A. ERMAKOV, *On a distributed clustering process of Coffman, Courtois, Gilbert and Piret*).

A symmetry problem. Van den Berg and Ermakov have continued the study of a problem (posed several years ago by P.W. Kasteleyn) of percolation on reflection symmetric graphs. By conditioning on appropriate events, this led to an intuitively appealing combinatorial conjecture. This conjecture could be proved for a restricted class of graphs, but for general graphs the problem remains still open.

Coalescing random walks in vacuum. Ermakov became interested in a system of coalescing random walks, in which each particle may change the direction of movement only at the times of collisions with other particles. Somewhat surprising results, in particular the independence and identical distribution of the intervals between collisions of a particle, were established, and the particle density and other relevant quantities were computed for any given time, both for the discrete and the continuous case. The relation between the density of particles in such a system and the return time for a simple random walk is basically the same as for the system of coalescing simple random walks, though the reasons for this relation are quite different in these cases (and not completely intuitively explained). A paper with these results is in preparation.

Dynamic Boolean Models. Van den Berg, Meester (Utrecht) and White (Utrecht), have completed a study on Dynamic Boolean models. A paper has been submitted for publication (J. VAN DEN BERG, R. MEESTER AND D. WHITE, *Dynamic Boolean models*).

Coalescing (simple) random walks. Van den Berg and Kesten (Cornell) have studied several problems concerning the asymptotics (as time goes to infinity) of coalescing simple random walks on a (hyper)cubic

lattice. This led, for sufficiently high dimensions, to better bounds for the particle density. Kesten has more recently obtained other new results by similar techniques (a combination of differential inequalities, coupling arguments and correlation-like inequalities). The hope is to make the method suitable for lower dimensions, and for models with more complicated interactions or more types of particles (like reaction-diffusion systems).

Epidemics. Van den Berg's cooperation with Grimmett (Cambridge) and Schinazi (Colorado Springs) has led to a paper on exponential decay results for locally dependent random graphs, with applications to spatial epidemics (J. VAN DEN BERG, G.R. GRIMMETT AND R. SCHINAZI, *Exponential decay results for locally dependent random graphs and applications to spatial epidemics*).

Disjoint occurrences of events. Van den Berg has continued his study of Reimer's proof (this year Reimer obtained a Polya prize for his proof). In particular, Van den Berg tries to obtain similar results for 'sampling without replacement'. The idea is to construct proper maps with the independent case. This led to complicated combinatorial-geometric problems. A. Steenbeek has tried to find a proper construction by computer search. Some partial progress has been made, and the search is going on.

BS2.3. Reliability and availability of networks
(Boxma, Van der Duyn Schouten)

Maintenance policies for multicomponent systems. The study of preventive maintenance policies for multicomponent systems has been continued. In collaboration with Nederland-Haarlem attention has been given to the specific aspects of these policies applied to the replacement of light bulbs in traffic control systems.
A review paper has been written on the interval availability analysis of failure prone systems.

Coordination of maintenance and production. In cooperation with Shell Research the study of the system effectiveness of a multi component production line with only one buffer at the output-end has been continued. Special attention has been given to the improvement of basic approximations to compute system effectiveness.

BS2.4. Performance analysis and control of computer and communication networks
(Boucherie, Boxma, Dumas, Núñez Queija)

ABR. Boxma and Núñez Queija have studied performance issues of ABR (Available Bit Rate) traffic in ATM networks by means of a 2-dimensional Markov chain. Specifically the problem of varying available capacity for ABR traffic has been addressed. This study resulted in report BS-R9613, in which the steady-state probabilities are determined using matrix-geometric and spectral-expansion arguments. Núñez Queija has further investigated possible extensions of the model in order to capture other important features of ABR. These extensions and some new insights are currently being processed into an article. Núñez Queija has also become interested in fluid flow models as an alternative approach to the problem and will study this possibility in the near future.

Polling systems. D. Down has examined the stability of a very broad class of polling models. This class includes polling models with multiple servers. His approach, which provides simple and intuitive proofs of stability, is based on the consideration of associated fluid limit models. A polling study of Boxma and Down (which will be published in 1997) has led to a question regarding Rouché's theorem in complex function theory; a paper of Cohen and Down on the latter subject has been accepted for publication.

Fluid queues. Recent measurements in high-speed communication networks have revealed that often traffic conditions occur that exhibit long-range dependence and burstiness over a wide range of time scales. It turns out that such phenomena can be modeled with a fluid queue fed by on/off sources with heavy-tailed on-period distributions. In two studies, Boxma has assumed that one or more sources have a regularly varying on-period distribution. Under these conditions, he has obtained the buffer content distribution, and he has shown that its tail is also regularly varying. Some further papers are in preparation, including an invited survey of Boxma and Dumas.
Cohen has studied an ordinary M/G/1 queue with heavy-tailed service time distribution. He has proposed a particular class of regularly varying service time distributions with the attractive feature that the Laplace-Stieltjes transform can be determined explicitly. This LST is being used to derive a series development of the waiting time distribution and to give a detailed heavy-traffic analysis. In a second study, Cohen has related this M/G/1 queue to a fluid queue fed by an infinite number of identical on/off sources; their on-period distribution is the service time distribution of the M/G/1 queue. The behaviour of both queues is shown to be very similar.

Organization of Conferences, Workshops, Courses, etc.

- SMC50 (CWI, February 6,7; Boxma was chairman of the organization and program committees).
- CWI National Queueing Seminar (CWI, April 12 and November 1; organized by Boxma).
- Workshop IFIP Working Group 7.3 (Lausanne, October 11–12; organized by Boxma jointly with F. Baccelli).

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

- *21st Conference on the Mathematics of Operations Research*, Lunteren, January 9–11: Van den Berg, Boucherie, Boxma, Cohen, Núñez Queija.
- *Working visit Statistical Laboratory*, Cambridge, January 22–25: Van den Berg (lecture).
- *SMC 50 Conference*, Amsterdam, February 6–7: all members of BS2; lecture by J. van den Berg.
- *CWI National Queueing Seminar*, Amsterdam, April 12: all members of BS2.
- *Working visit to Technion*, Haifa, April 15–23: J.W. Cohen (lecture).
- *Symposium on Mathematical Models of Inventories*, Aarhus, May 29–30 : F.A. van der Duyn Schouten (invited lecture).
- *COST 242 Workshop*, Paris, June 4–5: Boxma (invited lecture), Núñez Queija.
- *LNMB Workshop*, Amsterdam, June 19–21: Núñez Queija.
- *14th Triennial Conference of IFORS*, Vancouver, July 8-12: F.A. van der Duyn Schouten (lecture).
- *26th Summer school on Probability Theory*, Saint-Flour, August 19–September 4: Ermakov (lecture).
- *Workshop Probabilistic methods in discrete mathematics*, DIMACS, Rutgers University, October 14–18: Van den Berg.
- *Performance '96*, Lausanne, October 7–11: Boxma (lecture), Núñez Queija.
- *WG7.3 Workshop*, Lausanne, October 11,12: Boxma, Núñez Queija (lecture).
- *Philips Natlab*, Eindhoven, October 30: Boxma (lecture).
- *CWI National Queueing Seminar*, Amsterdam, November 1: all members of BS2; lecture by Dumas.
- *Lunteren Stochastics conference*, November 11–13: Van den Berg, Boxma, Cohen, Ermakov.
- *Working visit Math. Institute*, Budapest, November 20–27: Van den Berg (lecture).
- *Meeting in honour of P. W. Kasteleyn*, Leiden, December 16: Van den Berg (lecture), Ermakov.
- *PAAP (Probabilistic Algorithms and Algorithmic Probability)*: several workshops attended by Van den Berg, Boxma and Ermakov.
- *Spatial Stochastics Seminar, CWI*, weekly: Van den Berg, Boxma, Ermakov (lecture).
- *Mark Kac Seminar*, monthly: Van den Berg, Ermakov.
- *Dynamical Systems Seminar, CWI and UvA*: occasionally attended by Van den Berg and Ermakov.
- *Stochastics Seminar UU*, occasionally attended by Van den Berg (lecture) and Ermakov.
- *Stochastics Seminar TUD*, occasionally attended by Van den Berg (lecture) and Ermakov.
- *AIO Courses in Stochastics*, attended by Ermakov (spring 1996).
- *Courses LNMB*, attended by Núñez Queija.
- *Internal BS Departmental seminar*, Amsterdam, regular: all members of BS, lectures by Boucherie and Núñez Queija.
- *Internal BS2 colloquium* Amsterdam, regular: all members of BS2 (attendance and lecture).

Memberships of Committees and Other Professional Activities

O.J. Boxma:

- Professor of Operations Research, Tilburg University.
- editor of the journals Markov Processes and Related Fields; Mathematics of Operations Research; Performance Evaluation; Queueing Systems.
- Member of IFIP Working Group 7.3.
- Member of the Committee for Conferences on Stochastic Processes of the Bernoulli Society for Mathematical Statistics and Probability.
- Member of the program committee of Performance '96 (Lausanne, October 1996).
- Member of the program committee of the Int. Conf. on Distributed Computer Communication Networks (Tel-Aviv, November 1996).
- Member of the program committee of the 9th Int. Conf. on Modelling Techniques and Tools for Computer Performance Evaluation (St Malo, June 1997).
- Chairman of the mathematics conference 'SMC50' (Amsterdam, February 6–7, 1996).
- Ph.D. advisor of W.B. van den Hout (*The power-series algorithm – a numerical approach to Markov processes*, Tilburg University, March 27).
- Member of the Ph.D. committee of M.J.A. van Eenige (TUE, September 17).
- Member of the Ph.D. committee of F.N. Gouweleeuw (VU, November 28).

- Member of the Ph.D. committee of E. van Bracht (TUD, December 20).
- Project leader NFI project 'Performance analysis and control of distributed computer systems'.
- Project leader SWON project 'Regular variation in broadband ISDN'.
- Member of several CWI committees (WBG, IR, jubilee committee, restructuring committee).

J.W. Cohen:

- Member of the advisory board of Telecommunication Systems.
- Honorary member of the IAC of ITC.
- member of the program committee of the ITC congresses and seminars.

F.A. van der Duyn Schouten:

- Member of the Ph.D. committee of R. Wildeman (EUR, October 10).
- Member of the Ph.D. committee of F.N. Gouweleeuw (VU, November 28).

Visitors

- P. Major (Budapest), January 15–19.
- N.D. Vvedenskaya (IPIT, Moscow), May 21.
- K. Sigman (Columbia Univ., New York), June 4–11 and June 24.
- H. Kesten (Cornell), July 17–August 20.
- B. Toth (Budapest), September 9–13.
- A. Gandolfi (Rome), September 9–13.
- S.C. Borst (Lucent), September 10–11.
- M.A. Pollatschek (Technion, Haifa), September 16–17.
- B. Tsybakov (IPIT, Moscow), November 18.

Miscellaneous

Consultancy:

- Baltzer Publ. Cy. (Boxma, Núñez Queija).
- Boxma has taught a course on queueing theory for LNMB (graduate network on the mathematics of operations research).
- Boxma participates in the INTAS project 'Limit theorems for stochastic discrete event systems'; the grant has recently been renewed.
- A SWON proposal of Boxma has been accepted.
- Boxma has been involved in proposals for two TTI's (Technologische TopInstituten): *Logistics and transportation* and *Telematics*. A decision is expected in the Spring of 1997.

Papers in Journals and Proceedings

N. BAYER (1996). On the identification of Wiener-Hopf factors. *Queueing Systems* **23**, 293–300.

N. BAYER, O.J. BOXMA (1996). Wiener-Hopf analysis of an M/G/1 queue with negative customers and of a related class of random walks. *Queueing Systems* **23**, 301–316.

J. VAN DEN BERG, A. ERMAKOV (1996). A new lower bound for the critical probability of site percolation on the square lattice. *Random Structures and Algorithms* **8**, 199–212.

J. VAN DEN BERG (1996). A note on disjoint-occurrence inequalities for marked Poisson point processes. *J. Appl. Probab.* **33**, 420–426.

R.J. BOUCHERIE, O.J. BOXMA (1996). The workload in the M/G/1 queue with work removal. *Prob. Eng. Inf. Sci.* **10**, 261–277.

O.J. BOXMA (1996). Fluid queues and regular variation. *Performance Evaluation* **27 & 28**, 699–712.

O.J. BOXMA, V.I. LOTOV (1996). On a class of one-dimensional random walks. *Markov Processes and Related Fields* **2**, 349–362.

O.J. BOXMA, R. NÚÑEZ QUEIJA (1996). Preface to author and subject indexes, volumes 1–21. *Queueing Systems* **24**, 177–178; author index:, 179–212; subject index:, 213–309.

J.W. COHEN, D.G. DOWN (1996). On the role of Rouché theorem in queueing analysis. *Queueing systems* **23**, 281–291.

F.A. VAN DER DUYN SCHOUTEN (1996). Maintenance policies for multi component systems: an overview. S. ÖZEKICI (ed.). *Reliability and Maintenance of Complex Systems (NATO ASI Series, vol. 154)*, Springer, Berlin, 117–136.

B. POURBABAI, J.P.C. BLANC, F.A. VAN DER DUYN SCHOUTEN (1996). Optimizing flow rates in a queueing network with side constraints. *European Journal of Operational Research* **88**(3), 586–591.

CWI Reports

BS-R9602. J.W. COHEN. *On the symmetrical shortest queue and the compensation approach.*

BS-R9605. D.G. DOWN. *On the stability of polling models with multiple servers.*

BS-R9609. R.J. BOUCHERIE, O.J. BOXMA, K. SIGMAN. *A note on negative customers, GI/G/1 workload, and risk processes.*

BS-R9612. J.W. COHEN. *On the asymmetric clocked buffered switch.*

BS-R9613. R. NÚÑEZ QUEIJA, O.J. BOXMA. *Analysis of a multi-server queueing model of ABR.*

BS-R9614. O.J. BOXMA. *Regular variation in a multi-source fluid queue.*

BS-R9615. J.W. COHEN. *On a zero-drift nearest-neighbour random walk.*

Other Publications

J. VAN DEN BERG, R. MEESTER, D. WHITE. *Dynamic Boolean models*, Report 979–Math. Institute, UU.

O.J. BOXMA (1996). Queueing Theory. *Images of SMC Research 1996*, W.A.M. ASPERS AND H.M. NIELAND (eds.). SMC, Amsterdam, 221–231.

System and Control Theory (BS3)

Staff

- Dr. ir. J.H. van Schuppen (Group leader and senior researcher.)
- Dr. U. Başer (On leave from Department of Mathematics, Istanbul Technical University. From February 1, 1996, till August 1, 1996.)
- Ir. J.J.H. Fey (Master level student (TWAIO). Funded by Eindhoven University of Technology. From December 1, 1995 till April 1, 1996.)
- Drs. J.M. van den Hof (Doctoral student (OIO); till September 1, 1996.)
- Drs. K. Karamazen (Doctoral student (OIO); funded by SWON; since August 1, 1996.)
- Ir. A.A.F. Overkamp (Doctoral student (OIO); till July 1, 1996.)
- Dr. A.J. van der Schaft (Senior researcher. Part time 0.1. CWI funded.)
- Prof. dr. J.M. Schumacher (Senior researcher. Also, part time 0.2, Professor at Tilburg University.)
- Dr. A.A. Stoorvogel (Senior researcher. Part time 0.1 till June 30, 1996. Funded by KNAW through a fellowship and in part by CWI.)
- Dr. ir. P.R. de Waal (Post-doc. Till March 1, 1996. Funded by NWO through an NFI project.)
- Dr. K.C. Wong (Post-doc. Funded by an ERCIM fellowship. Till June 1, 1996.)

External Funding and International Cooperation

National projects:

- Project NFI 62-354 *Performance analysis and control of distributed computer systems*. Financed by the Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO) through the Nationale Faciliteit Informatica (NFI).
- Groot Project *Mathematical modelling of open dynamical systems*. Financed by NWO/SMC. Approved in 1995.

Projects funded by the European Commission:

- DACCORD (TR 1017) financially supported by the Telematics Applications Programme – Sector Transport, 1996–1998.

Scientific Report

J.H. van Schuppen. Van Schuppen carried out research on control of hybrid systems. The model used, a hybrid control system, is based on the hybrid automaton model of J. Sifakis, R. Alur, and coworkers. A control synthesis procedure has been formulated and sufficient conditions for controllability derived.

J.H. van Schuppen and A.A. Stoorvogel. Stoorvogel and Van Schuppen investigated approximation problems in terms of the divergence criterion both for Gaussian random variables and for stationary Gaussian processes.

J.H. van Schuppen. As part of the project DACCORD research was carried out on routing control and on integrated control of motorway networks. The project DACCORD (TR 1017) aims at developing control measures for motorway networks and testing these at test sites near Amsterdam, Paris, and Venice. The project involves 21 partners and is financially supported by the European Commission through the Telematics Applications Program – Sector Transport.

J.H. van Schuppen, A.A.F. Overkamp, P.R. de Waal. At the request of the Nederlandse Spoorwegen N.V., the national railway company, a model and control problems were investigated for control of railway traffic. The problem was to determine the optimal departure orders of trains from stations.

J.J.H. Fey, J.H. van Schuppen, K.C. Wong. Many industrial systems have continuous-time and discrete-event behaviour. To model, control, and simulate these systems, a hybrid process-algebra called χ is under development at the University of Eindhoven. In this four month project, control and verification of hybrid systems was studied using χ. Two industrial hybrid systems, a conveyor system and a biochemical plant for the production of ethanol, were used as examples.

J.M. van den Hof. The approximation problem for positive linear systems was studied. The approximation problem is to select a compartmental system in a specified class such that the external behaviour of this system fits the given data as well as possible, according to a criterion. To solve this problem, also a positive linear observer for linear compartmental systems was derived. A positive linear observer is a linear observer which provides a positive approximation of the state.

Van den Hof completed her thesis on system theory and system identification of compartmental systems. In this thesis the steps of a procedure for system identification have been followed, such as selection of the model class, experimentation, realization and parametrization, selection, and evaluation. A large part of the thesis concerns the realization problem of positive linear systems.

A.A.F. Overkamp. Overkamp completed his thesis on supervisory control motivated by layered network architectures. In this thesis he describes a supervisory control framework for nondeterministic systems based on failure semantics. Also a modeling approach is suggested that simplifies the supervisory control problem for partial observations. His work on the characterization of maximal solutions for the decentralized supervisory control problem in terms of Nash equilibria is included in the thesis. A paper on the latter topic was presented at the Workshop on Discrete Event Systems 1996 in Edinburgh.

P.R. de Waal. A paper was completed and submitted on team problems in discrete spaces. The problem is motivated by decentralized stochastic control of communication networks.

K.C. Wong. Wong and Van Schuppen studied a problem in the design of communication channels in decentralized supervisory control of discrete-event systems. A paper was presented at the Workshop on Discrete Event Systems 1996 in Edinburgh.

J.M. Schumacher, A.J. van der Schaft. Van der Schaft and Schumacher continued their joint work on the modeling of hybrid systems based on a complementarity principle. A first paper on this subject appeared in *Mathematics of Control, Signals, and Systems* and a second manuscript was completed and submitted to *IEEE Transactions on Automatic Control*. The work by Van der Schaft and Schumacher on hybrid systems forms part of an NWO-sponsored 'Groot Project' entitled 'Mathematical modeling of open dynamical systems'. This project, which involves cooperation between CWI and the universities of Groningen and Twente, received approval in 1995. All three PhD positions available within the project were filled in August 1996. Related research on hybrid systems takes place in a TUE/KUB project entitled 'Dynamics under inequality constraints', which is co-supervised by Schumacher together with P.P.J. van den Bosch (TUE / Dept. of EE). Late in 1996 visa problems were solved for a third PhD student to take part in the work on hybrid systems using the complementarity formulation.

J.M. Schumacher, U. Başer. Schumacher cooperated with U. Başer, who visited CWI from February until August 1996. Dr. Başer was supported by the Turkish national science organization TUBITAK. Two manuscripts are in preparation on topics concerning the description of impulsive-smooth behavior such as occurs in multimodal systems.

J.M. Schumacher. During the summer of 1996, Schumacher was asked by CWI management to start up CWI activities in the area of Financial Mathematics. This resulted in a study group on this topic which met five times in the fall semester and drew attendances of ten to twenty, from CWI as well as from other institutes. In cooperation with A. Bagchi (University of Twente), Schumacher prepared a proposal to the Mathematics Section (SWON) of the national science organization NWO to make 1997 a Special Year on the Mathematics of Finance. This proposal received a positive response.

Schumacher completed the work on an edited volume entitled 'System Dynamics in Economic and Financial Models', to be published by Wiley. The volume, whose other editors are C. Heij (EUR), B. Hanzon (VU), and C. Praagman (RUG), is a spin-off of a workshop held in Oegstgeest in May/June 1995 that was co-organized by the editors. The volume will appear in 1997.

K. Karamazen. Karamazen started work as 'oio' at CWI on August 1, 1996. He followed courses in the graduate program of the research school DISC and at the Department of Electrical Engineering, University of Twente.

Organization of Conferences, Workshops, Courses, etc.

- *15th Benelux Meeting on Systems and Control,* Mierlo, March 6–8, 1996. Main organizers: J.M. Schumacher, S. Weiland (TUE).
- *16th Benelux Meeting on Systems and Control,* Houffalize, Belgium, March 5-7, 1997. J.M. Schumacher is member of the Organizing Committee and Dutch contact person.

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

- Working visit to Universität Würzburg, Department of Mathematics, January 18–20, J.M. Schumacher. Lecture *Complementary-slackness modeling of hybrid systems*.
- Jour Fixe, Center for Economic Research, Tilburg University, January 23. J.M. Schumacher.
- Working visit to Rijksuniversiteit Limburg, Maastricht, January 25. J.M. van den Hof and J.H. van Schuppen. Lecture by J.H. van Schuppen, *System identification with information theoretic*

criteria. Lecture by J.M. van den Hof, *Structural identifiability from input-output observations of linear compartmental systems*.

- Lecture by A.J. van der Schaft during working visit to Lund Institute of Technology, Department of Automatic Control, Lund, Sweden, January 25. Lecture *The complementary-slackness class of hybrid systems*.
- Symposium SMC50, CWI, Amsterdam, February 6 and 7. J.M. van den Hof, A.A.F. Overkamp, A.J. van der Schaft, J.M. Schumacher, J.H. van Schuppen, P.R. de Waal, K.C. Wong. J.H. van Schuppen acted as chairman of a session.
- Jubilee Symposium 'De waarde van wetenschap' ('The value of science'), February 8. J.H. van Schuppen.
- Meeting of project DACCORD, at Hague Consulting Group, The Hague, February 12. J.H. van Schuppen.
- Mathematical Finance seminar, Tinbergen Institute, February 23, and later meetings (monthly). J.M. Schumacher.
- Working visit to the Agricultural University of Wageningen, Wageningen, February 29. J.M. van den Hof and J.H. van Schuppen. Discussions with Prof. G. van Straten and members of his group on problems of modeling and control for environmental studies.
- *15-th Benelux Meeting on Systems and Control*, Mierlo, The Netherlands, March 6–8. U. Başer, J.J. Fey, J.M. van den Hof, A. Overkamp, A.J. van der Schaft, J.M. Schumacher, and K.C. Wong. Lecture by J.M. van den Hof *Realization of positive linear systems*. Lecture by A. Overkamp *Remodeling of the supervisory control problem with partial observations*. Lecture by K.C. Wong *Conflict resolution in modular control of discrete-event systems*. Lecture by U. Başer *Almost diagonalization by dynamic output feedback with internal stability*. Lecture by A.J. van der Schaft *Hybrid systems described by complementary-slackness conditions*.
- Modeling Day, University of Groningen, March 19. Lectures by A.J. van der Schaft and J.M. Schumacher.
- Colloquium of Department BS, CWI, Amsterdam, April 4. Lecture by J.M. van den Hof, *Realization of positive linear systems*.
- Meeting of project DACCORD, The Hague, April 5. Lecture by J.H. van Schuppen, *Coordinated control for dynamic traffic management*.
- SMC/AE Symposium on Informatics, Amsterdam, April 11–12. A.A.F. Overkamp, J.H. van Schuppen, K.C. Wong.
- Lecture by K.C. Wong at the Departmental Colloquium of the Department BS of CWI, May 2, *Decentralized supervision of discrete-event systems with communication*.
- Working visit to the Department of Mathematics and Computer Science of the Vrije Universiteit in Amsterdam on May 9. J.M. van den Hof and J.H. van Schuppen. Lecture by J.H. van Schuppen *Positive linear algebra motivated by control and system theory*. Lecture by J.M. van den Hof *Realization of positive linear systems*.
- Mathematical finance seminar, Tinbergen Institute, Amsterdam, May 31. J.H. van Schuppen. Lecture *Introduction to stochastic control for mathematical finance*.
- Working visit to Rijksinstituut voor Volksgezondheid en Milieubeheer (National Institute for Public Health and Environmental Protection), Bilthoven, June 3. J.M. van den Hof and J.H. van Schuppen. Discussion with Dr. P.H.M. Janssen, Dr. P.S.C. Heuberger, and Dr. W. Slob.
- Participation in the ESA International Workshop on Advanced Mathematical Methods in the Dynamics of Flexible Bodies, ESA-ESTEC, Noordwijk, The Netherlands, June 3–5. J.M. Schumacher. Lecture *Some modeling aspects of unilaterally constrained dynamics*.
- Summer School Applications of modern nonlinear control theory, Zeist, June 5–6. J.H. van Schuppen.
- International Symposium MTNS96, St. Louis, MO, U.S.A., June 24–28. J.M. van den Hof and J.H. van Schuppen. Lecture by J.M. van den Hof titled *Minimality of realizations of positive linear systems*. Lecture by J.H. van Schuppen titled *Positive linear algebra for realization of positive linear systems*. Lecture by J.H. van Schuppen titled *Risk-sensitivity of stochastic control problems*. On the program was another lecture by J.M. van den Hof, J.H. van Schuppen, and G. Picci that was presented by the last mentioned person. J.H. van Schuppen chaired three sessions one of which was a special topics session. He also participated in the meeting of the Steering Committee of the International Symposia MTNS.
- Symposium on Analysis and Operator Theory, Vrije Universiteit, Amsterdam, July 19. J.H. van Schuppen.
- International Workshop on Discrete Event Systems (WODES96), August 19–21, Edinburgh, Scotland. A. Overkamp, J.H. van Schuppen. Lecture by A.

Overkamp titled *A characterization of maximal solutions for decentralized discrete event control systems*. Lecture by J.H. van Schuppen titled *Decentralized supervisory control of discrete event systems with communication*. J.H.van Sschuppen was Chairman of a plenary session.

- ERCIM Workshop Systems and Control, August 26 and 27, Prague, Czech Republic. J.M. Schumacher, J.H. van Schuppen. Lecture by J.M. Schumacher titled *The complementary-slackness class of hybrid systems*. Opening lecture by J.H. van Schuppen titled *Control of hybrid systems – An introduction*. J.H. van Schuppen was chairman at the meeting of the Steering Committee of the ERCIM Working Group Control and System Theory.
- DISC System Theory Day, University of Groningen, September 12. J.M. van den Hof. Lecture by J.M. van den Hof *Realization of positive linear systems*.
- Lecture by A.J. van der Schaft during Workshop HCM-project NACO, Grenoble, France, September 17. Lecture *Physical hybrid systems*.
- 1996 ERNSI Workshop System Identification, September 23–25, Cambridge, United Kingdom. J.H. van Schuppen. He was chair of a session and chair of the council of team leaders. Lecture *Approximation of Gaussian measures*.
- Meeting of DACCORD project, The Hague, October 3 and 4. J.H. van Schuppen. Lecture.
- Working visit to the University of Notre Dame, Department of Mathematics and Department of Electrical Engineering, October 9–11, J.M. Schumacher. Lecture *Hybrid dynamics and complementarity problems*.
- Working visit to Prof. S.K. Mitter, M.I.T., October 11. J.H. van Schuppen.
- Workshop Hybrid Systems 4, Ithaca, New York, U.S.A., October 12–14. J.M. Schumacher, A.J. van der Schaft, J.H. van Schuppen. Lecture by J.H. van Schuppen *Control synthesis for hybrid systems*. Lecture by J.M. Schumacher *The complementarity formalism for hybrid systems*.
- Working visit to the Department of Electrical Engineering and Computer Science, University of Michigan at Ann Arbor, MI, U.S.A., October 15–17. J.H. van Schuppen. Lecture on October 16 *Decentralized supervisory control with communication*. Lecture on October 17 *Control synthesis for hybrid systems*.
- Lecture by A.J. van der Schaft at the Department of Electrical Engineering, Delft University of Technology, October 30, *Hybrid systems described by the complementarity formalism*.
- Working visit to the Mechanical Engineering Department, Delft University of Technology, November 15. J.H. van Schuppen. Lecture *Control of hybrid systems*.
- Working visit to the University of Leuven, Belgium, November 22, J.M. Schumacher.
- Invited lecture by J.M. Schumacher at the meeting of the Social Sciences and Economics Section of VVS (Dutch Statistical Association), Utrecht, December 4. *Causality of systems*.
- Lecture by J.M. Schumacher at University of Twente, December 6. *Basics of option pricing.*
- Working visit to the University of Twente, Enschede, December 17. J.H. van Schuppen. Discussion with Prof. J. van Amerongen.
- Participation in the meeting NWO Groot Project Wiskundige modellering van open dynamisch systemen, University of Twente, Enschede, December 20. K. Karamazen, A.J. van der Schaft, J.M. Schumacher, J.H. van Schuppen.

Memberships of Committees and Other Professional Activities

J.H. van Schuppen:

Editorial work

- Co-Editor of the journal *Mathematics of Control, Signals, and Systems* since 1994.
- Department Editor of *Journal of Discrete Event Dynamic Systems* since 1990.
- Editor of special issue of *CWI Quarterly 9* (1996), number 3 (Sep.) on control and system theory.

Doctoral thesis committees

- Thesis committee Dr. Xiaode Yu, Delft University of Technology, April 25.
- Thesis committee Dr. ir. N.W.A. Arends, Eindhoven University of Technology, June 17.
- Thesis committee Dr. Dott. D. Brigo, Vrije Universiteit, October 29, as formal thesis advisor.
- Thesis committee Dr. ir. A.A.F. Overkamp, University of Groningen, November 8, as thesis advisor.
- Thesis committee Dr. J.M. van den Hof, University of Groningen, November 8, as thesis advisor.

Organizational and administrative tasks

- Coordinator of the project *System identification* that is financed by the European Commission through the Human Capital and Mobility Program, 1993–1996.
- Chairman of the Steering Committee of the ERCIM Working Group Control and System Theory, since November 1995.

Conference organization

- Member of the Steering Committee, of the International Symposia on the Mathematical Theory of Networks and Systems since 1989.

- Member of the EUCA Administrative Council till May 1996 (EUCA = European Community Control Association).
- Member of the Program Committee of the 3rd Workshop on Discrete Event Systems (WODES96).
- Member of IFAC Technical Committee on Modeling, Identification, and Signal Processing since 1994. (IFAC = International Federation of Automatic Control). Since 1994.
- Member of IFAC Technical Committee on Stochastic Systems since 1994.
- Member of the Program Committee of the Workshop on Real-Time and Hybrid Systems to be held in March 1997 at Grenoble, France. Reviewed papers.
- Member of the International Program Committee of the 1999 European Control Conference, since December 1996.

Membership in research institute and graduate school

- Dutch Institute of Systems and Control (DISC), since September 1995.

J.M. Schumacher:

Outside appointments

- Professor of Mathematics (0.2), Tilburg University, since 1987

Editorial work

- Associate editor, Systems & Control Letters
- Managing editor, CWI Tracts and Syllabi Series

Organizational and administrative work

- Member of the Management Team of the Dutch Institute of Systems and Control (DISC)

Program committees

- Benelux Meeting on Systems and Control 1996, Mierlo
- Benelux Meeting on Systems and Control 1997, Houffalize
- Hybrid Systems '97, University of Notre Dame

Doctoral thesis committees

- Ph.D. committee C. Simões, Twente University, April 12
- Ph.D. committee M.M.A. de Rijcke, Eindhoven University of Technology, September 30
- Ph.D. committee D. Brigo, Vrije Universiteit, October 29
- Ph.D. advisory committee F. Kraffer, Department of Applied Mathematics, Twente University

Membership of research schools

- Dutch Institute of Systems and Control (DISC).
- Center for Economic Research (CentER).

Visitors

- Prof. R. Ober, University of Texas, Dallas, Texas, U.S.A., January 8. Lecture *Infinite-dimensional system theory - Balanced realizations – Symmetric systems*.
- Prof. O. Maler, Verimag, Grenoble, France, April 23 and 24. Lecture *Synthesis of discrete controllers for timed systems* and *Decidability and undecidability of hybrid systems*.
- Dott. D. Brigo, IRISA, Rennes, France, May 16–June 21. Lecture *Diffusion processes, manifolds of exponential densities, and nonlinear filtering*.
- Prof. G. di Masi, University of Padova, Padova, Italy, October 28–29. Lecture *Discrete-time Bayesian adaptive control over an infinite horizon*.
- Prof. R.K. Boel, University of Ghent, Ghent, Belgium, November 7–8. Lecture on November 7 *Controlled Petri nets and control of discrete event systems*.
- Dr. A. Puri, University of California, Berkeley, CA, U.S.A., November 11–12. Lecture on November 12 *Design and verification of hybrid systems*.

Doctoral degrees

- Dr. Dott. D. Brigo, *Filtering by projection on the manifold of exponential densities.* Vrije Universiteit, October 29. J.H. van Schuppen thesis advisor, with Prof. A.H.Q.M. Merkies and Dr. B. Hanzon.
- Dr.ir. A.A.F. Overkamp, *Discrete event control motivated by layered network architectures*. University of Groningen, November 8. J.H. van Schuppen thesis advisor.
- Dr. J.M. van den Hof, *System theory and system identification of compartmental systems*. University of Groningen, November 8. J.H. van Schuppen thesis advisor.

Miscellaneous (Research for the national railway company on railway traffic control)

Werkgroep Systeemtheorie (Seminar Systems and Control)

- The purpose of the Werkgroep Systeemtheorie is to study new developments of system and control theory. The doctoral students of the research group and the senior staff members are the main beneficiaries of this activity. A small number of participants from universities in The Netherlands partici-

pate in the study group. At the meetings part of a book or papers are presented by one of the participants.

The following topics were covered:

- *Hybrid systems*. Ten meetings in the spring of 1996. There were about 10 to 15 participants both from control theory and from computer science. Organizer J.H. van Schuppen.
- *Study group Mathematics of Finance*. Five meeting in the fall semester of 1996. Organizer J.M. Schumacher.

Doctoral students taking courses

- K. Karamazen followed the courses *Mathematical models of systems* and *Design methods for control systems* in the graduate program of DISC, as well as a course on physical systems modeling at the Department of Electrical Engineering, University of Twente.

Theses and books

- D. Brigo, *Filtering by projection on the manifold of exponential densities*. Ph.D. thesis.
- J.M. van den Hof, *System theory and system identification of compartmental systems*. Ph.D. thesis.
- A.A.F. Overkamp, *Discrete event control motivated by layered network architectures*. Ph.D. thesis.
- S.A. Smulders, *Control of freeway traffic flow*, CWI Tract, Volume 80, CWI, Amsterdam.

Papers in Journals and Proceedings

A.H.W. GEERTS, J.M. SCHUMACHER (1996). Impulsive-smooth behavior in multimode systems. Part I: State-space and polynomial representations. *Automatica* **32**, 747–758.

A.H.W. GEERTS, J.M. SCHUMACHER (1996). Impulsive-smooth behavior in multimode systems. Part II: Minimality and equivalence. *Automatica* **32**, 819–832.

G.M. KOOLE (1996). Stochastic control with partial observations and no recall. *Proceeding 35th Conference on Decision and Control*, IEEE Press, New York, 1773–1774.

A. OVERKAMP, J.H. VAN SCHUPPEN (1996). A characterization of maximal solutions for decentralized discrete event control problems. In *International Workshop on Discrete Event Systems (WODES96)*, IEE, London, 278–283.

J. ROSENTHAL, J.M. SCHUMACHER, E.V. YORK (1996). The behavior of convolutional codes. *IEEE Trans. Inform. Th.* IT-42, 1881–1891.

A.J. VAN DER SCHAFT, J.M. SCHUMACHER (1996). The complementary-slackness class of hybrid systems. *Math. Contr. Sign. Syst.***9**, 266–301.

J.H. VAN SCHUPPEN (1996). Introduction to the special issue on control and system theory. *CWI Quarterly* **9**, 161–164.

A.A. STOORVOGEL, J.H. VAN SCHUPPEN (1996). System identification with information theoretic criteria. S. BITTANTI, G. PICCI (eds.). *Identification, adaptation, learning*, Springer-Verlag, Berlin, 289–338.

K.C. WONG, J.H. VAN SCHUPPEN (1996). Decentralized supervisory control of discrete-event systems with communication. *International Workshop on Discrete Event Systems (WODES96)*, IEE, London 1996, 284–289.

CWI Reports

BS-R9601. G. KOOLE. *A transformation method for stochastic control problems with partial observations*.

BS-R9607. M.S. RAVI, J. ROSENTHAL, J.M. SCHUMACHER. *Homogeneous behaviors*.

BS-R9611. A.J. VAN DER SCHAFT, J.M. SCHUMACHER. *Complementarity modeling of hybrid systems*.

BS-R9616. A.A. STOORVOGEL, J.H. VAN SCHUPPEN. *Approximation problems with the divergence criterion for Gaussian variables and processes*.

BS-R9606. K.C. WONG, J.H. VAN SCHUPPEN. *Decentralized supervisory control of discrete-event systems with communication*.

BS-N9601. J.J.H. FEY. *Control and verification of industrial hybrid systems using models specified with the formalism* χ.

Other Publications

J.M. SCHUMACHER (1996). review of: B. van Keulen, *H_∞-control for distributed parameter systems: a state-space approach*. *Mededelingen Wiskundig Genootschap 39*, 206–207.

Image Analysis and Spatial Stochastics (BS4)

Staff

- K. Dzhaparidze, senior researcher
- H.J.A.M. Heijmans, senior researcher
- R. Helmers, senior researcher
- R. van der Horst, programmer (0.5 fte)
- M.S. Keane, group leader (0.8 fte)
- A. Mancham, Ph.D. student (NWO, until August 1)

- F.K. Potjer, Ph.D. student (until October 1)
- A.G. Steenbeek, programmer (0.5 fte)
- S.J. van Strien, advisor (UvA, until April 1)
- I.W. Mangku, Ph.D. student (Indonesian cooperation, from August 1)
- B.A.M. Schouten, Ph.D. student (NWO, from February 1)

Scientific Report

In 1996, research highlights in BS4 included the following items:

- A six-month visit to BS4 by Dr. A. Tuzikov, Minsk.
- A four-month visit to BS4 by Professor Paul Shields, an internationally acclaimed expert in information theory and dynamical systems
- Departure of two of our graduate students for positions elsewhere (one at CBS and one outside mathematics)
- Departure of our advisor van Strien, who accepted a professorship at Warwich University in England
- Commencement of work for our two new Ph.D. students Mangku and Schouten.

The following details form a summary of the individual activities and collaborations in 1996.

The research of K. Dzhaparidze was carried out in 3 different directions. Most of the attention was devoted to general principles of statistical inference for stochastic processes. Dzhaparidze, Spreij (VU, Amsterdam) and Valkeila (Helsinki) completed a contribution to the Liptser Volume. A preprint appeared as a report of the University of Helsinki. In this paper basic notions such as Hellinger integrals and Hellinger processes were extended from usual binary experiments to abstract parametric families of experiments. This offered the possibility for asymptotic treatment of abstract statistical experiments: in the forthcoming paper the same authors study the basic LAN property of such experiments.

The work carried out in the recent years on Gelfond's modification of the Abel-Goncharov interpolation series was continued and results were obtained which enlarge considerably the convergence class of functions. A paper by Dzhaparidze on this subject is under preparation.

Dzhaparidze was involved in organizing a special issue of *CWI Quarterly* devoted to Mathematical Finance. He has revised his lecture notes of the course on the *Option Theory* given at the University of Nijmegen. Part I of these notes was accepted to the special issue mentioned above. The consecutive Part II and Part III will be submitted to the same journal.

The effort of H.J.A.M. Heijmans and I.S. Molchanov to put mathematical morphology in the framework of convolution lattices has resulted in a report; in 1997 it will appear in the *Journal of Mathematical Imaging and Vision*. The collaboration of Heijmans with C. Ronse (Université Louis Pasteur, Strasbourg) on the design of so-called annular filters has resulted in two technical reports which have both been submitted for publication.

In the literature, one finds two concepts for expressing the similarity of shapes: distance functions measuring assimilarity, and similarity measures expressing how similar two shapes are. Similarity measures can be used to compute 'how symmetric a given shape is', e.g. with respect to reflection in a given line. For many objects, presence or absence of symmetry is a major feature, and therefore the problem of object symmetry identification is of great interest in image analysis and recognition, computer vision and computational geometry. H.J.A.M. Heijmans and A. Tuzikov have developed a new approach towards the construction of similarity and symmetry measures for convex shapes which are invariant under various transformation groups such as rotations, affine transformations, etc. Their approach is based on Minkowski addition and the Brunn-Minkowski inequality. A first report on this work has appeared; in this report attention is restricted to the 2-dim case. Currently, they are trying to extend their results to the 3-dim case.

There exists increasing interest in the development of tools that consider images at different scales of resolution. In this respect pyramidal image structures are of particular interest. A well-known instance of such a structure is the wavelet transform, but there exist others, such as the Gaussian pyramid. In collaboration with Prof. J. Goutsias (Johns Hopkins University, Baltimore), H.J.A.M. Heijmans is investigating pyramid structures based on morphological operators. Ultimately, this should lead towards the construction of a kind of 'morphological wavelet transform'.

A grey-scale image partitions the underlying space into regions where the grey-level is constant, the so-called flat zones. Such operators can delete edges, but they cannot change them, neither their shape nor their location. As a result, connected operators are well-suited for many imaging tasks, such as segmentation, filtering, and coding. The aim of this project is to develop a consistent mathematical theory for connected operators, and to investigate their implementation using a tailor-made graph structure. First

steps towards this goal were made by H.J.A.M. Heijmans and F.K. Potjer (the latter left CWI on October 1). Two or three papers are in preparation.

The research of R. Helmers in the general area of bootstrap resampling schemes was continued. Earlier work on bootstrapping the local time of the empirical process (CWI report BS-R9422) and on strong laws for generalized L-statistics with dependent data (CWI report BS-R9436, joint with D. Gilat (Tel Aviv)) was – in slightly revised form – accepted for publication by *Statistics and Decisions* and *Commentationes Mathematicae Universitates Carolinae* respectively. Both papers will appear early in 1997. The paper with M.H. Wegkamp (Leiden; currently Yale) on wild bootstrapping in finite populations with auxiliary information (CWI report BS-9520) was tentatively accepted by the *Scandinavian Journal of Statistics*. Further, joint research with A.J. van Es (Amsterdam) and M. Hušková (Prague), on various resampling plans for elementary symmetric polynomials was completed. The resulting paper was submitted for publication to a journal. The cooperation with M. Hušková (Prague) was continued during a working visit of R. Helmers to Prague. Problems involving the estimation of change-points and uses of bootstrap resampling were discussed. Joint work with H. Putter (Amsterdam) on a quantile problem in nonparametric regression was almost completed. A report will appear in 1997.

In cooperation with Helmers, I.W. Mangku has started – after a five month training period January/June – his Ph.D. research on August 1 with the study of statistical estimation problems for inhomogeneous spatial Poisson processes. Some preliminary results were obtained.

Keane completed an article together with R.D. Gill (Utrecht) on quantum measurement, and continued his work with T. Hamachi (Fukuoka) on noncommunicative Bernoulli schemes. The article on random coin tossing with M.D. Harris (Delft) has been accepted for publication in Probability Theory and Related Fields. Further, Keane's article with Bulinski (Moscow) on random fields was published. Collaboration with Hewlett-Packard Laboratories in Bristol was continued, Keane has spent a month there. The departure of Mancham retarded the project on stochastic lung models. Basic work in ergodic theory with Keane's student Serafin (dissertation in March 1996 in Delft) is almost ready for publication.

Organization of Conferences, Workshops, Courses, etc.

- Seminar on *Mathematical Finance* at the Tinbergen Institute, Amsterdam. Organized monthly by Dzhaparidze and Spreij.
- Seminar *Spatial Stochastic*: A weekly seminar on mathematical aspects of image analysis, stochastic geometry, and spatial statistics. Tuesdays.
- Seminar *Dynamics in Amsterdam*: A weekly seminar on dynamical systems and ergodic theory. Thursdays.
- Workshop *Design Methodologies for Signal Processing* with Special Session on *Pan-European Cooperation and Technology Transfer*, Zakopane, Poland, August 28–30, H.J.A.M. Heijmans (Programme Chair).
- Lunteren Conference on Stochastics, November 11–13. Organized by R. Helmers (joint with J.Th. Runnenburg (Amsterdam), W.R. van Zwet (Leiden)).
- Workshop Ergodic Theory, Churanov, Czechia, 3–10 February 1996. Organized by M.S. Keane and D. Volny (Prague).
- Image Tech Workshop, Atlanta, 16–19 March, Keane was member of advisory board.

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

- Workshop on *Statistical Inference for Stochastic Processes*, Sanbjerg, Denmark, 29 April–3 May (lecture by K. Dzhaparidze)
- Conference on *Mathematical Finance*, Humboldt University, Berlin, October 2–4, K. Dzhaparidze.
- Invited lecture at the 'Mathematics Seminar' of the Philips Research Laboratory, March 15, H.J.A.M. Heijmans.
- Working visit to *Silesian Technical University*, Gliwice, Poland, March 20–27, H.J.A.M. Heijmans (4 lectures: 2 for undergraduates, 1 for Ph.D. students, 1 for scientific staff).
- Working visit to *Johns Hopkins University*, Baltimore, USA, May 8–11, H.J.A.M. Heijmans.
- Symposium *Mathematical Morphology and its Applications to Image and Signal Processing – ISMM'96*, Atlanta, USA, May 11–13, H.J.A.M. Heijmans (1 invited lecture, 1 contributed lecture), F.K. Potjer (lecture).
- Seminar *Connected Operators*, Barcelona, June 14–16, H.J.A.M. Heijmans (invited lecture).
- *Algemeen CWI Colloquium*, October 8, H.J.A.M. Heijmans.
- Workshop *Design Methodologies for Signal Processing* with Special Session on *Pan-European Cooperation and Technology Transfer*, Zakopane, Poland, August 28–30, H.J.A.M. Heijmans.

- Summer School *Wavelets and Signal Processing* Zakopane, Poland, September 1–3, H.J.A.M. Heijmans.
- Statistics Seminar, University of Groningen, January 25: Invited lecture by R. Helmers.
- Environmental Statistics and Earth Science, Satellite Meeting on the 4th World Congress of the Bernoulli Society, Brno, Czech Republic, August 20–25, Lecture by R. Helmers.
- 4th World Congress of the Bernoulli Society for Statistics and Probability, Vienna, Austria, August 26–31, Lecture by R. Helmers.
- Working visit (+ invited lecture), Charles University, Prague, Czech Republic, November 25–December 5, R.Helmers
- Lunteren conference on Stochastics, November 11–13: K. Dzhaparidze, R. Helmers, M. Keane, I.W. Mangku.
- Courses AIO Network Stochastics (biweekly), attended by I.W. Mangku.
- Bristol, UK, 26 February – 8 March, and 10–22 October, working visits to Hewlett-Packard Laboratories by M. Keane.
- Corvallis, Oregon 20–24 March, working visit to Oregon State University by M. Keane.
- Budapest, Hungary, 15–26 April, working visit to Hungarian Academy of Science by M. Keane.
- Wierzba, Poland, 29 May – 2 June, conference on the occasion of Professor Ryll-Nordzewski's 70th birthday, invited lecture by M. Keane.
- Berlin, Germany, 25–30 August, Conference on Ergodic Theory, invited lecture by M. Keane.
- Groningen, 24 September, lecture in staff colloquium by M. Keane.
- Dublin, Ireland, 2–5 November, Public Lecture at Trinity College Dublin, delivered by M. Keane.
- Billund, Denmark, 8–9 November, invited lecture by M. Keane.
- New Dehli, India, 7–20 December, working visit to Indian Statistical Institute by M. Keane.

Memberships of Committees and Other Professional Activities

K. Dzhaparidze:
- Member of the research network in pursuance of the Human Capital Programme, EC project 'Statistical inference for stochastic processes'.

H.J.A.M. Heijmans:
- Member of editorial board, Journal of Mathematical Imaging and Vision.
- Editor of electronic newsletter *Morphology Digest.*
- Participant of the COPERNICUS (1994) project *BENEFIT Concerted Action for Stimulation of East-West Collaborations in the Areas of Microelectronics and Signal Processing*.
- Member of programme committee Symposium *Mathematical Morphology and its Applications to Image and Signal Processing - ISMM'96*, Atlanta, USA, May 11–13.
- Programme chair of Workshop *Design Methodologies for Signal Processing*, Zakopane, Poland, August 28–30.
- Member of programme committee Summer School on *Wavelets and Signal Processing*, Zakopane, Poland, September 1–3.

R. Helmers:
- Advisor Coopers & Lybrand, Amsterdam.
- Member organizing committee 'Lunteren conference on Stochastics'.
- Participation in cooperation project 'Applied Mathematics and Computational Methods' (1995–1999) between The Netherlands and Indonesia.
- Member of the A-team, CWI.
- Member steering committee Statistical Auditing of the Limperg Institute.
- Ph.D. committee, M.H. Wegkamp, Leiden University, June 26.

M.S. Keane:
- Head of Probability project, Stieltjes Research School.
- Member of Governing Board, Mathematical Research Institute (Research School).
- Regular Member of the Royal Netherlands Academy of Arts and Sciences.
- Editorial Boards: Indagationes Mathematicae, CWI Tracts, CWI Syllabi, Dynamics and Stability of Systems, Journal of Probability and Mathematical Statistics.
- Member Akademieraad voor de Wiskunde.
- Thesis advisor, Jacek Serafin, 12 March 1996 (TU Delft).
- Thesis committee, Fabien Durand, 29 November 1996, Marseille, Président de Jury.
- Thesis committee, Igor Serov, 3 December 1996, TU Delft.

Visitors

- A. Tuzikov, Academy of Sciences, Minsk, Belarus, December 1995–September 1996.
- B. Toth, Budapest, 20 May–20 June 1996.
- T. Hamachi, Fukuoka, July–August 1996.
- P. Shields, Toledo, September–December 1996.
- E. Valkeila, (Helsinki), December 1996.
- R.K. Sembiring (Bandung), December 1996.

- Visiting lecturers in the seminar Dynamics in Amsterdam: D. Estep (Atlanta); O. Diekmann (Utrecht); M. Konstatin (Atlanta); D. Sattinger (Minneapolis); T. Schmidt (Corvallis); E. Coven (Middletown); L. Dingjun (Nanjing); F. Ruymgaart (Lubbock); D. Szasz (Budapest); R. Nussbaum (New Brunswick); J.-P. Thouvenot (Paris); M. Nie (Amsterdam); P.C. Shields (Toledo); R. McLachlan (New Zealand); B. Lemmens (Amsterdam); T. Hill (Atlanta); J. Geronimo (Atlanta).
- Visiting lecturers in the Spatial Stochastics Seminar: Perez (Rennes), D. Maslen (Utrecht), R.L. Karandikar (New Delhi), J.S. Geronimo (Georgia Institute of Technology), M.A. Lifshits (St-Petersburg), A. Tuzikov (Minsk, Belarus), A. Gandolfi (Rome), B. Toth (Budapest), Richard Gill (UU), Kathrin Berkner (University of Bremen), Makoto Maejima (Keio University, Yokohama), Aernout van Enter (Inst. Theoretische Fysica, RUG), Thierry Van Effelterre (CAN / RIACA), Peter Major (Mathematical Institute of the Hungarian Academy of Sciences), Robert Burton (TUD), Remco van der Hofstad (UU), Ted Hill (VUA), A.S.Gajrat (RUL), Hermann Thorisson (Reykjavik), Olle Haggstrom (UU), Paul C. Shields (Toledo), M.H. Wegkamp (RUL), D. Brigo (IRISA/INRIA).

Miscellaneous (Consultancy, knowledge transfer, etc.)

- BBC mediabestedingen: A realisability study on 'Automatic detection of commercials in radio broadcasts' has been carried out. (H.J.A.M. Heijmans and B.A.M. Schouten).
- RWS. The consultation project for the North Sea Directorate, Ministry of Transport and Public Works, was continued. The problem is to estimate the intensity of oil pollution in the North Sea. Normal and bootstrap based confidence limits for the total amount of oil pollution in a given period of time were obtained and applied to the real data sets supplied by RWS. The extensive calculations needed to obtain our results were performed by R. van der Horst. This project will be continued in 1997.
- Coopers–Lybrand: Research concerning inference on rare errors is being carried out as part of an ongoing consultation project (R. Helmers, R. van der Horst).
- Lecture on Fractal Image Locking, CWI in Bedrijf, by M. Keane, October 4.

Papers in Journals and Proceedings

K. DZHAPARIDZE, P. SPREIJ (1996). On optimality of regular projective estimators for semimartingale models III: one step improvements. *Stochastics and Stochastics Reports* **56**, 63–74.

H.J.A.M. HEIJMANS (1996). Self-dual morphological operators and filters. *Journal of Mathematical Imaging and Vision* **6**, 15–36.

H.J.A.M. HEIJMANS (1996). Morphological filters for dummies. P. MARAGOS, R.W. SCHAFER, M.A. BUTT (eds). *Mathematical Morphology and its Applications to Image and Signal Processing*, Kluwer Academic Publishers, 127–137.

H.J.A.M. HEIJMANS, P.K. GHOSH (1996). Metric convexity in the context of mathematical morphology. P. MARAGOS, R.W. SCHAFER, M.A. BUTT (eds). *Mathematical Morphology and its Applications to Image and Signal Processing*, Kluwer Academic Publishers, 7–14.

A. TUZIKOV, G.L. MARGOLIN, H.J.A.M. HEIJMANS (1996). Efficient computation of a reflection symmetry measure. *Proceedings ICPR'96, vol. B*, 236–240.

C. RONSE, H.J.A.M. HEIJMANS (1996). The algebraic basis of mathematical morphology. Part II: openings and closings. T. SZOPLIK (ed). *Morphological image processing: principles and optoelectonic implementations*, SPIE, 178–201.

F.K. POTJER (1996). Region adjacency graphs and connected morphological operators. P. MARAGOS, R.W. SCHAFER, M.A. BUTT (eds). *Mathematical Morphology and its Applications to Image and Signal Processing*, Kluwer Academic Publishers, 111–118.

R. HELMERS (1996). Bootstrap Resampling, *Images of SMC Research 1996*, 245–254.

R. HELMERS, H. PUTTER (1996). Bootstrap resampling: a survey of recent research in The Netherlands. *Proceedings of the SEAMS Regional Conference on Mathematical Analysis and Statistics, 20–36*, Yogyakarta, Indonesia, July 10–13, 1995 (invited paper).

A. MANCHAM, I.S. MOLCHANOV (1996). Stochastic model of randomly perturbed images and related estimation problems. *Proceedings in Image Fusion and Shape Variability Techniques International conference* held in Leeds, UK, 3–5 July 1996, 44–49.

R.D. GILL, M.S. KEANE (1996). A geometric

proof of the Kochen-Specker no-go theorem. *J. Phys. A:Math. Gen* **29**, L289–L291.

A.V. BULINSKI, M.S. KEANE (1996). Invariance principle for associated random fields. *Journal of Mathematical Sciences* **81**(5), 2905–2911.

M.S. KEANE (1996). Ergodic Theory. *Images of SMC Research*, Stichting Mathematisch, 89–96.

T. FUJITA, S. ITO, M. KEANE, M. OHTSUKI (1996). On almost everywhere convergence of the modified Jacobi-Perron algorithm; a corrected proof. *Ergodic Theory and Dynamical Systems* **16**, 1345–1352.

CWI Reports

BS-R9604. H.J.A.M. HEIJMANS, C. RONSE. *Annular filters for binary images*

BS-R9610. H.J.A.M. HEIJMANS, A. TUZIKOV *Similarity and symmetry measures for convex sets based on Minkowski addition*

Other Publications

K. DZHAPARIDZE, P. SPREIJ, E. VALKEILA (1996). *On Hellinger Processes for Parametric Families of Experiments*, Preprint 115, Report of the University of Helsinki, submitted for publication to the *Liptser Volume*.

K. DZHAPARIDZE, M. VAN ZUIJLEN (1996). *Introduction to option pricing in a securities market I: binary models*, to appear in CWI Quarterly 9(4).

H.J.A.M. HEIJMANS (1996). Morphological image processing. *Images of SMC Research*, Stichting Mathematisch Centrum, 255–264.

C. RONSE, H.J.A.M. HEIJMANS (1996). A lattice-theoretical framework for annular filters in morphological image processing. *LSIIT report ERII-RR96/19*, Université Louis Pasteur, Strassbourg.

A.J. VAN ES, R. HELMERS, M. HUŠKOVÁ (1996). *On a crossroad of resampling plans: Bootstrapping elementary symmetric polynomials*, 15 p., submitted for publication.

R. HELMERS (1996). *Spatial Poisson processes and oil pollution in the North Sea*, consultation report for North Sea Department, Ministry of Transport and Public Works, 35p.

M. HARRIS, M. KEANE (1996). *Random Coin Tossing*, Report 95–33, Faculteit TWI, Delft University of Technology.

DEPARTMENT OF NUMERICAL MATHEMATICS

Staff 1996

- Discretization of Evolution Problems – NW1
  - J.G. Verwer
  - P.J. van der Houwen
  - J.G. Blom
  - W. Hundsdorfer
  - B.P. Sommeijer
  - M. van Loon
  - E.J. Spee
  - J.J.B. de Swart
  - W.A. van der Veen
  - J. Kok
  - W.M. Lioen
  - P.M. de Zeeuw
- Boundary Value Problems, Multigrid and Defect Correction – NW2
  - P.W. Hemker
  - B. Koren
  - W.J.H. Stortelder
  - Ir. J. Noordmans
- Large-Scale Computing – NW3
  - H.J.J. te Riele
  - H.A. van der Vorst
  - J. Kok
  - W.M. Lioen
  - M. Nool
  - D.T. Winter
  - H. Boender
  - R.-M. Elkenbracht-Huizing
  - A. van der Ploeg
- Secretary: S. Panka-van der Wolff

Discretization of Evolution Problems – NW1

Staff

- Dr. J.G. Verwer, group leader
- Prof. dr. P.J. van der Houwen, researcher, head of department
- Drs. J.G. Blom, researcher
- Dr. W. Hundsdorfer, researcher
- Dr. B.P. Sommeijer, researcher
- Dr. ir. M. van Loon, postdoc
- Drs. E.J. Spee, junior researcher (OIO)
- Drs. J.J.B. de Swart, junior researcher (OIO)
- Drs. ir. W.A. van der Veen, junior researcher (OIO)
- Drs. J. Kok, project member, detached from NW3
- Drs. W.M. Lioen, project member, detached from NW3
- Drs. P.M. de Zeeuw, project member, detached from NW2

Scientific Report

In 1996 research was organized through four main projects:

Equations of fluid mechanics and related topics. This HCM project started in 1994 and was finished end of 1996. In 1996 the available budget has been used mainly for working and conference visits and for the International Workshop 'Innovative Time Integrators', held at CWI from Oct. 30–Nov. 1. This meeting was organized jointly with the University of Valladolid (Prof. J.M. Sanz-Serna). Thirty-four invited lectures were presented. A full account can be found in the CWI Report NM-N9602.

Algorithms for transport equations arising in pollution studies and studies on sediment transport in shallow seas and rivers. Belongs to CWI's research program 'Mathematics and the Environment').

Within the HPCN project for Environmental Applications, a fully implicit time integration method has been constructed for the numerical solution of a coupled transport-chemistry model in 3D. A comparison with a previously developed split method reveals that both stability and accuracy are improved. Within this class of implicit methods we considered two candidates which are both unconditionally stable: the second-order BDF method and the third-order Radau method. The implicit relations are solved by an iteration process in which the 'Approximate Factorization' technique has been employed to reduce the amount of work per iteration. It turns out that 2 (BDF) to 3 (Radau) iterations are sufficient to solve the underlying implicit relation. To further enhance the computational speed both methods have been extended by a Domain Decomposition (DD) technique. First tests show that the number of iterations is only slightly increased in the BDF approach by adding more subdomains, whereas the Radau method turns out to be more sensitive. Implementations on the CRAY C90 and the NEC SX4 demonstrate that the methods show good vector performance. Using several vector processors to cope with the DD approach results in almost linear speed-up.

Parallel IVP algorithms. This project deals with parallel Runge-Kutta and other block methods for ordinary differential equations. The major activity is concentrated in an STW project for the design of parallel algorithms for solving circuit analysis and control engineering problems. One of the main topics this year was the incorporation of a parallel iterative linear system solver, which is designed especially for Runge-Kutta methods (NM-R9616 and NM-R9619). Together with E. Messina, guest researcher of the department, we looked at the extension of these linear solvers to the linear systems arising in Runge-Kutta-Nyström methods (NM-R9613). Furthermore, we experimented with sparse-matrix methods for use in the linear system solvers (based on NM-R9520). We also started investigations on Runge-Kutta waveform relaxation methods (NM-R9617) and the design of parallel methods for implicit differential ial equations (based on NM-R9526). Finally, to test the new developed software, a number of real-life test problems was collected in NM-R9615.

Algorithms for atmospheric flow problems. Belongs to CWI's research program 'Mathematics and the Environment'.
The research concerns the numerical modelling of the long range transport and chemical exchange of atmospheric air pollutants. Numerical issues involve advection schemes, stiff chemistry ODE solvers, splitting methods, grid generation/adaptation and implementations on super and parallel computers. In 1996 we worked on the following projects:

EUSMOG – This 4 –year Ph.D. project (M. van Loon) was finished end of March 1996. Aim has been the development and implementation of numerical algorithms in an operational smog prediction model of the RIVM. In 1996 M. van Loon has finished his Ph.D. thesis (University of Amsterdam, June 17).
LOTOS – The objective is to develop a three-dimensional, long term ozone simulation model. This LOTOS model should replace at due time an

existing regional forecasting model in use at TNO. The model is developed in close cooperation with TNO researchers, where the focus lies on physical, meteorological and chemical aspects. The CWI research focuses on the design of the mathematical model for a so-called hybrid (terrain following and pressure based) coordinate system and, in particular, of tailored numerical algorithms and implementations on super and parallel computers. The project is carried out as part of the TASC project which is funded by the Dutch HPCN program (see below). Duration is 4 years (1996–1999). The first year (1996) has been spent on the model definition and the coordinate transformation and pilot studies on parallelism and use of a preprocessor for the automatic generation of the chemical kinetics system and related sparse matrix routines.

CIRK – This project is similar to the LOTOS project, but here the objective is to develop a three-dimensional model for transport and exchange of chemical constituents in the whole of the global troposphere/stratosphere. Support for this project is obtained from the RIVM. Cooperation exists with research groups from the IMAU/UU and the KNMI. Duration is 4 years (1994–1997). In 1996 much effort was spent on implementing, testing and comparing three Cray C90 3D solvers for a specific benchmark problem.

NCF – This one-year project is linked with the CIRK project and concerns the particular Cray C90 implementation issues. Support is provided by the NCF/Cray University Grant program. The project started in 1996, February 1 and lasts until January 31, 1997.

RIFTOZ – Within The Netherlands, the main part of this EU project is carried out by TUD and TNO. The aim is to analyse regional differences in tropospheric ozone over Europe. One of the key activities therefore involves recovering ozone concentrations from available measurements. For this purpose, the existing model LOTOS of TNO is applied with a data assimilation technique (extended Kalman filter) to incorporate the measurements. Little experience exists with extended Kalman filtering applied to highly nonlinear atmospheric models. Use of the extended Kalman filter in LOTOS is examined at CWI by Dr. M. van Loon (one year postdoc position) by order of TUD. Because the process is computationally expensive, the resulting code will be implemented on a vector/supercomputer.

GENERAL – Numerical algorithms were studied for the computation of various physical and chemical phenomena modelled by systems of nonlinear advection-diffusion-reaction equations. The focus was on atmospheric transport-chemistry problems, but other promising fields of applications are not excluded. In 1996, the existing cooperation with the Center for Global and Regional Environmental Research (CGRER), University of Iowa, was continued on benchmarking stiff ODE solvers for atmospheric chemical kinetic problems. Further, we examined second order IMEX (Implicit-Explicit) schemes and splitting methods applicable to a wide class of time-dependent PDEs.

Euler-Chebyshev methods. Special methods based on the stabilization of the forward Euler scheme by means of Chebyshev polynomials have been constructed. These methods are suitable for the integration of parabolic Volterra and Fredholm integral equations (NM-R9612).

Research consortium TASC. Belongs to CWI's research program 'Mathematics and the Environment. Research groups from CWI, IMAU, KNMI, RIVM, RWS, TNO, TUD and WL have formed the interdisciplinary research consortium TASC (Transport Applications and Scientific Computing). Co-ordination takes place at CWI. Three main tasks are distinguished: (I) Numerical algorithm and software development, (II) Implementation of fully integrated models, and (III) Application to real life problems. The TASC partners CWI, TNO, TUD and WL participate in the Dutch HPCN program (ICES support) through the project 'HPCN for Environmental Applications'. This project has started January 1996 and is planned to last 4 years. Research activities concern simulation of atmospheric air pollution and pollution in shallow water.

Organization of Conferences, Workshops, Courses, etc.

- TASC Symposium 4 'High Performance Computing in Environmental Modelling', June 12, EUROSIM Conference, TU Delft.
  Speakers were J.G. Blom (CWI): An evaluation of the Cray T3D programming paradigms in atmospheric chemistry/transport models, E.A.H. Vollebregt (TUD): The PARALLEL Project: Parallel simulation of 3D flow and transport models, E.D. de Goede (WL): A domain decomposition method for the 3D shallow water equations, P. Wilders (TUD): Parallel transport with unstructured finite volumes and implicit time stepping, B.P. Sommeijer (CWI): Modeling three-dimensional bio-chemical transport in shallow water.
- TASC Symposium 5 'Global Atmospheric Transport Modelling', September 30, CWI.

Speakers are D.L. Williamson (NCAR): Semi-Lagrangian transport as the basis for global atmospheric models, M. Heimann (MPI Hamburg): Inverting atmospheric transport to determine surface sources of long-lived atmospheric tracers using the adjoint technique, J. Lelieveld (IMAU): Methane Emission and distribution modeling, A. Sandu (University of Iowa): Benchmarking stiff ODE solvers for atmospheric chemistry problems: Rosenbrock methods, E.J. Spee (CWI): A vectorized three-space dimensional global transport-chemistry code, A. Petersen (IMAU): Representation of the boundary-layer in atmospheric chemistry models, M.C. Krol (IMAU): Modeling of global photodissociation rates, P. van Velthoven (KNMI): Atmospheric transport in off-line chemistry-transport models.

- TASC Symposium 6 'The TASC Project HPCN for Environmental Applications', December 16, CWI. Speakers are R. van Liere (CWI): Computational steering of transport of air pollutants, G. Stelling (WL): Numerical difficulties arising from local sources, B.P. Sommeijer (CWI): Time integration methods with domain decomposition for 3D bio-chemical transport in shallow water, P. Wilders (TUD): Scalability for parallel transport with Krylov-Schwarz domain decomposition.
- HCM Workshop 'Innovative Time Integrators', October 30–November 1, CWI, organized by J.G. Verwer (CWI) and J.M. Sanz-Serna (Univ. of Valladolid). Thirty-four lectures were presented at this international workshop. Part of the participants came from groups taking part in the HCM Project 'The Equations of Fluid Mechanics and Related Topics', and part from other groups inside and outside the EU. See CWI Report NM-N9602 for names and abstracts.

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

- ERCIM Workshop Parallel Numerical Algorithms and Applications, Zürich, May 28: J.G. Blom (On the implementation of atmospheric chemistry-transport problems).
- Volterra Centennial: Second International Conference on the Numerical Solution of Volterra and Delay Equations, Tempe, Arizona, May 29–30: P.J. van der Houwen (Euler-Chebyshev methods for parabolic integro-differential equations).
- EUROSIM Conference, TU Delft, June 12: J.G. Blom (An evaluation of the Cray T3D programming paradigms in atmospheric transport/chemistry problems), B.P. Sommeijer (Modeling three-dimensional bio-chemical transport in shallow water).
- Fifth Workshop on Numerical Solutions of Fluid Flows in Spherical Geometry, Breckenbridge, Colorado, June 12–14: W. Hundsdorfer (Numerical advection and time splitting on the sphere), E.J. Spee (A vectorized three-space dimensional global transport-chemistry code).
- Conference on Adaptive Grid Methods in Computational PDEs, Edinburgh, July 1–5: J.G. Verwer (The VLUGR Solvers).
- Second World Congress of Nonlinear Analysts, Athens, July 10–17: P.J. van der Houwen and W.A. van der Veen (Waveform Relaxation methods for implicit differential equations).
- International Conference on Computational and Applied Mathematics, Leuven, July 21–26: P.J. van der Houwen (On the solution of implicit differential equatiuons on parallel computers).
- Meeting of the WOG (The Flemish Organization of Scientific Research), September 5–7: P.J. van der Houwen (Splitting methods for 3D transport models with interaction terms).
- Dutch Numerical Mathematics Conference, Woudschoten, Zeist, September 25–27: W. Hundsdorfer, E.J. Spee (A vectorized three-space dimensional global transport-chemistry code).
- First REMAPE (Regional Modelling of Air Pollution in Europe) Workshop, Copenhagen, September 26–27: J.G. Verwer (Benchmarking Stiff ODE Solvers).
- HCM Workshop 'Innovative Time Integrators', October 30–November 1, CWI: P.J. van der Houwen (Solving implicit differential equations on parallel computers), W. Hundsdorfer (Stability results for implicit-explicit linear 2-step methods), B.P. Sommeijer (Vector/parallel time integration methods for 3D bio-chemical transport in shallow water).
- Working visit to University of Lund, November 3–23: J.J.B. de Swart (Parallel Iterative Linear System Solvers for Runge-Kutta methods).
- TU Dresden, November 10–13: J.G. Verwer (Numerical Algorithms in Air Pollution Modelling).
- Electricité de France, Paris, December 18: M. van Loon (Numerical Smog Prediction), J.G. Verwer (Numerical Algorithms in Air Pollution Modeling).

Memberships of Committees and Other Professional Activities

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).
- Advisor PDE chapters Numerical Algorithms Group (NAG).
- Editor NUMDIFF-7 Proceedings.
- Co-chairman Biennial Conference on Numerical Methods for Differential Equations (NUMDIFF).
- Member Board of International Association for Mathematics and Computers in Simulation (IMACS).
- Chairman Users Committee STW project 'Parallel Codes for Circuit Analysis and Control Engineering'.
- Member Committee Wetenschappelijk Gebruik Supercomputers (WGS).
- Member Board Numerical Mathematics Society (WGN).
- Member Scientific Committee Institute for Advanced Studies 'Stieltjes'.

W. Hundsdorfer:

- Editor CWI Quarterly.
- Member Users Committee STW project 'Parallel Codes for Circuit Analysis and Control Engineering'.

J.G. Verwer:

- Senior Editor 'Applied Numerical Mathematics'.
- Program Leader of CWI's research program 'Mathematics and the Environment'.
- Coordinator Research Consortium TASC.
- Coordinator of the TASC project 'HPCN for Environmental Applications'.
- Chairman HCM Workshop Innovative Time Integrators and co-editor of related special issue of 'Applied Numerical Mathematics'.
- Co-advisor Ph.D. thesis M. van Loon.

Visitors

- P. Rosa, University of Coimbra, Feb. 26–27.
- T. Mitsui, University of Nagoya, May 24–25: Linear Stability for Neutral Delay-Differential Systems and its Application to Numerical Step-Size Estimation.
- F. Potra, University of Iowa, June 25–26: Numerical Aspects in Air Quality Modeling and Optimization.
- J. Silva Santos, University of Coimbra, June 23–30.
- C. Pflaum, University of Würzburg, Aug. 1–8: Recent Developments in Sparse Grids.
- M. Heimann, Max-Planck-Institut für Meteorologie, Hamburg, Sept. 29–30: Inverting atmospheric transport to determine surface sources of long-lived atmospheric tracers using the adjoint technique.
- A. Sandu, University of Iowa, Sept. 24–30: Benchmarking stiff ODE solvers for atmospheric chemistry problems: Rosenbrock methods.
- E. Messina, University of Naples, March 29–October 11.
- All speakers of the Workshop 'Innovative Time Integrators', held at CWI, Oct. 30–Nov. 1, see CWI Report NM-N9602.

Papers in Journals and Proceedings

J.G. BLOM, R.A. TROMPERT, J.G. VERWER (1996). Algorithm 758: VLUGR2: A vectorizable adaptive grid solver for PDEs in 2D. *ACM Trans. Math. Softw.* **22**, 302–328.

J.G. BLOM, J.G. VERWER (1996). Algorithm 759: VLUGR3: A vectorizable adaptive grid solver for PDEs in 3D. II. Code Description. *ACM Trans. Math. Softw.* **22**, 329–347.

J.G. BLOM, CH. KESSLER, J.G. VERWER (1996). An evaluation of the cray T3D programming paradigms in atmospheric chemistry/transport models. (to appear in *Proceedings of EUROSIM conference*, Delft 1996).

P.J. VAN DER HOUWEN (1996). The development of Runge-Kutta methods for partial differential equations. *Appl. Numer. Math.* **20**, 261–272.

P.J. VAN DER HOUWEN, B.P. SOMMEIJER (1996). Iteration of Runge-Kutta methods with block-triangular Jacobians. *ZAMM* **76**, 367–375.

P.J. VAN DER HOUWEN, B.P. SOMMEIJER, J.J.B. DE SWART (1996). Parallel predictor-corrector methods. *J. Comput. Appl. Math.* **66**, 53–71.

P.J. VAN DER HOUWEN, B.P. SOMMEIJER (1996). CWI contributions to the development of parallel Runge-Kutta methods. *Appl. Numer. Math.* **22**, 327–344.

W.M. LIOEN (1996). On the diagonal approximation of full matrices. *J. Comput. Appl. Math.* **75**, 35–42.

B.P. SOMMEIJER, J. KOK (1996). Splitting methods for three-dimensional bio-chemical transport. *Appl. Numer. Math.* **21**, 303-320.

J.J.B. DE SWART, J.G. BLOM (1996). Experiences with sparse matrix solvers in parallel ODE software. *Computers Math. Applic.* **31**, 43–55.

J.G. VERWER, J.G. BLOM (1996). On the coupled solution of diffusion and chemistry in air pollu-

tion models. *Proceedings of the Third International Congress on Industrial and Applied Mathematics (ICIAM/GAMM 95)*, EDWIN KREUZER, OSKAR MAHRENHOLTZ (eds.). ZAMM, Issue 4: Applied Sciences, especially Mechanics, Akademie Verlag, 454–457.

J.G. VERWER, J.G. BLOM, W. HUNDSDORFER (1996). An implicit-cxplicit approach for atmospheric transport-chemistry problems. *Appl. Numer. Math.* **20**, 191–209.

J.G. VERWER, J.G. BLOM, M. VAN LOON, E.J. SPEE (1996). A comparison of stiff ODE solvers for atmospheric chemistry problems. *Atmospheric Environment* **30**, 49–58.

J.G. VERWER (1996). Explicit Runge-Kutta methods for parabolic partial differential equations. *Appl. Numer. Math.* **22**, 359–380.

CWI Reports

NM-R9603. A. SANDU, J.G. VERWER, M. VAN LOON, G.R. CARMICHAEL, F.A. POTRA, D. DABDUB, J.H. SEINFELD. *Benchmarking stiff ODE solvers for atmospheric chemistry problems I: Implicit versus explicit.*

NM-R9605. W. HUNDSDORFER. *Trapezoidal and midpoint splittings for initial-boundary value problems.*

NM-R9606. W. HUNDSDORFER. *A note on stability of the Douglas splitting method.*

NM-R9612. P.J. VAN DER HOUWEN, B.P. SOMMEIJER. *Euler-Chebyshev methods for integro-differential equations.*

NM-R9613. P.J. VAN DER HOUWEN, E. MESSINA. *Parallel linear system solvers for Runge-Kutta-Nyström methods.*

NM-R9614. A. SANDU, J.G. VERWER, J.G. BLOM, E.J. SPEE, G.R. CARMICHAEL. *Benchmarking stiff ODE solvers for atmospheric chemistry problems II: Rosenbrock methods.*

NM-R9615. W.M. LIOEN, J.J.B. DE SWART, W.A. VAN DER VEEN. *Test set for IVP solvers.*

NM-R9616. P.J. VAN DER HOUWEN, J.J.B. DE SWART. *Parallel linear system solvers for Runge-Kutta methods.*

NM-R9617. P.J. VAN DER HOUWEN, W.A. VAN DER VEEN. *Waveform relaxation methods for implicit differential equations.*

NM-R9619, E. MESSINA, J.J.B. DE SWART, W.A. VAN DER VEEN. *Parallel iterative linear solvers for Multistep Runge-Kutta methods.*

NM-R9620. E.J. SPEE, P.M. DE ZEEUW, J.G. VERWER, J.G. BLOM, W. HUNDSDORFER. *Vectorization and parallelization of a numerical scheme for 3D global atmospheric transport-chemistry problems.*

NM-R9621. P.J. VAN DER HOUWEN, B.P. SOMMEIJER, J. KOK. *The iterative solution of fully implicit discretizations of three-dimensional transport models.*

NM-R9623. J. FRANK, W. HUNDSDORFER, J.G. VERWER. *Stability of implicit-explicit linear multistep methods.*

NM-N9602. J.G. VERWER, J.M. SANZ-SERNA. *Workshop innovative time integrators.*

NM-N9603. W. HUNDSDORFER. *Numerical solution of advection-diffusion-reaction equations – lecture notes.*

Other Publications

M. VAN LOON (1996). *Numerical Methods in Smog Prediction*, Ph.D. Thesis, University of Amsterdam.

Boundary Value Problems, Multigrid and Defect Correction – NW2

Staff

- Prof. dr. P.W. Hemker, group leader
- Dr. ir. B. Koren, senior researcher
- Ir. W.J.H. Stortelder, Ph.D. student
- Ir. J. Noordmans, Ph.D. student

Scientific Report

P.W. Hemker and *J. Noordmans* continued research on sparse-grid related algorithms for three dimensional problems. The work aims at the use of adaptive box-methods for sparse grids. Initiated by the framework of a BRITE-EURAM programme in 1993, the purpose of this research is the efficient solution of 3D flow problems. The software package, based on the BASIS3 module, has been extended for finite element discretisation of general linear elliptic equations on a system of grids, both with classical and with hierarchical basis functions. First, much effort was spent on the proper construction of the discrete linear systems, later the emphasis was put more on solution methods for these equations. The main results of the investigations have been reported at the 5th European Multigrid Conference, held in Stuttgart, Germany, October 1–4, and have been submitted for publication in its proceedings. Recently a theoretical study has been started on an efficient iterative solution method for such hierarchical systems.

Based on previous work, and as an interesting opportunity for application of the sparse-grids tech-

nique, *J. Noordmans* worked on the solution of the highly anisotropic Stokes equations. A paper on this research was presented at the ECCOMAS'96 conference.

The study on theoretical aspects related with semi-coarsening and partially ordered sets of approximations was continued by *P.W. Hemker* and *C. Pflaum* (Univ. Marburg, Germany). For this purpose, in August *C. Pflaum* visited CWI for a week. Some joint work was completed and a report on this work appeared as NM-R9611.

In the framework of the STW project 'Parameterindentificatie en model-analyse voor niet-lineaire dynamische systemen", *W.J.H. Stortelder* continued the development of the parameter estimation software tool 'spIds'. Additions have been made with respect to global optimisation and the investigation of nonlinearity measures.

The cooperation of *Stortelder* with *Prof. J.D. Pintér* (Techn. Univ. Nova Scotia, Canada) and *J.J.B. de Swart* (NW1) led to a paper on the computation of Fekete point sets, which was completed and submitted.

Joint work of *Prof. J.C. Merchuk* (Dept. of Chem. Engng, BGU, Beer Sheva, Israel) and *Stortelder* resulted in completion of a first paper on the application of the newly developed parameter identification techniques to a biochemical problem. This paper was submitted for publication. The cooperation is still vivid and preparations were made for a second joint paper.

Supported by a renewed grant from NWO to stimulate cooperation with researchers from the former Soviet Union, the joint work between *Prof. G.I. Shishkin* (Institute of Mathematics and Mechanics, Ekaterinburg, Russia) and *P.W. Hemker* was continued. The subject of this research was mesh adaptation and ϵ-uniform convergence for singular perturbation problems.

Also, together with *Prof. A.O.H. Axelsson* (KUN) and several Russian colleagues, a workshop on this subject and other new aspects of numerical analysis was organised in Moscow, May 9–13. Here *Shishkin, Hemker* and *Noordmans* reported on their recent research.

Further, *Prof. Shishkin* visited CWI during the month October 1996. During this month the publication of new papers was prepared, and a visit was made to the Mathematisches Forschungsinstitut Oberwolfach, Oberwolfach (Germany), where a special RIP Workshop was organised on 'Shishkin Meshes and Applications', October 21–25.

P.W. Hemker was guest editor for a Special Issue of the journal Applied Numerical Mathematics that is devoted to recent advances in Multigrid Methods. The volume, that will consist of 14 contributions from participants of the Oberwolfach Meeting on 'Multilevel Methods and Applications', April 30–May 6, 1995, was completed during the year. It is expected that the issue will appear in February 1997.

In cooperation with *H. Deconinck* (Von Karman Institute for Fluid Dynamics, Brussels), *B. Koren* edited a book on the research done in the first and second phase of the BRITE-EURAM Aeronautics R&D Programme of the European Union. The book will appear in Vieweg's series 'Notes on Numerical Fluid Mechanics'.

Koren continued his research on multiple semi-coarsening and sparse-grid solution methods for the three-dimensional, compressible Euler equations. The first sparse-grid results are promising. A joint publication with *P.W. Hemker* and *J. Noordmans* will appear in the Proceedings of the Fifth European Multigrid Conference, October 1–4, Stuttgart. In cooperation with *C.T.H. Everaars*, the distributed computing aspects of the sparse-grid approach were investigated (with the Manifold language compiler), a publication on this work is in preparation. The other research of *Koren* concerned the investigation of monotonicity bounds for explicit multi-stage time-stepping schemes applied in solving advection problems. A report on this work is in preparation.

In the two-month period February–March 1996, *Koren* paid eight half-day consultancy visits to MacNeal-Schwendler's European Development Center (MSC-EDC) in Gouda. A report was written on the development of computational methods for forging processes at MSC-EDC. The report gives suggestions for possible future work. Also for MSC-EDC, in the second half of 1996, *Koren* started a feasibility study on mixed Riemann solvers for the computation of multi-phase flows of gases, liquids and explosives. The work is directed towards for instance the safety improvement of aircraft with respect to bird strikes and on-board explosions.
For Akzo/Nobel Central Research in Arnhem, together with an MSc-student from the Delft University of Technology (*D. Lanser*), *Koren* started the development of a tool to compute the compressible air flow in a nozzle, which is used for drawing fibres in melt spinning processes. (Melt spinning is a process to make non-woven cloth, a basic product in the production of many other products, ranging from carpets and roofings to wound-dressings.) Akzo/Nobel's goal is to have a design tool for the nozzle in order to reduce its relatively large running costs.

Together with *C.B. Vreugdenhil* (University of Utrecht), *Koren* was invited to give a course on numerical methods for advection-diffusion problems, at the University of Coimbra, Department of Mathematics.

For MARIN in Wageningen, together with *P.W. Hemker* and *H.T.M. van der Maarel* from MARIN, *Koren* wrote a research proposal for the development of improved computational methods for hydrodynamic ship design. The aim of this research is to improve the reliability and efficiency of MARIN's viscous CFD technology. The direct use lies in flow topology studies (flow separation, re-attachment, vortex formation, etc.) around ship hull forms, at various sailing conditions (speed, trim, sinkage).
In cooperation with *B. Gravendeel* from Holec, Ridderkerk, *Koren* also wrote a research proposal for the development of a computational method for the governing equations of magnetohydrodynamics (MHD), which describe the physics in a conducting fluid. The method will be applied to study e.g. MHD ship propulsion systems. The research initiative originates from the recently founded Society for Electromagnetic Power Technology (EMVT), a consortium consisting of KEMA, Holec, ELIN and some other companies and institutes (among which CWI).

Organization of Conferences, Workshops, Courses, etc.

P.W. Hemker:
- AMS – BeNeLux Congress, Antwerp, Belgium, May 22–25. Session Numerical Mathematics.
- Conference on Algebraic Multilevel Iteration Methods with Applications, KU Nijmegen, June 13–15, P. Hemker (program committee)

B. Koren:
- BRITE Meeting, CWI, January 26.

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

- Working visit to University Maastricht, January 3: Hemker (Parameter idendification in biochemical systems).
- Working visit to MARIN, Wageningen, January 11: Hemker, Koren.
- Working visit to the Math. Dept of the Agricultural University of Wageningen, January 15: Stortelder.
- BRITE Meeting, CWI, January 26: Hemker, Koren (Semi-coarsening in three directions for Euler-flow computations in three dimensions), Noordmans, De Zeeuw.
- Consultancy visits to MacNeal-Schwendler (E.D.C.) B.V., Gouda (on computational forging), February 1,7,22,28, March 8,14,21, April 4: Koren.
- Working visit INRIA Sophia-Antipolis, February 10–14: Hemker (Instationary flows and flows at low Mach numbers).
- Kontaktgroep Numerieke Stromingsleer, NLR, Amsterdam, March 11: Noordmans.
- Soiree Wiskunde en Informatica, Amsterdam, March 12: Hemker, Stortelder.
- Working visit to the Math. Dept of the Technical University of Eindhoven, March 28: Stortelder.
- Wiskunde Colloquium TU Eindhoven, April 17: Hemker (IJle roosters en multiroostertechnieken gebaseerd op half-vergroving).
- Working visits to the Dept. of Chem. Eng., Ben Gurion University of the Negev, April 18-30 and October 17–26: Stortelder.
- Working visits to MacNeal-Schwendler (E.D.C.) B.V., Gouda (with B. van Leer), April 23,24,26, May 9,10: Koren.
- BRITE Workshop, Von Karman Institute for Fluid Dynamics, Brussels, April 29: Hemker (Sparse grids and semi-coarsening multigrid techniques), Koren.
- Working visit, Moscow State University, Moscow, Russia, May 9–13: Hemker (Sparse grids and semi-coarsening multigrid techniques), Noordmans (Solutions of highly anisotropic Stokes equations for lubrication problems).
- '5th SIAM Conference on Optimization' (Victoria, BC, Canada), May 20–24: Stortelder (Parameter estimation in dynamic systems).
- AMS BeNeLux Meeting, Universitaire Instelling Antwerpen, May 22–25: Hemker (laudatio W. Hackbusch for Brouwer Award), Koren.
- Workshop on Iterative Methods, CERFACS Toulouse, France, June 7–12: Hemker (Navier-Stokes and semiconductor modelling: Two applications of adaptive non-linear Finite Volume Multigrid. A survey, June 10).
- Conference on Algebraic Multilevel Iteration methods with Applications, KUN Nijmegen, June 13–15: Hemker.
- Working visit to KEMA, Arnhem (with P.J. van der Houwen), June 21: Koren.
- IFIP Working Group 2.5, Oxford, England, July 6–7: Hemker.
- Working Conference 'Quality of Numerical Software', Oxford, England, July 8–12: Hemker.
- Symposium Elektromagnetische Vermogenstechnologie, Arnhem, August 22: Koren.

- 19th International Congress of Theoretical and Applied Mechanics, Kyoto, August 25–30: Koren (Large-eddy simulation with accurate implicit subgrid-scale diffusion).
- Third ECCOMAS Computational Fluid Dynamics Conference, Paris, September 9–13: Koren (A computational method for high-frequency oleodynamics, application to hydraulic shock-absorber designs).
- Second ECCOMAS Conference on Numerical Methods in Engineering, Paris, September 9–13: Noordmans (Solutions of highly anisotropic Stokes equations for lubrication problems).
- Course on numerical methods for advection-diffusion problems (together with C.B. Vreugdenhil), University of Coimbra, September 16–20: Koren (A robust upwind discretisation method for advection, diffusion and source terms; Comparative evaluation of various space-discretization methods; Stability of explicit time integration methods for flux-limited dvection schemes; Monotone, higher-order accurate multi-D upwinding; Multi-D upwinding and multigridding; Solution-adaptive multigridding; Multiple semi-coarsened grids and sparse grids for 3D flow problems).
- 21ste Conferentie Numerieke Wiskunde, Woudschoten, September 25–27: Hemker, Koren, Noordmans.
- Fifth European Multigrid Conference, EMG'96, University Stuttgart, Germany, October 1–3: Hemker (Three-dimensional multigrid on partially ordered sets of grids).
- Afscheidscollege Prof. dr. M.H.C. Paardekooper, KUB Tilburg, October 11: Hemker.
- Working visit, SRTCA (Shell, Amsterdam), October 14: Stortelder.
- Oberwolfach meeting 'Shishkin Meshes and Applications' October 21–25: Hemker (Philosophical issues; Test problems).
- Working visit, Akzo/Nobel (Arnhem), October 31: Stortelder.
- Working visits on behalf of Akzo/Nobel-project, Delft University of Technology, September 30, December 19; Akzo/Nobel Central Research, Arnhem, October 21; CWI, November 11: Koren.
- Consultancy visits to MacNeal-Schwendler (E.D.C.) B.V., Gouda (on the computation of multi-phase flows of gases, liquids and explosives), October 1,10, November 7: Koren.
- Working visit, IWR, Universität Heidelberg, (Heidelberg, Germany), November 11–22: Stortelder.
- Kenniskring Amsterdam, November 13: Hemker.
- Working visit to Holec, Ridderkerk, October 29: Koren.

Memberships of Committees and Other Professional Activities

P.W. Hemker:

- Professor of Industrial Mathematics, University of Amsterdam.
- Working Group 2.5 on Numerical Software, IFIP (member).
- Numerical Algorithms Group, NAG Inc. (member).
- STW Users Committee, Project 'Parameter Identification' (chair).
- Ph.D. committee R. Martin (Université de Nice – Sophia Antipolis, France, February 12) (rapporteur).
- Habilitation committee H. Guillard (l'Université de Provence (Aix-Marseille I), France , February 14) (examinateur).
- Ph.D. committee E. Brakkee (TUD, April 15 (member).
- Ph.D. committee M. van Loon (UvA, June 17 (member).
- Ph.D. committee P. Ferket (TUE, October 14) (2nd advisor).

B. Koren:

- Secretary Werkgemeenschap Numerieke Wiskunde.
- Editor 'Het Nummer' (newsletter Werkgemeenschap Numerieke Wiskunde).
- Member Ph.D. committee M. Zijlema (Delft University of Technology, April 9).
- Member Ph.D. committee Z.W. Zhu (Free University of Brussels, September 3 (private defence), September 17 (public defence)).
- Member post-graduation committee P.A. Mendes Martins Rosa (University of Coimbra, September 20).
- Member MSc committee M. Baro (Delft University of Technology, November 28).

Visitors

- Ir. H.C. Stoker (University of Twente), February 23.
- Drs. E. Hendrix, (Agriculture University, Wageningen), March 25.
- Dr. H.T.M. van der Maarel (MARIN, Wageningen), April 3.
- Prof. B. van Leer (University of Michigan, Ann Arbor) 'Numerical integration of stiff hyperbolic systems: why and how', May 6.
- Prof. dr. H-G. Roos (Univ. Dresden, Germany) 'Numerical singular perturbation problems', June 24.

- Prof. V.P. Il'in (Computing Center, Siberian branch,Russian Acad. Sci., Novosibirsk, Russia) 'Problems in numerical linear algebra', July 20–August 13.
- Dr. C. Pflaum (University of Marburg, Germany) 'Sparse grids', August 4–12.
- Prof. G.I. Shishkin (Institute of Mathematics and Mechanics, Ekaterinburg, Russia) 'Numerical schemes satisfying ϵ-uniform convergence', October 4–31.
- Prof.dr. S. Nepomnyaschikh (Computing Center, Siberian branch,Russian Acad. Sci., Novosibirsk, Russia) 'Domain decomposition methods for anisotropic elliptic problems', December 4.
- Drs. S.J. van der Wal (SRTCA, Amsterdam), December 19.
- During the year two trainees did their practical work in NW2: D.E.A. Van Odijck (UvA, Amsterdam): February 1–July 30; M. Baro (TU Delft): February 1–October 31.
- J.-M. Couveignes (Ecole Normale Superieure, Paris, France), January 12 (Schoof's algorithm and the computation of the cardinality of elliptic curves over finite fields — a survey).
- A.K. Lenstra (Bellcore, Morristown, NJ, USA), February 19–23.
- Igor Shparlinski (Macquarie University, Sydney, Australia), May 10 (A Linear Lower Bound on the Depth of Arithmetic Circuits Breaking the Diffie-Hellman Cryptosystem and Polynomial Representation of the Discrete Logarithm).
- J.H. Conway (Princeton University, USA), May 23–24 (The Symmetries of Things).
- Raymond Hon-fu Chan (The Chinese University of Hong Kong), September 13 (Iterative methods for Toeplitz Systems).

Miscellaneous

P.W. Hemker:
- Consultant for Philips Research Laboratories, Eindhoven.
- Review of papers for various journals, refereeing of project proposals.
- Capita selecta course 'Advanced Scientific Computing" at the University of Amsterdam, on the subject 'Finite Element Methods".

B. Koren:
- Review of some journal papers and research proposals (STW and NCF)

W. Stortelder:
- Review of papers for the Journal of Global Optimization and IEEE Transactions on Signal Processing.

Papers in Journals and Proceedings

H. DECONINCK, B. KOREN (1996). Algorithm development in CFD: multidimensional upwinding and multiple semi-coarsening multigrid. J.-A. DÉSIDÉRI, C. HIRSCH, P. LE TALLEC, M. PANDOLFI, J. PÉRIAUX (eds.). *Computational Methods in Applied Sciences '96, Invited Lectures and Special Technological Sessions of the Third ECCOMAS Computational Fluid Dynamics Conference and the Second ECCOMAS Conference on Numerical Methods in Engineering*, Wiley, Chichester, 496–502.

P.A. FARRELL, P.W. HEMKER, G.I. SHISHKIN (1996). Discrete approximations for singularly perturbed boundary value problems with parabolic layers, *Journal of Computational Mathematics* **14** 71–97.

P.A. FARRELL, P.W. HEMKER, G.I. SHISHKIN (1996). Discrete approximations for singularly perturbed boundary value problems with parabolic layers, *Journal of Computational Mathematics* **14**, 183–194.

P.A. FARRELL, P.W. HEMKER, G.I. SHISHKIN (1996). Discrete approximations for singularly perturbed boundary value problems with parabolic layers. *Journal of Computational Mathematics* **14**, 273–290.

P.W. HEMKER (1996). Corrigendum on remarks on sparse-grid finite-volume multigrid. *Advances in Computational Mathematics* **5**, 125–126.

P.W. HEMKER (1996). Solution of 3D elliptic systems by semi-refinement. *Analele Stiintifice ale Universitatii Ovidius Constanta, Seria Matematica* **3**, 63–82.

B. KOREN (1996). Improving Euler computations at low Mach numbers. *International Journal of Computational Fluid Dynamics* **6**, 51–70.

B. KOREN, P.F.M. MICHIELSEN, J.W. KARS, P. WESSELING (1996). A computational method for high-frequency oleodynamics, application to hydraulic-shock-absorber designs. J.-A. DÉSIDÉRI, C. HIRSCH, P. LE TALLEC, M. PANDOLFI, J. PÉRIAUX (eds.). *Computational Fluid Dynamics '96, Proceedings of the Third ECCOMAS Computational Fluid Dynamics Conference*, 725–731. Wiley, Chichester, 226–238.

J. NOORDMANS (1996). Solutions of highly anisotropic Stokes equations for lubrication problems. J.-A DÉSIDÉRI, P. LE TALLEC, E. OÑATE, J. PÉRIAUX, E. STEIN (eds.). *Proceedings of the second ECCOMAS Conference on Numerical Metods in Engineering*, John Wiley & Sons, 960–965.

W. STORTELDER (1996). Parameter estimation in chemical engineering, a case study for resin production. F. KEIL, W. MACKENS, H. VOSS, J. WERTHER (eds.). *Scientific Computing in Chemical Engineering*, Springer-Verlag Berlin Heidelberg, 226–238.

W. STORTELDER (1996). Parameter estimation in dynamic systems. *Mathematics and Computers in Simulation* **42**, Nos. 2-3, 135–142.

W.J.H. STORTELDER (1996). Parameter estimation in nonlinear models by using total least squares. J. GOTTLIEB, P. DUCHATEAU (eds.). *Parameter Identification and Inverse Problems in Hydrology, Geology and Ecology*, Kluwer Academic Publishers, 249–259.

CWI Reports

NM-R9601. C. BEETS, B. KOREN. *Large-eddy simulation with accurate implicit subgrid-scale diffusion.*

NM-R9610. W. STORTELDER. *Parameter estimation in chemical engineering; a case study for resin production.*

NM-R9611. P.W. HEMKER, C. PFLAUM. *Approximation on partially ordered sets of regular grids.*

NM-N9601. B. KOREN. *Computational forging in the Eulerian formulation at MacNeal-Schwendler (E.D.C.) B.V.*

Other Publications

B. KOREN, P.M. DE ZEEUW (eds.) (1996). *Het Nummer*, volumes **34** and **35**, Stichting Mathematisch Centrum, Amsterdam.

Large-Scale Computing – NW3

Staff

- Dr. ir. H.J.J. te Riele, group leader
- Prof. dr. H.A. van der Vorst, advisor (until April 1996)
- Drs. J. Kok, researcher (0.8 fte in NW1.2)
- Drs. W.M. Lioen, programmer (0.6 fte in NW1.3)
- Drs. M. Nool, programmer
- D.T. Winter, programmer (0.4 fte from CST)
- Drs. H. Boender, Ph.D. student, seconded from RUL until Nov. 1, 1996
- Drs. R.-M. Elkenbracht-Huizing, Ph.D. student until Oct. 1, 1996, NWO/RUL
- Dr. A. van der Ploeg, researcher from March 16 onwards

Scientific Report

Introduction

The central research theme of NW3 is High Performance Scientific Computing. Attention is focused on the optimization and comparison of mathematical and numerical algorithms on massively parallel processors, on parallel vector processors and on clusters of workstations, and the development and use of tools for enhancing portability of parallel software, and for performance evaluation of parallel hardware. In addition, members of this group support parallel computing projects in other CWI groups. In particular, J. Kok and W.M. Lioen have worked in NW1 for 80% resp. 60% of their time.

For these tasks the group had access to SGI and Sun workstations and compute servers in the CWI network, to the Cray C98/4256, the IBM SP2, and the Parsytec CC at SARA, to a NEC SX-4 at NLR, and to a Cray T3D in Eagan (MN, USA).

Scientific collaboration exists with (the groups of) Dr. W. Bosma (Univ. of Amsterdam), Prof. R.P. Brent (The Australian National University, Canberra, Australia), Prof. J. Cannon (University of Sydney, Australia), Prof. G.L. Cohen (University of Technology, Sydney, Australia), Prof. J.-M. Deshouillers (Univ. of Bordeaux II), Prof. J.P. Goedbloed (FOM Institute for Plasmaphysics Rijnhuizen), Dr. A.K. Lenstra (Citicorp Bank, New York, USA), Dr. P.L. Montgomery (San Rafael, California, USA), Prof. A. van der Poorten (ceNTRe for Number Theory Research, Macquarie University, Sydney, Australia), Prof. M. van der Put (RUG), Dr. R.D. Silverman (Queues Enforth Development Inc., Cambridge, Massachusetts, USA), Prof. R. Tijdeman (RUL), Prof. H.A. van der Vorst (UU) Prof. S.S. Wagsteylf, Jr. (Perdue Univ. West Lafayette, USA).

The research in NW3 is divided into the two projects *NW 3.1: Parallel numerical algorithms* and *NW 3.2: Computational number theory*.

Report on NW 3.1: Parallel numerical algorithms

(a) *Parallel computation of eigenvalues of non-Hermitian generalized eigenproblems arising in linear magnetohydrodynamics (MHD)* (M. Nool, A. van der Ploeg, H.J.J. te Riele). This project was started in September 1993, jointly with Utrecht University and the FOM Institute for Plasmaphysics Rijnhuizen. In September 1995, a project proposal named *Parallel Computational Magneto-Fluid Dynamics: Nonlinear dynamics of thermonuclear, astrophysical, and geophysical plasmas and fluids* was approved by the 'Dwarsverbandcommissie Massaal Parallel Rekenen' of NWO. In this project several in-

stitutes are collaborating, including the Mathematical and Astronomical Institutes of Utrecht University, the FOM Institute for Plasmaphysics Rijnhuizen, and CWI. CWI's share in this project is focused on the generalized eigenvalue problems arising in the CASTOR finite-element spectral code which has been developed at FOM Rijnhuizen for the (in-)stability investigation of tokamak plasmas.

An existing code for the Jacobi-Davidson method for solving large sparse generalized eigenvalue problems has been extended in order to find several eigenvalues in an efficient way. To improve the convergence behaviour of the JD-method, several parallelisable solvers for block tridiagonal systems of linear equations generated by the CASTOR code have been studied. The most promising method is a combination of domain decomposition and block cyclic reduction, which is called the DDCR-method (CWI Report NM-R9618). Speed-ups obtained on the CRAY T3D (see also the report below on the Cray Research Grant project) come quite close to the theoretical upper bounds for the speed-up that can be obtained when communication is instantaneous. The DDCR-method has also been implemented in High Performance Fortran (HPF) on the IBM SP2 at SARA. From numerical experiments it turns out that for this method it is indeed possible to obtain high efficiency – comparable with that obtained on the Cray T3D – by using HPF (a report will appear in 1997). In addition, solvers for block penta- and block heptadiagonal systems of linear equations have been developed. Such systems arise in computations in two and three dimensions, both in the so-called VAC-code (of the FOM Institute Rijnhuizen) and in CASTOR when a finite-element in more than one direction is used. Preconditioning techniques have been developed which strongly improve the convergence behaviour of iterative methods in the VAC-code. A block-form of the well-known Eisenstat trick guarantees that the memory requirements for the preconditioner are very low, and the matrix-vector multiplication with the preconditioned matrix costs about the same number of floating point operations as the matrix-vector multiplication with the unpreconditioned matrix (a paper on this work will appear in the Proceedings of HPCN97, to be held in Vienna, in April 1997).

In March a one-year Cray Research Grant project (CRG 96.16) was started. Aim of this project is to develop an efficient code on a Cray T3D parallel computer with 128 processors for the solution of the generalized eigenvalue problem $Ax = \lambda Bx$ as this arises in the CASTOR code, and to find out to what extent parallel computers like the T3D are suited as a tool to increase the size of these eigenvalue problems for applications in magnetohydrodynamics and astrophysics. Starting point was an existing sequential code (developed by Albert Booten) implementing the Jacobi-Davidson method for solving large sparse generalized eigenvalue problems. The most expensive step in this method is the approximate solution of a 'correction' equation $(A - \theta B)x = y$ for some given value of θ. Different parallel programming methods, based on either using the T3D as a virtual shared memory machine, or as a distributed memory machine with explicit commands for communicating data between processors, have been used to parallelize the code for the Cray T3D. A comparison of these programming methods for the most time-consuming parts of the JD algorithm (in particular: the preconditioning of the correction equation and the computation of matrix-vector products) has shown that the latter approach (distributed memory) is more efficient than the former one (virtual shared memory) with respect to communication time, wall-clock-time and the use of memory. A report will appear in the spring of 1997.

(b) *ERCIM Parallel Processing Network* (H.J.J. te Riele). The ERCIM Parallel Processing Network is a network of ERCIM researchers interested in all aspects of parallel processing, from parallel hardware to applications. A resubmission, in February 1997, of a project proposal to the Networks Activity of the Training and Mobility of Researchers Programme of the European Commission, named *Advancing parallel processing exploitation by interfacing applications, programming and architectures (APPEL)* was prepared during meetings held in Zürich (28 and 29 May) and Pisa (12 and 13 December). Project Coordinator is Herman te Riele. This proposal is prepared by representatives from the ERCIM research institutes CCL (the former RAL), CNR/CNUCE, CWI, FORTH, GMD, INRIA, and IWR/ETH, and from Dolphin (Norway) and QSW (Italy), companies involved in the development of networks of workstations and supercomputers, respectively.

On May 28, an ERCIM PPN Workshop on 'Parallel Numerical Algorithms and Applications' was held in Zürich, as part of the activities organised on the occasion of SGFI Switzerland joining ERCIM. On December 12, an ERCIM PPN workshop was held in Pisa, Italy. This was devoted to the PQE 2000, an Italian project to develop a hybrid parallel computer system combining both MIMD and SIMD architectures.

Report on NW 3.2: Computational number theory
(a) *Factorization with the Number Field Sieve (NFS)* (R.-M. Elkenbracht-Huizing, W.M. Lioen, P.L. Montgomery, H.J.J. te Riele). In this project the number field sieve method and its suitability to factor general numbers is being studied.

Elkenbracht-Huizing continued her study of the idea to use more than two polynomials in the NFS. This turned out to be useful for 'classical sieving' but not for the version called 'line sieving'. The results were reported in the Proceedings of the ANTS-II Conference, held in Bordeaux, May 18–23.

The CWI NFS program has been used to contribute about 30% of the sieving work necessary to factor an RSA challenge number of 130 digits. The factorization of this record size number was accomplished on April 10, 1996, which established a new world record for general numbers. The most time-consuming part of this effort, the sieving, was started in September 1995 and completed in January 1996. It was carried out on a great variety of workstations at many different locations. One of the crucial last steps, the solution of a huge, sparse, linear system of equations of order about 3,500,000 with, on average, 39 non-zero entries per column, was (and had to be) carried out on the Cray C90 at SARA. For this step Peter Montgomery's Cray implementation of his block Lanczos algorithm was used: it took 67.5 CPU-hours and 700 Mbyte of central memory on the Cray C90 to complete this step of the NFS-algorithm. Much publicity was given to this new record in the press, and on radio and television. A report was presented at the ASIA-CRYPT conference in Kyongju (Korea) and published in the Proceedings.

Many other large numbers were factored with the NFS and the GNFS method as contributions to the original Cunningham table.

Elkenbracht-Huizing wrote a concise history of factoring, thereby concentrating on the ideas and methods which led to the Number Field Sieve. This was published in the November issue of the journal *Nieuw Archief voor Wiskunde*.

The results of Marije Elkenbracht-Huizing's studies in the past four years of the Number Field Sieve factorization method were brought together in a doctor's thesis which will be defended in the first half of 1997 at the University of Leiden.

(b) *The number of relations in the quadratic sieve algorithm* (H. Boender, W.M. Lioen, H.J.J. te Riele). For the single large prime variation of the quadratic sieve factoring algorithm a formula was derived for the average numbers of complete and incomplete relations per polynomial, directly generated by this algorithm. From this, and from a known formula for predicting the number of complete relations generated by the incomplete relations, practical hints for the optimal choice of the parameter values in the single large prime variation of the quadratic sieve have been derived. In addition, theoretical estimates for the total number of smooth integers in a given interval have been compared with actual countings, and good agreement between the two figures was found. A report (NM-R9622) was submitted for publication.

The results of Henk Boender's studies in the past four years of the quadratic sieve factorization method were brought together in a doctor's thesis which will be defended in the first half of 1997 at the University of Leiden.

(c) *Extending the Cunningham table* (P.L. Montgomery, H. Boender, R.-M. Elkenbracht-Huizing, H.J.J. te Riele, W.M. Lioen, D.T. Winter). Montgomery and Boender continued to factor numbers of the form $a^n \pm 1$ ($13 \leq a < 100$) for the extended Cunningham table with the help of the ECM, NFS and MPQS factoring methods. Most of the work was carried out on 70 SGI workstations at CWI and 70 SGI, Sun, and HP workstations at Leiden University. In the first Update to this table (NM-R9419, September 1994), the factorizations were complete for $n \leq 58$ and there were no composite numbers left smaller than 10^{86}. In the second Update (NM-R9609) the factorizations were complete for $n \leq 67$ and there were no composites left smaller than 10^{94}. These updates gave 959 and 882 new factorizations, respectively. Additional factorizations were provided by Andreas Müller, Paul Leyland, Robert Silverman, Thomas Sosnowski and MullFac (The *Isle of Mull Factoring Group* consisting of Richie Edwards, Willie Gough, George Sassoon and Vivian Stephens).

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

(d) *Factoring Fermat numbers with the 'Number Cruncher'* (H.J.J. te Riele). Since March 6, CWI's Computational Number Theory group has a so-called Dubner Number Cruncher running. The Dubner Number Cruncher is a board which plugs into an IBM-compatible PC. The board has a digital signal processing chip (LSI Logic L64240 MFIR) which can perform 1.28×10^9 multiply/add operations per second. The board costs US $2,500, but for certain applications it reaches near-supercomputer speed! For example, carrying out a Fermat pseudo-primality test of a number with 1,000 decimal digits, costs 4.4

sec. on the Cruncher and 2.1 sec. on a Fujitsu VP 2200/10 supercomputer. For numbers of 10,000 digits, the Cruncher is 1.5 times faster than the Fujitsu.

We have started to use the Cruncher to look for factors of Fermat numbers with H.W. Lenstra's Elliptic Curve method. This project is carried out jointly with several other Crunchers, operated by Richard Brent and Harvey Dubner.

(e) *Amicable and related numbers* (H.J.J. te Riele). The report with many hundreds of new amicable triples announced to appear in 1995 has been further delayed until 1997.

(f) *Diophantine inequalities and continued fractions* (H.J.J. te Riele). The comparative study (with Richard Brent and Alf van der Poorten) of three known algorithms for the computation of the continued fraction of algebraic numbers (which are defined as roots of polynomials with integer coefficients) was provisionally concluded. Experiments were carried out with the help of implementations in GP/PARI and MAGMA. An extended abstract appeared in the Proceedings of the ANTS-II meeting of May 1996 in Bordeaux.

(g) *The Goldbach conjecture* (H.J.J. te Riele). The Goldbach conjecture states that every even number > 2 can be expressed as a sum of two prime numbers. In cooperation with Jean-Marc Deshouillers from the University of Bordeaux II, new computations were started with the aim to extend the upper bound for the numbers for which the Goldbach conjecture is known to be true. The motivation for this study was the discovery of a more efficient algorithm for the numerical verification of the Goldbach conjecture, and possibilities to improve the results for Goldbach's *three primes conjecture* which asserts that every number > 5 can be written as a sum of three primes. As a first step, the bound for which the Goldbach conjecture is known to be true was extended by a factor of 25 from 4×10^{11} to 10^{13}.

Organization of Conferences, Workshops, Courses, etc.

Beeger Lecture

- The purpose of the Beeger Lecture is to promote research and exchange of ideas in the area of Computational Number Theory. It is funded by CWI. An advisory Committee consisting of Dr. G. van Oortmerssen (Director of CWI), Prof. H.W. Lenstra, Jr. (Berkeley), Prof. R. Tijdeman (Leiden), and Dr. H.J.J. te Riele proposes a candidate for this biennial lecture.
- The third Beeger Lecture (organized by H.J.J. te Riele) was presented by John Conway during the AMS BeNeLux Congress in Antwerp, on Wednesday May 22. The title was: 'The Symmetries of Things'.

Working Group Large-Scale Computing

- This group meets once every three or four weeks, and discusses new developments in high performance scientific computing. Participants came from the University of Amsterdam, Utrecht University, Delft University of Technology, the FOM Institute for Plasmaphysics Rijnhuizen, and CWI. In 1996, ten meetings took place (organized by Te Riele). The dates, speakers and their subjects were:
  January 19: Auke van der Ploeg (Vakgroep Wiskunde, Groningen University), ILU-ontbindingen: een kwestie van verdeel en heers
  March 8: Walter Hoffmann (University of Amsterdam), Review of the article: M. Arioli, I.S. Duff, D. Ruiz, and M. Sadkane, Block Lanczos techniques for accelerating the block Cimmino method, *SIAM J. Sci. Comput.*, **16** (1995), 1478–1511.
  Walter Lioen (CWI), Review of the article: David W. Walker and Jack J. Dongarra, MPI: A Standard Message-Passing Interface, *SIAM News*, January/February 1996, pp. 1, 8–9.
  March 29: Dik Winter (CWI), Review of the article: David M. Smith, A multiple-precision division algorithm, *Math. Comp.*, **65** (1996), 157–163.
  Kees Dekker (Delft Univ. of Technology), Review of the article: Residual smoothing techniques for iterative methods, *SIAM J. Sci. Comput.*, **15** (1994), 297–312.
  April 19: Jos van Dorsselaer (Utrecht University), Review of the article: S.H. Lui and G.H. Golub, Homotopy method for the numerical solution of the eigenvalue problem of self-adjoint partial differential operators, *Numerical Algorithms* **10**, (1995), 363–378.
  Margreet Nool (CWI), Review of the article: Thomas Huckle and Marcus Grote, Parallel Preconditioning with Sparse Approximate Inverses, *SIAM J. Sci. Comput.*, to appear in March 1997.
  May 31: Martin van Gijzen (Utrecht University), Parallel 2D ocean circulation simulations.
  July 5: Karl Meerbergen (Utrecht University), Implicitly restarted Arnoldi and purification for the shift-invert transformation.
  September 13: Raymond H. Chan (The Chinese University of Hong Kong), Iterative nethods for Toeplitz Systems.
  Henk A. van der Vorst (Utrecht University), A pa-

rallelizable and fast algorithms for very large generalized eigenproblems.
October 16: Dik Winter (CWI), Seymour Cray = Scientific Computing.
Auke van der Ploeg (CWI), Some experiences with preconditioning in the Jacobi-Davidson method.
November 6: Ben Sommeijer (CWI), Vector/parallel time integration methods for 3D biochemical transport in shallow water.
December 13: Maya Neytcheva (Faculty of Mathematics and Informatics, Catholic University Nijmegen) Some basic facts for efficient implementation of iterative solution methods on massively parallel computers.
Jos van Dorsselaer (Utrecht University), Computing eigenvalues occurring in continuation methods with the Jacobi-Davidson QZ method.

Working Group Parallel Computation in Magnetohydrodynamics and Astrophysics

- This group started in October 1993 to discuss the progress in the NWO pilot MPR (Massaal Parallel Rekenen) project 'Parallel Computation in Magnetohydrodynamics and Astrophysics'. In this project are collaborating the FOM Institute for Plasmaphysics Rijnhuizen, Utrecht University (the Mathematical and Astronomical Institutes) and CWI (as unofficial partner). In September 1995 NWO approved the follow-up of this pilot project in a four-year MPR project named *Parallel Computational Magneto-Fluid Dynamics: Nonlinear dynamics of thermonuclear, astrophysical, and geophysical plasmas and fluids.* CWI now is an official partner and new partners are the Computational Physics and Geodynamics Research Institutes of Utrecht University, the Institute for Marine and Atmospheric Research Utrecht, and the Computational Physics Institute of Delft University of Technology. The group met five times, namely on February 14 (FOM Rijnhuizen), April 17 (CWI), June 6 (Mathematical Institute, Utrecht University), September 4 (FOM Rijnhuizen), October 30 (CWI). During the meeting of June 6, Auke van der Ploeg and Margreet Nool gave presentations on 'Developments in preconditioning' resp. 'On how to speed up the Jacobi Davidson method for MHD problems'.

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

- *Distributed Computing* Workshop, Amsterdam, January 9, W.M. Lioen, H.J.J. te Riele.
- Symposium *Computational Science in Nederland*, Utrecht, 25 april, M. Nool, A. van der Ploeg, H.J.J. te Riele, J. de Swart, J.G. Verwer.
- *Numerical Analysis Day*, Utrecht, May 2, M. Nool, H.J.J. te Riele, P. de Zeeuw.
- *ANTS-II Symposium*, Bordeaux, May 18–23, H. Boender, R.-M. Elkenbracht–Huizing (A multiple polynomial general number field sieve), H.J.J. te Riele (A comparative study of algorithms for computing continued fractions of algebraic numbers).
- *AMS BeNeLux Congress*, Antwerpen, May 22–24, H.J.J. te Riele (On amicable pairs based on Euler's ϕ–function).
- *ERCIM Workshop on Parallel Numerical Algorithms*, Zürich, May 28–29, J.G. Blom (An evaluation of the Cray T3D programming paradigms in atmospheric chemistry/transport models), M. Nool (Parallel implementational aspects of the Jacobi-Davidson algorithm for the generalized eigenvalue problem), H.J.J. te Riele (Parallel and numerical aspects of the new world record for factoring large numbers).
- *Working visit* to Peter Montgomery (San Rafael, Ca.) and to Prof. H.W. Lenstra, Jr. (Univ. of California, Ca.), June 25–26, R.-M. Elkenbracht-Huizing.
- Symposium on the *Riemann Hypothesis* (in celebration of the centenary of the Prime Number Theorem), Seattle, Washington, USA, August 12–15, H.J.J. te Riele (Numerical experiments with respect to real-variable conditions equivalent to the Riemann Hypothesis).
- *The fifth Conference of the Canadian Number Theory Association*, Ottawa, Canada, August 17–22, H.J.J. te Riele (On ϕ–amicable pairs).
- *Conferentie van Numeriek Wiskundigen*, Zeist, September 25–27, M. Nool, A. van der Ploeg, H.J.J. te Riele.
- Symposium *De Kunst van het Afronden*, ter gelegenheid van het afscheid van Prof. Giel Paardekooper van de Katholieke Universiteit Brabant, Tilburg, October 11, P.W. Hemker, H.J.J. te Riele, B.P. Sommeijer.

Memberships of Committees and Other Professional Activities

H.J.J. te Riele

- Organiser of ERCIM Workshop on 'Parallel Numerical Algorithms and Applications', Zürich, Switzerland, May 28.
- Proposal Coordinator and Applications–task coordinator of the ERCIM project proposal 'Advancing parallel processing exploitation by interfacing applications, programming and architectures (APPEL)' for the Training and Mobility of

Researchers Programme (TMR) of the European Commission.
- Secretary of the Advisory Committee for the 'Beeger Lecture'.
- Editor of Nieuw Archief voor Wiskunde (Section Expository Papers).
- Referee of papers for various scientific journals.
- Reviewer for 'Mathematical Reviews' and the 'Zentralblatt für Mathematik'.
- Chairman CWI - Bibliotheekcommissie.
- Member of the 'CWI Nameboard Board' (of the SMC personnel on the occasion of SMC's 50th anniversary).

J. Kok
- Secretary of the organising committee of the Conferentie van Numeriek Wiskundigen in Zeist.
- Secretary of the 'Adviescommissie Numerieke Wiskunde'.
- Member CWI committee Overleg Computer-Voorzieningen.
- Member CWI A-team.
- Member Algemeen CWI Colloquium.

W.M. Lioen
- Brandwacht/persluchtmaskerdrager.
- EHBO/reanimatie.
- Member 'Klankbordgroep'.
- Correspondent of the 'CWI Mededelingen'.

Papers in Journals and Proceedings

G.T. ANTHONY, H.M. ANTHONY, B. BITTNER, B.P. BUTLER, M.G. COX, R. DRIESCHNER, R. ELLIGSEN, A.B. FORBES, H. GROSS, S.A. HANNABY, P.M. HARRIS, J. KOK (1996). Reference software for finding Chebyshev best-fit geometric elements. *Precision Engineering* **19**, 28–36.

H. BOENDER, H.J.J. TE RIELE (1996). Factoring integers with large-prime variations of the quadratic sieve. *Experimental Mathematics* **5**, nr. 4, 101–117.

A. BOOTEN, H. VAN DER VORST (1996). Cracking large-scale eigenvalue problems, Part I: Algorithms, Part II: Implementations. *Computers in Physics* **10**(3), 239–242 (Part I), resp. nr. 4, 331–334 (Part II).

A. BOOTEN, D. FOKKEMA, G. SLEIJPEN, H. VAN DER VORST (1996). Jacobi-Davidson methods for generalized MHD-eigenvalue problems. *Zeitschrift für Angewandte Mathematik und Mechanik* **76**, Supplement 1, 131–134.

R.P. BRENT, A.J. VAN DER POORTEN, H.J.J. TE RIELE (1996). A comparative study of algorithms for computing continued fractions of algebraic numbers. H. COHEN (ed.). *Algorithmic Number Theory: Second International Symposium, ANTS-II* (Talence, France, 18–23.05.1996), Springer–Verlag, Berlin, 37–49.

G.L. COHEN, H.J.J. TE RIELE (1996). Iterating the sum-of-divisors function. *Experimental Mathematics* **5**(2), 91–100.

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R.-M. ELKENBRACHT-HUIZING (1996). Historical background of the number field sieve factoring method. *Nieuw Archief voor Wiskunde***14**(3), 375–389.

CWI Reports

NM-R9609. R.P. BRENT, P.L. MONTGOMERY, H.J.J. TE RIELE. *Factorizations of* $a^n \pm 1$, $13 \leq a < 100$: update 2.

NM-R9622. H. BOENDER. *The number of relations in the quadratic sieve algorithm*.

NM-R9618. A. VAN DER PLOEG. *Reordering strategies and LU-decomposition of block tridiagonal matrices for parallel processing*.

DEPARTMENT OF SOFTWARE TECHNOLOGY

Staff 1996

- Computational Models – AP1
  - J.W. de Bakker
  - A. Corradini
  - B.P.F. Jacobs
  - C.H.M. van Kemenade
  - J.J.M.M. Rutten
  - D. Turi
  - M. van Wezel
- Concurrency and Real-Time Systems – AP2
  - J.F. Groote
  - D.J.B. Bosscher
  - W.O.D. Griffioen
  - H.P. Korver
  - S.P. Luttik
  - J.M.T. Romijn
  - J. van Wamel
  - J.P. Warners
- Extensible Programming Environments – AP3
  - P. Klint
  - T.B. Dinesh
  - A. van Deursen
  - J. Heering
  - J. Kamperman
  - D. Naidich
  - H.R. Walters
- Algebraic and Syntactic Methods – AP4
  - J.W. Klop
  - G. Barthe
  - I. Bethke
  - H. Elbers
- Secretary: J.J. Bruné-Streefkerk

Computational Models – AP1

Staff

- Prof. dr. J.W. de Bakker, department head and group leader
- Dr. A. Corradini, TMR fellow (from September 1)
- Dr. B.P.F. Jacobs, post-doc (till September 1)
- Drs. C.H.M. van Kemenade, OIO
- Dr. J.J.M.M. Rutten, researcher
- Drs. D. Turi, OIO (till May 1)
- Drs. M. van Wezel, junior researcher (OIO)

Scientific Report

The book Control Flow Semantics, written by *De Bakker* and dr. E.P. de Vink (Vrije Universiteit Amsterdam) and collecting more than a decade of research in semantics by AP1 and its associates, was published in the spring of 1996 by The MIT Press. The authors undertook various efforts to further disseminate their work, including the preparation of two tutorial papers (presented at Topology conferences in Maine, USA/Prague) and a lectures series in Macau/Beijing. In joint work with Van Breugel (formerly AP1, now at Pisa University), De Bakker moreover completed a contribution to the Festschrift in honour of Robin Milner's 60th anniversary. The theme of this paper is second order communication and concurrency.

As new project, in a collaboration also involving Rutten, prof. dr. J.N. Kok (RU Leiden) and the company Hollandse Signaal, a beginning was made with the study of formal properties (semantics, refinement) of coordination languages.

During the first part of his one-year stay at CWI, *Corradini* has started to study the theory of coalgebras and of coalgebraic specifications, partly developed at CWI during the last decade. He also started addressing some open questions in the theory, in cooperation with Jan Rutten and Bart Jacobs (Katholieke Universiteit Nijmegen). In particular they aim at formulating and proving a coalgebraic version of Birkoff's completeness theorem of equational deduction; and at investigating the relationship between the definition of bisimulation as suitable relation on coalgebras and that as span of open maps by Joyal et al.

Corradini also continued previous work on an abstract, categorical representation of term graphs and term graph rewriting (in cooperation with Fabio Gadducci (Technical University of Berlin)), based on s-monoidal categories, and aimed at providing a clearer understanding of the relationship between term graphs and terms, and between the corresponding rewriting theories. He also continued to work on a opfibrational presentation of phenomena arising in the double-pushout theory of graph rewriting with Richard Banach (University of Manchester).

Jacobs has been employed by the NWO 'HOOP' project on 'Higher Order Object-Oriented Processes' until 1/9/1996. His study of object-oriented concepts in a co-algebraic framework resulted in a specification language for object-oriented and hybrid systems (combining discrete and continuous dynamics). Minimal realisations of specifications can be described as terminal models (in suitable categories). The most recent work (which is being continued in Nijmegen after the end of the HOOP project) concerns coinductive proof techniques for establishing refinements between coalgebraic specifications, involving bisimulations and invariants. Such proofs can be formalised and checked in mechanised proof systems like PVS.

Rutten has continued the work on coalgebras as a general framework for infinite data types, transition systems, and dynamical systems. The earlier results on a calculus for transition systems have been generalized to classes of systems (coalgebras) of a large family of well-behaved functors, thus constituting a theory of universal coalgebra, along the lines of universal algebra. The main ingredients are coalgebras, homomorphisms and bisimulations, and special attention is given to coinductive definitions and proofs. Amongst others, a Birkhoff theorem for covarieties of coalgebras has been proved. The theory of coalgebra has been applied to obtain models for probabilistic transition systems and programming languages (in joint work with E.P. de Vink, Free University of Amsterdam).

Rutten has continued his work on generalized (ultra)metric domain theory, based on the work of F. Lawvere on generalized metric spaces. The results on completion, topology, and powerdomains for generalized ultrametric spaces, all based on the metric Yoneda embedding, have been extended to generalized metric spaces (in joint work with M. Bonsangue (Free University of Amsterdam) and F. van Breugel (University of Pisa)). Furthermore, an enriched-categorical account of the notion of limit has been obtained, using weighted (co)limits. The theory has been used to relate closed balls and so-called formal balls, which play a role in Lawson's and Edalat's work on approximation and computability.

Turi has been working at the completion of his thesis *Functorial Operational Semantics and its Denotational Dual*, which has been defended at the Free University, Amsterdam, on June 6, 1996. The no-

tion of 'functorial operational semantics' introduced in this thesis is a categorical formulation (and generalization) of 'well-behaved' structural operational semantics based on labelled transition systems. This notion has several desirable properties (such as congruence of the associated strong bisimilarity, and existence of a dual denotational semantics) and it subsumes existing, concrete schemes (such as GSOS) for guaranteeing such good behaviour. All this is achieved via use of the category theory of monads and comonads. The thesis also contains a coalgebraic treatment of the theory of non-well-founded sets which simplifies and improves some aspects of Peter Aczel's original presentation.

Van Kemenade continued his research on Evolutionary Computation methods and their applications. Work on evolutionary Air Traffic Flow management (ATFM) was done in cooperation with J.N. Kok (Leiden University) and J.M. van den Akker (National Aerospace Laboratories NLR). This year a project started on the application of neural networks for unsupervised classification. In the project there is cooperation with R.J. Mokken (CCSOM, University of Amsterdam), H. La Poutré (Leiden University) and P. LaPotin (CRREL, Hanover USA). Also research on the foundations of evolutionary computation was carried out. As a result robust selection schemes for evolutionary algorithms were obtained.

Van Wezel continued working on applications of neural networks. First, as a follow up of a project started in 1995, neural network inspired methods were developed to extract useful information from marketing and sales data. Second, for a joint project with Nijenrode University, a data visualization and clustering tool was developed for an MS-windows environment. This tool uses various neural network techniques and is now in use at the Directorate-General of Public Works and Water Management.

At Leiden University, Van Wezel has been active organizing the ALP-colloquium and researching neural network methods for Multidimensional Scaling (MDS).

Organization of Conferences, Workshops, Courses, etc.

- The SMC/Academia Europaea Symposium on Informatics was held in Amsterdam, April 11, 12, as part of the festivities on the occasion of the 50th anniversary of the Stichting Mathematisch Centrum. The venue of the Symposium was the CWI on April 11 and the KNAW Trippenhuis on April 12.
  J.W. de Bakker – chair of the AE section on Informatics – was chairman of the symposium.
  The program of the meeting was the following:

  April 11
  - R. Milner (Cambridge), Calculi for Interactive Behaviour
  - A. Razborov (Moscow), Lower Bounds for Propositional Proofs
  - B. Buchberger (Linz), Future Directions in Symbolic Math Systems: Combining Algebra and Logic
  - G. Berry (Sophia Antipolis), The Esterel Language: from Mathematical Semantics to Industrial Applications
  - A. Salomaa (Turku), Patterns and Pattern Languages
  - K. Mehlhorn (Saarbrücken), The LEDA Platform of Combinatorial and Geometric Computing

  April 12
  - M. Broy (Munich), The Role of System Modeling in Science and Society
  - I. Havel (Prague), Sending Messages to Unknown Recipients
  - D. Bjoerner (Macao), Software Support for Infrastructure Systems: Research Issues in an Enabling Technology for a Developing World
  - G. Kahn (Sophia Antipolis), Computer Science and Computer Technology
- ACG – the Amsterdam Concurrency Group. ACG is an – on average biweekly – seminar in which ongoing research on semantics is discussed by members and former members of AP1, and invited visitors. External participants include dr. E. de Vink (VUA), prof.dr. J.N. Kok (RUL), M. Bonsangue (VUA), dr. F.C. van Breugel, drs. J.J. den Hartog (VUA), and dr. J.M. Jacquet (Namur).

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

- *De Waarde van Wetenschap, SMC 50 jaar Jubileumcongres*, Amsterdam, February 8: J.W. de Bakker.
- *Workshop on Probabilistic Algorithms and Algorithmic Probability* Utrecht University (PAAP I), Februari 21 and Nijmegen University (PAAP II), March 15 C.H.M. van Kemenade.
- *Jaarvergadering Nederlandse Vereniging voor Theoretische Informatica*, Utrecht, March 1: J.W. de Bakker, J.J.M.M. Rutten.
- *Leiden Evolutionary Algorithm Day* Leiden University, March 8: C.H.M. van Kemenade (the Cluster Evolution Strategy).

- *Soiree Wiskunde en Informatica, Een Gouden Bruiloft, SMC 50 jaar*, Amsterdam, March 12: J.W. de Bakker.
- *SMC/Academia Europaea Informatics Symposium*, Amsterdam, April 11–12: J.W. de Bakker.
- *Coordination '96*, Cesena, Italy, April 15–17: J.W. de Bakker, J.J.M.M. Rutten.
- *IPA dagen* Veldhoven, April 15–16, C.H.M. van Kemenade (Evolutionary Optimization).
- *Review ESPRIT Basic Research Action Coordination*, Cesena, Italy, April 18: J.W. de Bakker.
- *Seminar on Semantics of Concurrent Systems*, Dagstuhl, Germany, May 5–8: J.W. de Bakker (Semantics for Unguarded Recursion).
- *Conference on Modern Algebra and its Applications*, Nashville, USA, May 14–18: J.J.M.M. Rutten (Invited Lecture: An Introduction to Coalgebra by Examples: Transition Systems and Dynamical Systems).
- *Working visit University of Tulane*, Prof. M. Mislove, New Orleans, USA, May 19–25: J.J.M.M. Rutten.
- *Working visit Imperial College*, London, UK, May 20–21: B.P.F. Jacobs (Talk: Inheritance and Cofree Constructions.
- *IEEE Conference on Evolutionary Computation ICEC '96*, Nagoya, Japan, May 20–22: C.H.M. van Kemenade (Cluster Evolution Strategies, enhancing the sampling density function using representatives).
- *International Conference on Neural Networks*, Washington D.C., USA, June 2–6: M.C. van Wezel (Determining the Number of Dimensions Underlying Customer-choices with a Competitive Neural Network).
- *AMAST '96*, Munich, Germany, July 1–5: B.P.F. Jacobs (Co-algebraic Specifications and Models of Deterministic Hybrid Systems).
- *ECOOP 1996*, Linz, Austria, July 8–12: B.P.F. Jacobs (Inheritance and Cofree Constructions).
- *8th Prague Topological Symposium*, Prague, Czech Republic, August 18–22: J.W. de Bakker (Metric Control Flow Semantics).
- *Working visit University of Pisa*, Pisa, Italy (dr. F. van Breugel): August 21–23: J.J.M.M. Rutten.
- *CONCUR '96*, Pisa, Italy, August 26–28: J.J.M.M. Rutten.
- *Dagstuhl Seminar 9637 Graph Transformations in Computer Science*, Dagstuhl, Germany, September 9–13: A. Corradini.
- *Introduction 1996*, Dutch Institute for Programming and Algorithmics (IPA), Noordwijk, September 17: J.W. de Bakker, J.J.M.M. Rutten (Invited lecture: Trends in semantics).
- *Parallel Problem Solving from Nature IV*, Berlin, Germany, September 22–26: C.H.M. van Kemenade (Evolutionary Air Traffic Flow Management for Large 3D-problems *and* Explicit filtering of building blocks for Genetic Algorithms (poster-presentation)).
- *Second International Workshop Computation and Approximation*, Darmstadt, Germany, September 25–29: J.J.M.M. Rutten (Invited lecture: Weighted colimits and formal balls in generalized metric spaces).
- *IFIP WG 2.2 meeting*, Macau, September 21–27: J.W. de Bakker (Metric Semantics for Action Refinement).
- *IFIP WG 2.2 Seminar*, Beijing, China, September 29–October 5: J.W. de Bakker (3 lectures on Semantics for 27 languages).
- *Electors' Meeting Chair Computer Science*, University of Oxford, Oxford, UK, October 15–16: J.W. de Bakker.
- *Study day on Spatial Statistics for Remote Sensing* ITC, Enschede, October 16: C.H.M. van Kemenade.
- *Jubileumsymposium Prof. dr. M. Rem 25 jaar TUE*, Eindhoven, November 1: J.W. de Bakker.
- *Eighth Dutch conference on Artificial Intelligence* Utrecht. November 21–22: C.H.M. van Kemenade (Comparison of Selection Schemes for Evolutionary Constrained Optimization).
- *IPA, Bijeenkomst Onderzoeksleiders*, Veldhoven, November 28: J.W. de Bakker.
- *Workshop EU ESTA Working Party 'Towards a user-friendly Information Society'*, Brussels, Belgium, December 9: J.W. de Bakker.

Memberships of Committees and Other Professional Activities

J.W. de Bakker:

- Professor of Computer Science, Vrije Universiteit Amsterdam
- Member Koninklijke Nederlandse Akademie van Wetenschappen
- Member Akademieraad voor de Wiskunde
- Member Selection committee Natuurwetenschappen, Programma Akademieonderzoekers
- Member Academia Europaea and chairman Section Informatics, A.E.
- Member EU European Science and Technology Assembly
- Editor Cambridge University Press Tracts in Theoretical Computer Science
- Consulting editor, Wiley Series in Parallel Computing

- Editor Theoretical Computer Science
- Editor Fundamenta Informaticae
- Associate editor Journal of Computer and System Sciences
- Member IFIP Working Group 2.2 on Formal Description of Programming Concepts
- Board member IPA, Dutch Graduate School Institute for Programming and Algorithmics
- Project leader SION project HOOP: Higher Order and Object-Oriented Processes
- Site leader, EU Human Capital and Mobility Network/Fellowships to Institutes project EUROFOCS
- Member ESPRIT Working Group Coordina
- Reviewer EU Basic Research Action Coordination
- Project leader SION project COLA: Coordination Languages
- Program Committee member COORDINATION '97, Berlin, September 1997
- Elector Professorship of Computing Science, Oxford University
- Referee INTAS/RFBR programme
- Chairman SION Evaluation Committee
- Chairman, SMC/Academia Europaea Informatics Symposium, 11,12 April, Amsterdam
- Member Steering Committee European Educational Forum (IPA, BRICS – Aarhus, TUCS – Turku)
- Member Ph.D. Committee A. Thijs, RUG
- Member Ph.D. Committee M. Dezani-Ciancaglini, KUN
- Member Ph.D. Committee N.W. Keesmaat, RUL
- Thesis advisor D. Turi, VUA, June 6
- Thesis advisor M. Bonsangue, VUA, November 21

A. Corradini:

- European Coordinator of the TMR Network GETGRATS, 'General Theory of Graph Transformation Systems'
- Co-editor (with Ugo Montanari) of Mathematical Structures in Computer Science, Vol. 6, No. 6, Cambridge University Press, special issue dedicated to the SEGRAGRA'95 Workshop, held in Volterra, Italy from August 28 to September 1, 1995.

B.P.F. Jacobs:

- Co-advisor of D. Turi, May 1996 (in the context of SION project 'Non-well-founded sets and programming language semantics')

J.J.M.M. Rutten:

- Co-advisor of D. Turi, May 1996 (in the context of SION project 'Non-well-founded sets and programming language semantics')
- Member of the SION project 'CoLa: Formal methods and refinement for Coordination Languages'
- Member 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 the 'Nieuwsbrief van de NVTI'
- Member of the programme committee of CONCUR'96
- Member of the publicity board of ICALP'97
- Member of the programme committee of MFPS'97 (Mathematical Foundations of Programming Semantics)

Visitors

- M. Schellekens, Imperial College, London, March 5–6 (Complexity and topology).
- F.C. van Breugel, University of Pisa, Pisa, March 12–13 (A Labelled Transition Semantics for the Synchronous π I-Calculus).
- J.-M. Jacquet, University of Namur, Namur, March 26 (μ -log 2 as a coordination language).
- M. Mislove, University of Tulane, New Orleans, November 19 (Domain-theoretic Models for Nondeterminism).
- P. Panangaden, BRICS, Aarhus, November 26 (Bisimulation for Labelled Markov Processes).

Papers in Journals and Proceedings

J.W. DE BAKKER, B.P.F. JACOBS, J.J.M.M. RUTTEN (1996). Semantics. In *Images of SMC Research 1996*, Stichting Mathematisch Centrum, Amsterdam, 297–303.

J.W. DE BAKKER, E.P. DE VINK (1996). A metric approach to control flow semantics. *Papers on General Topology and Applications*, Annals of the New York Academy of Sciences, **806**, 11–27.

M.M. BONSANGUE, F.C. VAN BREUGEL, J.J.M.M. RUTTEN (1996). Alexandroff and Scott topologies for generalized ultrametric spaces. *Proceedings of the 11th Summer Conference on General Topology and Applications*, Annals of the New York Academy of Sciences, **806**, 49–69.

A. CORRADINI, R. HECKEL, H. EHRIG, M. LOEWE (1996). Horizontal and vertical structuring of graph transformation systems. *Mathematical Structures in Computer Science* **6**(6), 613–648.

B.P.F. JACOBS (1996). Objects and classes, coalgebraically. B. FREITAG, C.B. JONES. C. LENGAUER. H.-J. SCHEK (eds.). *Object-Orientation with Parallelism and Persistence*, Kluwer Acad. Publ., 83–103.

B.P.F. JACOBS (1996). Inheritance and cofree constructions. P. COINTE (ed.). *European Conference on Object-Oriented Programming*, Springer LNCS 1098, 210–231.

B.P.F. JACOBS (1996). Coalgebraic specifications and models of deterministic hybrid systems. M. WIRSING, M. NIVAT (eds.). *Algebraic Methods and Software Technology*, Springer LNCS 1101, 520–535.

B.P.F. JACOBS (1996). On Cubism. *Journal of Functional Programming* **6**, 379–391.

C.H.M. VAN KEMENADE (1996). Cluster Evolution Strategies, enhancing the sampling density function using representatives. *Proceedings of the IEEE conference on Evolutionary Computation (IEEE-ICEC 1996)*, 637–642.

C.H.M. VAN KEMENADE (1996). Explicit filtering of building blocks for genetic algorithms. *Proceedings of the Parallel Problem Solving from Nature (PPSN-IV 1996)*, 494–503.

C.H.M. VAN KEMENADE, J.M. VAN DEN AKKER, J.N. KOK (1996). Evolutionary air traffic flow management for large 3D-problems. *Proceedings of the Parallel Problem Solving from Nature (PPSN-IV 1996)*, 910–919.

C.H.M. VAN KEMENADE (1996). Comparison of selection schemes for evolutionary constrained optimization. *Proceedings of the Eight Dutch Conference on Artificial Intelligence (NAIC-1996)*, 245–254.

J.J.M.M. RUTTEN (1996). Elements of generalized ultrametric domain theory. *Theoretical Computer Science* **170**, 349–381.

MICHIEL C. VAN WEZEL, JOOST N. KOK, K. SERE (1996). Determining the number of dimensions underlying customer-choices with a competitive neural network. *Proceedings of the IEEE International Conference on Neural Networks (ICNN '96)* **1**, 484–490.

CWI Reports

CS-R9602. P. DI GIANANTONIO. *A golden ratio notation for the real numbers.*

CS-R9607 B.P.F. JACOBS. *Automata and behaviour in categories of processes.*

CS-R9609. B.P.F. JACOBS. *Coalgebraic specifications and models of deterministic hybrid systems.*

CS-R9636. M.M. BONSANGUE, F.C. VAN BREUGEL, J.J.M.M. RUTTEN. *Generalized metric spaces: completion, topology, and powerdomains via the Yoneda embedding.*

CS-R9647. C.H.M. VAN KEMENADE. *Explicit filtering of building blocks for genetic algorithms.*

CS-R9648. C.H.M. VAN KEMENADE. *Cluster evolution strategies - enhancing the sampling density function using representatives* -.

CS-R9649. C.H.M. VAN KEMENADE. *Comparison of selection schemes for evolutionary constrained optimization.*

CS-R9650. C.H.M. VAN KEMENADE, J.M. VAN DEN AKKER, J.N. KOK. *Evolutionary air traffic flow management for large 3D-problems.*

CS-R9652. J.J.M.M. RUTTEN. *Universal coalgebra: a theory of systems.*

Other Publications

B. BACK, T. LAITINEN, K. SERE, M. VAN WEZEL (1996). Choosing Bankruptcy Predictors Using Discriminant Analysis, Logit Analysis, and Genetic Algorithms, TUCS (Turku Centre for Computer Science) Technical Report No. 40.

J.W. DE BAKKER, E.P. DE VINK (1996). *Control Flow Semantics, Foundations of Computing Series*, The MIT Press, 564 pp.

J.W. DE BAKKER, E.P. DE VINK (1996). Metric control flow semantics. A.W. MUSSCHENGA, M.A. KAASHOEK, W.B. DREES (eds.). *De eigen wijsheid van wetenschap en geloof, Essays in gedachtenis aan Maarten Maurice*, VU Uitgeverij, Amsterdam, 34–48.

R. BANACH, A. CORRADINI (1996). *An Opfibration Account of Typed DPO and DPB Graph Transformation: General Productions*, Technical Report UMCS-96-11-2, University of Manchester, Department of Computer Science.

B.P.F. JACOBS (1996). *Hybrid systems of coalgebras plus monoid actions*, Technical Report CSI-R9614, Nijmegen University.

B.P.F. JACOBS (1996). *Behaviour-refinement of object-oriented specifications with coinductive correctness proofs*, Technical Report CSI-R9618, Nijmegen University.

W.A. KOSTERS AND M.C. VAN WEZEL (1996). *Understanding Customer Choice Processes Using Neural Networks*, Technical Report 96-33, Leiden University.

J.J.M.M. RUTTEN (1996). Domain equations. *Control Flow Semantics*, J.W. DE BAKKER AND E. DE VINK (eds.)., MIT Press, pp. 531–537.

D. TURI (1996). *Functorial Operational Semantics and its Denotational Dual*, Ph.D. Dissertation, Vrije Universiteit Amsterdam.

M.C. VAN WEZEL, J.N. KOK AND W.A. KOSTERS (1996). *Two Neural Network Methods for Multidimensional Scaling*, Technical Report 96–35, Leiden University.

Concurrency and Real-Time Systems – AP2

Staff

- Dr. ir. J.F. Groote, group leader
- Drs. D.J.B. Bosscher, junior researcher (OIO)
- Drs. W.O.D. Griffioen, junior researcher (OIO)
- Dr. H.P. Korver, post doc
- Drs. S.P. Luttik, junior researcher (OIO) (from September 1)
- Drs. J.M.T. Romijn, junior researcher (OIO)
- Dr. J. van Wamel, project member (from October 15)
- Ir. J.P. Warners, junior researcher (OIO)

Scientific Report

Jan Friso Groote started working on January 1 1996 as the group leader in succession of Frits Vaandrager who left for Nijmegen University. The research started with an orientation phase where time was invested in several CWI related topics to get better acquainted with the new environment.

First attention was paid to the research within the group AP3 on reverse engineering and the year 2000 problem. After this attention was paid to the implementation of the propositional theorem prover *HeerHugo* in a parallel environment. Using PVM (Parallel Virtual Machine) an implementation was made on a network of workstations at CWI, on the SP2 at SARA and on the parsytec machine at the UvA. Due to the fact that a parallel checker cannot use global information about a propositional formula, the performance of the parallel checker was disappointing. The sequential variant of HeerHugo has been improved throughout the year and has been improved with several factors in performance. It has been applied to prove safety of railway control, to prove consistency of databases (for NedCar).

After this attention has focussed to PAMs (Parallel Abstract Machines) which are very low level highly parallel devices and exercises took place with implementing elementary data structures on these machines in order to understand their suitability for actual computing.

Focus then shifted to verification of protocols. The verification of the distributed summing protocol was finished, and a general theorem on paralellising an arbitrary but bounded number of parallel processes was proved.

Then an improvement was made of the μCRL toolset. Several components (tools) were replaced by improved components, using ARM (Abstract Rewriting Machine) developed within AP3. This boosted performance with a factor 20.

The language μCRL has been extended with a syntax to denote timing features. The question of an appropriate semantics and a clean axiomatisation that allow to verify real live protocols have been addressed. It is expected that in the second quarter of 1997 this work will be finished.

An important change in the timed version of μCRL will be that a distinction will be made between constructors and functions in abstract datatypes. A major advantage of this is a cleaner treatment of induction. It also allows a more structural approach to infinite and large state spaces. It has been investigated how these can be used in relation to the μCRL toolset.

Doeko Bosscher spent 1996 mostly for work preparing his Ph.D. thesis. In this year also the most important of this thesis evolved, a proof of the open problem Robin Milner whether exists a classification of regular process graphs which can be expressed with regular expressions modulo bisimulation.

David Griffioen worked on the formalization of (part of) Input/Output-Automata theory using PVS. PVS is fit for formalizations as these, thanks to its highly readable syntax and expressive type system. An important theorem is proved using PVS, it states how one can prove that one automaton implements an other automaton. Furthermore a protocol is proved correct in PVS, during this case study the powerful decision procedures (oa. for arithmetic) were very useful. In reasoning on IO-automata the notion of potentially infinite sequences is of high importance. Together with Marco Devillers these sequences are formalized in PVS, and a number of important lemmas are proved.

Judi Romijn has spent most of her time in January until May on the formal specification of a fragment of the P1394 serial bus protocol, as given in the standard by IEEE. The specification has been constructed and typechecked in the theorem proving system PVS in collaboration with drs. David Griffioen and is to be presented in an article together with a few correctness criteria for this fragment, of which the proof will be given in an intuitive manner. This article is written under the supervision of prof. Frits Vaandrager. It will be finished and submitted to an appropriate conference in the beginning of 1997. In June, Romijn has polished the final version of the article accepted for publication in the LNCS volume 'Formal Systems Specification – The RPC-Memory Specification Case Study'. From June until November Romijn has worked together with

dr. Jan Springintveld (KUN) and ir. Jean Moonen (Philips) at Philips Research Laboratories Eindhoven on the development of a tool environment (Phact) for conformance testing of VHDL designs. This project was supervised by dr. Ron Koymans and prof. Loe Feijs (both Philips). In August Romijn managed to run Phact completely on a small VHDL design. On September 15, Romijn gave a presentation at the Second Dutch Testing Day about Phact. In September and October, Romijn and Springintveld finished both confidential and public documentation concerning Phact and the example tested. A first attempt to publish an article on Phact has not succeeded. On November 15, a workshop organized by Moonen, Koymans, Romijn, and Springintveld took place in Eindhoven, where Phact was presented with talks and a demonstration. About 15 people attended this workshop. Romijn visited the autumn school on verification organized by BRICS in Aarhus, Denmark and the school on embedded systems organized by IPA in Veldhoven in October and November. In December, Romijn continued her work on the article concerning the P1394 serial bus protocol.

Henri Korver worked on the development of two tools: 1) a transformation tool (written in ASF+SDF and PEARL) which converts Nedcar formulas into proposition formulas 2) a simulator for μCRL. The latter tool is implemented by means of C, ASF+SDF and TCL/TK. Moreover, he documented this tool by a type-checked μCRL specification.

Bas Luttik works as an OIO in SION project 612-33-008, 'A Modular Toolset for muCRL developed using muCRL' (halftime on CWI and halftime on UvA). As a first step in this project he specified a part of the protocol described the P1394 Standard for a Serial Bus, to gain some experience in using muCRL and to test the existing components of the toolset. This brought to light a problem in the linearizator-module of the toolkit; this module is currently under revision.

Jos van Wamel is concerned with the MPEG2 decoder being built at Philips. At the Systems Laboratory Eindhoven of Philips a system support environment is developed for a 'one chip' DVB (Digital Video Broadcast) source decoder.

Support on system compliance test issues is given by a group from Philips RL Eindhoven. In particular responsibility for MPEG2 stream generation and analysis, and the testing of interactive aspects of the control software Application Programming Interface of the IC is assumed. Part of the project is subcontracted to the CWI.

Joost Warners is working on the satisfiability problem of propositional logic in general. More specific, he is considering various techniques and approaches to solve this problem, and also how this problem relates to other types of problems. In this respect a CWI report has appeared in which it is shown that general 0-1 programming problems can be linearly transformed to satisfiability problems. Furthermore, in connection with his work in Delft, he has been working on nonlinear approaches to general 0-1 problems.

Organization of Conferences, Workshops, Courses, etc.

- Phact: A Tool Environment for Automated Conformance Testing of VHDL Designs" (workshop). Philips Research Laboratories Eindhoven November 15, 1996 (organization: Moonen, Koymans, Romijn, Springintveld).

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

- *COST 247 meeting*, Madrid, Spain, February 11–14: J.F. Groote (A specification and Implementation of Components of a μCRL toolbox).
- *3e Specificatiedag*, Enschede, Holland, March 21: J. Romijn.
- *ERCIM Formal Methods Working Group*, Oxford, UK, March 18–20: J.F. Groote (Formal specification and implementation of components of a μCRL toolbox, and Bisimulation is decidable for BPA_δ (for Doeko Bosscher)).
- *Strategic Directions*, Boston, USA, June 14–15: J.F. Groote.
- *Universität Karlsruhe*, Germany, June 5: J.F. Groote (HeerHugo, a propositional theorem prover).
- *COST 247 meeting*, Maribor, Slovenia, June 17–19: J.F. Groote (session chair).
- *ICALP '96*, Paderborn, Germany, July 7–12: D. Bosscher (Regularity of a Large Class of Context-Free Processes is Decidable), W.O.D. Griffioen.
- *CAV '96*, New Brunswick, USA, July 30–August 3: W.O.D. Griffioen (Verification of an Audio Protocol with Bus Collision ..).
- *IPA Workshop*, Noordwijk, September 16–20: J.F. Groote.
- *BRICS Autumn School on Verification*, Aarhus, Denmark, October 28–November 1: W.O.D. Griffioen, J. Romijn.
- *COST 24 meeting*, Antalya, Turkey, November 4–5: J.F. Groote (The verification of a distributed summing algorithm).

- *ISCIS XI*, Antalya, Turkey, November 6–11: J.F. Groote (Equivalence of the concave optimisation method and d'Agostino's tableaux for proposition logic) and H.P. Korver (On Automating Process Algebra Proofs).
- *Ordina workshop*, Amsterdam, October 29: H.P. Korver.
- *IPA Introductiedagen*, Noordwijk. 17–20 September: S.F.M. Luttik. J.P. Warners. J.F. Groote.
- *Advances in Combinatorial Optimization*, Imperial College London, March 27–29: J.P. Warners (Potential reduction algorithms for structured combinatorial optimization problems).
- *Statistische Dag 1996*, Jaarbeurs congreszaal, Utrecht. April 3: J.P. Warners (A potential reduction approach to the frequency assignment problem).
- *Seminar on Timed and Hybrid Systems*, Nijmegen, The Netherlands. July 12: J. Romijn (The Observational Power of Clocks) W.O.D. Griffioen (Automatic symbolic verification of embedded systems).
- *Second Dutch Testing Day*, Nijmegen, The Netherlands. September 15: J. Romijn (The Philips Tool Environment for Conformance Testing of VHDL Protocol Designs).
- *Phact: A Tool Environment for Automated Conformance Testing of VHDL Designs* (workshop), Philips Research Laboratories Eindhoven, November 15: J. Romijn (Test Execution in Phact, Cadence Leapfrog: A Tiny Introduction).
- *IPA School on Embedded Systems*, Veldhoven, The Netherlands, November 25–29: J. Romijn and W.O.D. Griffioen.

Memberships of Committees and Other Professional Activities

Research group:
- HCM Cooperation Network EXPRESS – Expressiveness of Languages for Concurrency. (10 December 1993 – 10 December 1997)
- European Research Action on Verification and Validation Methods for Formal Descriptions (COST Project 247)
- Society for Theoretical Computer Science in The Netherlands (Nederlandse Vereniging voor Theoretische Informatica)
- Member Dutch Graduate School 'Institute for Programming Research and Algorithms'

J.F. Groote:
- Editor special issue 'Science of Computer Programming' (with M. Rem).
- Reviewer Zentralblatt für Mathematik.
- Program committee member of 11th International Symposium on Computer and Information Sciences (ISCIS XI,1996, Antalya, Turkey).
- Program committee member of COST 247 International Workshop on Applied Formal Methods in System Design, June 17–19, 1996, Maribor, Slovenia.
- Member of National Management Committee of the Europese COST 247 project 'formal specification and verification/validation and testing of software using formal specification techniques'. Chair of workpackage 2 'Analysis and validation techniques for distributed systems' (1994–)
- Coordinator EXPRESS (1996–)
- Member of EATCS.

D.J.B. Bosscher:
- Member of EATCS.

Visitors

- Roland Bol. 30 September 1996. Uppsala University (The Place of Formal Methods during Requirements Engineering Processes).
- Oliver Kullmann. November 13, 1996. Universität Frankfurt.

Papers in Journals and Proceedings

J. BENGTSSON, D. GRIFFIOEN, K. KRISTOFFERSEN, K. LARSEN, F. LARSSON, P. PETTERSSON, W. YI (1996). Verification of an Audio Protocol with Bus Collision Using UPPAAL. R. ALUR AND T.A. HENZINGER (eds.). *Proceedings of the 8th International Conference on Computer Aided Verification*, LNCS 1102, Springer-Verlag, New Brunswick, NJ, USA, 244–256.

J.M.T. ROMIJN (1996). Tackling the Dagstuhl'94 specification problem with I/O automata. M. BROY, S. MERZ, K. SPIES (eds.). *Formal Systems Specification – The RPC-Memory Specification Case Study*, LNCS 1169, Springer-Verlag, 437–476.

J.M.T. ROMIJN, F.W. VAANDRAGER (1996). A note on fairness in I/O automata. *Information Processing Letters* **59**(5), 245–250.

N.A. LYNCH, F.W. VAANDRAGER (1996). Action transducers and timed automata. *Formal Aspects of Computing* **8**(5), 499-538.

N.A. LYNCH, F.W. VAANDRAGER (1996). Forward and backward simulations, II: Timing-based systems. *Information and Computation* **128**(1), 1–25.

N.A. LYNCH, R. SEGALA, F.W. VAANDRAGER, H.B. WEINBERG (1996). Hybrid I/O automata. R. ALUR, T.A. HENZINGER, E.D. SONTAG (eds.). *Hybrid Systems III*, LNCS 1066, Springer-Verlag, 496–510.

F.W. VAANDRAGER (1996). Hybrid systems. *Images of SMC Research 1996*, Stichting Mathematisch Centrum, Amsterdam, 305–316.

R.N. BOL, J.F. GROOTE (1996). The meaning of negative premises in transition system specifications. *Journal of the ACM* **43**(5), 863–914.

J.F. GROOTE (1996). Hiding propositional constants in BDDs. *Formal Methods in System Design* **8**, 91–96.

J.F. GROOTE (1996). Concurrency theory will set standards for description and analysis of software, Computing Surveys, 28A(4), December, `http://www.acm.org/surveys/1996/GrootePosition/GrootePosition.html`

J.F. GROOTE, H. VAN MAAREN (1996). Equivalence of the concave optimisation method and d'Agostino's tableaux for propositional logic. V. ATALAY, E.A. (eds.). *Proceedings of the Eleventh International Symposium on Computer and Information Sciences (ISCIS-XI)*, Antalya, Turkey, 41–51.

J.F. GROOTE, J.C. VAN DE POL (1996). A bounded retransmission protocol for large data packets. A case study in computer checked verification. M. WIRSING, M. NIVAT (eds.). *Proceedings of AMAST'96*, Munich, Lecture Notes in Computer Science 1101, Springer-Verlag, 536-550.

J.F. GROOTE, M.P.A. SELLINK (1996). Confluence for Process Verification. *Theoretical Computer Science B (Logic, semantics and theory of programming)* **170**(1-2), 47–81.

D.J.B. BOSSCHER, W.O.D. GRIFFIOEN (1996). Regularity for a Class of Context-free Processes is decidable. *Proceedings of TACS '96, LNCS 1099*, Springer-Verlag, 182–193.

H.P. KORVER, M.P.A. SELLINK (1996). On Automating Process Algebra Proofs. V. ATALAY, E.A. (eds.). *Proceedings of the Eleventh International Symposium on Computer and Information Sciences (ISCIS-XI)*, Antalya, Turkey, 815–826.

CWI Reports

CS-R9617. J.M.T. ROMIJN. *Tackling the Dagstuhl'94 specification problem with I/O automata.*

CS-R9626. J.F. GROOTE. *A note on n similar parallel processes.*

CS-R9631. J.P. WARNERS. *A linear-time transformation of linear inequalities into conjunctive normal form.*

CS-R9632. H.P. KORVER. *Building a simulator in the μCRL toolbox. A case-study in modern software engineering.*

CS-R9640. J.F. GROOTE, J. SPRINGINTVELD. *Algebraic verification of a distributed summation algorithm.*

Other Publications

J.F. GROOTE. J. SPRINGINTVELD (1996). *Algebraic Verification of a Distributed Summation Algorithm*, Technical Report CSI-R9627, Department of Mathematics and Computer Science, University of Nijmegen.

H. KORVER, J. VAN DER VORST (1996). Succes NedCar afhankelijk van integratie systemen. *Automatisering Gids (weekblad over informatietechnologie)*, 30e jaargang nr. 27/28, vrijdag 5 juli, 1996.

S.P. LUTTIK, P. RODENBURG (1996). *Transformations of Reduction Systems*, Technical Report P9615. Programming Research Group. University of Amsterdam.

J.P. WARNERS (1996). *A Nonlinear Approach to a Class of Combinatorial Optimization Problems*, Faculty of Technical Mathematics and Informatics, Delft University of Technology Technical Report 96–119.

T. TRAFALIS, T. TERLAKY, J.P. WARNERS, C. ROOS (1996). *Unsupervised Neural Network Training via a Potential Reduction Approach*, Faculty of Technical Mathematics and Informatics, Delft University of Technology Technical Report, 96–172.

C. ROOS, T. TRAFALIS, T. TERLAKY, J.P. WARNERS (1996). *Solving Linear Systems with Low Rank Updates*, Faculty of Technical Mathematics and Informatics, Delft University of Technology, Technical Report, 96–149.

Extensible Programming Environments – AP3

Staff

- Dr. T.B. Dinesh, project member (supported by SION)
- Dr. A. van Deursen, project leader (since March 1)
- J. Heering, project leader
- Drs. J. Kamperman, project member (until November 1)
- Prof. dr. P. Klint, group leader
- Dr. D. Naidich, project member (until August 15, supported by NWO)
- Dr. H.R. Walters, project member (supported by SION)

Scientific Report

The group is involved in the design, implementation, and promotion of the ASF+SDF system for

interactive language development and incremental programming environment generation. The system, which was developed in cooperation with INRIA Sophia-Antipolis and other partners in the ESPRIT GIPE and GIPE II projects, incrementally generates an interactive environment for the language being developed, so the latter can be used immediately. It is primarily a development tool for application languages. The system is distributed to commercial and academic customers by the Connexité company in Sophia-Antipolis as well as by CWI itself.

In response to the needs expressed by several large Dutch banks, the emphasis in the group's work has been shifting towards the development of tools for system renovation, reverse engineering and software maintenance, and their incorporation in the ASF+SDF system. In particular, the Resolver project on the renovation of software for financial and banking applications started in the beginning of 1996 and is expected to run until mid 1998. It is financed and supported by ABN Amro and Roccade (DPFinance) and partly funded by the Dutch Ministry of Economic Affairs via the Senter project #ITU95017 *SOS Resolver*. The research is performed by CWI (see AP3.3 below), ID Research, and the University of Amsterdam.

AP 3.1 Implementation, maintenance, and promotion of the ASF+SDF system

The advances made by the group in the prototyping and automatic implementation of programming and domain specific languages using the ASF+SDF language development system were collected in the book A. van Deursen, J. Heering, P. Klint (eds.), *Language Prototyping: An Algebraic Specification Approach*, AMAST Series in Computing, Vol. 5, World Scientific, 1996, with contributions by A. van Deursen, T.B. Dinesh, J. Heering, P. Klint, E.A. van der Meulen (currently MeesPierson), F. Tip (currently IBM T.J. Watson Research Center), and E. Visser (University of Amsterdam).

AP3.2 Generation of tools for program analysis and optimization from formal language definitions, and their integration into the ASF+SDF system

(a) (Bergstra/Dinesh/Field/Heering/Naidich—supported in part by SION project *Generic Tools for Program Analysis and Optimization* and an NWO visitor's grant) PIM is an equational logic for symbolic execution and program transformation of imperative languages. The enrichment of its lazy store component was presented at ESOP '96 by Field and Heering. The full paper was revised and accepted for publication in *ACM Trans. Progr. Languages and Systems* (CS-R9646). The resistance to inductive mechanical verification of PIM's lazy store component was successfully overcome by Dinesh and Naidich (CS-R9630). Furthermore, Naidich put implicit induction procedures in a general framework (CS-R9620). Work on enrichment of PIM with loop transformations as used by restructuring compilers was started, but not yet finished.

(b) (Kamperman/Walters—supported in part by SION project *Generic Tools for Program Analysis and Optimization*) The notion of 'minimal term rewriting systems' (MTRS) was developed. Their properties make it possible to execute them directly (without translation) on the Abstract Rewriting Machine (ARM), which was developed earlier. On the other hand, arbitrary term rewriting systems can be translated to MTRSs. An abstract representation for term rewriting systems, called EPIC, was developed in conjunction with a compiler using the MTRS translation method. Apart from this, an application programming interface for the ARM software was developed, facilitating its use as a library by theorem provers and similar applications.

(c) Dinesh continued working with S. Üsküdarlı (University of Amsterdam) on building a meta-environment for visual languages, based on the ASF+SDF Meta-Environment. Prettyprinting visual terms in generated visual language environments was investigated and some heuristics were developed for maintaining the necessary *Share-Where* annotations during term rewriting. S. Üsküdarlı's Ph.D. thesis on this subject was finished.

AP3.3 Resolver (van Deursen/Klint—supported by ABN Amro, Roccade (DPFinance) and Senter project #ITU95017)

In 1996, the first release of the Resolver project *Program Analysis for System Renovation* focusing on analysis techniques for legacy programs, was completed. Three case studies were performed: year 2000 compliance, euro conversion, and conversion to OO-Cobol. The CWI contribution to the project has been in the areas of year 2000 compliance, literature study, evaluation of existing renovation tools, and origin tracking.

Organization of Conferences, Workshops, Courses, etc.

- P. Klint and J.W. Klop (AP4) continued the organization of the monthly VIP (Vragen uit de Informatica Praktijk) colloquium during the first semester. Lectures: January 19, Leo Runia; February 23, Tan Nieuwenhuyzen; March 29, Wil van der Aalst.

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

- *Working visit University of Wales, Swansea* (K. Meinke), Swansea, UK, January 22–24: J. Heering (A Complete Transformational Toolkit for Compilers).
- *Visit Philips Medical Systems*, Best, March 20: P. Klint (Systeemrenovatie).
- *COORDINATION '96*, Cesena, Italy, April 15–17: P. Klint (The ToolBus coordination architecture).
- *ESOP '96*, Linkoping, Sweden, April 22–24: T.B. Dinesh, J. Heering (A Complete Transformational Toolkit for Compilers).
- *Theory of Visual Languages*, Gubbio, Italy, May 30: T.B. Dinesh (Specifying Input and Output of Visual Languages).
- *Visit HISCOM*, Leiden, May 30: P. Klint (Systeemrenovatie).
- *AMAST '96*, Munich, Germany, July 1-5: A. van Deursen (Industrial Applications of ASF + SDF), P. Klint (The ToolBus coordination architecture: a demonstration).
- *Working visit IBM T.J. Watson Research Center*, July 25–26: J.F.Th. Kamperman (Minimal Term Rewriting Systems).
- *Rewriting Techniques and Applications '96*, New Brunswick, USA, July 27–August 3: J. Kamperman and H.R. Walters (System demonstration EPIC).
- *IEEE Symposium on Visual Languages VL '96*, Boulder, USA, September 3–6: T.B. Dinesh (The VAS formalism in VASE).
- *IPA week*, Noordwijk, September 19: P. Klint (Building distributed applications with the ToolBus; Systeemrenovatie).
- *PLILP/EAPLS*, Aachen, Germany, September 24–25: P. Klint.
- *Working visit University of Bergen*, Bergen, Norway (M. Haaveraaen), September 30–October 2: J. Heering (The ASF+SDF System and its Use for Program Transformation).
- *SAGA Coordination Meeting*, University of Wales, Swansea, UK, October 16–18: J. Heering (Optimizing C++ Programs).
- *ERCIM Workshop User Interfaces for All*, Prague, Czech Republic, November 7–8: T.B. Dinesh (Guiding User Interfaces Equationally).
- *SOFSEM*, Milovy, Czech Republic, November 22–25: P. Klint (Core technologies for system renovation).
- *ICSM/WERE Software Maintenance/Reverse Engineering*, Monterey, USA, November 6–10: A. van Deursen.
- *Working visit University of Wales, Swansea* (J.V. Tucker), Swansea, UK, November 26–27: J. Heering (The ASF+SDF Language Prototyping System).
- *Visit DPFinance*, Amersfoort, December 19: P. Klint (The Resolver Questionnaire).

Memberships of Committees and Other Professional Activities

J. Heering:

- External Ph.D. examiner B. Hearn, The Design and Implementation of Typed Languages for Algebraic Specification, University of Wales, Swansea, January 23, 1996 (Ph.D. advisor K. Meinke).
- External Ph.D. examiner K. Stephenson, An Algebraic Approach to Syntax, Semantics and Compilation, University of Wales, Swansea, November 27, 1996 (Ph.D. advisor J.V. Tucker).
- PC chair HOA '97.

P. Klint:

- President European Association for Programming Languages and Systems (EAPLS).
- Member steering committee ETAPS (European Joint Conferences on Theory and Practice of Software).
- Member advisory board ID Research.
- Ph.D. advisor J.F.Th. Kamperman, Compilation of Term Rewriting Systems, University of Amsterdam, September 16, 1996.
- Member Ph.D. committee D. Koelma, March 8; M. Beemster, March 28; J. Hillebrand, December 12.
- PC member ESOP '96, TAPSOFT '97, DPLE '97.

H.R. Walters:

- Ph.D. advisor (with P. Klint) J.F.Th. Kamperman, Compilation of Term Rewriting Systems, University of Amsterdam, September 16, 1996.

Visitors

- D. Naidich, University of Iowa/Kiev, January 1 - August 15 (NWO grant).

Papers in Journals and Proceedings

J.A. BERGSTRA, T.B. DINESH, J. FIELD, J. HEERING (1996). A complete transformational toolkit for compilers. *Programming Languages and Systems (ESOP '96)*, Lecture Notes in Computer Science, Vol. **1058**, Springer-Verlag, 92–107.

J.A. BERGSTRA, P. KLINT (1996). The discrete time ToolBus. *Algebraic Methodology and Software Technology (AMAST '96)*, Lecture Notes in Computer Science, Vol. 1101, Springer-Verlag, 286–305.

J.A. BERGSTRA, P. KLINT (1996). The ToolBus coordination architecture. *Coordination Languages and Models (COORDINATION)*, Lecture Notes in Computer Science, Vol. **1061**, Springer-Verlag, 75–88.

M. VAN DEN BRAND, P. KLINT, C. VERHOEF (1996). Core technologies for system renovation. *Theory and Practice of Informatics (SOFSEM'96)*, Lecture Notes in Computer Science, Vol. **1175**, Springer-Verlag, 235–255. Invited paper.

M. VAN DEN BRAND, A. VAN DEURSEN, P. KLINT, S. KLUSENER, E.A. VAN DER MEULEN (1996). Industrial applications of ASF+SDF. *Algebraic Methodology and Software Technology (AMAST '96)*, Lecture Notes in Computer Science, Vol. **1101**, Springer-Verlag, 9–18.

T.B. DINESH, S. USKUDARLI (1996). Specifying input and output of visual languages. *Proceedings Workshop on Theory of Visual Languages*, Workshop held in conjunction with AVI '96, Gubbio, Italy.

P.H. HARTEL, J.F.TH. KAMPERMAN, H.R. WALTERS, ET AL. (1996). Benchmarking implementations of functional languages with 'Pseudoknot' - a float-intensive benchmark. *J. Functional Programming* **6**, 621–655.

J.F.TH. KAMPERMAN, H.R. WALTERS (1996). Minimal term rewriting systems. *Recent Trends in Data Type Specification (ADT '95)*, Lecture Notes in Computer Science, Vol. **1130**, Springer Verlag, 274–290.

S. USKUDARLI, T.B. DINESH (1996). VAS formalism in VASE. *Proceedings of 1996 IEEE Symposium Visual Languages (VL '96)*.

H.R. WALTERS, J.F.TH. KAMPERMAN (1996). A model for I/O in equational languages with don't care non-determinism. *Recent Trends in Data Type Specification (ADT '95)*, Lecture Notes in Computer Science, Vol. **1130**, Springer Verlag, 522–535.

H.R. WALTERS, J.F.TH. KAMPERMAN (1996). EPIC: An equational language—Abstract machine and supporting tools (extended abstract). *Rewriting Techniques and Applications 1996 (RTA '96)*, Lecture Notes in Computer Science, Vol. **1103**, Springer Verlag, p. 427.

CWI Reports

CS-R9601. J.A. BERGSTRA, T.B. DINESH, J. FIELD, J. HEERING. *A Complete Transformational Toolkit for Compilers.* Full version of paper presented at ESOP '96. Also Technical Report RC 20342, IBM T. J. Watson Research Center, Yorktown Heights.

CS-R9604. H.R. WALTERS, J.F.TH. KAMPERMAN. *Epic 1.0 (unconditional) An equational programming language.*

CS-R9605. H.R. WALTERS, J.F.TH. KAMPERMAN. *Simulating TRSs by minimal TRSs: a simple, efficient, and correct compilation.*

CS-R9619. C. BROVEDANI, A.S. KLUSENER. *A verification of the Bakery protocol combining algebraic and model-oriented techniques.*

CS-R9620. D. NAIDICH. *On generic representation of implicit induction procedures.*

CS-R9622. M. VAN DEN BRAND, A. VAN DEURSEN, P. KLINT, A.S. KLUSENER, E.A. VAN DER MEULEN. *Industrial applications of ASF+SDF.*

CS-R9630. D. NAIDICH, T.B. DINESH. *Implicit induction techniques for the verifications of PIM - a transformational toolkit for compilers.*

CS-R9646. J.A. BERGSTRA, T.B. DINESH, J. FIELD, J. HEERING. *Towards a complete transformational toolkit for compilers.* To appear in *ACM Trans. Programming Languages and Systems*.

Other Publications

A. VAN DEURSEN, J. HEERING, P. KLINT (eds). (1996). *Language Prototyping: An Algebraic Specification Approach*, AMAST Series in Computing, Vol. **5**, World Scientific.

A. VAN DEURSEN (1996). An overview of ASF+SDF. *Language Prototyping*, Chapter 1.

A. VAN DEURSEN (1996). The static semantics of Pascal. *Language Prototyping*, Chapter 2.

T.B. DINESH (1996). A kernel object-oriented language. *Language Prototyping*, Chapter 3.

T.B. DINESH (1996). Typechecking with modular error handling. *Language Prototyping*, Chapter 4.

A. VAN DEURSEN, P. KLINT, F. TIP (1996). Origin tracking and its applications. *Language Prototyping*, Chapter 7.

J. HEERING (1996). Second-order term rewriting specification of static semantics: an exercise. *Language Prototyping*, Chapter 8.

A. VAN DEURSEN AND T.B. DINESH (1996). Origin tracking for higher-order term rewriting systems. *Language Prototyping*, Chapter 9.

A. VAN DEURSEN, P. KLINT, G. WIJERS (eds). (1996). *Program Analysis for System Renovation, Resolver Release I.*

A. VAN DEURSEN, P. KLINT, G. WIJERS (1996). Program analysis for system renovation – an overview of Resolver Release I. *Program Analysis for System Renovation*, pp. 1-1 – 1-7.

A. VAN DEURSEN, P. KLINT, A. SELLINK (1996). Validating Year 2000 Compliance. *Program*

Analysis for System Renovation, pp. 2-1 – 2-47.

A. VAN DEURSEN, P. KLINT (1996). The resolver questionnaire for renovation tools. *Program Analysis for System Renovation*, pp. 7-1 – 7-9.

A. VAN DEURSEN, P. KLINT (1996). Selected tool evaluations. *Program Analysis for System Renovation*, pp. 8-1 – 8-21.

A. VAN DEURSEN (1996). A comparison of software refinery and ASF+SDF. *Program Analysis for System Renovation*, pp. 9-1 – 9-45.

A. VAN DEURSEN (1996). Origin tracking for system renovation. *Program Analysis for System Renovation*, pp. 15-1 – 15-20.

M. VAN DEN BRAND, P. KLINT, C. VERHOEF (1996). *Re-engineering Needs Generic Programming Language Technology*, Report P9618, Programming Research Group, University of Amsterdam. To appear in *ACM SIGPLAN Notices*.

M. VAN DEN BRAND, P. KLINT, C. VERHOEF (1996). *Reverse engineering and system renovation: an annotated bibliography*, Report P9603, Programming Research Group, University of Amsterdam. To appear in *ACM Software Engineering Notices*.

T. B. DINESH, S. USKUDARLI (1996). *Specifying Input and Output of Visual Languages*, Report P9610, Programming Research Group, University of Amsterdam. Extended version with Share-Where maintenance of paper presented at the Workshop on Theory of Visual Languages.

G. DOWEK, J. HEERING, K. MEINKE, B. MOELLER (eds). (1996). *Higher-Order Algebra, Logic, and Term Rewriting(HOA '95)*, Lecture Notes in Computer Science, Vol. **1074**, Springer-Verlag.

J.F.TH. KAMPERMAN (1996). *Compilation of Term Rewriting Systems*, Ph.D. Thesis, University of Amsterdam.

P. KLINT (1996). *Een Nieuwe Softwarecrisis?*, TELEAC/OU documentary (broadcast May 19 and September 1).

P. KLINT (1996). *Het Jaar 2000 Probleem*, interview in NCRV's 'Hier en Nu' (broadcast October 21).

P. KLINT, G. WIJERS (1996). De renovatie van systemen: verbouw of nieuwbouw? *Informatie* **38**(6), 6–11.

Algebraic and Syntactic Methods – AP4

Staff

- Prof. dr. J.W. Klop, group leader
- Dr. G. Barthe, post-doc SMC/LAW
- Dr. I. Bethke, postdoc, SION, part-time position 0.5
- Drs. H. Elbers, junior researcher (OIO), SION
- Drs. F. van Raamsdonk, researcher, SION (till February 1)

Scientific Report

Jan Willem Klop continued also this year the cooperation with Z.M. Ariola (Univ. of Oregon), on the subject of lambda calculus with explicit recursion. An extensive report has been completed on this subject that has been accepted for publication in Information and Computation. Another ongoing activity was the participation in writing a book on term rewriting together with co-editors R.C. de Vrijer (VUA) and M. Bezem (UU), and various chapter contributors. The book is scheduled for completion in draft version towards the end of 1997.

Gilles Barthe has pursued his work in the framework of the WINST project. He worked on the combination of type theory and term rewriting and its applications to proof checking together with H. Elbers (see publications). He also started working on control operators, continuation-passing style translations and classical type theories for proof-checking; this joint work with J. Hatcliff and M.H. Soerensen is reported in the publications.

Inge Bethke continuing her work as chapter contributor for a forthcoming book on term rewriting systems, wrote an introductory chapter on completion of equational specifications. Moreover, last year's work in cooperation with J.W. Klop and R.C. de Vrijer (VUA) on completability of partial combinatory algebras has been presented at LICS 96 and has appeared in the proceedings. Furthermore, together with J.W. Klop the study of sequentiality properties of rewriting systems was started.

Hugo Elbers continued his Ph.D. work in the framework of the project WINST. The main goal of research for the WINST project is the use of algorithms in formal verification. An interface between the proof checker LEGO and the Computer Algebra System REDUCE for automating equational reasoning has been implemented. A formal system based on type theory and term rewriting has been developed for formalizing mathematics. A prototype of a proof development system based on this formal system has been designed. The implementation of this prototype is in the testing phase.

On May 13, 1996, *Femke van Raamsdonk* defended her Ph.D. thesis entitled 'Confluence and Normalisation for higher-order Rewriting' at the Vrije Universiteit Amsterdam. The thesis was written un-

der supervision of J.W. Klop in the framework of NWO/SION project 612-316-606, Extensions of Orthogonal Rewrite Systems: Syntactic Properties.

Organization of Conferences, Workshops, Courses, etc.

- J.W. Klop organized a symposium day of the NVTI (Nederlandse Vereniging voor Theoretische Informatica), on March 1, Utrecht.
- J.W. Klop is organizing together with P. Klint the CWI Colloquium VIP (Vragen uit de Informatica Praktijk).

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

- *HCM Cluster meeting on Formal Methods for Correct Software Developments*, Brussels, Belgium, January 28–29: J.W. Klop.
- *Ph.D. promotion K.H. Rose*, DIKU, Copenhagen, Denmark, February 9–11: J.W. Klop.
- *TMR meeting*, Rome, Italy, March 16–19: H. Elbers.
- *Working visit University of Glasgow*, Glasgow, UK (dr. F. Kamareddine), June 1–30: G. Barthe.
- *Working visit University of Manchester*, Manchester, UK (prof. P. Aczel), July 1–5: G. Barthe.
- *LICS '96*, New Brunswick, USA, July 25–August 2: I. Bethke (Completing partial combinatory algebras).
- *International School on Type Theory and Term Rewriting*, Glasgow, UK, September 12–15: G. Barthe (Decreasing diagrams), J.W. Klop (Classical pure type systems).
- *EXPRESS meeting: Expressiveness in Concurrency*, Dagstuhl, Germany, September 15–20: J.W. Klop (Rewriting in Concurrency).
- *DISCO '96*, Karlsruhe, Germany, September 18–20: H. Elbers (Towards Lean Proof Checking).
- *CSL '96*, Utrecht, September 21–27: G. Barthe (On the subject reduction property for algebraic types systems), J.W. Klop.

Memberships of Committees and Other Professional Activities

J.W. Klop:

- Professor in Computer Science at the Free University of Amsterdam.
- Coordinator HCM Network EXPRESS (joint with J.F. Groote).
- Scientific Secretary of Nederlandse Vereniging voor Theoretische Informatica (NVTI).
- Editor of NVTI nieuwsbrief.
- Thesis advisor F. van Raamsdonk, VUA.
- Member Ph.D. Committee D. Turi, VUA, June 6.
- Member Ph.D. Committee P. Severi, TUE, June 18.
- Member Ph.D. Committee A. Overkamp, RUG.
- Member Ph.D. Committee A. Thijs, RUG.
- Member Ph.D. Committee M. Bonsangue, VUA.
- Member Ph.D. Committee M. Dezani-Ciancaglini, KUN.
- External examiner P.A. Mellies, ENS Paris.
- Member Science Committee IPA.

Visitors

- Z. Ariola, University of Oregon, USA, July.

Papers in Journals and Proceedings

Z.M. ARIOLA, J.W. KLOP (1996). Equational term graph rewriting. *Fundamenta Informaticae* **26**(3,4), 207–240.

G. BARTHE (1996). Implicit coercions in type systems. *Proceedings of Types'95*, LNCS 1158, 1–16.

G. BARTHE, H. GEUVERS (1996). Modular properties of algebraic type systems. *Proceedings of HOA'95*, Springer LNCS 1074, 37–56.

G. BARTHE, H. GEUVERS (1996). Congruence types. *Proceedings of CSL'95*, Springer LNCS 1092, 36–51.

G. BARTHE, M. RUYS, H. BARENDREGT (1996). A two-level approach towards lean proof-checking. *Proceedings of Types'95*, Springer LNCS 1158, 16–35.

G. BARTHE, H. ELBERS (1996). Towards lean proof checking. J. CALMET, C. LIMONGELLI (eds.). *Proceedings of 4th International Symposium on Design and Implementation of Symbolic Computation Systems, DISCO '96*, Karls-ruhe, Germany, Springer LNCS 1128, 61–62.

G. BARTHE, J. HATCLIFF, M.H. SOERENSEN (1997). CPS translations and applications: the cube and beyond. *Proceedings of the Second ACM-Sigplan Workshop on Continuations*, 4–31.

I. BETHKE, J.W. KLOP (1996). Collapsing partial combinatory algebras. G. DOWEK, J. HEERING, K. MEINKE, B. MÖLLER (eds.). *Higher-Order Algebra, Logic, and Term Rewriting (HOA '95)*, LNCS 1074, Springer-Verlag, 57–73.

I. BETHKE, J.W. KLOP, R. DE VRIJER (1996). Completing partial combinatory algebras with unique head-normal forms. *Proceedings 11^{t}h Annual IEEE Symposium on Logic and Computer Science*, IEEE Computer Society Press, New Brunswick, New Jersey, 448–454.

I. BETHKE, P. RODENBURG (1996). Equational constructor induction. *Fundamenta Informaticae* **25**(1) 1–16.

Y. TOYAMA, J.W. KLOP, H.P. BARENDREGT (1995). Termination for direct sums of left-linear complete term rewriting systems. *JACM* **42**(6), 1275–1304.

CWI Reports

CS-R9651. Z.M. ARIOLA, J.W. KLOP. *Lambda calculus with explicit recursion.*

Other Publications

Z.M.ARIOLA, J.W. KLOP (1996). *Lambda Calculus with Explicit Recursion*, Technical Report CIS-TR-96-04, Dept. of Information Science, Univ. of Oregon.

G. BARTHE, F. KAMAREDDINE, A. RIOS (1996). *Explicit Substitutions for Control Operators*, Tech. Rep, University of Glasgow.

I. BETHKE, J.W. KLOP (1996). Rewriting. *Images of SMC Research 1996*, Stichting Mathematisch Centrum, 325-335.

M. BEZEM, J.W. KLOP, V. VAN OOSTROM (1996). *Diagram Techniques for Confluence*, Department of Philosophy, Utrecht University, Logic Group Preprint Series No.166.

M. BOGNAR, J.W. KLOP (1996). *A Note on Some Abstract Confluence Criteria*, Technical report IR-411, Vrije universiteit, Amsterdam.

DEPARTMENT OF ALGORITHMICS AND ARCHITECTURE

Staff 1996

- Algorithms and Complexity – AA1
  - P.M.B. Vitányi
  - L. Fortnow
  - H.M. Buhrman
  - J. Tromp
  - A. Berthiaume
  - F. Gruau
  - J. Garay
  - J.-H. Hoepman
  - R. Cramer
  - S. Brands
  - H.H. Ehrenburg
  - P.D. Grünwald
  - H.A.N. van Maanen
  - B. Terhal
  - W. van Dam
  - D. van Melkebeek
- Interoperable Multimedia Systems – AA3
  - D.C.A. Bulterman
  - A.M. Bleeker
  - L.G.L.T. Meertens
  - H.G.P. Bosch
  - J.A.F.C. van Disseldorp
  - H.L. Hardman
  - J.-H. Hoepman
  - A.J. Jansen
  - K.S. Mullender
  - S. Pemberton
  - G. van Rossum
  - L.W. Rutledge
  - L. Salvail
  - M. Theodoridou
  - O.J.M. Weber
- Databases – AA4
  - M.L Kersten
  - A.P.J.M. Siebes
  - F. van Dijk
  - K. van 't Hoff
  - J. Pellenkoft
  - J.F.P. van den Akker
  - R. Choenni
  - J.R. Castelo
  - F.C.J. Bos
  - M.A. van den Brink
  - M.B. Dee
  - W.H.A. Fieten
  - D.T. Menger
  - M.F.C. Toneman
- Secretary: M.W. Hegt

Electronic dissemination

As of April 1993 technical reports have been distributed widely through the CWI FTP server. This channel is becoming the predominant and timely distribution means for gray literature, its use is an indication of the world interest in the results produced at CWI. In particular, since the top 5 number of copies extracted reach a more focussed and interested audience than can be expected from publishing in an international conference proceedings.

In 1996 19845 (1995:14760, 1994:11037, 1993:5319) copies of internal CWI reports were obtained from outside sources. The top-20 reports accessed from CWI in 1996 are shown below. It indicates that there is quite some interest in older reports.

access 1996	1993 – 1995	report
2210	3779	AA/CS-R9406
953	1263	AA/CS-R9531
831	1479	AA/CS-R9429
523	727	AA/CS-R9521
419	774	AA/CS-R9430
230	447	AA/CS-R9354
199	252	AA/CS-R9556
169	169	AP/CS-R9611
168	177	AP/CS-R9567
160	470	AP/CS-R9457
155	372	CST/CS-R9304
142	172	NW/NM-R9511
142	386	AA/CS-R9455
138	319	CST/CS-R9306
129	313	AA/CS-R9258
117	117	AM/AM-R9613
113	200	AA/CS-R9458
108	206	BS/BS-R9503
106	129	NW/NM-R9513
104	179	AP/CS-R9438

Algorithms and Complexity – AA1

Staff

- Prof. dr. P.M.B. Vitányi, group leader
- Prof. dr. L. Fortnow (sabbatical University of Chicago)
- Dr. H. M. Buhrman, postdoc, NFI
- Dr. J. Tromp, postdoc (from April), CWI/NFI
- Dr. A. Berthiaume, postdoc (until July), NFI
- Dr. F. Gruau, postdoc
- Dr. J. Garay (sabbatical IBM)
- Dr. J.-H. Hoepman, junior researcher (oio)(until October), NFI
- Dr. R. Cramer (oio)
- Drs. S. Brands (oio)
- Drs. H.H. Ehrenburg, junior researcher (oio), CWI
- Drs. P.D. Grünwald, junior researcher (oio), SION
- Drs. H.A.N. van Maanen, junior researcher (oio) (until March), SION
- Drs. B. Terhal, UvA
- Drs. W. van Dam, UvA
- Drs. D. van Melkebeek, TMR (EU)

Scientific Report

The project works at algorithmic methods and complexity analysis. Specific subjects are 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.

Multiple Computing Agents & Machine Learning

Learning and data compression. *Vitányi* proved the common belief that the better a theory compresses the data concerning some phenomenon under investigation, the better we have learned, generalized, and the better the theory predicts unknown data. This is the basis of 'Occam's razor' paradigm about 'simplicity'. This belief is vindicated in practice but apparently has not been rigorously proved in a general setting. Making these ideas rigorous involves the length of the shortest effective description of some object: its Kolmogorov complexity. We treat the relation between data compression and learning and show that compression is almost always the best strategy, both in hypotheses identification by using the minimum description length (MDL) principle and in prediction methods in the style of R. Solomonoff.

In the ideal form of minimum description length induction where each individual hypothesis and each individual data sample is maximally compressed. For various reasons this is not done or considered desirable in the praxis of the 'minimum description length (MDL)' method of J. Rissanen and the 'minimum message length (MML)' method of C. Wallace. The shortest descriptions which are conceivably effective are those of least Kolmogorov complexity. Such shortest effective descriptions cannot be constructively found. Theoretically, however, they can be used to rigorously analyze the relation between shortest description length reasoning and Bayesianism. The analysis gives evidence why in practice the latter is prone to overfitting and the former isn't. Technically, we use the novel notion of individual randomness of objects as expressed by P. Martin-Löf's randomness tests. Minimum description length reasoning using shortest effective descriptions coincides with Bayesian reasoning using the universal prior distribution, provided the minimum description length is reached for those hypotheses with respect to which the data sample is individually random in the sense of Martin-Löf. Technically, we show that almost always the best hypothesis is the one that compresses the data most, in the ISIS'96 conference. The best (most likely) hypothesis is not necessarily the best predictor: The best prediction may result from a weighted combination of all hypotheses. Thus, the fact that data compression is the provably best strategy to identify the most probable hypothesis does not imply that it helps giving the best prediction. While the previous approach does not work directly, we can still prove that the best prediction is the one that results in the least additional (most compressed) incremental hypothesis, Invited Paper ECML'97, and paper submitted to *IEEE Trans. Inform. Th.*. This material is also (partially) covered in the Second Edition of the textbook *An Introduction to Kolmogorov Complexity and Its Applications* to appear in '97 and the Chinese translation of an abbrieviated version, to be published by the Chinese Science Press.

Grünwald continued his research on Nonmonotonic Logic and Causation. The results obtained in 1995 were extended in two ways. Firstly, the formal framework was greatly simplified, making the work much more accessible. Secondly, for two different existing approaches to nonmonotonic temporal reasoning, a formal proof was given that the author's approach can be seen as a generalization of them. The results are summarized in two papers which are currently under review *Causation and Nonmonotonic Temporal Reasoning* and *Nonmonotonic Temporal Reasoning as a Search for Explanations*; a prelimi-

nary version has been accepted for NAIC '96 and was nominated for Best Paper.

Grünwald, P. Kontkanen, P. Myllymäki, T. Silander, and *H. Tirri* (Univ. of Helsinki), worked on Bayesian and MDL methods for learning problems. Because the group has a lot of expertise in the field and one of the members is a professional programmer, P. Grünwald decided to temporarily stop his own work in grammar learning and work together with them on the learning problems they study. This led to the paper *Comparing Predictive Inference Methods for Discrete Domains* that will be published in the proceedings of AISTATS-97, and to some more work, both theoretical and practical, which should be published in 1997. Specifically, the 'predictive distributions' of the so-called 'naive Bayes model' were computed. These distributions are based on Rissanen's new definition of stochastic complexity. Also, 'Jeffrey's Prior Distribution' was derived for the naive Bayes model, and it was tested how well these concepts work on several real-world data sets. The results were surprisingly good.

Tromp showed that computing the absolute minimum decision tree is NP-complete, (with T. Hancock, T. Jiang, M. Li). They have shown that approximating minimum decision trees is also NP-hard, even approximation to within some polynomial factor. Consequently, approximation heuristics have to be used. This result resolved an old practically important problem and was published in 'Information and Computation' in '96. Together with John Kececioglu and Ming Li, he showed how partial results on the genetic sequencing problem of how to infer a DNA sequence from erroneous copies, to be published in 'Theoret. Comput. Sci.'.

Evolutionary Computing. *Vitányi* proposed a novel (in this area) notion of highly probable fitness optimization through evolutionary computing runs on small size populations in a very general setting. This has applications to evolutionary learning. Based on rapidly mixing Markov chains, the approach pertains to most types of evolutionary genetic algorithms, genetic programming and the like. For systems having associated rapidly mixing Markov chains and appropriate stationary distributions the new method finds optimal programs (individuals) with probability almost 1. Algorithmically, the novel approach prescribes a strategy of executing many short computation runs, rather than one long computation run. Given an arbitrary evolutionary program it may be infeasible to determine whether its associated matrix is rapidly mixing. In our proposed structured evolutionary program discipline, the development of the program and the guaranty of the rapidly mixing property go hand in hand. We conclude with a tentative toy example, Invited Paper ALT'96.

Ehrenburg did research in implementation of improved and faster versions of genetic programming (GP). The use of a directed acyclic graph (DAG) to represent a population in genetic programming offers several advantages, one of which is the efficient use of space. We improve on previous methods to evaluate a DAG and offer two new ways of evaluating a population. The first method uses a linked list and a negligible amount of space. In the second method each node is evaluated only once on all fitness cases and the results are cached. Using a DAG also facilitates the use of complicated genetic operators. As an example, he introduced a context-preserving genetic operator based on the building block hypothesis, which accurately combines two similar trees into a new tree. This work was published at the '96 Stanford GP Conference, and Ehrenburg joined for 3 months John Koza's GP group at Stanford University.

Gruau used GP to develop learning algorithms for constructing optimal neural networks and circuits. He also ran the Charlemagne robot locomotion project. The project uses Genetic programming and cellular encoding to evolve a neural network, to control the locomotion of the robot Charlemagne, to make it turn, follow walls. Extensions using local vision are considered. Cellular encoding is efficient when highly regular structures are to be generated, and vision, low level vision at least, involves repeating a great number of time the same pattern of connections so as to achieve translation invariance. We have already accomplished the locomotion controler. The project was done jointly with Dominique Quatravaux and cooperation with Michel Cosnard and Phil Husband. One of the challenge was to evaluate the fitness of the neural network with a real robot instead of a simulated one. We supplied syntactic constraints which limits the range of possible neural networks. We had a modular approach, we first generated an ANN to control one leg, with some interface neurons whose role is precisely determined. This sub-ANN is afterwards included in a general architecture.

This way we evolved a neurocontroller for the locomotion of an 8-legged robot. He developed new concepts that allows to combine evolution and hand programming. Gruau published a research report 'Cellular encoding for interactive evolutionary robotics', together with K. Quatramaran. The paper was accepted for publication at the European Conference

on Artificial Life, September 1997. Gruau is also working on a model of massive parallelism, based on cell division,and organized the first Autonomous Football Robotics Tournament, at ECAL '97.

Buhrman and *J. Balcazar*, pursued the work on learning circuits with easy descriptions. The main result is that there is a close connection between learnability and complexity theoretic assumptions. It is proven that Circuits with easy descriptions are learnable with membership queries in polynomial time if and only if every NE predicate is E solvable. This and related results can be found in the manuscript *Characterizing the Learnability of Kolmogorov Easy Circuit*, which can be found in the NEUROCOLT ftp directory.

Grünwald and *M. Steijvers* (Indiana University) finalized the results obtained in 1995. It was shown (by the end of '95) that a very simple recurrent neural network is able to recognize a simple context sensitive formal language. What makes this result interesting is the fact it has frequently been claimed that the representational power of recurrent neural networks does not go beyond that of finite-state automata. In 1996, the authors wrote a paper 'A Recurrent Network that performs a context-sensitive prediction task' that was accepted for presentation at the Annual Cognitive Science Conference.

Vitányi gave invited plenary lectures/tutorials at ISIS'96 in Melbourne, Australia, and for ALT'96 in Sidney, Australia. He was program committee member for many conferences in the area including ISIS96, ALT97, ISAIM97, SNAC97, ECML97.

Distributed and Network Computing

Buhrman, Hoepman and *Vitányi* studied compact routing tables in computer networks using the novel tool of the *incompressibility method* to Distributed Algorithms. They obtained optimal upper and lower bounds for compact routing tables for shortest-path routing in computer networks, routing with different stretch factors, and full-information routing. Several open problems in that area were resolved and a new technique was introduced. The notion of Kolmogorov complexity gives a nice and new handle on obtaining new results in this area of distributed computing. It seems that this approach is fruitful and that many applications lay waiting for us. Results concerning routing can be found in 'Optimal Routing Tables', in proceedings of PODC'96, Philadelphia, USA.

Hoepman continued his investigation of mobile computing. How does 'mobility' change the way we (must) think about distributed algorithms? Are there any new fundamental problems involved? What are the main applications for mobile computing, and how must we design systems supporting those applications? The ultimate challenge is to device the core algorithms needed for truely large scale mobile computing.

Hoepman completed his Ph.D. Thesis 'Communication, Synchronization, and Fault-Tolerance' which was successfully defended on the 28th of June, 1996.

Buhrman, F. Franklin (AT&T, USA), *J. Garay, Hoepman, Tromp*, and *Vitányi* formulated a new type of search problem called *mutual search*, where players located in the nodes of a network are required to locate each other by posing 'anybody at node i?' queries. They designed algorithms showing that the minimal number of queries required by two players in a network of n nodes is considerably less than the $n - 1$ queries one naively expects to be optimal. We also give upper and lower bounds for the deterministic worst case. These bounds are almost sharp (within 5 percent). They also exhibit a simple randomized algorithm whose cost beats the determinstic lower bound, and a deterministic algorithm for more than players with a cost well below n for a number of players roughly below square root of n. The graph-theoretic framework they formulate for expressing and analyzing algorithms for this problem may be of independent interest.

Besides being a new type of search problem with potentially many applications, these results are bound to have an impact on the field of secure multi-party computation, where is typically assumed that the bad players already form a coalition that is fully coordinated. These results have been submitted to PODC'97.

Garay (on leave of absence from IBM) and *Amotz Bar-Noy* (Tel-Aviv University) worked on the problem of Video on Demand (VOD) scheduling from a resource allocation perspective. For the case when the length of the movie and the notification time on requests are linearly related (for example, notifying users within 15 min. after their requests for 2-hour movies), they designed a simple algorithm which achieves constant competitiveness. That is, the ratio between the revenue achieved by any other algorithm – including the off-line algorithm which can 'foresee' all future requests – and theirs is bounded by a constant. Since logarithmic bounds were known for small notification times, this result is a step forward towards a complete characterization of the VOD resource allocation problem. Inspired by the result above, they present a new VOD scheme that has the potential for practical realization. The two popular

approaches suggested so far – Full VOD and Near VOD – take rather extreme views to the functionality/price tradeoff. In their work they suggest a third approach – Shared VOD – that gives a more balanced tradeoff between functionality and price. These results have been submitted to the IEEE Transactions on Networking journal.

Garay, M. Bellare (Univ. of San Diego, USA), and *T. Rabin* initiated a broad study of the 'batch verification' problem. Roughly, given a polynomial time-computable boolean relation R and a sequence of n instances, the problem is to verify that the relation holds for each instance i. The naive way to figure this out is to compute the relation for each instance i, but this takes n computations of R. Can one do any better? Indeed. They designed probabilistic batch verifiers, or tests, for basic mathematical relations R that are much more efficient than the naive ones. In particular, they found surprisingly fast verifiers for modular exponentiation. The first application of their result is to cryptography, where modular exponentiation is a common component of a large number of protocols (e.g., digital signatures-RSA, DSS). Another relation is the batch checking of degrees of polynomials, which underlies (verifiable) secret sharing, which in turn underlies many secure distributed protocols. A second application of these results is to program checking, where batch verification provides faster checkers, in the sense of Rubinfeld and Blum. These checkers also have stronger properties than standard ones, and illustrate how batch verification can not only speed up how we do old things, but also enable us to do new things. Some of these results are submitted to CRYPTO'97.

Garay and *P. Berman* (Penn State University) studied the problem of designing algorithms in situations where there is some information concerning the typical conditions that are encountered when the respective problem is solved. The basic goal is to assure efficient performance in the typical case, while satisfying the correctness requirements in every case. They introduced 'adaptability,' a new measure for the quality of an algorithm, which generalizes the competitive analysis of Sleator and Tarjan. This new notion applies to sequential, parallel and distributed algorithms alike. In a nutshell, a 'hint' function conveys certain information about the environment in which the algorithm operates. Adaptability compares the performance of the algorithm against the 'specialist'-an algorithm specifically tuned to the particular hint value. From this perspective, finding that no single algorithm can adapt to all possible hint values is not necessarily a negative result, provided that a family of specialists can be constructed. Their case study of the Distributed Consensus problem provides examples of both kinds. To fulfill the requirements of one of the cases they consider, they present the first consensus algorithm that is simultaneously optimal in number of processors, early-stopping property (that is, it runs in time proportional to the actual number of faults), and total number of communicated bits. In their new parlance, the algorithm 'adapts' to the number of faults hint under both cost measures number of rounds and total number of bits. These results have been submitted for publication.

Tromp, Vitányi and *M. Li* resolved the difficult and error-prone problem of how to construct concurrent wait-free variables (for asynchronous interprocess communication) which was published in 'J. Assoc. Comp. Mach.' in '96.

Tromp published several other papers on small weight bases for Hamming codes in 'Theoret. Comput. Sci.' '96 and the vector space of the automatic reals also in 'Theoret. Comput. Sci.' '96.

Vitányi was program committee member of WDAG97.

Physics and Computation & Quantum Computing

Physics of Computation: *Vitányi*. Research was started in the direction of coherent quantum computing, a promising radically new approach to parallel computing which – if realized – will overcome both the interconnect problem and the heat dissipation problem, and moreover will perform way beyond the possibilities of classical high performance parallel computing. *Vitányi and M. Li* did further work on reversible computing and reversible simulation of irreversible computations, and several lower bounds on energy dissipation in real computation were derived as well as time and space versus heat dissipation tradeoffs was reported in the IEEE Computational Complexity Conference '96 and in the 'Proc. Royal Soc. London, Ser. A' in '96. Results on lower bounds for time-space use in reversible computations was presented at PhysComp'96 in Boston, and a version together with *J. Tromp* was submitted to 'Physica D'. This work has already led to several follow-up papers and interest in groups (like at MIT) implementing reversible electronic logic chips. *Vitányi* was also program committee member of PhysComp'96 in Boston.

Quantum Computing: The goal of this pilot project is to establish theoretical and practical principles to develop physically realizations of coherent quantum computers, and to develop theory and ap-

plications of reversible unitary algorithms for such machines which improve the capabilities of machines based on classical physics (by an exponential factor).

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 year evidence has arisen that the proposed coherent quantum computers may be 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 Algorithms and Complexity group at CWI cooperates with the Theoretical Physics Department and the Computer Science and Logic Department of the University of Amsterdam.

Berthiaume (Aladdin-NFI Fellow) collaborated with Louis Salvail (now at CWI) on quantum cryptography. Following a result of Dominic Mayers (now at Princeton), one of the main primitive of quantum cryptography was proven insecure against a cheating party equipped with a quantum computer. Salvail and Berthiaume tried to improve the primitive to circumvent the problem. Unfortunately, the only (unpublished) result was that an even simpler primitive, namely blind coin-flipping, was also impossible.

The stabilization scheme (initially developed in Berthiaume's thesis) was studied further in collaboration with the Oxford group and its efficiency analyzed in more details. The results were accepted for publication in a special issue on quantum computation of the SIAM Journal of Computation. This special issue will appear in 1997.

He wrote a chapter on 'Quantum Computation' in Complexity Theory Retrospective II (editors: Lane Hemaspaandra and Alan L. Selman) and gave a minicourse on quantum computation at Bsic Research in Computer Science (BRICS) group at the University of Aarhus, Denmark. BRICS also published the lecture notes from this course.

Barbara Terhal has considered the computational power of a particular quantum spin system. On the basis of the current understanding of the dynamics of these spin systems, it was found that the dynamics of the system would not lead to an exponential speed-up in time complexity. She has subsequently worked on an information theoretic analysis of quantum algorithms. She has set up a novel framework which highlights the strong connection between group theory and quantum algorithms. She has given a generalization of a quantum search algorithm on the basis of this analysis. Future research will involve work on quantum algorithms in connection with group theory. The information theoretical framework will be used to classify and possibly develop quantum algorithms that relate to Abelian, but also non-Abelian groups.

Buhrman's interest in quantum computing has been increased after the seminar/workshop series by A. Berthiaume at the CWI. A first offspring is a refinement of the celebrated factoring algorithm by Shor. It is shown that this algorithm can be altered to have zero error probability, meaning that the algorithm will yield an outcome with very high probability and that this outcome is always correct. This has been published as a note in SIGACT News.

Van Dam completed his Master's thesis at the University of Nijmegen. This thesis was entitled 'Quantum Cellular Automata' and was written under the supervision of Paul Vitányi (CWI Amsterdam) and Kees Koster (University of Nijmegen).

The model of quantum cellular automata is used to describe parallel, uniform, quantum computing. Van Dam proved the existence of a universal quantum cellular automaton which can simulate any other QCA. It was also shown that quantum cellular automata can be simulated by quantum Turing machines, a question originally posed by E. Bernstein and U. Vazirani in 1993. An abstract of this thesis was presented at the Fourth Workshop on Physics and Computation in Boston and was published in the corresponding conference proceedings.

He also worked on the *expected information gain* of measurements on quantum mechanical systems. The question is addressed how one should design a measurement procedure in order to obtain a maximum amount of information of an unknown quantum system. This research will contribute to a better insight into the theory of quantum information and may also lead to a practical application in the analysis of quantum mechanical devices.

Algorithms and Complexity

Buhrman and *L. Longpré* (Univ. Texas, El Paso, USA) gave a new definition of resource bounded measure in terms of Compressibility, a notion akin to Kolmogorov Complexity. This new notion enables them to prove new results concerning resource bounded measure. Results can be found in 'Compressi-

bility and Resource Bounded Measure', in the proceedings of the STACS'96 in Grenoble.

Buhrman and *L. Fortnow* (on sabbatical from Univ. of Chicago) studied resource bounded Kolmogorov Complexity. Most notably are two theorems in resource bounded Kolmogorov complexity that allow many applications in complexity theory. The results can be found in 'Resource Bounded Kolmogorov Complexity Revisited' in the proceedings of the STACS'97, Germany. They also obtained new results on the question whether 2 questions to Satisfiability yield more information than 1 question. These results have been published in 'Two Queries', and are submitted for publication. After preliminary talks on these results (Dagstuhl and Würzburg) other groups have already been using these results.

Buhrman, S. Fenner (Univ. of Maine), *and L. Fortnow* studied resource bounded measure and obtained sevral results. These results can be found in 'Results on Resource bounded Measure' in the proceedings of the ICALP'97 in Bolonga, Italy.

Buhrman formulated together with *P. Orponen* (Univ. of Jyväskylá, Finland) during a visit in early December in Helsinki and Jyväskylá, Finland, a framework for resource bounded logical depth. Preliminary results indicate that NP complete problems are computationally deep unless the polynomial time hierarchy collapses. The results suggest that the notion of logical depth captures exactly those sets with high 'useful' information, in contrast to Kolmogorov complexity that captures randomness.

Buhrman, *Vitányi* and *M. Li* embarked on a systematic study to the properties of Kolmogorov Random Graphs. Old and several new properties are discovered. The theory of individual random graphs (Kolmogorov random graphs) was extended with close estimates of mean and variance of occurrence frequencies of all graphs of given size as subgraphs of an individual high-complexity graph. These new results imply that all subgraphs of appropriate given size occur with certainty. They investigated the similarity and differences between global form properties such as that some property occurs with high probability, and local properties such as that some property holds for every object of high Kolmogorov complexity. A difference is that in the latter case all properties which hold locally hold simultaneously for the local object, while this is not the case for high-probability local properties. These results can be found in 'Kolmogorov Random Graphs and the Incompressibility Method' and will be presented at the 'IEEE Conf. on Compression and Complexity of sequences 1997'

Buhrman presented the paper written with *T. Thierauf* (Univ. of Ulm) 'Complexity of Generating and Checking Proofs of Membership' at the STACS'96 in Grenoble, France.

Tromp studied, in search of the simplest possible concrete definition of Kolmogorov Complexity, universal computation in Combinatory Logic and Lambda Calculus. In support of this work, and to make the results more accesible, he developed some familiarity with the fast emerging Internet and object oriented language Java.

Tromp, *M. Li*, and *L. Zhang* studied the difficulty in quantitatively comparing evolutionary trees. They disproved several Theorems in a 1973 journal paper by Smith and Waterman. Together with several coauthors, Tromp resolved open problems in distances (nearest neighbour interchange distance) between evolutionary trees (phyllogenetic trees) that have serious impact in biology. The results can be found in 'On the Nearest Neighbour Interchange Distance between Evolutionary Trees' and was accepted for the Journal of Theoretical Biology.

Fortnow, and *R. Downey* give some evidence that the tools used in Ladner's proof giving incomplete NP sets must create large easy gaps. These results are published in 'Uniformly Hard Languages'.

Fortnow, inspired by his work on autoreducibility with Buhrman and Torenvliet, showed some work in the direction of separating the complexity classes NL and NP. Part of this work gives the first nontrivial machine-independent time-space trade-off for satisfiability. These results 'Nondeterministic Polynomial Time versus Nondeterministic Logarithmic Space' were accepted for Computational Complexity Theory 97.

Fortnow is program committee member of 29th ACM Symposium on the Theory of Computing (1997).

Van Melkebeek is a visting Ph.D. student from The University of Chicago. He joined his adviser Lance Fortnow, who is spending a sabbatical year at CWI. Dieter van Melkebeek is working on computational complexity theory. He has investigated structural properties of sparse sets, and will continue this line of research. He also started working on pseudorandomness and derandomization. He orginizes the biweekly seminar on complexity theory intended for researchers in the Amsterdam area, which takes place alternately at CWI and at the University of Amsterdam.

Cramer, *Schoenmaker*, and *Grennaro*, working on electronic voting protocols, revealed a secure and more efficient voting mechanism. The results will be

published in the European Journal on Telecommunication and in Eurocrypt'97 as 'Secure and Optimally Efficient Multi-Authority Election Scheme'.

Cramer, *Schoenmaker* , *Franklin*, and *Yung* also working on issues related to electronic voting developped a fast protocol, 'Secure Secret Ballot Election Schemes with Linear Work' at Eurocrypt'96.

Cramer and *Damgård* continued there research, trying to modualize Cryptographic and zero Knowledge protocols. This work culminated in several papers and was accepted at major international conferences. 'Linear Zero-Knowledge: A Note on Efficient Zero-Knowledge Proofs and Arguments' at STOC'97, 'New Generation of Secure and Practical RSA-based Signatures' at Crypto'96, 'Efficient and Provable Security Amplifications' (together with *P. Pedersen*, at Cambridge Security Protocols 1996, and 'On Monotone Function Closure of Perfect and Statistical Zero-Knowledge'

Cramer finished his Ph.D. Thesis 'Modular Design of Secure yet practical cryptographic protocols' and defended it successfully on January 31 1997.

Buhrman is program committee member of CCC'97 to be held in Ulm, Germany.

Vitányi and M. Li analyzed the theory of time-bounded universal distributions and their applications in 'simple pac-learning' and 'universal average case complexity.'

The 2nd revised and extended edition of 'An Introduction to Kolmogorov Complexity and Its Applications', Springer-Verlag, New York, was prepared. The book was translated into Chinese (to appear with 'Chinese Science Press', Beijing).

Vitányi was/is program committee member of ICALP'96 in Paderborn, COCOON'97 in Shanghai, WADS97 in Canada, LFCS'97 in Russia, IEEE Compression and Sequences Conf 97 in Italy.

Organization of Conferences, Workshops, Courses, etc.

- NFI. The national (NFI-supported) project ALADDIN – research and education in concurrent systems – organized the ALADDIN Distributed Algorithms Seminar bi-weekly alternating between University of Utrecht and CWI; the ALADDIN Distributed Algorithms Colloquium Series (one day events) and the ALADDIN Distributed Algorithms Lecture Series. Dr. J. Garay (IBM T.J. Watson Research, USA) was ALADDIN visiting expert. *Vitányi* was invited plenary speaker at Aladdin related subjects at both WADS'95 and MFCS'95.
- ESPRIT. The CWI is partner of the ESPRIT BRA III NeuroCOLT Working Group 8556 on fundamental understanding of learning and of when and how it can be implemented algorithmically. Particular classes of adaptive systems will also be studied, including neural networks with discrete and continuous activations. *Vitányi* is work area manager of two out of three work areas. In machine learning theory *Vitányi* is invited tutorial speaker at the ISIS'96 conference and invited plenary speaker at the ALT'96 conference, both in Australia.
  Partners are the CWI, the universities of RWTH Aachen, Universitat Pompeu Fabra, Barcelona, Technische Universität Graz, University of Helsinki, London School of Economics, University of London, Ecole Normale Supérieure de Lyon, University of Milan, Université de Mons, Royal Holloway College, University of London. A first Workshop 'EuroCOLT' was organized in December 1993 at Royal Holloway College in London. The conference was attended by 70 participants. Apart from yearly meetings, successively in London, Barcelona, Helsinki, Graz, and Amsterdam, the 2nd 'EuroCOLT' Workshop took place in Barcelona in March 1995 with *Vitányi* as program committee chair.
- ALADDIN. This group is already mentioned above.
- IFIP. CWI (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.

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

H. Buhrman:

- *Symposium on Theoretical Computer Science 1996*, Grenoble, France, 22–24 February (Talk: Compressibility and Resource Bounded Measure)
- *Barbados Mc Gill Workshop on Probabilistic Checkable Proofs*, Holetown, Barbados, 26 February–2 March
- *COLORET meeting in Barcelona,* Barcelona, Spain, 23 March–1 April (Talk: CD compleixty)
- *Dagstuhl workshop on Information and Randomness in Complexity Theory,* Wadern, Germany, 15–19 July (Talk: Resource bounded Kolmogorov Complexity)
- *Working visit to K. Wagner, Univ. of Würzberg,* Würzberg, Germany, 22–26 July (Talk: Resource Bounded Kolmogorov Complexity)

- *Dagstuhl workshop on Complexity Theory*, Wadern, Germany, 1–4 October (Talk: SIx Hypotheses)
- *Working visit to S. Homer, Univ. of Oxford*, Oxford, England, 17 October–2 November (Talk: Kolmogorov Complexity and Applications)
- *Work visit to P. Orponen, Univ. of Jyväskylä*, Jyväskylä, Finland, 16–22 December (Talk: Longlived Renaming made Fast)

P.M.B. Vitányi:

- *ICALP96 PC Meeting* Informatik, Universität Paderborn, Duitsland. February 1–2 (Talk: Introduction to Kolmogorov Complexity)
- *Dagstuhl Seminar 'Distributed Time Services'*, Dagstuhl Castle, Universtät Saarlandes, Saarbrücken, 10–16 March (Talk: Time driven algorithms)
- *Working Visit Computer Science Department*, University of Waterloo, Toronto, Canada, April 9–May 20 (Talk: Compact Routing Tables in Computer Networks) (Talk: Physics of Computation and the Quantum Computing Challenge)
- *1996 Federated Computer Research Conference*, Philadelphia, Pennsylvania, USA. (ACM Symp. Theor. Comp., ACM Symp. Principles Distr. Comp., IEEE Complexity Th. Conf, etc.) May 21–28 (Talk: Optimal Routing Tables) (Talk: Reversible Simulation of Irreversible Computation)
- *PAAP Workshop*, Nijmegen University, Nijmegen (Talk: Introduction to Kolmogorov Complexity and Its Applications) May 30.
- *Jan van Leeuwen's 25th Anniversary Jubilee*, Utrecht University, Utrecht, The Netherlands (Talk: Compact Routing Tables and the Incompressibility Method) June 3.
- *3rd Quantum Computation Workshop*, ISI Institute, Turin, Italy, June 30–July 8 (Talk: Reversible Simulation of Irreversible Computation)
- *ISIS: Information, Statistics and Induction in Science Conference*, Melbourne, Australia, August 19–23 (Tutorial: Introduction to Kolmogorov Complexity and Its Applications) (Talk: Ideal MDL and Its Relation To Bayesianism)
- *Working Visit Computer Science Department*, Monash University, Melbourne, Australia , August 24–Sept 20 (Talk: Physics of Computation and the Quantum Computing Challenge). (Talk: Induction and Prediction by Data Compresion) (Talk: Ideal MDL and Its Relation To Bayesianism) (Talk: Introduction to Kolmogorov Complexity and Its Applications) (Talk: Average Case Complexity and Kolmogorov Complexity)
- *Working visit Computer Science Department*, University of New South Wales, and Sidney Institute of Technology, Sidney, Australia, September 21–October 4 (Tutorial: Introduction to Kolmogorov Complexity and Its Applications) (Talk: Average-Case Analysis of Compact Routing Tables Using Kolmogorov Complexity)
- *Seventh International Workshop on Algorithmic Learning Theory (ALT) Conference*, Sidney, Australia (Sidney, Australia), October 22–26 (Talk: Genetic fitness optimization using rapidly mixing Markov chains)

L. Fortnow:

- *Dagstuhl Workshop on Structural Complexity Theory*, Dagstuhl, Germany, September 30–October 4 (Talk Two Queries)
- *Universiteit van Amsterdam* (Talk Generic Oracles)
- *Universiteit Twente* [Ulrich Faigle], Twente, October 22. (Talk Optimality and Domination in Repeated Games with Bounded Players)
- *Universiteit Utrecht* (Talk Minimal Sets)
- *Oxford University* [Steve Homer], Oxford, England, October 28–November 1
- *Oberwolfach Workshop on Computational Complexity*, Oberwolfach, Germany, November 11–14 (Talk Resource-Bounded Kolmogorov Complexity Revisited)
- *Amsterdam Vitányi Jubilee* (Talk 25 years of P versus NP)
- *Universität Ulm* [Thomas Thierauf], Ulm, Germany, December 9–12 (Talk Resource-Bounded Kolmogorov Complexity Revisited)
- *Universität Würzburg* [Klaus Wagner], Würzburg, Germany, December 13 (Talk Two Queries)

J. Garay:

- *CWI Cryptography Working Group*
- *Symp. on the Principles of Distributed Computing*, Philadelphia, PA, May
- *Schloß Dagstuhl*, Dagstuhl, Germany, June
- *Penn State University*, University Park, PA, August
- *VII School of Computer Science*, Universidad Nacional de Mexico, La Paz, Mexico, September
- *10th International Workshop on Distributed Algorithms*, Bologna, Italy, October

P.D. Grünwald:

- *NeuroCOLT Second Yearly Meeting*, Villard de Lans, France, February 11–14 (Making Sense of MDL)
- *TARK-6 (6th conference on Theoretical Aspects of Rationality and Knowledge)*, Zeeuwse Stromen, The Netherlands, March 17–20 (Causation and Nonmonotonic Temporal Reasoning, talk given in rump session)

- *IPA School Days*, De Koningshof, Veldhoven, April 15–16 (Kolmogorov Complexity & the MDL Principle)
- *Working visit to the University of Helsinki*, (COSCO group, P. Myllymaki and H. Tirri), Helsinki, Finland, May 4–10 (The MDL Principle: What it is and Why it Works)
- *NATO Summer School on Learning in Graphical Models*, Erice, Sicily, September 27–October 7 (Rissanen's new Stochastic Complexity and Prior Distributions – presented as a poster)
- *Working visit to the University of Helsinki*, (COSCO group, P. Myllymaki and H. Tirri). Helsinki, Finland, October 26–31
- *NAIC '96 (Dutch Conference on Artificial Intelligence)*, Utrecht, November 21–22 (Causal Networks and Nonmonotonic Temporal Reasoning)

J.-H.Hoepman:
- *Instituut voor Programmatuurkunde en Algoritmiek*, Veldhoven, April 16 (Mobile Computing)
- *Rijksuniversiteit Groningen* April 22 (Mobile Computing)
- *Dagstuhl Seminar Real-Time Systems*, Schloß Dagstuhl, Germany, March 11–15
- *Distributed Algorithms (WDAG)*, Bologna, Italy, October

J. Tromp:
- *CWI, Amsterdam Complexity Seminar*, November 22 (Talk: Polynomial-time Approximation Schemes for Euclidean TSP and other Geometric Problems)
- *Free University Amsterdam*, February 10 (Talk: A Combinatory Logic based definition of Kolmogorov complexity)

D. van Melkebeek:
- *CWI, Amsterdam Complexity Seminar*, October 25 (Talk: Reductions in Circuit Complexity: An Isomorphism Theorem and a Gap Theorem)

B. Terhal:
- *Weizmann Institute of Science,Group of Complex Systems*, Rehovot, Israel, 1 March–2 April
- *ISI Workshop on Quantum Computation*, Villa Gualino, Turin Italy, 17 June–1 July
- *Vakgroep Geschiedenis en Grondslagen van de Wiskunde en Natuurwetenschappen*, UU Utrecht, January 12 (Talk: Quantum Computation)
- *Instituut voor Theoretische Fysica*, UvA Amsterdam, January 29 (Talk: Quantum Computation)
- *Instituut voor Programmatuurkunde en Algoritmiek*, Veldhoven, April 15 (Talk: Quantum entanglement and the teleportation of a qubit)

W. van Dam:
- *ISI Workshop on Quantum Computation*, Villa Gualino, Turin Italy, 17 June–7 July (Talk: Quantum cellular automata)
- *Fourth Workshop on Physics and Computation*, Boston, USA, November 22–24 (Talk: A universal quantum cellular automaton and Space-energy trade-off in reversible simulations)

A. Berthiaume:
- *Académie des Grands Montréalais*, Montréal, Canada, March (Talk: L'ordinateur Quantique et correction d'erreurs)
- *Université de Montréal*, Montréal, Canada, April (Talk: Complexité et stabilisation des Calculs)
- *Instituut voor Programmatuurkunde en Algoritmiek*, Veldhoven, April (Talk: Quantum Computers)
- *General CWI Colloquium* June (Talk: Quantum Computation Basics)
- *Phillips Corporation*, June (Talk: Computing the Modern Way)

Memberships of Committees and Other Professional Activities

P.M.B. Vitányi:
- Invited speaker at the *Seventh International Workshop on Algorithmic Learning Theory*, Coogee Holiday Inn, Sidney, Australia, October 23–25, 1996.
- Tutorial speaker at the *conference on Information, Statistics and Induction in Science (ISIS)*, Melbourne, Australia, 20–23 August, 1996.
- Invited speaker, Distributed Time Sevices Workshop, Dagstuhl Castle, Saarbrücken, Germany.
- Invited Speaker at the Computer Science Department, Monash University, Melbourne, Australia.
- Invited Speaker at the Computer Science Department, University of New South-Wales, Sidney, Australia.
- Invited Speaker at the Computer Science Department, Sidney Institute of Technology, Sidney, Australia.
- Invited Speaker at the PAAP Workshop, Nijmegen University, 1996.
- Invited speaker *International Computing Research Seminar*, University of Waterloo, Canada.
- Invited Speaker at the Computer Science Department, University of Paderborn, Paderborn, Germany.
- Invited Speaker at the Computer Science Department, Utrecht University, The Netherlands at Jan van Leeuwen's 25th Anniversary Seminar.
- Professor of Computer Science, Universiteit van Amsterdam.
- Guest Editor, 'J. Computer and System Sciences', special issue on Computational Learning Theory, 1994–.

- Editor 'Distributed Computing', Springer-Verlag, since 1987.
- Editor, '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, The Fifth International Symposium on Artificial Intelligence and Mathematics 4–6 January 1998, Ft. Lauderdale, Florida.
- Program Committee, 11th International Workshop on Distributed Algorithms, WDAG-11, Saarbrücken, Germany, 1997.
- Program Committee, Compression and Complexity of SEQUENCES 1997, In cooperation with the IEEE Data Compression Conference Positano (Amalfitan Coast) – Salerno, Italy June 11–13 1997.
- Program Committee, School on Natural Computation (SNAC), 25–29.8.1997, Turku, Finland.
- Program Committee, Algorithmic Learning Theory Conference, Hong Kong, 1997.
- Program Committee, *5th bi-annual Workshop on Algorithms and Data Structures*, WADS'97, Halifax, Canada, in August 1997.
- Program Committee, 10th European Conference on Machine Learning, Prague, Czech Republic, 1997.
- Program Committee, Fourth International Conference on 'Logical Foundations of Computer Science' (LFCS'97) on July 6–12, 1997, in Yaroslavl, Russia.
- Program Committee, Third Annual International Computing and Combinatorics Conference (COCOON'97), Shanghai, China, August 1997.
- Program Committee, conference on Information, Statistics and Induction in Science (ISIS), Melbourne, Australia, 20–23 August, 1996.
- Program Committee, PHYSCOMP96 (IEEE Physics and Computation Conference), Boston, Mass., 1996.
- Program Committee, International Conference on Algorithms, Languages, and Programming, Paderborn (ICALP), Germany, 1996.
- Project leader NFI project ALADDIN: Algorithmic Aspects of Parallel and Distributed Computing, 1992–1997.
- Amsterdam Site Manager of ESPRIT BRA III NeuroCOLT Working Group 8556: Neural and Computational Learning, 1994–1997.
- Steering Committee, International Workshop on Distributed Algorithms (WDAG), since 1990.
- Steering Committee, Annual European Conference on Computational Learning Theory (EuroCOLT).
- Member IFIP WG 1.2 on Descriptive Complexity and Applications, since 1991. co-chair of IFIP WG 1.4 on Computational Machine Learning.
- Publiciteits commissie van het Wiskundig Genootschap (Publicity Committee Dutch Mathematical Society), since 1989.
- Ph.D. Committee D. Alstein, Technological University Eindhoven, 1995 (member).
- Ph.D. Supervisor in 1996 of B. Terhal, R. Cramer, H.H. Ehrenburg, P. Grünwald, B. Olivier, J.-H. Hoepman, W. van Dam, J. van Maanen, University of Amsterdam.
- 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).
- Dutch Institute for Programming and Algorithmics (IPA) (member).
- Onderzoekschool Logica (OzL) (member).
- Project leader various SION projects in Machine Learning, Multiple Computing Agents, Cryptography and Randomness, Quantum Computing.

J.-H. Hoepman :

- Organizer ALADDIN Colloquium Series
- Organizer bi-weekly ALADDIN Seminars.

H. Buhrman:

- Member of the program committee for 12th annual conference on Computational Complexity, Ulm, 1997.

L. Fortnow:

- Editor, Information and Computation.
- Editor, Chicago Journal of Theoretical Computer Science.
- Member, IEEE Conference on Computation Complexity Conference Committee.
- Member, 29th ACM Symposium on the Theory of Computing (1997) Program Committee.

D. van Melkebeek:

- Organizer bi-weekly Seminar on Computational Complexity Theory.

Visitors

- A. Berthiaume (Univ. Montréal, Canada)
- J. Garay (IBM T.J. Watson Research, Yorktown Heights, N.Y., USA)
- F. Gruau (Stanford University, Stanford, USA)
- A. Panconesi (Freie Universität Berlin, Germany)
- D. Breslauer (MPI, Saarbrücken, Germany)
- C. Lynch (INRIA & CRIN, Nancy, France)
- M. Franklin (At&T Bell Labs, Murray Hill, USA)
- L. Lamport (DEC Systems Research Lab., Palo Alto, USA)
- P. Berman (Pennsylvania State Univ., USA),
- J. Halpern (IBM Research Center Almaden, Cal., USA)
- D. Peled (At&T Bell Labs, Murray Hill, USA)
- C. Smith (Univ of Maryland, College Park, USA)
- A. Bar-Noy (IBM T.J. Watson Res, Yorktown Heights, USA)
- K. Yamanishi (NEC Resaerch, Tokyo, Japan)
- D. Coppersmith (At&T Bell Labs, Murray Hill, USA)
- D. Quatravaux (Ecole Normale Supériere, Paris, France)

Papers in Journals and Proceedings

M. BELLARE, J. GARAY, T. RABIN (1996). Distributed pseudo-random bit generators–a new way to speed-up shared coin tossing. *Proceedings 15th Annual Symp. on Principles of Distributed Computing*, 191–200.

A. BERTHIAUME (1996). *Complexity Theory Retrospective II*, chapter Quantum Computation, Springer-Verlag.

H. BUHRMAN (1996). A short note on shor's factoring algorithm. *SIGACT News* **27**(1), 89–90.

H. BUHRMAN, S. FENNER, L. FORTNOW (1997). Results on resource bounded measure. *Proceedings of ICALP'97*.

H. BUHRMAN, L. FORTNOW (1997). Resource-bounded kolmogorov complexity revisited. *Proceedings of the 14th Symposium on Theoretical Aspects of Computer Science*, volume 1200 of *LNCS*, Springer, Berlin, 105–116.

H. BUHRMAN, L. FORTNOW, L. TORENVLIET (1997). Six hypotheses in search of a theorem. *Proceedings of the 12th IEEE Conference on Computational Complexity*. IEEE, New York. To appear.

H. BUHRMAN, M. FRANKLIN, J. GARAY, J.-H. HOEPMAN, J. TROMP, P. VITÁNYI (1996). Mutual search. Submitted for publication.

H. BUHRMAN, J.-H. HOEPMAN, P. VITÁNYI (1996). Optimal routing tables. *Proceedings of the 15h ACM Symposium on Principles of Distributed Computing*, 134–142.

H. BUHRMAN, M. LI, P. VITÁNYI (1996). Kolmogorov random graphs. Submitted for Publication.

H. BUHRMAN, L. LONGPRE (1996). Compressibillity and resource bounded measur. PUECH, REISCHUK (eds.). *13th Annual Symposium on Theoretical Aspects of Computer Science*, number 1046 in Lecture Notes in Computer Science, Springer, 13–24.

H. BUHRMAN, P. ORPONEN (1996). Random strings make hard instances. *J. Computer and System Sciences* **53**(2), 261–266.

H. BUHRMAN, T. THIERAUF (1996). The complexity of generating and checking proofs of membership. C. PUECH, R. REISCHUK (eds.). *13th Annual Symposium on Theoretical Aspects of Computer Science*, number 1046 in Lecture Notes in Computer Science, Springer, 75–86.

H. BUHRMAN, L. TORENVLIET (1996). P-selective selfreducible sets: A new characterization of p. *J. Computer and System Sciences* **53**(2), 210–217.

R. CRAMER, I. DAMGÅRD (1996). New generation of secure and practical rsa-based signatures. *Proceedings of Crypto '96*.

R. CRAMER, I. DAMGÅRD (1997). Fast and secure immunization against man-in-the-middle impersonations. *Proceedings of Eurocrypt '97*.

R. CRAMER, I. DAMGÅRD (1997). Linear zero-knowledge: A note on efficient zero-knowledge proofs and arguments. *Proceedings of ACM STOC '97*, to appear.

R. CRAMER, I. DAMGÅRD, P. PEDERSEN (1996). Efficient and provable security amplifications. *Proceedings of 4th Cambridge Security Protocols*, volume 1189 of *LNCS*, 101–110.

R. CRAMER, I. DAMGÅRD, B. SCHOENMAKERS (1996). Proofs of partial knowledge and simplified design of witness hiding protocols. *CWI Quarterly (Special Issue on Cryptography)* **8**(2), 111–127, June 1995, appeared in 1996.

R. CRAMER, M. FRANKLIN, B. SCHOENMAKER, M. YUNG (1996). Secure secret ballot election schemes with linear work. *Proceedings of Eurocrypt '96*, LNCS.

R. CRAMER, B. SCHOENMAKER, R. GENNARO (1997). A secure and optimally efficient multi-authority election scheme. *European Journal on Telecommunication Systems*, accepted for publication.

R. CRAMER, B. SCHOENMAKER, R. GENNARO (1997). A secure and optimally efficient multi-authority election scheme. *Proceedings of Eurocrypt '97*.

W. VAN DAM (1996). A universal quantum cellular automaton. TOMMASO TOFFOLI, MICHAEL BIAFORE, JO AO LE AO (eds.). *Proceedings of the Fourth Workshop on Physics and Computation*, New England Complex Systems Institute, 323–331.

J. FEIGENBAUM, L. FORTNOW, S. LAPLANTE, A. NAIK (1996). On coherence, random-self-reducibility, and self-correction. *Proceedings of the 11th IEEE Conference on Computational Complexity*, IEEE, New York, 59–67.

S. FENNER, L. FORTNOW, W. GASARCH (1996). Complexity theory newsflash. A Parody. *SIGACT News* **23**(3), 126.

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S. FENNER, L. FORTNOW, L. LI (1996). Gap-definability as a closure property. *Information and Computation* **130**(1), 1–17.

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CWI Reports

CS-R9618. I. DAMGÅRD, R. CRAMER. *On monotone function closure of perfect and statistical zero-knowledge.*

Other Publications

J. BALCÁZAR, H. BUHRMAN (1996). *Characterizing the Learnability of Kolmogorov Easy Circuit ExPressions*, Technical Report NC-TR-96-020, NeuroCOL.

A. BERTHIAUME (1996). *Quantum Computation Mini Course*, Lecture notes for Basic Research in Computer Science (BRICS), University of Aarhus. NS-96-1.

H. BUHRMAN, L. FORTNOW (1996). *Two Queries*, Technical Report CS-96-20, University of Chicago Department of Computer Science.

R. CRAMER (1996). *Modular Design of Secure yet Practical Cryptographic Protocols*, Ph.D. thesis, University of Amsterdam, Januari 1997. Completed November 1996.

W. VAN DAM (1996). *Quantum Cellular Automata*, M.Sc. dissertation, Computing Science Institute, University of Nijmegen, The Netherlands.

R. DOWNEY, L. FORTNOW (1996). *Uniformly Hard Languages*, Technical Report CS-96-12, University of Chicago Department of Computer Science.

F. GRUAU, K. QUATRAMARAN (1996). *Cellular encoding for interactive evolutionary robotics 225*, CWI, p. 24.

L. FORTNOW, S. LAPLANTE (1996). *Extractors for Kolmogorov Complexity*, Technical Report CS-96-25, University of Chicago Department of Computer Science.

M. STEIJVERS, P.D. GRÜNWALD (1996). *A Recurrent Network that Performs a Context-sensitive Prediction Task*, Technical Report NC-TR-96-035, Neurocolt Technical Report Series.

J. BALCAZAR, H. BUHRMAN (1996). *Characterizing the Learnability of Kolmogorov Easy Circuit Expressions*, Neurocolt Report NC-TR-96-020.

Awards

A. Berthiaume:

- Doctoral Prize from the Natural Sciences and Engineering Research Council of Canada. NSERC is the national research funding agency and this prize is awarded to the two best Canadian theses in all areas of science.

- Excellence Prize from 'L'Académie des Grands Montréalais'. The prize is awarded to the science thesis that made the most significant impact in the field.
- The Governor General's Gold Medal. Each Canadian university awards one gold medal each year to the scientific thesis that contributed the most to its field.

L. Fortnow:
- Fulbright Scholar Award.
- NWO grant.

Interoperable Multimedia Systems – AA3

Staff

- Dr. D.C.A. Bulterman, group leader
- Drs. A.M. Bleeker, (OIO), SION
- Prof. L.G.L.T. Meertens, group leader
- Ir. H.G.P. Bosch, researcher (1 June–1 November)
- J.A.F.C. van Disseldorp (trainee, from 1 September)
- H.L. Hardman, M.Sc., researcher
- Dr. J.-H. Hoepman, researcher (1 June–1 November)
- A.J. Jansen, programmer
- Drs. K.S. Mullender, programmer
- S. Pemberton, senior researcher
- Drs. G. van Rossum, researcher (until 1 February)
- L.W. Rutledge Sc.D., post-doc (from 1 September)
- L. Salvail Ph.D. post-doc (from 1 February)
- M. Theodoridou, M.Sc., visiting researcher
- ir. O.J.M. Weber, junior researcher (OIO), STW

Scientific Report

Interoperability of independently-developed multimedia applications is a research area of theoretic, strategic and pragmatic relevance. The central research issue of the Interoperable Multimedia Systems group is to develop formalisms and tools that support the concept of interoperability in its broadest sense. The research issues include the development of mechanisms that support abstract modelling, authoring, and runtime implementation of multimedia applications at the systems and user levels. The applications studied cover a broad spectrum of concerns, but all share a need for presentation on heterogeneous environments and a requirement for long life-cycles to recover the high costs of multimedia data definition. The core problems include the development of document activity specification that can be used as the basis for transportable applications, the development of protocol rules for adaptive communication of multimedia data, and distributed resource allocation algorithms.

During 1996, the group participated in the following national and international research projects: ACELA (NL/STW) on the construction of interactive books, conducted within the project AA-3.1 Interactive Books (Meertens, Pemberton, Weber); CHAMELEON (EU/Esprit-IV 20597) on the development of multimedia authoring systems for adaptive documents, conducted within AA-3.2 Multimedia Authoring Environments (Bulterman, Hardman, van Rossum, Jansen, Mullender, Rutledge, Theodoridou); SEMPER (EU/ACTS-0032), on multimedia support within secure electronic marketplaces, conducted within AA-3.3 Distributed Multimedia Applications (Bulterman, Bosch, Hoepman, Mullender, Salvail) and STEM (EU/Telematics) on Sustainable Telematics for Environmental Management, conducted within AA-3.3 Distributed Multimedia Applications (Bulterman, Hardman, Theodoridou).

Dick Bulterman. Together with Lambert Meertens, Bulterman directed the AA-3 group as it shifted a significant amount of its focus to multimedia activity. During this year, he published several papers on various aspects of multimedia systems design and authoring. He served as associate program chair and associate editor for a variety of leading conferences and journals during the year. He participated in the EU's CHAMELEON, SEMPER and STEM projects during the year.

Lambert Meertens. Together with Annette Bleeker he conducted research described under AA2, Cryptology. Together with Steven Pemberton and Olaf Weber he worked mainly within the Acela project, focussing on architectural and user interface issues of systems for electronic publishing, in particular for interactive books, for data structuring, presentation and its abstraction from pure content issues, data delivery, including integration with the World Wide Web, and interoperability. Among the issues investigated in this project were requirements for authoring systems, the design of a software bus for interfacing to external mathematical applications, and type systems for the interchange of mathematical objects with external applications. Together with Steven Pemberton he participated in the COCA project (Cooperative Open Component Architecture), a joint initiative of Utrecht University, Technological University Eindhoven and CWI.

Peter Bosch. Bosch returned to CWI (where he was a member of the Amoeba group in the late

1980's) as a short-term researcher working on the SEMPER electronic commerce project. His principal responsibility was to evaluate system and OS requirements for supporting short-duration video over ATM networks. He left CWI for the University of Twente in November.

Jeroen van Disseldorp. As a visitor from Utrecht University, van Disseldorp worked together with Pemberton on constraint-driven code generation.

Lynda Hardman. Ms. Hardman continued work on her dissertation in the area of hypermedia information models. She published several papers on various aspects of hypermedia authoring and on hyperstructured document design. She was a frequent presenter at conferences and workshops in conjunction with the activities of AA3.2. She contributed significantly to the STEM project. She participated in the CHAMELEON project during the year. She also found time to deliver her first child in April 1996.

Jaap-Henk Hoepman. Hoepman moved to AA3 after serving as an NFI researcher in the group AA1. His principal responsibility was to evaluate and implement security algorithms for use by the SEMPER electronic commerce project. He completed his Ph.D. in November and joined KPN Research at the end of the year.

Jack Jansen. Jansen contributed to the CMIFed/CHAMELEON runtime environments. He also worked on multi-platform support for CMIFed, specifically on the Macintosh port of this environment. His CMIFed work focussed on issues of scheduling the runtime execution of multimedia data fragments. He was also involved in OR activities at CWI. He was also a member of the board of the NLUUG.

Sjoerd Mullender. Mullender worked on implementation aspects of the CMIFed runtime environment. In particular, he worked on a uniform thread-based window interface and on support for media drivers within CMIF. He also contributed to the SEMPER project, providing expertise on systems architecture and applications design and to the CHAMELEON project.

Steven Pemberton. The work, performed partly within the Acela project, focussed on architectural and user interface issues of systems for electronic publishing, in particular for interactive books, for data structuring, presentation and its abstraction from pure content issues, data delivery, including integration with the World Wide Web, and interoperability.

Guido van Rossum. Van Rossum worked on developing and supporting the Python VHLL, which he invented at CWI. After many years of especially productive service to CWI in the ABC, Amoeba and CMIF projects, he left the Institute in early 1996 to join the CNRI in Reston, VA (USA).

Lloyd Rutledge. Dr. Rutledge joined CWI in October as a post-doc with the CHAMELEON project. His particular area of interest is the use of standard document description languages and formats (such as HyTime and MHEG) to describe complex multimedia applications.

Louis Salvail. Salvail joined CWI in February as a post-doc working on the SEMPER electronic commerce project. His principal contribution has been on the implementation of the security architecture and the design and evaluation of advanced services for secure electronic transactions.

Maria Theodoridou. Ms. Theodoridou worked on various aspects of the CMIFed authoring environment in AA-3.2. Specifically, she worked to develop a number of applications that demonstrated the features of this system. She developed a multi-platform application for CD-ROM entitled Pictures at a Mondrian Exhibition together with composer David Little, based on a musical piece of the same name. She also contributed heavily to the STEM project's architecture and interface for use by land managers throughout Europe.

Olaf Weber. Weber worked on the Acela project. His work concentrated on architectural issues for interactive books in general, and those concerning mathematical subject matter specifically.

Organization of Conferences, Workshops, Courses, etc.

- CHAMELEON Project Meeting, January 16–17: D.C.A. Bulterman
- SEMPER Fall Workshop, September 2–9: D.C.A. Bulterman
- STEM Final Review Meeting, December 8–11: D.C.A. Bulterman and M. Theodoridou

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

- W3C Technical Meeting, Nice, January 11–12: S. Pemberton
- ACM CHI '97 Meeting, Atlanta, January 12–14: S. Pemberton
- CHAMELEON meeting, Paris, January 26: D.C.A. Bulterman, H.L. Hardman
- Authoring Support for Interactive Multimedia Presentations, SWI/UvA, January 30: H.L. Hardman
- STEM project meeting, Valencia, ES, February 3–5: D.C.A. Bulterman and H.L. Hardman
- SEMPER project meeting, Zürich, CH, February 6: D.C.A. Bulterman

- HyTime workshop, Brussels, Belgium, February 28: H.L. Hardman
- Elsevier, Amsterdam, March 7: S. Pemberton
- CHAMELEON meeting, London, UK, March 12: D.C.A. Bulterman, H.L. Hardman
- SEMPER project meeting, Brussels, March 13: D.C.A. Bulterman, K.S. Mullender, L. Salvail
- CHAMELEON meeting, Paris, France, March 21: D.C.A. Bulterman
- STEM project meeting, Edinburgh, UK, March 22: D.C.A. Bulterman
- Invited Talk, Boston University, Boston, MA, April 4: D.C.A. Bulterman
- Invited Talk, U. Mass/Lowell, Lowell, MA, April 5: D.C.A. Bulterman
- W3C Technical Meeting, Nice, April 1–2: S. Pemberton
- ACM CHI '96, Vancouver, April 15–17: S. Pemberton
- SEMPER project meeting, Caen, April 24: L. Salvail
- CHAMELEON meeting, London, UK, April 24: D.C.A. Bulterman
- W3C Technical Meeting, Nice, May 1–2: S. Pemberton
- WWW Conference, Paris, May 5–10: S. Pemberton
- SEMPER project meeting, Zaragoza, May 15: L. Salvail
- STEM project meeting, Assynt, UK, May 15: M. Theodoridou
- ICFP, Philadelphia, PA, May 24–26: L.G.L.T. Meertens
- CALCOMP project meeting, Kiel, Germany, May 28: L.G.L.T. Meertens
- SEMPER project meeting, Darmstadt, May 21–23: K.S. Mullender, L. Salvail
- AVI '96, Gubbio, IT, May 27: D.C.A. Bulterman
- CHAMELEON meeting, Athens, Greece, May 29: D.C.A. Bulterman
- STEM project meeting, Edinburgh, UK, September 16: M. Theodoridou
- ACM/NSF/MIT Strategic Directions in Computing Research workshop, Cambridge, MA, June 14–15: D.C.A. Bulterman
- W3C Technical Meeting, Nice, June 6–19: S. Pemberton
- IFIP WG 2.1 Meeting, Rancho Santa Fe, CA, June 10–14: L.G.L.T. Meertens (Types as sets)
- W3C Technical Meeting, Nice, June 21–29: S. Pemberton
- CHAMELEON meeting, London, UK, June 24: D.C.A. Bulterman
- SEMPER project meeting, Hildesheim, Germany, July 7: J.-H. Hoepman, L. Salvail
- ACM CHI '97 Meeting, Atlanta, July 5–8: S. Pemberton
- CHAMELEON meeting, London, UK, July 7: D.C.A. Bulterman
- CHAMELEON meeting, St. Andrews, UK, July 23–24: D.C.A. Bulterman and A.J. Jansen
- SIGCHI EC Meeting, Toulouse, July 27–28: S. Pemberton
- International Workshop on Image Databases and Multimedia Systems, Amsterdam, August 22–23: H.L. Hardman
- CHAMELEON meeting, Madrid, ES, September 19: D.C.A. Bulterman
- SAS/PLILP/ALP, Aachen, Germany, September 24–27: L.G.L.T. Meertens (Calculate polytypically!)
- SEMPER project meeting, Zürich, Switzerland, October 2: D.C.A. Bulterman
- W3C Real-Time Multimedia Workshop, Nice, France, October 11–12: D.C.A. Bulterman
- CommerceNet Global Summit, San Francisco, CA, October 14: D.C.A. Bulterman
- Informatica Colloquium Philips Research Laboratories, Eindhoven, October 16: L.G.L.T. Meertens (A calculus for distributed programming)
- CHAMELEON meeting, Madrid, ES, October 19–23: K.S. Mullender
- Fifth International Workshop on Object Orientation in Operating Systems, Seattle, WA, October 25–28: H.G.P. Bosch
- SIMOS working group, San Miniato, October 27–28: H.L. Hardman
- CHAMELEON meeting, Paris, October 29–30: D.C.A. Bulterman and L.W. Rutledge
- CHAMELEON meeting, Athens, GR, October 29–31: A.J. Jansen
- Jubileum Martin Rem, Eindhoven, November 1: L.G.L.T. Meertens (De esthetica van het onderzoek)
- ACM CHI '97 Meeting, Boston, November 8: S. Pemberton
- CALCOMP project meeting, Oxford, UK, November 8–10: L.G.L.T. Meertens
- Multimedia Modelling '96, Toulouse, November 12–15: D.C.A. Bulterman and L.W. Rutledge
- Kenniskring Multimedia, Amsterdam, November 13: H.L. Hardman
- Open Hypertext Workshop, Southampton, England, December 7–8: H.L. Hardman and L.W. Rutledge
- SEMPER project meeting, Arhus, DK, December 11–12: L. Salvail

- ACM CHI '97 Meeting, New York, December 12–13: S. Pemberton
- Informatiewetenschap '96, Delft, December 13: H.L. Hardman

Memberships of Committees and Other Professional Activities

D.C.A. Bulterman:
- Technical director, ESPRIT-IV CHAMELEON project
- CWI project leader, ACTS SEMPER project
- CWI project leader, TELEMATICS STEM project
- Editorial board, Multimedia Systems Journal (ACM/Springer)
- Editorial board, Multimedia Tools and Applications Journal (Kluwer)
- Program committee, ACM Multimedia '96 (San Francisco; associate chair)
- Program committee, Multimedia Modelling '96 (Toulouse)
- Member, ACM/NSF Human-Computer Interaction policy group (Boston, June 1996)
- Member, SION Stuurgroep Multimedia
- Referee: ACM TOIS, IEEE Multimedia

H.L. Hardman:
- Reviewer: ACM Hypertext '96, Multimedia Modelling '96
- Reviewer: IEEE MM magazine, ACM/Springer Multimedia Systems, ACM Computing Reviews, Multimedia Tools and Applications.
- Video reviewer, CHI '96
- Program committee, The Missing Link workshop (Hypermedia Usability Research & The Web), May '96
- Editorial board, New Review of Hypermedia and Multimedia
- Committee member, Vereniging Werkgemeenschap Informatiewetenschap

L.G.L.T. Meertens:
- Member IFIP Working Group 2.1 on Algorithmic Languages and Calculi
- Member of the Visiting Committee for Computer Science University Education in The Netherlands 1995/1996
- Project leader in the STW project Acela
- Member Program Committee IFIP TC2 Working Conference on Algorithmic Languages and Calculi, Bisschofsheim (France) (1997)
- Member Ph.D. committee D.T. Tuijnman, A Categorical Approach to Functional Programming, February 2 (University of Ulm, Germany)
- Member Ph.D. committee M. Massink, Functional Techniques in Concurrency, February 5 (KUN)
- Member Ph.D. committee M.P.A. Sellink, Computer-Aided Verification of Protocols – The Type Theoretic Approach (UU)
- Member Ph.D. committee B. van Linder, Modal Logic for Rational Agents, June 19 (UU)
- External examiner M. Chi Tai Fong, General Hashing, October 22 (University of Auckland, New Zealand)

S. Pemberton:
- Editor-in-chief ACM SIGCHI Bulletin
- Member ACM SIGCHI Executive Committee
- Member NNI (Dutch Standards Authority) Software Ergonomy Committee
- Chair, W4G (European World Wide Web Working Group)
- Acela project manager
- Advisor to Amsterdam and Haarlem Chamber of Commerce on WWW issues

Visitors

- Frits Berger, Nijmegen (Hardman)
- David Lowe, UT Sydney (Hardman)
- Elisabeth Andre, DFKI, Saarbrücken (Hardman)
- H. Lie, (Pemberton)

Papers in Journals and Proceedings

L. MEERTENS (1996). Calculate Polytypically!, Programming Languages: Implementations, Logics and Programs. H. KUCHEN, S.D. SWIERSTRA (eds.). *Proc. Eighth International Symposium PLILP '96*, LNCS 1140, Springer-Verlag, 1–16.

D.C.A. BULTERMAN (1996). Challenges in Human-Computer Interfaces: Making the Technology Serve the User. *ACM Computing Surveys* **28**(4).

D.C.A. BULTERMAN (1996). Multimedia User Interfaces: Who Should Interface to Whom?. *Proc. AVI '96, Gubbio*, IT.

D.C.A. BULTERMAN (1996). Network-Based Multimedia: Experiences from the CMIF Project. *Proc. Real-Time Multimedia Workshop*, Sofia-Antipolis.

P. BOSCH, S. MULLENDER (1996). PFS: A Distributed and Customizable File System. *Proc. of the Fifth International Workshop on Object Orientation in Operating Systems*, Seattle, WA, USA.

M. WORRING, C. VAN DEN BERG, H.L. HARDMAN (1996). System Design for Structured Hypermedia Generation. *Procs. of Visual Information Systems '96*, Melbourne, 254–261.

Databases – AA4

Staff

- Prof. dr. M.L Kersten, department head and group leader
- Dr. A.P.J.M. Siebes (project leader)
- Drs. F. van Dijk (programmer)
- K. van 't Hoff (programmer)
- Ir. J. Pellenkoft (oio)
- Drs. J.F.P. van den Akker (oio)
- Dr. ir. R. Choenni (postdoc, till 1 Nov 1996)
- J.R. Castelo Comp.Eng. (Erasmus fellow, since October)
- F.C.J. Bos (HIO stagiair, from March 11 till June 11)
- M.A. van den Brink (HIO stagiair, from March 11 till June 11)
- M.B. Dee (HIO stagiair, from March 11 till June 11)
- W.H.A. Fieten (TUE stagiair, since September)
- D.T. Menger (HIO stagiair, from March 11 till June 11)
- M.F.C. Toneman (RUU stagiair, May 13–August 31)

Scientific Report

Database Architectures
Effective exploitation of distributed platforms for database management requires better solutions for load balancing to improve response time in a loosely coupled system; dynamic query optimization to exploit data – and processing skew, techniques for database browsing, and adaptive storage structures.

Monet is a database kernel developed in our group since 1993 to experiment with implementation techniques for novel application domains on parallel and distributed processing platforms. Its salient features include: a fully decomposed storage scheme (binary model), adaptive indexing to speed-up query processing, inter-operator parallelism, implicitly by looking for facilities to delegate as much as possible or to advise the lower level OS-primitives on the intended behavior, extensibility and portability.

The activities in 1996 concentrated on performance evaluation of the database kernel on specific applications and benchmarks. *P. Boncz (UvA), W. Quak (UvA)* and *M. Kersten* reported on the results obtained for the SEQUOIA benchmark, a very large test case for Geographical Information System support. This activity took place in the context of the National project MAGNUM, a cooperation between CWI, UT, TUE, and UvA.

The next step in this research concerned exploration of the Monet architecture to provide the functionality required in an object-oriented environment. *P. Boncz (UvA)* developed an ODMG interface and compiler. Initial performance results were obtained by hand-compilation of the OO–7 benchmark and published at BNCOD'96. Both performance experiments convincely demonstrated that a main-memory departure to develop a DBMS provides excellent performance also in disk-based environments.

After the summer period research and development focussed on preparatory actions to deal with complex decision support queries, such as represented by the TPC-D benchmark, and data cube operations. The key research question is to isolate the necessary database primitives to support this class of applications on highly parallel platforms.

Despite substantial funding obtained from the National HPCN project IMPACT research activities were limited due to lack of manpower.

Our visitor *S. Sidorov* studied several strategies for extending Monet with temporal facilities. A module was developed and with the help of *P. Boncz* integrated in the system.

Several students, from TUE, and HIO 'Oost Nederland', obtained their final education. One project focussed on development of a Java-based mockup of the Data Surveyor system (*M. Dee & D. Menger*). A second project concerned development of a graphical user interface for querying GIS databases (*F. Bos & M van den Brink*).

Query optimization. Pellenkoft, Galindo and *Kersten* continued their cooperation by focussing on the problem of counting superfluous transformations in query optimizers. Several papers were prepared and major progress can be reported on the finalization of the Ph.D. thesis.

Active Databases. An active database system is characterized by a set of active objects, i.e., event-condition-action pairs, which describe actions to be taken upon encountering an event in a particular database state.

Van den Akker and *Siebes* continued their work on the autonomous data model DEGAS. The research has been focussed on the development of dynamical and temporal aspects of DEGAS. The results of this work have been published at CAiSE and the DEXA workshop. Moreover, the relationship between active databases and intelligent agents has been clarified. The results of this research will be published at the first Co-operative Agents workshop in Kiel.

Furthermore the development of a query language for DEGAS has been started, the results of which

will be published shortly. Finally, design rules for DEGAS have been defined and applied to a workflow example. These results will also be published in the near future.

Database applications. The group balances the theoretical and architectural studies with database applications. In 1993 we started a new project on data mining.

Data mining. Databases contain much more information than that what can be found using conventional query-languages. An example of such 'hidden' information is the set of risk-profiles that can be derived from an insurance database. The discovery of such higher order information is commonly called data mining.

The research in this year has been focussed on the EC-funded project KESO. *Choenni, Kersten,* and *Siebes* have worked on multi-query optimization issues in data mining. *Siebes* has continued his work on the conceptual foundations of KESO. In particular he has shown how well-known data mining algorithms fit naturally in the KESO framework. *Toneman* has produced a master thesis on genetic algorithms in data mining.

Finally, *Kersten* and *Siebes* developed an architecture of the KESO system to be realized with the partners from Data Distilleries, GMD, and the University of Helsinki.

All this work has been published at international workshops and conferences.

Performance monitoring . The Mercury project aims at further extending the use of the Software Testpilot as a means to control and predict the performance of database technology. In the startup year 1996, K. van 't Hoff designed and implemented a database for performance administration. The underlying platform is an Oracle Web server.

Web-based applications. As of April *P. De Bra* joined the group on a parttime basis. The initial activities have been focussed on preparing a project proposal for the EU and STW. Research activities became centred on creation of the Acoi database, aimed to provide a large-scale experimentation platform for multi-media databases. A student *Fieten* was attracted to develop necessary enquiry techniques to enable remote, democratic incremental indexing.

H. Sprangers developed a successful web site for the Stedelijk Museum, which proved a valuable exercise in getting experience in the requirements posed by such applications on the database infrastructure.

Organization of Conferences, Workshops, Courses, etc.

- KESO. CWI is prime contractor of the ESPRIT-IV project KESO. Its day-to-management is done by A. Siebes. Several working meetings have been organized and substantial effort has been invested in reporting the project's progress towards the CEC.
- Data Distilleries. CWI is co-founding partner in Data Distilleries, established to further develop and exploit data mining technology. To facilitate quick take up of the research results A. Siebes has given several lectures to interested parties, e.g., Avero, Centraal Beheer, Zilveren Kruis, ABN/AMRO, ING bank, Postbank, and Dutch Rail, and provided educational and promotional support for data mining projects. M. Kersten has spent a few days in September to improve the product development organization.

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

- Microsoft, Redmond (USA), January: A. Pellenkoft.
- Invited Tutorial *Data Mining*, EDBT, Avignon, France, March 28: A. Siebes, M.L. Kersten.
- Databasedag, Antwerpen, April 16: J. van den Akker, A. Pellenkoft, (*Duplicate free transformation-based join enumeration*).
- Dagsthul workshop Performance Enhancement in Object Bases, Apr 1–4: M.L. Kersten (*Stinky, a new media IO device*).
- AIO cursus Informatiesystemen, Papendal, Arnhem, April 22–24: J. van den Akker.
- Conference on Advanced Information Systems Engineering (CAiSE*96), Heraklion, Kreta, Griekenland: J. van den Akker, (*DEGAS: Capturing Dynamics in Objects*).
- Datawarehouse Conference Benelux, Eindhoven, March 20: M.L. Kersten (*Datawarehouse concepts*).
- NGI-Databaseclub, Nuland, May: A. Pellenkoft.
- Keynote speaker Unicom Conference: Data Mining 96, London (UK), May: A. Siebes, (*Data Mining in* KESO).
- Mercury meeting, IFATEC, Saint Quentin, France, M.L. Kersten, K van 't Hoff.

- IFIP 6.2 Working Group Database, Antwerpen, June 24–26: M.L. Kersten *GIS Database Applications*).
- Invited Tutorial *Data Mining: what it is and how it is done*, SEDB'96, San Miniato Italy, July: A. Siebes.
- LID'96 Panel Discussion, San Miniato Italy, July: A. Siebes (*Deductive Databases: Challenges, Opportunities, and Future Directions*).
- 7th International Conference and Workshop on Database and Expert Systems Applications, Zürich, Zwitserland: J. van den Akker, (*Object Histories as a Foundation for an Active OODB*).
- University Paris VI, J. Bolous Ph.D. defense, July 19: M.L. Kersten.
- Multi-media dag, CWI Amsterdam, September 3: M.L. Kersten, (*Multi-medi database research*).
- Heriot-Watt University, Edinburgh, September 4–5: K. van 't Hoff.
- Mercury Review, ICL, Manchester, September 30: K. van 't Hoff.
- ERCIM XCOM meeting, Rutherfordslab, UK, September 16: M.L. Kersten.
- ERCIM Database Working Group on Heterogeneous Information Management, Prague, Czech Republic: J van den Akker.
- Databasedag, Groningen, November 5: A. Pellenkoft.
- Invited Tutorial *Data Mining*, SIKS Course, November: A. Siebes
- Invited Tutorial *Data Mining*, NLUUG, Najaars Congres, Ede, November: A. Siebes.
- IFIP 6.2 working group on databases, Washington, November 7–9: M.L. Kersten (*Data cube optimization*).
- Invited Lecture *Data Mining*, CSN96, Utrecht, November: A. Siebes
- Invited Tutorial *Data Mining*, SOFSEM'96, Milovy, Czech Republic, November: A. Siebes.
- Tandem (HPRC), Scotland, December 1996, A. Pellenkoft.
- Univ. de Versailles, Ph.D. Defense L. Bouganim, December 12: M.L. Kersten.

Membership of Committees and Other Professional Activities

M.L. Kersten:

- Professor of Computer Science, University of Amsterdam
- Non-executive board member of Consultdata B.V., Amsterdam
- Co-founder of Data Distilleries B.V., Amsterdam
- Member editorial board 'The VLDB Journal', Springer-Verlag
- Member editorial board 'Distributed and Parallel Databases', Kluwer
- Member IFIP working group 2.6 Databases
- Member CEC evaluation committee ESPRIT-IV, Database Systems
- CEC reviewer of ESPRIT IV project TOOBIS
- Member executive committee ERCIM
- European coordinator VLDB 1996.
- Tutorial coordinator EDBT 96
- Member program committee PDIS '96, Miami
- Member program committee SOFSEM '96, Brno
- Member program committee VLDB '96, Bombay
- Member program committee Int. Workshop on Image Databases and Multi Media Search,Amsterdam
- Member program committee SOFSEM '97, Milovy, Czech Republic
- Member program committee Digital Libraries '97, Italy
- Member program committee EURO-PAR '97, Germany
- Member program committee RIDS '97, Zürich
- Member program committee ICDE '97, Birmingham
- Member program committee ACM SIGMOD '97
- Rijksgecommitteerde HIO 'Oost-Nederland'
- Member Ph.D. committee drs. T. Gevers (University of Amsterdam)
- Member Ph.D. committee drs. J. Bolous (Paris VI, July 1996)
- Member Ph.D. committee drs. L. Bouganim (Univ. Versailles, Dec 1996)

A.P.J.M. Siebes:

- Co-founder of Data Distilleries B.V., Amsterdam
- Member program committee KDD'96, Portland
- Member program committee PKDD'97, Trondheim
- Member program committee 7th IFIP 2.6 Working Conference on Database Semantics (DS-7), Leysin, Switzerland
- Member program committee KDD'97, Newport Beach

Visitors

- Drs. H. Sprangers (Visitor, Jan–Dec)
- Prof. dr. P.M.E. De Bra (Visitor TUE, April 1–December 31)
- Prof. S. Sidorov (Visitor Technical University of Cluj, Romania, August 15–November 15)

Papers in Journals and Proceedings

J. VAN DEN AKKER, A. SIEBES (1996). DEGAS: Capturing Dynamics in Objects. *Advanced Information Systems Engineering – Proceedings of CAiSE*96*, Springer-Verlag LNCS 1080, Heraklion, Crete, Greece, 82–98.

J. VAN DEN AKKER, A. SIEBES, (1996). Object Histories as a Foundation for an Active OODB. *Proceedings of the Seventh International Workshop on Database and Expert Systems Applications (DEXA'96)*, IEEE Computer Society, Zürich, Switzerland 2–8.

P. BONCZ, F. KWAKKEL, M.L. KERSTEN (1996). High performance support for O–O traversal in Monet. *Proc. BNCOD'96*, Edingburgh (UK).

P. BONCZ, W. QUAK, M.L. KERSTEN (1996). Monet and its geographical extensions. *Proc. EDBT'96*, Avignon (France).

M. HOLSHEIMER, M.L. KERSTEN, ARNO SIEBES (1996). Data Surveyor: Searching the Nuggets in Parallel. U.M. FAYYAD, G. PIATETSKY-SHAPIRO, P, SMYTH, R. UTHURUSAMY (eds.) *Advances in Knowledge Discovery and Databases*, AAAI Press/MIT Press, 447–467.

N.J. NES, M.L. KERSTEN, A. JONK, (1996). Database support for line clustering, *ASCI conference*, Vosse-Meren, 277–282.

N.J. NES, C. VAN DEN BERG, M.L. KERSTEN (1996) Database support for image retrieval using spatial-color features. *First International Workshop on Image Databases and Multi-Media Search*, 210–217.

A. SIEBES (1996). Data Mining: What it is and how it is done. *Proc. SEDB96*, San Miniatio, Italy, 329–344.

A. SIEBES. (1996) Data Mining and the KESO project. *Proc. SOFSEM'96*, Springer Verlag, LNCS 1175, Milovy, Czech Republic, 161–177.

A. SIEBES, S. TSUR, J. ULLMAN, L. VIEILLE, C. ZANIOLO (1996). Deductive Databases: Challenges, Opportunities and Future Directions. *Logic in Databases*, Springer-Verlag, LNCS 1154, San Miniato, Italy, 225–229.

S. WROBEL, D. WETTSCHEREK, I. VERKAMO, A. SIEBES, H. MANNILA, F. KWAKKEL, W. KLÖSGEN (1996). User Interactivity in Very Large Scale Data Mining. W. DILGER, M. SCHLOSSER, J. ZEIDLER, A. ITTNER (eds.). *Proc. FGML-96 (Annual Meeting of the GI Special Interest Group Machine Learning*, Computer Science Technical Report No. CSR-96-06, TU Chemnitz-Zwickau, 125–130.

CWI Reports

CS-R9608. J.F.P. VAN DEN AKKER, A.P.J.M. SIEBES. *DEGAS: A temporal active data model based on object autonomy.*

CS-R9637. R. CHOENNI, A.P.J.M. SIEBES, *A framework for query optimization to support data mining.*

CS-R9638. R. CHOENNI, M.L. KERSTEN, J.F.P. VAN DEN AKKER, A. SAAD. *On multi-query optimization.*

CS-R9639. J. PELLENKOFT, C.A. GALINDO-LEGARIA, M.L. KERSTEN. *Complexity of transformation-based optimizers and duplicate-gree generation of alternatives.*

Other Publications

R. CHOENNI, H.M. BLANKEN, H. WAGTERVELD (1996). *Automating Physical Database Design*, Handbook on Data Management.

M.L. KERSTEN (1996). Structuur in relaties tussen gegevens, Oratie, Univ. van Amsterdam.

M.L. KERSTEN ET.AL. (1996). Stinky: a new multi-media I/O device, Proceedings Dagsthul Workshop on Performance Enhancement in Object Bases, (Dagsthul, Germany).

DEPARTMENT OF INTERACTIVE SYSTEMS

Staff 1996

- Computer Graphics and Visualization – IS1
  - A.A.M. Kuijk
  - E.H. Blake
  - I. Diaz de Etura
  - S. Haritakis
  - R. van Liere
  - P.C. Marais
  - J.D. Mulder
  - J. van de Poll
  - T. van Rij
  - M. in ’t Veld
  - J.J. van Wijk
  - C.A. Wüthrich
- Interaction and Parallelism – IS2
  - F. Arbab
  - C.L. Blom
  - F.J. Burger
  - P.A. J. Bouvry
  - C.T.H. Everaars
  - R.H.M.C. Kelleners
- Interaction and Multimedia – IS3
  - P.J.W. ten Hagen
  - F.C. Heeman
  - I. Herman
  - H. Noot
  - G.J. Reynolds
  - M.M. de Ruiter
- Logic Programming and Computational Linguistics – IS4a
  - K.R. Apt
  - E. Marchiori
  - S. Marzola
  - E. Monfroy
  - F. van Raamsdonk
  - A. Schaerf
  - F. Teusink
  - A.S. Troelstra
- Logic and Computational Linguistics – IS4b
  - D.J.N. van Eijck
  - J.M.G.G. de Nivelle
  - P.J.E. Dekker
  - A.V. Groenink
  - J. Jaspars
  - S. van Dongen
- Secretary: J.J. Bruné-Streefkerk

Computer Graphics and Visualization – IS1

Staff

- Dr. A.A.M. Kuijk (group leader)
- Prof. dr. E.H. Blake
- I. Diaz de Etura
- S. Haritakis
- Ir. R. van Liere (researcher)
- Dr. P.C. Marais
- Drs. J.D. Mulder (Ph.D. student)
- J. van de Poll
- Drs. T. van Rij (researcher)
- M. in 't Veld
- Dr. J.J. van Wijk (project leader)
- Dr. C.A. Wüthrich

Scientific Report

Computer Graphics. Kuijk completed his thesis on a raster graphics system which he defended successfully in September 1996 at the University of Amsterdam.

As a follow-up to this work he investigated a second generation rasterizer, suited for image synthesis and reconstruction of wavelet coded images. The first principles of this system have been simulated and a patent is applied for.

Van Rij continued her work on ADMIRE, a rule-based system that serves to optimize the performance of graphics applications by dynamically selecting rendering algorithms, data structures and level of detail on a per-object basis. The rules that serve to select the appropriate rendering algorithm and level of detail were analysed, improved and tested by means of an experimental setup. Van Rij hopes to finish her thesis in the coming year.

Computational Steering. The goal of the computational steering project is to study methods and techniques that allow for interactive control of simulations. The techniques are incorperated into the Computational Steering Environment. Particular emphasis is placed in applying new techniques to industrial problems.
A number of research topics were addressed in 1996:

- 3D presentation, interaction and viewing.
- visualization environments for high performance computing.
- high level input and control.

J.D. Mulder continued work on 3D presentation, interaction and viewing. The work involves research and develop of novel interaction techniques which allow users to specify visualizations in intuitive ways.

J. Harkes, M. Hoogendoorn, J. Kniesmeier, W. de Leeuw, R. van Liere started work on high performance distributed visualization systems. This work involves applying computational steering to high performance computing problems. This work is performed in a joint HPCN project with ACE, Arcobel, CAP-Volmac and FEL-TNO on high performance visualization.

K.E. Shahroudi and J.J. van Wijk continued work on the SION funded project. The goal of this work is to research high level input techniques for interactive scientific visualization.

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

- *Workshop on Scientific Visualization in Physics,* Febuary, Bliefeld: R. van Liere.
- *EG ViSC workshop*, April, Prague: R. van Liere.
- *HPCN'96*, April, Brussels: R. van Liere.
- *11th Eurographics Workshop on Computer Graphics Hardware*, Poitiers, August 26–27: A.A.M. Kuijk.
- *Eurographics'96*, Poitiers, August 28–30: A.A.M. Kuijk.
- *Conference on Inverse Methods*, LeCroisic, June: K.E. Shahroudi.
- *EG ViSC workshop*, Prague: J.J. van Wijk.
- *Super Computing '96*, November: Pittsburgh: R. van Liere.

Memberships of Committees and Other Professional Activities

A.A.M. Kuijk:
- Member Programme Committee Eurographics Workshop on Graphics Hardware.
- Member Programme Committee International Workshop on Implicit Surfaces

J.J. van Wijk:
- Chairman Eurographics Working Group on Visualization in Scientific Computing.

Papers in Journals and Proceedings

J.J. VAN WIJK, H.J.W. SPOELDER, W.-J. KNIBBE, K.E. SHAHROUDI (1996). Interactive exploration and modelling of large data sets: a case study with Venus Light Scattering Data. *Proceedings IEEE Visualization'96*, ACM Press.

K.E. SHAHROUDI (1996). Flipping the analytical coin: closing the information flow loop in high speed analysis. *Proceedings Second International Conference on Inverse Methods LeCroisic*, France.

R. VAN LIERE, J.D. MULDER, J.J. VAN WIJK (1996). Computational steering. *Proceedings High Performance Computing and Networking*, Brussels.

R. VAN LIERE, J.J. VAN WIJK (1996). CSE: a modular architecture for computational steering. *Proceedings EG Workshop on Visualization in Scientific Computing*, Springer-Verlag.

Other Publications

A.A.M. KUIJK (1996). *On a Layered Object-Space Based Architecture for Interactive Raster Graphics*, Ph.D. Thesis, Universiteit van Amsterdam.

Interaction and Parallelism – IS2

Staff

- Dr. ir. F. Arbab (group leader)
- Drs. C.L. Blom (programmer)
- F.J. Burger (programmer)
- P.A.J. Bouvry Ph.D. (post-doc, NFI)
- Drs. C.T.H. Everaars (programmer, 0.7 fte)
- Ir. R.H.M C. Kelleners (Ph.D. student, SION, until July 1)
- E. Monfrog

Scientific Report

Enhancement and debugging of the Manifold language compiler, its run-time system, and support utilities continued in 1996, as we tested running real applications and porting our implementation to various platforms. Manifold now runs on SGI IRIX 5.3, 64-bit SGI systems running IRIX 6.3, Solaris 5.2, and IBM SP1/2. By the end of 1996, the implementation of the basic Manifold system was stable. Maintenance and enhancement of the basic system, as well as enhancement to the utilities, programming libraries, and support tools still continue. Implementation of the external atomic process interface library was started in 1996. This interface library is required by some of the applications we must support, and its implementation will be complete in early 1997. This interface will allow a Manifold application to use processes running on various platforms, including those that do not support Manifold (e.g., Cray and NEC SX systems), as atomic processes.

Our visual programming environment, Visifold, now generates proper Manifold code for our test cases. The work on the visual debugging component of Visifold was started by *B. Hille* who completed his Masters thesis in Computer Science at Sheffield Hallam University during his four month stay at CWI in our group. He devised a standard format for trace files to be produced by the Manifold run-time system in the debug mode, and developed the skeleton of a trace file interpreter that can play back and animate the events recorded in a trace file in our visual programming environment.

We continued to use the Manifold system to run real examples, and our software has been licensed to six universities and research centers as well. We obtained very promising results applying Manifold to parallelize and distribute some of the programs developed by the researchers in NW2, specifically, in the area of single and multi-grid domain decomposition and restructuring of their existing Fortran code for an Euler solver. Our collaboration with this group will continue in 1997.

We began to study the ways in which our system can be used in distributed constraint solving applications. We sought to fill the SION position left by the early departure of *R.C. Veltkamp* with a qualified candidate with a joint appointment in IS2 and IS4, to consolidate the activity of these two groups in this area. *E. Monfroy* was appointed to this position starting November 1, 1996.

R.H.M.C. Kelleners finished the first version of his prototype system for managing constraints in an object oriented world, using Manifold. His term at CWI expired at the end of June 1996 and he is now continuing his work on his Ph.D. at TU Eindhoven.

Prof. Papadopoulos at the University of Cyprus is working on using the underlying model of Manifold, the IWIM model, for modelling of Information Systems. The result of his collaboration with our group on coordination, especially in the area of soft real time applications, is an upcoming joint paper. A KIT proposal was submitted for funding through ESPRIT to support his keeping in touch with our group and to continue our collaboration, in conjunction with other academic institutions (Kings College, London; Katholieke Universiteit Nijmegen; National Technical University of Athens; The Technion; and Cairo University) and an industrial partner (Siemens).

Our joint work with colleagues from the Polish Academy of Sciences on Loosely Coupled Genetic Algorithms has been mutually fruitful and will continue. They have installed Manifold on their systems and joint papers reporting the results of this work are in preparation.

The separation of coordination from computation that is inherent in Manifold makes it interesting as a tool for combining digital circuit simulation programs of various modules to obtain a simulator for a more complex circuit consisting of those modules. *Prof. Mavaddat* of the University of Waterloo is

interested in pursuing the potential of this approach and, more generally, in the applications of Manifold in software design.

We started our collaboration with the Delft Hydraulics Labs to use Manifold in the design and implementation of their new software architecture for their shallow water modelling and simulation application, within the context of the HPCN Nice project. Among others, this activity involves restructuring of their existing Fortran solver code to run under the new architecture.

Professors Carol Tretkoff and Ken McAloon from Brooklyn College and CUNY Graduate Center, Brooklyn, NY, USA who were visiting IS4 during the summer of '96, spent part of their time to get acquainted with Manifold and its underlying model. They found it interesting enough to seriously consider Manifold for their work on linear programming libraries. Professor Tretkoff taught Manifold in her course in '96, and a number of her Ph.D. students are now using our system. Specifically, professor Tretkoff's proposal for doing search using Manifold was funded, and one of her Ph.D. students has started her Ph.D. work on 'Higher Order Libraries for Parallel Search Using a Coordination Language.'

Memberships of Committees and Other Professional Activities

F. Arbab:

- Editorial Board Member, *Computers & Graphics, An International Journal.*
- Editorial Board Member, *Parallel Computing* journal.
- Guest Co-editor, special issue of *Parallel Computing* on 'Coordination Languages and Systems,' to appear in Spring '98.

P.A.J. Bouvry:

- MSc examination committee member for *B. Hille*, Sheffield Hallam University, October 4–8, Sheffield, UK.

Organization of Conferences, Workshops, Courses, etc.

F. Arbab:

- Program Committee, PARCO '97.
- Co-chair, Eurographics Workshop on Programming Paradigms for Graphics '97.
- Program Committee, European School of Computer Science, Parallel Programming Environments for High Performance Computing, April 1996.

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

- F. Arbab: European School of Computer Science, Parallel Programming Environments for High Performance Computing, April 1–5, Alpe d'Huez, France.

F. Arbab:

- Coordination '96, April 1–5, Cesena, Italy.
- 2nd International Conference on the Design of Cooperative Systems, June 12–14, Juan-le-Pins, France.
- Invited visit and seminar, Computer Science Department, University of California, Irvine, August 16.
- Irregular '96, August 19–21, Santa Barbara, California.
- Euro-Par '96, August 27–29, Lyon, France.
- Software Automation Nederland, October 30, Utrecht.
- Invited visit and seminar, Lawrence Livermore National Laboratory, November 1, Livermore, California.
- International Conference on Software Maintenance '96, November 4–8, Monterey, California.
- Invited visit and seminar, Computer Science Department, University of Cyprus, November 23–26, Nicosia, Cyprus.

C.L. Blom:

- Euro-Par '96, August 27–29, Lyon, France.
- Software Automation Nederland, October 30, Utrecht.

P.A.J. Bouvry:

- European School of Computer Science, Parallel Programming Environments for High Performance Computing, April 1–5, Alpe d'Huez, France.
- Coordination '96, April 1–5, Cesena, Italy.
- Renpar8, May 20–24, Bordeaux, France.
- Software Automation Nederland, October 30, Utrecht.
- Invited visit and seminar, Polish Academy of Sciences, November 9–15, Warsaw.
- Invited visit and seminar, Computer Science Department, University of Umea, November 30–December 5, Sweden.
- MSc examination committee member for *B. Hille*, Sheffield Hallam University, October 4–8, Sheffield, UK.

F.J. Burger:

- Euro-Par '96, August 27–29, Lyon, France.

C.T.H. Everaars:

- Irregular '96, August 19–21, Santa Barbara, California.

- Software Automation Nederland, October 30, Utrecht.

Visitors

- Mr. B. Hille, Sheffield Hallam University, June 3–October 3.
- Prof. dr. Peter Wegner, Brown University, July 1–July 2.
- Prof. dr. G.A. Papadopoulos, University of Cyprus, June 20–July 20.
- Mr. Wojciech Kwedlo, Polish Academy of Sciences, July 14–September 14.
- Dr. Franciszek Seredynski, Polish Academy of Sciences, August 1–September 1.
- Prof. dr. Farhad Mavaddat, University of Waterloo, Canada, September 15–30.

Papers in Journals and Proceedings

F. ARBAB (1996). The Manifold Project. *European School of Computer Science, Parallel Programming Environments for High Performance Computing*, IMAG-INRIA Grenoble, Alpe d'Huez, France.

F. ARBAB (1996). The IWIM model for coordination of concurrent activities. P. CIANCARINI, C. HANKIN (eds.). *Coordination Languages and Models: Proceedings of Coordination '96*, Lecture Notes in Computer Science, Vol. 1061, Springer-Verlag, Cesena, Italy, 34–56.

F. ARBAB (1996). IWIM: a communication model for cooperative systems. *Proceedings of the 2nd International Conference on the Design of Cooperative Systems*, INRIA, Juan-le-Pins, France, 567–585.

F. ARBAB, C.L. BLOM, F.J. BURGER, C.T.H. EVERAARS (1996). Reusable coordinator modules for massively concurrent applications. (distinguished paper) L. BOUGE, P. FRAIGNIAUD, A. MIGNOTTE, Y. ROBERT (eds.). *Proceedings of Euro-Par '96*, Lyon, France, Lecture Notes in Computer Science, Vol. 1123, Springer-Verlag, 664–677.

J. BŁAŻEWICZ, P. BOUVRY, F. GUINAND, D. TRYSTRAM (1996). Scheduling complete intrees on two uniform processors with communication delays. *Information Processing Letters* **58**(5), 255–263.

P. BOUVRY, F. ARBAB (1996). Manifold, a concurrent coordination language and its environment. *European School of Computer Science, Parallel Programming Environments for High Performance Computing*, IMAG-INRIA Grenoble, Alpe d'Huez, France.

P. BOUVRY, F. ARBAB (1996). Visifold: a visual environment for a coordination language. P. CIANCARINI, C. HANKIN (eds.). *Coordination Languages and Models: Proceedings of Coordination '96*, Cesena, Italy, *Lecture Notes in Computer Science* **1061**, Springer-Verlag, 403–406.

P. BOUVRY, F. ARBAB (1996). Visifold: un langage visuel destine a la programmation concurrente et son environnement. *Proceedings of Renpar8*, Bordeaux, France.

P. BOUVRY, JOAO-PAULO KITAJIMA, B. PLATEAU, D. TRYSTRAM (1996). ANDES: Evaluating mapping strategies with synthetic programs. *Journal of Systems Architecture* **42**(5), 351–365.

C.T.H. EVERAARS, F. ARBAB (1996). Coordination of distributed/parallel multiple-grid domain decomposition. A. FERREIRA, J. ROLIM, Y. SAAD, AND T. YANG (eds.). *Proceedings of Irregular '96*, Santa Barbara, California, Lecture Notes in Computer Science, Vol. 1117, Springer-Verlag, 131–144.

C.T.H. EVERAARS, F. ARBAB, F.J. BURGER (1996). Restructuring sequential Fortran code into a parallel/distributed application. *Proceedings of the International Conference on Software Maintenance '96*, Monterey, California, IEEE, 13–22.

G.A. PAPADOPOULOS, F. ARBAB (1996). Coordination of systems with real-time properties in manifold. *Proceedings of the 20th Annual International Computer Software and Applications Conference (Compsac '96)*, IEEE, Seoul, Korea.

CWI Reports

CS-R9621. F. ARBAB, C.L. BLOM, F.J. BURGER, C.T.H. EVERAARS. *Reusability of coordination programs*.

CS-R9627. C.T.H. EVERAARS, F. ARBAB. *Coordination of distributed/parallel multiple-grid domain decomposition*.

CS-R9628. F. ARBAB, C.T.H. EVERAARS, F.J. BURGER. *Restructuring sequential fortran code into a parallel/distributed application*.

Other Publications (including software packages and documentation)

F. ARBAB (1996). *Manifold Version 2: Language Reference Manual*, CWI.

C.T.H. EVERAARS (1996). *A Manifold Tutorial*, CWI.

B. HILLE (1996). *DebFold: a Visual Tracing Tool*, MSc thesis, Sheffield Hallam University, UK.

Software:

F. ARBAB. *mc: the Manifold language compiler.*

F. ARBAB. *DTh: a package for building applications with distributed threads.*

F. ARBAB. *build: a utility for building distri-*

buted and parallel applications.

F. ARBAB. *mlink: the Manifold linker.*

F. ARBAB. *decoy: a utility to produce fake Manifold modules.*

F. ARBAB. *config: a utility for run-time configuration of distributed applications.*

C. L. BLOM. *Manifold interface library for atomic manners and internal atomic processes.*

C. L. BLOM. *Manifold interface library for external atomic atomic processes.*

C. L. BLOM. *Manifold Builtin Library.*

F. J. BURGER. *the Manifold run-time system modules.*

P. BOUVRY. *Visifold: a visual programming environment for Manifold.*

B. HILLE. *DebFold: a visual tracing tool.*

Documentation:

F. ARBAB. *DTh: a package for building applications with distributed threads.*

F. ARBAB. *build: a utility for building distributed and parallel applications.*

F. ARBAB. *mlink: the Manifold linker.*

F. ARBAB. *decoy: a utility to produce fake Manifold modules.*

F. ARBAB. *config: a utility for run-time configuration of distributed applications.*

F. ARBAB. *Manifold interface library for atomic manners and compliant atomic processes.*

Interaction and Multimedia – IS3

Staff

- Drs. P.J.W. ten Hagen (head of department, group leader, project leader MADE)
- Drs. F.C. Heeman (project member MADE)
- Dr. I. Herman (senior researcher and Workpackage Manager MADE)
- Drs. J.E.A. van Hintum (Ph.D. student MADE)
- Drs. H. Noot (programmer MADE)
- Dr. G.J. Reynolds (project member MADE)
- Drs. M.M. de Ruiter (programmer MADE)

Scientific Report

Multimedia Fundamentals. The fundamental parts of the PREMO standard and the systems services part were harmonized with the modelling and interaction component. The complete set was reviewed by international experts. This completes the technical design work. It is now expected that after some technical detailing the standard can be delivered in 1997. Several workshops were held and coorganized to have PREMO experts meet. Some were official ISO meetings, others took place in the framework of the EU sponsored computer graphics network under the HCM programme.

Multimedia Systems. The final review of the MADE project was held in January. After this the reduced team assisted in preparing for the industrialization of the result. In the second half of the year a reorientation of the research direction towards information engineering was started. Van Hintum finished the first complete draft of his Ph.D. thesis on constraints in multimedia, applied to quality of services.

Organization of Conferences, Workshops, Courses, etc.

- PREMO Workshop at University of York, UK, March 18–22, organized by P.J.W. ten Hagen,. Further attended by I. Herman.
- ISO/IEC JTC1/SC24/WG6 meeting in Osaka, Japan, June 12–21 organized by P.J.W. ten Hagen. I. Herman also attended. Both also participated in the PREMO meeting and the SC24 meeting in the same period.
- MADE, final review meeting was held in Paris on Januari 25–26, attended by P.J.W ten Hagen and I. Herman.
- The ERCIM computer graphics network. Several workshops were organized under Task2 of this EU HCM network. P.J.W. ten Hagen as chair of Task 2 coorganized workshops in Abingdon, UK on Sound in Multimedia on Januari 15–16, attended by I. Herman, *On intelligent User Interfaces for Multimedia* in Marina di Carrara (It) on februari 12 and 13, attended by P.J,W. ten Hagen and I. Herman. Another PREMO related study meeting was held in Bonn May 29–30; Finally a workshop on formal specifications of PREMO was held in York on October 30–31 and attended by I. Herman.
- IMA meeting in Santa Clara, USA on December 5: P.J.W. ten Hagen participated as ISO liaison officer, I. Herman presented the Harmonisation version of PREMO and MSS.

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

- Working Visits to Industry
  P.J.W. ten Hagen payed working visits to industry: SYLLOGIC on Januari 31, with K. Apt; HSA on 27 of March, with I. Herman (with presentation); IPO on April 17 with F. Kuijk and T. van Rij; Telewold on June 27 with D. Bulterman; Philips Re-

search on August 19, with I. Herman; SKF on October 28 with R. van Liere.
- Working Visits to Academia, Delft Hydrolicson February 21 with F. Arbab; In the context of orientation on digital libraries visits were made by P.J.W. ten Hagen, I. Herman and M. Hazewinkel to University of Bonn on 9–10 October, to Stanford University (USA) on 5–6 December and to Virginia Tech on 12–13 December.
- P.J.W. ten Hagen and I. Herman made several visits to Brussels to participate in the ESPRIT week, the HPCN event and several meetings concerning ESPRIT and Telematics project proposals.
- P.J.W. ten Hagen and I. Herman participated in Workshop on the Future of Eurographics, Amsterdam, 13 May–14 May
- I. Herman participated in:
  Eurographics Executive Committee Meeting, Paris, 12 March
  Eurographics EG'96 Programme Committee, Paris, 13 March
  ITEA Jury participation, Paris, 10 Sept–11 Sept, and London, 22 October
  ERCIM DELOS Workshop, Bonn, 7–8 October
  MMM'96 Conference, Toulouse, 12–15 November (Invited speaker)
- Eurgraphics 97 conference in Poitiers, France was attended by I. Herman, P.J.W. ten Hagen, A.A.M. Kuijk, M.M. de Ruiter.

Papers in Journals and Proceedings

I. HERMAN, G.J. REYNOLDS, J. VAN LOO. PREMO: An emerging standard for multimedia. Part I: Overview and Framework. *IEEE MultiMedia* **3**, (Fall 1996).

I. HERMAN, G.J. REYNOLDS, J. VAN LOO. PREMO: An emerging standard for multimedia, Part II: Specification and Applications. *IEEE MultiMedia* **3**, (Winter 1996).

CWI Reports

CS-R9606. D. WANG, I. HERMAN, G.J. REYNOLDS. *Open Inventor and PREMO*.

Memberships of Committees and Other Professional Activities

P.J.W. ten Hagen:
- Fellow of EUROGRAPHICS.
- Member of the Executive Committee of EUROGRAPHICS.
- State of the Art reports co-chair of the organising committee of the EG97 annual conference.
- Member of the Eurpean Steering Committee for Computer Graphics.
- Co-chair of the ERCIM CGN worksop series.
- Member of IFIP W.G. 5.2 on CAD.
- Member of IFIP W.G. 5.10 on Computer Graphics.
- Project leader of ESPRIT MADE for CWI.
- Project leader of the HPCN project on High Performance Visualisation.
- Chairman of ISO/IEC JTC1/SC24 WG6 on Multimedia.
- Liaison for ISO to IMA.
- Liaison for ISO to OMG.
- Member of the advisory subcommittee for mathematics and computer science of the Dutch Aerospace Laboratory.
- Member of the advisory board of the 'Post Hogere Technisch Onderwijs' school in Amsterdam.
- Member of the editorial board of the Journal Research in Engineering Design.

Logic Programming and Computational Linguistics – IS4a

Staff

- Prof. dr. K.R. Apt, group leader, since March 1, 1987
- Dr. E. Marchiori, project member (0.5), from November 1 on a leave of absence at the University of Venice, Italy
- S. Marzola, guest student (supported by the Leonardo da Vinci project), from October 1
- Dr. E. Monfroy, project member, from November 1
- Dr. F. van Raamsdonk, project member, from February 1
- Dr. A. Schaerf, researcher, till April 1
- Dr. F. Teusink, project member, till September 1
- Prof. dr. A.S. Troelstra, visiting professor, from September 1

Scientific Report

K.R. Apt finished his work on the book on logic programming and Prolog. In the book both the foundations of logic programming and programming in Prolog are considered. The theory of logic programming is applied to systematically deal with programming issues such as termination, occur-check freedom, partial correctness and absence of run-time errors. The book was published in 1996 by Prentice Hall.
Further, K.R. Apt worked with *A. Schaerf* on a programming language proposal that combines the

advantages of imperative and logic programming in order to deal in a natural way with algorithmic problems that involve search. A paper on this subject was accepted for the 24th Annual SIGPLAN-SIGACT Symposium on Principles of Programming Languages (POPL '97).
Finally, he worked on the final versions of three journal papers that appeared in 1996.

E. Marchiori (working in the SION project 'Computational Intelligence for Constraint Logic Programming' and employed 50% at CWI and 50% at the University of Leiden) worked on the integration of genetic and constraint programming. She investigated new techinques for the integration of constraint logic programming and computational intelligence. In particular she studied how global optimization methods (like genetic algorithms) can be used to train neural networks, and she introduced a novel search technique to be used in applications, such as decision support and negotiation, which are subject to requirements that can only be partially satisfied. Moreover, she continued her research on proof techniques for the correctness and design of logic programs. In particular, she investigated termination of general logic programs and she introduced a logical framework for the design and study of abstract domains for static analysis of program properties.

S. Marzola, a guest student (supported by the Leonardo da Vinci project), worked on the subject of constraint propagation for linear constraints on finite domains.

E. Monfroy defended November 8th at the University of Nancy his Ph.D. thesis entitled 'Collaboration de Solveurs pour la Programmation Logique à Contraintes'. He has worked on cooperation between constraint solvers and studied nonlinear constraints.

F. van Raamsdonk defended her Ph.D. thesis entitled 'Confluence and Normalisation for Higher-Order Rewriting' at the Vrije Universiteit Amsterdam. She also worked on a translation from a subclass of logic programs to conditional rewriting systems. This translation is meant as a basis for the transformation of a logic programming language (for instance Prolog) to a functional programming language (for instance Miranda or Clean). A paper on this subject was accepted for the 14th International Conference on Logic Programming (ICLP'97).
Further, she studied so-called outermost-fair rewriting for higher-order term rewriting systems. A paper on this subject was accepted for the 3rd International Conference Typed Lambda Calculi and Applications (TLCA '97).
Finally, she worked on conditional rewriting with explicit conditions.

A. Schaerf, an ERCIM fellow, worked on the solution of various scheduling problems using constraint logic programming techniques. He also worked on timetabling problems using both constraint logic programming and local search techniques. His joint work with K.R. Apt is mentioned above.

F. Teusink finalized his work in the SION project 'Computational Aspects of Non-Monotonic Reasoning', by defending on September 30th at the University of Amsterdam his Ph.D. entitled 'Non-monotonic reasoning via Logic Programming'. He also worked on modularity of logic programs and had a paper on this at the Joint International Conference and Symposium on Logic Programming (JICSLP'96). Finally, he extended his previous work on Abductive Logic Programs to a journal version that appeared in Theoretical Computer Science.

A.S. Troelstra published with the Oxford University Press the monograph 'Basic Proof Theory', written jointly with H. Schwichtenberg. The text first introduces the basic types of formalization, proves cut elimination, with elementary applications, then normalization for natural deduction with applications. After this follow more specialized topics: increase in size under cut elimination and normalization, permutation of rules; resolution calculi; categorical logic for cartesian closed categories; application of the basic techniques to the modal logic **S4** and to linear logic, as well as an introduction to proofnets; provability of transfinite induction in first-order arithmetic; normalization for second–order logic and characterization of the provably recursive functions of analysis. He also wrote a historical survey of the developments leading from ideas having their origin in the constructive trend in the foundation of mathematics, in particular Brouwers intuitionism, to applications of these ideas ('formulas-as-types') in present-day computer science. This work was presented at the University of Munich on the occasion of receiving by Troelstra the Bauer Award.

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

- *FNRS Fundamental Computer Science Contact Group Meeting on Constraints*, Brussels, Belgium, 8 May: K.R. Apt (Arrays, Bounded Quantification and Iteration in Constraint Logic Programming).
- *Joint International Conference and Symposium on Logic Programming (JICSLP'96)*, Bonn, Germany, 2–6 September: K.R. Apt, F. Teusink.
- *Research School IPA Introduction Days*, Noordwijk, 16–20 September: K.R. Apt (Constraint Pro-

gramming).
- *Working visit, University of Munich*, Munich, Germany, 14–16 November: A.S. Troelstra (Relations between Constructivism and Computer Science).
- *Workshop on Abstract Interpretation of Logic Languages*, Jerusalem, Israel, 15–16 December: K.R. Apt (The Role of Unification in Logic Programming).
- *Working visit, University of Beersheva*, Beersheva, Israel, 17 December: K.R. Apt (How to Write an Article: Some Suggestions).
- *Working visit, University of Tel-Aviv*, Tel-Aviv, Israel, 18–19 December: K.R. Apt.
- *Working visit Université Henri Poincaré - Nancy I*, France, November 7,8: E. Monfroy (Solver Collaboration for Constraint Logic Programming).
- *2nd IMACS Conference on Applications of Computer Algebra* RISC, Linz, Austria, July: E. Monfroy (Solver collaborations for non-linear constraints).
- *2nd IMACS Conference on Applications of Computer Algebra* RISC, Linz, Austria, July: E. Monfroy and C. Ringeissen (Domain-Independent Constraint Solver Extension).
- *Journées du PRC-GDR AMI (Algorithmes, Modèles, Infographie)* La Bussière, Dijon, February: E. Monfroy (Collaboration de solveurs et d'outils mathématiques).
- *Journées du Groupe Déduction et Calcul Formel du PRC-GDR AMI* Jussieu, Paris, June E. Monfroy and C. Ringeissen (Extensions de Solveurs à l'aide d'un Environnement basé sur la Réécriture).

Memberships of Committees and Other Professional Activities

K.R. Apt:
- Member of the European Network in Computational Logic (initiated by the ESPRIT Basic Research Action 'Compulog'), since 1991.
- Professor of Computer Science, University of Amsterdam, since 1991.
- Editorial board, *Science of Computer Programming*, since 1981.
- Editorial board, *Information and Computation*, since 1987.
- Editorial board, *Journal of Logic and Computation*, since 1989.
- Editorial board, *Wiley/Teubner Series in Computer Science*, since 1989.
- Editorial board, *Fundamenta Informaticae*, since 1990.
- Editorial board, *Journal of Logic Programming*, since 1991.
- Editorial board, *CWI Tracts*, since 1992.
- Scientific Commission for Computer Science of the Belgian National Fund for Scientific Research, since 1990.
- Presentation of Master Class 'Logic Programming and Constraint Satisfaction' for Research School OZSL, February – March.
- Chairman of the ERCIM Working Group on Constraints, since September 1996.
- Program committee member, Mathematical Foundations of Computer Science (MFCS '96), Cracow, Poland, September 1996.
- Ph.D. supervisor of dr. F. Teusink.
- Co-organizer of 8th BENELOG – 8th Benelux Meeting on Logic Programming and PROLOG, Louvain-la-neuve, Belgium, September 9.
- Member Ph.D. committee, A. Montanari, September 20.

Visitors

- Ph. Codognet, INRIA, Rocquencourt, March 7–9.
- M. van Emden, University of Victoria, Canada, May 1–3.
- E. Monfroy, INRIA, Nancy, May 28–29
- K. McAloon, C. Tretkoff, July 1–31.

Papers in Journals and Proceedings

K.R. APT (1996). Arrays, bounded quantification and iteration in logic and constraint logic programming. *Science of Computer Programming* **26**(1–3), 133–148.

K.R. APT, M. GABBRIELLI, D. PEDRESCHI (1996). A closer look at declarative interpretations. *Journal of Logic Programming* **28**(2), 147–180.

K.R. APT, R. BEN-ELIYAHU (1996). Metavariables in logic programming, or in praise of ambivalent syntax. *Fundamenta Informaticae* **28**(1–2), 23–36.

S. ETALLE, F. TEUSINK (1996). A compositional semantics for normal open programs. M. MAHER (ed.). *Proceedings 1996 Joint International Conference and Symposium on Logic Programming*, The MIT Press, Cambridge, Mass.

E. MARCHIORI (1996). Prime factorizations of abstract domains using first-order logic. *Proceedings 5th Int. Conference on Algebraic and Logic Programming (ALP'96)*, Aachen, Germany.

E. MARCHIORI (1996). Forward-tracking: a technique for searching beyond failure). *Proceedings 8th IEEE Int. Conference on Tools with Artificial Intelligence (ICTAI'96)*, Toulouse, France.

E. MONFROY, M. RUSINOWITCH, R. SCHOTT (1996). Implementing non-linear constraints with

cooperative solvers. *Proceedings of ACM Symposium on Applied Computing (SAC'96)*, 63–72.

A. SCHAERF (1996). A survey of automated timetabling. To appear in *Artificial Intelligence Review*.

A. SCHAERF (1996). Tabu search techniques for large high-school timetabling problems. *Proceedings of the 13th American Conference on Artificial Intelligence (AAAI-96)*.

A. SCHAERF (1996). Scheduling sport tournaments using constraint logic programming. *Proceedings of the 13th European Conf. on Artificial Intelligence (ECAI-96)*.

F. TEUSINK (1996). Three-valued completion for abductive logic programs. *Theoretical Computer Science* **165**(1), 171–200.

A.S. TROELSTRA (1996). Choice sequences: a retrospect. *CWI Quarterly* **9**(1–2).

CWI Reports

CS-R9611. A. SCHAERF. *Tabu search techniques for large high-school timetabling problems.*

CS-R9641. E. MARCHIORI, F. TEUSINK. *Proving termination of logic programs with delay declarations.*

CS-R9642. E. MARCHIORI, F. TEUSINK. *Proving deadlock freedom of logic programs with dynamic scheduling.*

CS-R9645. K.R. APT, A. SCHAERF. *Search and imperative programming.*

Other Publications

K.R. APT (1997) (appeared in 1996). *From Logic Programming to Prolog*, Prentice Hall International, London, 328 + xviii pages.

E. MONFROY (1996). *Collaboration de Solveurs pour la Programmation Logique à Contraintes*, Ph.D. Thesis, Universitée Henri Poincaré - Nancy I.

E. MONFROY, C. RINGEISSEN (1996). *Domain-Independent Constraint Solver Extension*, Report 96-R-043, CRIN, Vandoeuvre-lès-Nancy.

E. MONFROY (1996). *An Environment for Designing/Executing Constraint Solver Collaborations*, Report 96-R-044, CRIN, Vandoeuvre-lès-Nancy.

F. VAN RAAMSDONK (1996). *Confluence and Normalisation for Higher-Order Rewriting*, Ph.D. Thesis, Vrije Universiteit Amsterdam.

F. TEUSINK (1996). *Non-Monotonic Reasoning via Logic Programming*, Ph.D. Thesis, University of Amsterdam.

A.S. TROELSTRA AND H. SCHWICHTENBERG (1996). *Basic Proof Theory*, Cambridge University Press, Cambridge, U.K., 344 + xi pages.

A.S. TROELSTRA (1996). *From Constructivism to Computer Science*, Technical report, Fac. WINS, University of Amsterdam.

Logic and Computational Linguistics – IS4b

Staff

- Prof. dr. D.J.N. van Eijck, (sub)group leader
- Dr. ir. J.M.G.G. de Nivelle, post-doc researcher (jointly with ILLC), since June 16
- Dr. P.J.E. Dekker, post-doc researcher, until April 1
- Drs. A.V. Groenink, Ph.D. student
- Dr. J. Jaspars, post-doc researcher, until April 1
- Ir. S. van Dongen, Ph.D. student (jointly with AM)

Scientific Report

In 1996, the group worked on topics on the borderline between natural language analysis and programming language analysis, including the study of incremental processing in semantics with the tools of dynamic logic, the connection between dynamic logic and theorem proving, connections between natural language interpretation knowledge representation, and the logic of ambiguity.

Jan van Eijck published a paper on presupposition and the logic of information updating, co-edited a book on generalized quantifier theory, and worked on the logic of ambiguity, jointly with *Jan Jaspars*. Also, he started work on integrating dynamic semantics and typed logic.

Hans de Nivelle, who joined the group in June, worked on implementation of unification based theorem proving, and on theorem proving for dynamic logic.

Annius Groenink continued the work on his Ph.D. project, on a hierarchy of grammar formalisms based on linear movement.

Jan van Eijck and *Jan Jaspars* wrote up their work on a framework for computation semantics for the FraCaS deliverables (European LRE project FraCaS), in particular on the logic of ambiguity and reasoning with underspecified representations.

Paul Dekker has joined the FraCaS effort in October, contributing a paper on event semantics to the FraCaS deliverables.

Stijn van Dongen continued his work on Classification of Keywords in Mathematical Abstracts, a

joint project with Department AM (Michiel Hazewinkel).

Organization of Conferences, Workshops, Courses, etc.

- Final Workshop NFI Project Structural and Semantic Parallels between Programming Semantics and Natural Language Semantics, January 15–17, at CWI.
- CWI Metadata Seminar, monthly (Stijn van Dongen), at CWI.

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

- *FRACAS Final Review*, Edinburgh, UK, February 19–23: D.J.N. van Eijck (Ambiguity and Reasoning), J. Jaspars (An Umbrella of Dynamic Logics), P.J.E. Dekker (Situations and Events).
- Final Workshop NFI Project *Structural and Semantics Parallels*, January 15–17: D.J.N. van Eijck (Dynamic Reasoning without Variables).
- Metadata Symposium, CWI, November 19: D.J.N. van Eijck (Applied Logic: From Book Writing to Hyperdocument Processing).
- Compulog Meeting, Oeiras, Portugal, November 30: D.J.N. van Eijck (Logic as the Emerging Science of Information Processing).
- FRACAS Meeting Copenhagen, March: P.J.E. Dekker (Situations and Events), J. Jaspars (Dynamics).
- Working visit University of Koblenz: J.M.G.G. de Nivelle (Resolution Games and Non-liftable Orders for Resolution).
- Lecture Series at University of Amsterdam on Resolution Based Theorem Proving, September and October: H. de Nivelle.
- Working visit to University of Potsdam, February: A.V. Groenink (Tractability Issues in Natural Language Parsing).

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 board of the Dutch Graduate School in Logic (since July, 1993)
- Coordinator of NFI project NF 102/62–356 ('Structural and Semantic Parallels in Natural Languages and Programming Languages'), funded by the Netherlands Organization for Scientific Research (NWO).
- Member of the FRACAS LRE Consortium (other partners: R. Cooper, Edinburgh, H. Kamp, Stuttgart and M. Pinkal, Saarbrücken).
- Program committee member of JELIA'96, Evora, Portugal, September/October 1996.

Visitors

- N.G. de Bruijn, Eindhoven, January 16–18.
- Fairouz Kamareddine, Glasgow, January 16–18.
- T. Borghuis, Eindhoven, January 16–18.
- G. Plotkin, January 16–18.
- M. Moortgat, Utrecht, January 16–18.
- N. Kurtonina, Leuven, January 16–18.
- M. Kracht, Berlin, January 16–18.
- G. Renardel de Lavalette, Groningen, January 16–18.

Papers in Journals and Proceedings

J. VAN EIJCK, F.-J. DE VRIES (1995). Reasoning about update logic. *Journal of Philosophical Logic* **24**, 19–45.

J. VAN EIJCK, H. KAMP (1996). Representing discourse in context. J. VAN BENTHEM, A. TER MEULEN (eds.). *Handbook of Logic and Language*, Elsevier, Amsterdam, 179–237.

J. VAN EIJCK (1996). Presuppositions and information updating. H. DE SWART M. KANAZAWA, C. PI NON (eds.). *Quantifiers, Deduction, and Context*, CSLI, Stanford, 87–110.

J. VAN DER DOES, J. VAN EIJCK (1996). Basic quantifier theory. *Quantifiers, Logic, and Language*, CSLI, Stanford 1–45.

J. VAN EIJCK (1996). Quantification and partiality. J. VAN DER DOES, J. VAN EIJCK (eds.). *Quantifiers, Logic, and Language*, CSLI, Stanford.

W VAN DER HOEK, J.O.M. JASPARS, E.G.C. THIJSSE (1996) Honesty in partial logic. *Studia Logica* **56**, 323–360.

J.O.M. JASPARS, E.G.C. THIJSSE (1996). Fundamentals of partial modal logic. P. DOHERTY (ed.). *Partiality, Modality and Nonmonotonicity*, CSLI Publications, Studies in Logic, Language and Information, 111–140.

J.O.M. JASPARS, E. KRAHMER (1996). A programme of modal unification of dynamic theories. DEKKER, STOKHOF (eds.). *Proceedings of the 10th Amsterdam Colloquium*, Amsterdam, ILLC, 425–444.

J.O.M. JASPARS, M. KAMEYAMA (1996). Preferences in dynamic semantics. DEKKER, STOKHOF (eds.). *Proceedings of the 10th Amsterdam Colloquium*, Amsterdam, ILLC, 445–464.

H. DE NIVELLE (1996). An algorithm for the retrieval of unifiers from discrimination trees, in Alferes. PEREIRA, ORLOWSKA (eds.). *Logics in Artificial Intelligence*, European Workshop JELIA '96, Springer, 18–33.

CWI Reports

CS-R9616. D.J.N. VAN EIJCK, J. JASPARS. *Ambiguity and reasoning.*

CS-R9634. A.V. GROENINK. *Mild context-sensitivity and tuple-based extensions of context-free grammar.*

CS-R9635. A.V. GROENINK. *Tractability issues in extraposition grammar.*

Other Publications

J. VAN DER DOES, D.J.N. VAN EIJCK, EDITORS (1996). *Quantifiers, Logic, and Language*, CSLI Lecture Notes, Stanford.

J. VAN EIJCK (1996). Simpleton domains. *A Quick and Dynamic Intellect (Liber Amicorum for Paul Vitanyi)*, CWI, Amsterdam.

J. VAN EIJCK (1996). On the borderline of logic, language, and computation. *Images of SMC Research*, Stichting Mathematisch Centrum, Amsterdam, 379–386.

J. VAN EIJCK (1996). Wat is filosoferen? F. GERAEDTS, L. DE JONG (eds.). *Ergo Cogito V: Pleidooi voor de filosofie*, Historische Uitgeverij, Groningen, 73–92.

P. BLACKBURN, J. JASPARS, M. DE RIJKE (1996). *Logics of Theory Change*, Technical Report 81, Comp. Linguistik, Universität des Saarlandes.

R. COOPER, R. CROUCH, J. VAN EIJCK, C. FOX, J. VAN GENABITH, J. JASPARS, H. KAMP, M. PINKAL, M. POESIO, S. PULMAN, E. VESTRE (1996). *Evaluation of Previous Work*, FraCaS deliverable LRE 62-051-D13, University of Edinburgh.

R. COOPER, R. CROUCH, J. VAN EIJCK, C. FOX, J. VAN GENABITH, J. JASPARS, H. KAMP, M. PINKAL, M. POESIO, S. PULMAN, E. VESTRE (1996). *A Strategy for Building a Framework for Computational Semantics*, FraCaS deliverable LRE 62-051-D14, University of Edinburgh.

R. COOPER, R. CROUCH, J. VAN EIJCK, C. FOX, J. VAN GENABITH, J. JASPARS, H. KAMP, D. MILWARD, M. PINKAL, M. POESIO, S. PULMAN (1996). *Building the Framework*, FraCaS deliverable LRE 62-051-D15, University of Edinburgh.

R. COOPER, R. CROUCH, J. VAN EIJCK, C. FOX, J. VAN GENABITH, J. JASPARS, H. KAMP, D. MILWARD, M. PINKAL, M. POESIO, S. PULMAN (1996) *Using the Framework*, FraCaS deliverable LRE 62-051-D16, University of Edinburgh.