Stichting Mathematisch Centrum

Scientific programme 1992

Part 2

Centrum voor Wiskunde en Informatica

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Centrum voor Wiskunde en Informatica

Contents

Introduction

In recent years CWI has annually presented a Scientific Programme/Long-Range Plan with detailed descriptions of the research plans, with reports on the research and lists of publications in the past year and with working plans for the following years.

In 1991, in addition to the Scientific Programme 1991, two main documents have become available, containing:

- the report on research in computer science, as presented to a visiting committee in September 1991;
- the Interim Policy Document 1993-1997, containing the current and future research policy of SMC/CWI, issued in November 1991.

All these documents contain relevant information on the research plan for 1992. The Scientific Programme 1992 is therefore restricted to the report on 1991 accompanied by a list of publications and to the envisaged developments in personnel in 1992. Only the research groups with a totally different plan in comparison with the previous Scientific Programme have a more detailed description.

As announced in the previous Scientific Programme for 1991, a number of research groups have been terminated during 1991. The research in *Analysis* (the former group AM 2, will be partly redirected and incorporated in AM 1 and AM 3. The former group BS 5 on *Statistics and Probability Theory* will participate mainly in BS 4 in order to support research in image analysis. The former group NW 3 has been transformed, and is now concentrating on *Large-Scale Computing*. The research of the group AA 3 (*Computer Systems and Ergonomics*) has been terminated; a final decision on the product-oriented part (the *Views* project) is expected during 1992.

The multidisciplinary research theme RT 1 *Image Processing*, announced in the previous Scientific Programme, is now concentrated in the research group BS 4 *Image Analysis*.

Department of Analysis, Algebra, and Geometry

HEAD OF DEPARTMENT: Prof.dr. M. Hazewinkel

LIST OF RESEARCH GROUPS

AM 1 Algebra, discrete mathematics, and computer algebra
AM 2 Analysis
AM 3 Modelling and analysis

		AM1	AM3	misc.	working	buget	ext.	de-		guests	remarks
					time in fte	time in fte	paid	tached			
appointed											
Hazewinkel	head dept.	0.40	0.40		1.00	1.00		-0.20			
Cohen	group leader	0.80			0.80	0.80					
Brouwer	researcher	0.10			0.10	0.10					
Sommeling	researcher	1.00			1.00	-		1.00	NWO		
Lisser	sc. programmer	1.00			1.00	1.00	0.50				
Koornwinder	proj. leader	1.00			1.00	1.00					
Dijkhuizen	jr.researcher	1.00			1.00	1.00					
Diekmann	group leader		0.60		0.60	0.60					
Metz	advisor		pm		pm	-					
Elhoussif	guest res.		0.25		1.00	-					
Heesterbeek	jr.researcher		0.60		0.60	0.60					
Neerven, van	jr.researcher		0.75		1.00	0.75					
Roerdink	researcher		0.20		0.20	0.20					
Temme	proj.leader		0.50		1.00	1.00					
Olde Daalhuis	jr.researcher		1.00		1.00	1.00					
Vries, de	proj.leader		1.00		1.00	1.00					
Heck				0.58	1.00	0.58	0.58				
Willems				0.44	0.75	0.44	0.44				
research time		5.30	4.90	0.58		10.63					
request	researcher	*			1.00						
request	jr.researcher	*			1.00						
request	jr.researcher	*			1.00						
request	researcher	*			1.00						
request	researcher	*			1.00						
request	jr.researcher		*		1.00						
request	jr. researcher		*		0.33						
request	jr. researcher		*		1.00						
request	guest res.			0.33	1.00						
request				0.42	1.00		0.42				

RESEARCH GROUP AM 1

TITLE: Algebra, discrete mathematics, and computer algebra

TITEL: Algebra, discrete wiskunde en computer algebra

LIST OF PROJECTS

AM 1.1 Subgroups of Lie groups;
AM 1.2 Geometrics and groups;
AM 1.3 Graphs and groups;
AM 1.4 Software development;
AM 1.5 Computer algebra.

REPORT ON 1991

AM 1.1 The existence of a subgroup of $E_8(C)$ isomorphic to $L(2, 61)$ has been established. This proves a conjecture of B. Kostant.

AM 1.2 The theory of hyperplanes has been studied. Necessary and sufficient conditions for a space to be embeddable in a projective space have been derived and applied to polar spaces.

AM 1.3 A lower bound has been given for the number of elements in a permutation group without fixed points.

AM 1.4 The package LiE has developed into shape: version 2 marks the end of the first computer algebra project in AM 1. Manual and software are ready for distribution.

AM 1.5 Progress has been made with the lecture notes mentioned in the Scientific Programme 1991. The first sketches of a project regarding canonical bases, quantum groups and Lie algebra presentations have been drawn.

PUBLICATIONS 1991

Papers in Journals and Proceedings

1. A.M. COHEN, G.C.M. RUITENBURG (1991). Generating functions and Lie groups. A.M. COEHN (ed.). *Computational Aspects of Lie Group Representations and Related Topics; Proceedings of the 1990 Computational Algebra Seminar at CWI, Amsterdam*, CWI Tract 84, CWI, 19-28.
2. A.M. COHEN (1991). Presentations for certain finite quaternionic reflection groups. J.W.P. HIRSCHFELD, D.R. HUGHES, J.A. THAS (eds.). *Advances in Finite Geometries and Designs*, Proceedings of the Third Isle of Thorns Conference 1990, 69-79.

3. A.M. COHEN, J. VAN BON (1991). Prospective classification of distance-transitive graphs. *Proceedings of the Combinatorics 1988 Conference*, Ravello, Mediterranean Press (to appear).
4. M.A.A. VAN LEEUWEN (1991). The Robinson-Schensted and Schützenberger algorithms and interpretations. A.M. COHEN (ed.). *Computational Aspects of Lie Group Representations and Related Topics; Proceedings of the 1990 Computational Algebra Seminar at CWI, Amsterdam*, CWI Tract 84, CWI, 65-88.
5. M.A.A. VAN LEEUWEN (1991). An application of Hopf algebra techniques to representation of finite classical groups. *Journal of Algebra 140*, 210-246.
6. M.A.A. VAN LEEUWEN (1990). An even more symmetric form of Zelevinsky's pictures. *Proceedings of 10. Kolloquium über Kombinatorik*, Bielefeld.

Other publications

7. A.M. COHEN (ed.) (1991). *Computational Aspects of Lie Group Representations and Related Topics; Proceedings of the 1990 Computational Algebra Seminar at CWI, Amsterdam*, CWI.
8. M.A.A. VAN LEEUWEN, A.M. COHEN, B. LISSER (1991). *LiE Manual, Version 2.0*, to be published by CAN.

RESEARCH GROUP AM 2

TITLE: Analysis

TITEL: Analyse

The project AM 2 as a whole has been discontinued per January 1, 1992.
Some of subprojects find a continuation as parts of AM 1 or AM 3.

REPORT ON 1991

Project Special functions and quantum groups (formerly project AM 2.1)
(T.H. Koornwinder, M.S. Dijkhuizen)
Koornwinder's research in 1991 comprised the following:
A paper was written on positive convolution structures associated with quantum groups. A general theory was developed and applications were made in special cases.

A paper was written on Askey-Wilson polynomials for root systems of type *BC*. These polynomials extend Macdonald's three-parameter class of q-polynomials associated with root system BC_n to a five-parameter family which is the n-variable analogue of the one-variable Askey-Wilson polynomials.

In yet unpublished work a rigorous rather than formal approach was given to Drinfeld's quasi-triangular Hopf algebras and to the quantum double.

In yet unpublished work it was shown that certain limit transitions in the Askey tableau of hypergeometric orthogonal polynomials can be considered in a more unified way as continuity properties on the parameter space viewed as a manifold with boundaries.

The Askey tableau was also implemented as a hypercard stack for the Apple Macintosh. This can be viewed as a small demonstration project how information about special functions can be stored in hypertext form.

Routines in Maple were developed for handling hypergeometric series, both in the classical and in the q-case.

Dijkhuizen's research in 1991 comprised:
In yet unpublished work a general but still incomplete framework was developed for handling quantum homogeneous spaces. A start was made with applying this theory to concrete examples.

In yet unpublished work partial results were obtained in writing down in a manageable form the defining relations for quantized function algebras of root systems other than A_n, notably for the case B_n. A fully exhaustive list of relations was obtained for the case B_1. A proof was supplied for a claim by Takeuchi regarding the quantum analogue of the double covering of $SO(3)$ by $SU(2)$.

PUBLICATIONS 1991

1. T.H. KOORNWINDER (1991). *Askey-Wilson polynomials for root systems of type BC*, CWI Report AM-R9112.
2. T.H. KOORNWINDER (1991). *Positive convolution structures associated with quantum groups*, CWI Rep. AM-R9105, to appear in Probability Measures on Groups X, H. HEYER (ed.), Plenum, 1992, pp. 249-268.
3. T.H. KOORNWINDER (1991). Handling hypergeometric series in Maple. C. BREZINSKI, L. GORI, A. RONVEAUX (eds.). *Orthogonal Polynomials and their Applications*, IMACS Annals on Computing and Applied Mathematics 9, Baltzer, 73-80.
4. T.H. KOORWINDER (1991). The addition formula for little q-Legendre polynomials and the $SU(2)$ quantum group. *SIAM J. Math. Anal. 22*, 295-301.
5. W. VAN ASSCHE, T.H. KOORNWINDER (1991). Asymptotic behaviour for Wall polynomials and the addition formula for little q-Legendre polynomials. *SIAM J. Math. Anal. 22*, 302-311.

Project Integrable systems and Grassmann manifolds (formerly project AM 2.2)
It has turned out that the KP equation can be seen as an infinite dimensional limit (of projective type) of matrix Riccati equations. These admit a rational covering linearization, i.e. they are rational quotients of linear dynamical systems. This persists in the limit. Other integrable systems also admit such covering linearizations. It is not yet clear whether these can be seen as specializations of the universal KP case.

This project has been discontinued as of January 1, 1992.

PUBLICATIONS 1991

1. M. HAZEWINKEL (1991). Soliton and Riccati equations, CWI Report AM-9103, to appear in *Proc. Conf. on Gaussian Random Fields*, T. HIDA (ed.), World Scientific.

Project Integrable systems: quantum and classical aspects (formerly project AM 2.3)
Discontinued as of January 1, 1992.

Project Ergodic theory and integrable systems (formerly project AM 2.4)
(J. de Vries)
Discontinued as of January 1, 1992. Book *Elements of Topological Dynamics* is (practically) ready. J. de Vries will start working on ergodic theory in 1992 (in particular: Lyapunov exponents and the multiplicative ergodic theorem of Oseledec) in connection with questions arising in mathematical biology.

Project Hopf algebras (formerly project AM 2.6)
A class of 'generators' for Hopf algebras has been found, i.e. a class of natural Hopf algebras that can be explicitly and simply described such that every

Hopf algebra is a quotient of one of these. Free Hopf algebras do not exist however.

A $(2n-1)$-dimensional family of quantum deformations of the classical group GL_n has been defined. Similar results were obtained by Takeuti and Tate-Artin-Schechtman. It remains to be proved that this is a maximal family (using Gerstenhaber-Schack cohomology).

Some of the ideas of this project are incorporated in the NWO application 'Bases in Lie algebras and quantum group' by A.M. Cohen, M. Hazewinkel, W. van der Kallen, B. de Wit.

This project will be continued in a modified more algorithmic form within AM 1.

PUBLICATIONS 1991

1. M. HAZEWINKEL (1991). Introductory recommendations for the study of Hopf algebras in mathematics and physics. *CWI Quarterly 4, no. 1.*

Other publications from AM

1. M. HAZEWINKEL (1991). *Encyclopaedia of Mathematics Vol. 7*, Orb-Ray, KAP.
2. M. HAZEWINKEL (1991). *Applied algebra*, preprint CWI.
3. M. HAZEWINKEL (1991). Symmetric problemen. A.W. GROOTENDORST (ed.). *Meetkundige structuren*, CWI Syllabus 28, 91-104.
4. M. HAZEWINKEL (1991). Wavelets understand fractals. *Wavelet course*, CWI, November 1991.

RESEARCH GROUP AM 3

TITLE: Modelling and analysis

TITEL: Mathematische modellering en analyse

LIST OF PROJECTS

AM 3.1 Infectious diseases;
AM 3.2 General functional analytic theory for structured population models;
AM 3.3 Banach space structure theory and semigroups of operators;
AM 3.4 Functional differential equations;
AM 3.5 Prey-predator patch problems;
AM 3.6 Evolutionary genetics;
AM 3.7 Dynamic cardiac magnetic resonance imaging;
AM 3.8 Three-dimensional reconstruction by confocal scanning laser microscopy;
AM 3.9 Ocean acoustic tomography.

REPORT ON 1991

Project AM 3.1 Infectious diseases
J.A.P. Heesterbeek worked, in collaboration with K. Dietz, D.W. Tudor (Tübingen) and O. Diekmann on the definition and the calculation of the basic reproduction ratio for models of sexually transmitted diseases that take pair formation into account. With J.A.J. Metz he derived an explicit expression for a saturating contact rate from a submodel for pairing on a fast time-scale. Professor F. Brauer (Madison, Wisconsin) spent part of his sabbatical at CWI, with partial support from NWO.

Project AM 3.2 General functional analytic theory for structured population models
Together with M. Gyllenberg and H.R. Thieme, O. Diekmann worked on abstract Stieltjes convolution equations that serve as cumulative formulations of structured population models. He lectured on this and other aspects of structured population models during the DMV seminar 'Populations Dynamik' in Blaubeuren. The workshop 'Functional Analytic Methods for Structured Population Models', organized in Woudschoten, November 18-23, 1990, by O. Diekmann, G. Greiner, J.A.P. Heesterbeek and J.M.A.M. van Neerven, marked the start of the EC Twinning Project Evolutionary Systems. Fifty-three scientists discussed common interests in differential equations and models from population biology.

Project AM 3.3 Banach space structure theory and semigroups of operators
J.M.A.M. van Neerven visited the functional analysis group in Tübingen (R. Nagel, G. Greiner and others) from September 1990 till April 1991. During this period and thereafter he obtained several new results concerning duality theory for semigroups of operators. His thesis 'The Adjoint of a Semigroup of Linear Operators' is now almost finished. In this respect the stimulating contacts with co-promotor B. de Pagter (Delft University of Technology) should be mentioned.

Project AM 3.4 Functional differential equations
Progress on the book on functional differential equations by O. Diekmann, S.A. van Gils, S.M. Verduyn Lunel and H-O. Walther is steady but slow.

Project AM 3.5 Prey-predator patch problems &
Project AM 3.6 Evolutionary genetics
During 1991 these projects did not get the attention they deserve, due to lack of time and researchers. It is hoped that the ESF Network on Dynamics of Complex Systems in Bio-Sciences (formally starting in September 1991) and the NWO priority program on Nonlinear Systems will help somewhat to remedy this situation.

Project AM 3.7 Dynamic cardiac magnetic resonance imaging
M. Zwaan completed his thesis on dynamical cardiac imaging by magnetic resonance imaging, which was successfully defended at the Free University Amsterdam, on February 28, 1991.

Project AM 3.8 Three-dimensional reconstruction by confocal scanning laser microscopy
J.B.T.M. Roerdink worked on the problem of developing efficient attenuation correction methods for 3-D confocal scanning laser microscopy. An analytic approximation to the (nonlinear) inversion problem was developed which could be efficiently implemented using the Fast Fourier Transform. The results will appear in a CWI Report.

Project AM 3.9 Ocean acoustic tomography
During 1991 this project did not get the attention it deserves. However, J.B.T.M. Roerdink devoted part of his time to activities for the CWI multidisciplinary research 'Mathematics and the Environment'.

Project Dynamical systems (formerly project AM 2.4)
In January of this year J. de Vries completed the manuscript for the book 'Elements of Topological Dynamics', but much time was needed for the polishing of the final chapters and for proof reading. In addition, he wrote a paper for publication in the CWI Quarterly, in which a new proof was explained for a 'general mathematical reader'. Finally, J. de Vries reported at the conference TOPOSYM 7 (Prague) on the development of Topological Dynamics during

the last five years. For the 'special proceedings' of that conference he wrote an elaborate survey.

Project Asymptotics (formerly project AM 2.5)
Stimulated by a recent paper by M.V. Berry, on hyperasymptotics for a class of differential equations, A.B. Olde Daalhuis investigated hyperasymptotic expansions for integrals, with application to confluent hypergeometric functions.

N.M. Temme investigated asymptotic inversions of a class of distribution functions occurring in probability theory, with special emphasis on gamma and beta distributions. He continued the collaboration with Dr. S.S. Sazhin (University of Sheffield, UK) in applying asymptotic methods to problems in space plasma physics.

PUBLICATIONS 1991

Papers in Journals and Proceedings

1. O. DIEKMANN (1991). Modelling infectious diseases in structured populations. B.D. SLEEMAN, R.J. JARVIS (eds.). *Ordinary and Partial Differential Equations, Vol. III*, Pitman RNiMS 254, 67-79 (Longman).
2. O. DIEKMANN, J.A.J. METZ (1991). Exact finite dimensional representations of models for physiologically structured populations. I. the abstract foundations of linear chain trickery. J.A. GOLDSTEIN, F. KAPPEL, W. SCHAPPACHER (eds.). *Differential Equations with Applications in Biology, Physics and Engineering*, Lecture Notes in Pure and Applied Mathematics 133, Marcel Dekker, 269-289.
3. O. DIEKMANN, M. KRETZSCHMAR (1991). Patterns in the effects of infectious diseases on population growth. *J. Math. Biol. 29*, 539-570.
4. O. DIEKMANN, M. GYLLENBERG, H.R. THIEME (1991). Perturbation theory for dual semigroups. V. Variation-of-constants formulas. PH. CLÉMENT, E. MITIDIERI, B. DE PAGTER (eds.). *Semigroup Theory and Evolution Equations*, Lecture Notes in Pure and Applied Mathematics 135, Marcel Dekker, 107-123.
5. O. DIEKMANN, S.A. VAN GILS (1991). The center manifold for delay equations in the light of suns and stars. M. ROBERTS, I.N. STEWART (eds.). *Singularity Theory and Its Applications*, Warwick, 1989, Part II (Springer LNiM) 1463, 122-141.
6. O. DIEKMANN, S.M. VERDUYN LUNEL (1991). A new short proof of an old folk theorem in functional differential equations. PH. CLÉMENT, E. MITIDIERI, B. DE PAGTER (eds.). *Semigroup Theory and Evolution Equations*, Lecture Notes in Pure and Applied Mathematics 135, Marcel Dekker, 101-106.
7. O. DIEKMANN, M.W. SABELIS, V.A.A. JANSEN (1991). Metapopulation persistence despite local extinction: predator-prey patch models of the Lotka-Volterra type. *Biol. J. Linnean Soc. 42*, 267-283.
8. O. DIEKMANN, J.A.P. HEESTERBEEK, K. DIETZ. The basic reproduction

ratio R_0 for sexually transmitted diseases, part I: Theoretical considerations, to appear in *Math. Biosc.*

9. O. DIEKMANN, A.M. DE ROOS, J.A.J. METZ. Studying the dynamics of structured population models: a versatile technique and its application to Daphnia, preprint, to appear in *Amer. Nat.*
10. O. DIEKMANN, M. GYLLENBERG, H.R. THIEME (1991). Semigroups and renewal equations on dual Banach spaces with applications to population dynamics. S. BUSENBERG, M. MARTELLI (eds.). *Delay Differential Equations and Dynamical Systems*, Springer LNiM 1475, 116-129.
11. G. GREINER, J.M.A.M. VAN NEERVEN. Adjoints of semigroups acting on vector-valued function spaces, to appear in *Israel J. Math.*
12. H. INABA (1990). Threshold and stability for an age-structured epidemic model. *J. Math. Biol. 28*, 411-434.
13. M.C.M. DE JONG, O. DIEKMANN. A method to calculate - for computer-simulated infections - the threshold value, R_0, that predicts whether or not the infection will spread, preprint, to appear in *Prev. Vet. Med.*
14. J.M.A.M VAN NEERVEN (1991). Reflexivity, the dual Radon-Nikodym property, and continuity of adjoint semigroups II. *Indag. Math. N.S. 2*, 243-250.
15. J.M.A.M. VAN NEERVEN (1991). On the topology induced by the adjoint of semigroup of operators. *Semigroup Forum 43*, 378-394.
16. J.M.A.M. VAN NEERVEN, B. DE PAGTER (1991). Certain semigroups on Banach function spaces and their adjoints. PH. CLÉMENT, E. MITIDIERI, B. DE PAGTER (eds.). *Semigroup Theory and Evolution Equations*, Lecture Notes in Pure and Applied Mathematics 135, Marcel Dekker.
17. J.M.A.M. VAN NEERVEN (1990). Reflexivity, the dual Radon-Nikodym property, and continuity of adjoint semigroups. *Indag. Math. N.S. 1*, 365-379.
18. J.M.A.M. VAN NEERVEN. A converse of Lotz's theorem on uniformly continuous semigroups, to appear in *Proceeding of the AMS.*
19. J.M.A.M. VAN NEERVEN, J.P.M. PIJN, A. NOEST, F.H. LOPES DA SILVA (1991). Chaos or noise in EEG signals: dependence on state and brain site. *Electroencephalography and Clinical Neurophysiology 79*, 371-381.
20. J.B.T.M. ROERDINK, H.J.A.M. HEIJMANS (1991). Mathematical morphology for structures without translation symmetry. *Second Quinquennial Review 1986-1991*, Dutch Society for Pattern Recognition & Image Processing, reprinted from Sign. Proc.15:271-277 (1988).
21. J.B.T.M. ROERDINK, M. ZWAAN. Cardiac magnetic resonance imaging by retrospective gating: mathematical modelling and reconstruction algorithms, to appear in *Eur. J. Appl. Math.*
22. S.S. SAZHIN, N.M. TEMME (1991). The threshold of parallel whistler-mode instability. *Annales Geophysicae, 9*, 30-31.
23. S.S. SAZHIN, N.M. TEMME (1991). Marginal stability of parallel whistler-mode waves (asymptotic analysis). *Annales Geophysicae 9*, 304-308.
24. M. ZWAAN. Dynamic MRI reconstruction as a moment problem. Part I.

The beating heart: a problem formulation, to appear in *Math. Meth. Appl. Sc.*

25. M. ZWAAN. Dynamic MRI reconstruction as a moment problem. Part II. Riesz bases in L^2-spaces of vector valued functions, to appear in *Math. Meth. Appl. Sc.*

Reports

26. AM-R9102 N.M. TEMME. *Asymptotic inversion of incomplete gamma functions*, to appear in Math. Computation.
27. AM-R9106 N.M. TEMME. *Asymptotic inversion of the incomplete beta function*, to appear in JCAM.
28. AM-R9107 A.B. OLDE DAALHUIS. *Hyperasymptotic expansions of confluent hypergeometric functions.*
29. AM-R91xx J.B.T.M. ROERDINK, M. BAKKER. *An FFT-based method for attenuation correction in confocal microscopy.*

Other publications

30. M. ZWAAN (1991). *Moment Problems in Hilbert Space with Applications to Magnetic Resonance Imaging.* Ph.D. thesis, Free University Amsterdam.

Department of Operations Research, Statistics, and System Theory

HEAD OF DEPARTMENT: Prof.dr.ir. O.J. Boxma

LIST OF RESEARCH GROUPS

BS 1 Combinatorial optimization and algorithmics
BS 2 Analysis and control of information flows in networks
BS 3 System and control theory
BS 4 Image analysis
BS * Statistics and probability theory

		BS1	BS2	BS3	BS4	consult. etc.	working time in fte	budget time in fte	ext. paid	de-tached		guests	remarks
appointed													
Boxma	head dept.		0.80				1.00	1.00		-0.20			
Schrijver	groupleader	0.80					0.80	0.80					
Coelho de Pina	jr. researcher	1.00					1.00	-				1.00	
Gerards	researcher	1.00					1.00	1.00					
Ko	guest res.	0.75					1.00	-				0.75	
Lageweg	researcher	1.00					1.00	1.00					
Lenstra	researcher	0.20					0.20	-		0.20	TUE		
Veltman	jr.researcher	0.92					1.00	0.92					
Duyn Schouten	proj. leader		0.20				0.20	-		0.20	KUB		
Berg, v.d.	researcher		1.00				1.00	1.00					
Borst	jr.researcher		1.00				1.00	1.00					
Cohen	advisor		pm				pm	-					
Combe	jr.researcher		0.75				1.00	0.75	NFI				
Resing	researcher		0.25				1.00	-					
Weel, de	researcher		0.58				1.00	0.58					
Wartenhorst	jr.researcher		0.79				1.00	0.79					
Schuppen, van	groupleader			0.70			0.70	0.70					
Schumacher	proj.leader			0.80			1.00	1.00		-0.20			
Kuijper	researcher			0.08			1.00	0.08					
Does, de	jr.researcher			1.00			1.00	1.00			NSRT		
Baddeley	groupleader				1.00		1.00	1.00					
Heijmans	proj. leader				1.00		1.00	1.00					
Gill	advisor				pm		pm	-					
Groen	advisor				pm		pm	-					
Cabo	jr.researcher				1.00		1.00	1.00					
van Lieshout	jr.researcher				1.00		1.00	-		1.00	VU		
Nacken	jr.researcher				1.00		1.00	-		1.00	SION		
van Pul	jr.researcher				1.00		1.00	-		1.00	STW		
Steenbeek	sc.programmer				1.00		1.00	1.00					
Helmers	researcher				0.50	0.50	1.00	1.00					
Dzhaparidze	researcher				0.50	0.50	1.00	1.00					
vd Horst	sc.programmer					0.50	1.00	1.00					
Berbee	researcher												
research time		5.67	5.37	2.58	8.00	1.50		18.62					
request	jr.researcher	*					1.00						
request	jr.researcher		*				1.00						
request	jr.researcher		*				1.00						
request	jr.researcher			*			1.00						
request	jr.researcher			*			1.00						
request	jr.researcher			*			1.00						
request	jr.researcher				*		1.00						

RESEARCH GROUP BS 1

TITLE: Combinational optimization and algorithmics

TITEL: Combinatorische optimalisering en algoritmiek

LIST OF PROJECTS

BS 1.1 Design and analysis of algorithms;
BS 1.2 Polyhedral methods and polynomial-time algorithms;
BS 1.3 Multicommodity flows and VLSI-layout;
BS 1.4 Computational geometry;
BS 1.5 Parallel computations;
BS 1.6 Multi-criteria machine scheduling problems;
BS 1.7 Interactive planning methods.

REPORT ON 1991

BS 1 Design and analysis of algorithms
Project members: Drs. B.J.B.M. Lageweg, Prof.dr. J.K. Lenstra.

A.M.H. Gerards. B.J. Lageweg and A. Schrijver evaluated and analyzed approaches to solve a distribution problem in the area of mail transport.

J.K. Lenstra continued his efforts to complete the book 'Scheduling' (with E.L. Lawler (University of California at Berkeley), A.H.G. Rinnooy Kan (Erasmus University, Rotterdam) and D. Shmoys (Cornell University)).

Moreover, J.K. Lenstra made progress in compiling and editing the volume 'Computation' in the series Handbook in Operations Research and Management Science.

BS 1.2 Polyhedral methods and polynomial-time algorithms
Project members: Dr.ir. A.M.H. Gerards, Prof.dr. A. Schrijver, Dr. F.B. Shepherd.

A.M.H. Gerards proved that in any graph which contains a node such that deleting that node yields an 'odd-K4 free' graph, the odd circuits have the so-called weak max-flow min-cut property. This provides further evidence for the correctness of Seymour's conjecture on this weak max-flow min-cut property. Part of this result is reported in a working paper 'Odd paths and cycles in planar graphs with two odd faces'. A full report will be prepared. The research will be continued.

A.M.H. Gerards revised the paper 'An Orientation Theorem for Graphs' which has been submitted to the Journal of Combinatorial Theory (Series B).

A.M.H. Gerards continued working on 'Matchings', a survey chapter in the 'Handbook of Operations Research and Management Science: Volume on Net-

works and Distributions' edited by M. Ball, T. Magnanti, C. Monma and G. Nemhauser.

A. Schrijver continued his writing on the book 'Polyhedral Combinatorics'.

F.B. Shepherd made substantial progress on proving a conjectured Lemma helpful in characterizing the minimal hypergraphs that do not have the so-called weak max-flow min-cut property (analogous to Seymour's characterization of minimal hypergraphs not having the strong max-flow min-cut property, and to Padberg's characterization of minimally imperfect graphs).

BS 1.3 Multicommodity flows and VLSI-layout

Project members: J. Coelho de Pina, Prof.dr. A. Schrijver, Dr. F.B. Shepherd.

A. Schrijver found a polynomial-time algorithm for finding k pairwise vertex-disjoint directed paths between given pairs of end points in a planar graph (polynomial-time for fixed k). This solves a problem posed by Shiloah. (The problem is NP-complete for nonfixed k, as well as for nonplanar graphs.)

With C. McDiarmid (Oxford) and B.A. Reed (University of Waterloo) A. Schrijver and F.B. Shepherd found an extension of an earlier method for induced circuits in planar graphs to the directed case. The results were described in the report 'Packing interfering paths in planar graphs' (Report BS-R9118). The results for the undirected case were described in the report 'Induced circuits in planar graphs' (BS-R9106).

With P.D. Seymour (Bell Communications Research) research was done on the conjecture that every directed graph with all outdegrees at least k contains a directed cycle of length at most n/k (rounded up). Progress was made on the cases $k=4$ and $k=n/2.867..$ (with M. de Graaf). Results are described in the preprint 'A note on directed triangles in directed graphs'.

Project BS 1.4 Computational geometry

Project members: Prof.dr. A. Schrijver, Dr. F.B. Shepherd.

F.B. Shepherd investigated, with B. Gamble (Northwestern University), W. Pulleyblank (IBM Research), and B.A. Reed (University of Waterloo), the complexity of finding a maximum right-angle-free subset among given points in the plane. The problem turns out to be NP-complete in general, but polynomial-time solvable for horizontally convex subsets of the integer lattice. The results are described in the report 'Right angle free subsets in the plane' (BS-R9110).

Attention has been focussed on problems in discrete and computational topology. A. Schrijver investigated Tait's flyping conjecture for knots. He proved the conjecture for well-connected knots. It gives a polynomial-time algorithm for testing if two alternating knots are the same. The results are described in the report 'Tait's flyping conjecture for well-connected links' (BS-R9037). (Meantime W. Menasco and M. Thistlethwaite have proved the conjecture in general.)

A. Schrijver found new connections of graphs embedded on the torus with the geometry of numbers. It implies sharp bounds relating the representativity of graphs on the torus and the existence of disjoint circuits in the graph. The

method also gives a classification of minimal graphs of given representativity. With M. de Graaf (University of Amsterdam) the method was applied to find the sharpest bound for the value given by N. Robertson and P.D. Seymour for the relation between the representativity and the existence of large grid minors. The results were described in the preprints 'Graphs on the torus and geometry of numbers', 'Classification of minimal graphs of given representativity on the torus', and 'Grid minors of graphs on the torus'.

BS 1.5 Parallel computations
Project members: Drs. B.J.B.M. Lageweg, Prof.dr. J.K. Lenstra, Drs. B. Veltman.

Certain types of scheduling problems that arise when a parallel computation is to be executed on a multiprocessor were studied. A model that allows for communication delays between precedence related tasks was defined, and a classification of various submodels was given. The model is different and more general than the models that have been considered in the literature. In the first place, by the combination of communication delays and multiprocessor tasks and, secondly, by the specification of communication delays by means of data sets. For the general model a constructive approximation algorithm to build schedules was developed and implemented. It incorporates priority rules to choose tasks and task-allocations. The algorithm allows the user to specify particular priority rules and a search depth: it is 'tunable'.

BS 1.6 Multi-criteria machine scheduling problems
Project members: Drs. J.A. Hoogeveen, Prof.dr. J.K. Lenstra.

A number of scheduling problems have been investigated. These problems can be described as follows. A set of n independent jobs has to be scheduled on a single machine, which can handle only one job at a time so as to minimize an objective function that is composed of a number of performance measures. Furthermore, this function is supposed to be nondecreasing in each of its arguments. A schedule defines for each job its completion time, such that the jobs do not overlap in their execution. The following problems have been investigated.

1. The problem of finding a schedule that minimizes a function of two arbitrary regular minmax performance measures, where regularity implies that the cost of a job cannot be decreased by increasing its completion time. The value of such a minmax criterion is determined for a given schedule by computing for every job its cost induced by its completion time and taking the maximum. We provide an algorithm for this problem that runs in at most order n to the power 4 time. Furthermore, we show how to extend this analysis to the problem of minimizing a function of K arbitrary regular minmax performance measures; for this problem an algorithm is provided that runs in at most order n to the power $K(K+1)-6$ time. The results were described in the report 'Single-machine scheduling to minimize a function of K maximum cost criteria' (BS-R9113).
2. The problem of finding a schedule that minimizes a function of maximum

promptness and maximum lateness. We show that this problem is solvable by an extended version of the algorithm that was developed to solve the problem of minimizing maximum earliness and maximum lateness.

3. The problem of finding a schedule that minimizes the sum of the deviations of the job completion times from a common due date that is restrictively small. We have developed an approximation algorithm for this problem with worst-case bound 4/3. This is joint work with S.L. van de Velde.
4. The problem of finding a schedule that minimizes the sum of the deviations of the job completion times from an almost common due date that is large enough. In this context, almost common means that the jobs overlap in their execution when completed at their respective due date.

Results were described in the reports A new lower bound approach for single-machine multicriteria scheduling' (Report BS-R9026), coauthored by S.L. van de Velde, (to appear in Operations Research Letters) and 'New lower and upper bounds for scheduling around a small common due date', coauthored by H. Oosterhout and S.L. van de Velde (Report BS-R9030).

BS 1.7 Interactive planning methods

Project members: Drs. B.J.B.M. Lageweg, Prof.dr. J.K. Lenstra.

B.J. Lageweg was engaged in the development of interactive planning systems for the allocation of aircraft to stands on Schiphol Airport. For the seasonal planning problem, decomposed as a series of assignment problems connected by suitably chosen objective functions, a new user interface has been implemented, which enables the user to specify his preferences in a flexible way.

PUBLICATIONS 1991

Papers in Journals and Proceedings

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5. A.M.H. GERARDS (1990). On matrices and cutting planes. W.J. COOK, P.D. SEYMOUR (eds.). *Polyhedral Combinatorics*, American Mathematical Society, Providence, R.I., 29-32.

6. A.M.H. GERARDS (1991). Compact systems for T-join and perfect matching polyhedra of graphs with bounded genus. *Operations Research Letters 10*, 377-382.
7. C. VAN HOESEL, A. SCHRIJVER (1990). Edge-disjoint homotopic paths in a planar graph with one hole. *Journal of Combinatorial Theory (B) 48*, 77-91.
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10. J.H.M. KORST, E.H.L. AARTS, J.K. LENSTRA, J. WESSELS (1991). Periodic multiprocessor scheduling. E.H.L. AARTS, J. VAN LEEUWEN, M. REM (eds.). *PARLE '91: Parallel Architectures and Languages Europe; Volume I: Parallel Architectures and Algorithms*, Lecture Notes in Computer Science 505, Springer, Berlin, 166-178.
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12. J.K. LENSTRA, D.B. SHMOYS, E. TARDOS (1990). Approximation algorithms for scheduling unrelated parallel machines. *Mathematical Programming 46*, 259-271.
13. L. LOVÁSZ, A. SCHRIJVER (1990). Matrix cones, projection representations, and stable set polyhedra. W.J. COOK, P.D. SEYMOUR (eds.). *Polyhedral Combinatorics*, American Mathematical Society, Providence, R.I., 1-17.
14. L. LOVÁSZ, A. SCHRIJVER (1991). Cones of matrices and set-functions, and 0-1 optimization. *SIAM Journal on Optimization 1*, 166-190.
15. C.L. MONMA, A. SCHRIJVER, M.J. TODD, V.K. WEI (1990). Convex resource allocation problems on directed acyclic graphs: duality, complexity, special cases, and extensions. *Mathematics of Operations Research 15*, 736-748.
16. A. SCHRIJVER (1990). Applications of polyhedral combinatorics to multicommodity flows and compact surfaces. W.J. COOK, P.D. SEYMOUR (eds.). *Polyhedral Combinatorics*, American Mathematical Society, Providence, R.I., 119-137.
17. A. SCHRIJVER (1990). Homotopic routing methods. B. KORTE et al. (eds.). *Paths, Flows, and VLSI-Layout*, Springer-Verlag, Berlin, 329-371.
18. A. SCHRIJVER (1991). Disjoint circuits of prescribed homotopies in a graph on a compact surface. *Journal of Combinatorial Theory (B) 51*, 127-159.
19. A. SCHRIJVER, P.D. SEYMOUR (1991). A simpler proof and a generalization of the zero-trees theorem. *Journal of Combinatorial Theory (A) 58*, 301-305.
20. A. SCHRIJVER (1991). Edge-disjoint homotopic paths in straight-line planar graphs. *SIAM Journal on Discrete Mathematics 4*, 130-138.
21. A. SCHRIJVER (1991). Decomposition of graphs on surfaces and a homotopic circulation theorem. *Journal of Combinatorial Theory (B) 51*, 161-210.

22. A. SCHRIJVER (1991). Short proofs on multicommodity flows and cuts. *Journal of Combinatorial Theory (B) 53*, 32-39.
23. A. SCHRIJVER (1991). Disjoint homotopic paths and trees in a planar graph. *Discrete and Computational Geometry 6*, 527-574.
24. A. SCHRIJVER, P.D. SEYMOUR (1990). Spanning trees of different weights. W.J. COOK, P.D. SEYMOUR (eds.). *Polyhedral Combinatorics*, American Mathematical Society, Providence, R.I., 281-288.
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26. B. VELTMAN, B.J. LAGEWEG, J.K. LENSTRA (1990). Multiprocessor scheduling with communication delays. *Parallel Computing 16*, 173-182.

Reports

27. BS-R9001 J.A. HOOGEVEEN. *Minimizing maximum earliness and maximum lateness on a single machine.*
28. BS-R9005 J.A. HOOGEVEEN. *Analysis of Christofides' heuristic: some paths are more difficult than cycles.*
29. BS-R9008 J.A. HOOGEVEEN, S.L. VAN DE VELDE. *Polynomial-time algorithms for single-machine multicriteria scheduling.*
30. BS-R9009 S.L. VAN DE VELDE. *Dual decomposition of single-machine problems.*
31. BS-R9010 S.L. VAN DE VELDE. *Duality-based algorithms for scheduling unrelated parallel machines.*
32. BS-R9012 G. DING, A. SCHRIJVER, P.D. SEYMOUR. *Disjoint paths in a planar graph - a general theorem.*
33. BS-R9013 G. DING, A. SCHRIJVER, P.D. SEYMOUR. *Disjoint cycles in directed graphs on the torus and the Klein bottle.*
34. BS-R9014 A. FRANK, A. SCHRIJVER. *Edge-disjoint circuits in graphs on the torus.*
35. BS-R9015 A. SCHRIJVER, P.D. SEYMOUR. *A simpler proof and a generalization of the zero-trees theorem.*
36. BS-R9017 A.W.J. KOLEN, J.K. LENSTRA. (1990). *Combinatorics in operations research.*
37. BS-R9026 J.A. HOOGEVEEN, S.L. VAN DE VELDE. *A new lower bound approach for single-machine multicriteria scheduling.*
38. BS-R9030 J.A. HOOGEVEEN, H. OOSTERHOUT, S.L. VAN DE VELDE. *New lower and upper bounds for scheduling around a small common due date.*
39. BS-R9037 A. SCHRIJVER. *Tait's flyping conjecture for well-connected links.*
40. BS-R9108 C.J.H. MCDIARMID, B.A. REED, A. SCHRIJVER, F.B. SHEPHERD. *Induced circuits in planar graphs.*
41. BS-R9110 B. GAMBLE, W. PULLEYBLANK, B.A. REED, F.B. SHEPHERD. (1991). *Right angle free subsets in the plane.*
42. BS-R9113 J.A. HOOGEVEEN. *Single-machine scheduling to minimize a function of K maximum cost criteria.*

43. BS-R9118 C.J.H. McDiarmid, B.A. Reed, A. Schrijver, F.B. Shepherd. *Packing interfering paths in planar graphs.*

Other publications

44. A.M.H. Gerards (1990). *Graphs and polyhedra - Binary spaces and cutting planes*, CWI Tract 73, CWI, Amsterdam.
45. G.A.P. Kindervater, J.K. Lenstra, M.W.P. Savelsbergh. *Sequential and Parallel Local Search for the TSP with Time Windows.* Report Erasmus University, Rotterdam.
46. B. Korte, L. Lovász, H.J. Prömel, A. Schrijver (eds.) (1990). *Paths, Flows, and VLSI-Layout*, Springer-Verlag, Berlin.
47. J.K. Lenstra, A.H.G. Rinnooy Kan, A. Schrijver (eds.) (1991). *History of Mathematical Programming: A Collection of Personal Reminiscences*, CWI & North-Holland, Amsterdam.

RESEARCH GROUP BS 2

TITLE: Analysis and control of information flows in networks

TITEL: Analyse en besturing van informatiestromen in netwerken

LIST OF PROJECTS

BS 2.1 Analysis of mathematical queueing models;
BS 2.2 Performance analysis of communication systems;
BS 2.3 Performance analysis of computer systems;
BS 2.4 Reliability and availability of networks.

REPORT ON 1991

BS 2.1 Analysis of mathematical queueing models
Project members: Dr. J. van den Berg, Prof.dr.ir. O.J. Boxma (project leader), Prof.dr.ir. J.W. Cohen (advisor).

J.W. Cohen continued his extensive study of two-dimensional random walks and workload processes in the first quadrant. A key role is played by the *hitting point identity*, a relation for the trivariate generating function of the joint distribution of the entrance time into the boundary and the components of the hitting point on the boundary. The hitting point identity leads to a functional equation for the generating functions of the distributions of the successive hitting points on the boundary. Conditions are derived for the hitting point process, and for the random walk itself, to be positive-, null- or nonrecurrent. The results are collected in a few reports [14, 18] and, in particular, in a monograph [25] that will be published in 1992.

Further research in this project has led to various queueing theoretic results that already have been published [5, 9] or for which a publication is in preparation.

BS 2.2 and 2.3 Performance analysis of computer and communication systems
Project members: Dr. J. van den Berg, Ir. S.C. Borst, Prof.dr.ir. O.J. Boxma (project leader), Prof.dr.ir. J.W. Cohen (advisor), Drs. M.B. Combé, Dr. J.A.C. Resing.

Because of the close connection between projects BS 2.2 and BS 2.3, we present a combined report.
An important part of these projects concerns the analysis and optimization of single-server multi-queue (polling) models, and the application of the results to distributed systems and communication networks. Part of this research is carried out in two externally funded projects that started in September 1990 (S.C. Borst, oio funded by the Dutch Graduate Network in Operations Research) and October 1990 (M.B. Combé, oio funded by NFI).

In the area of *polling optimization*, the major problem under investigation

has been the optimal static routing of the server along the queues (so as to minimize a weighted sum of the mean waiting times at the queues). For polling systems with exhaustive, gated or 1-limited service disciplines, simple and efficient rules for the route of the server have been derived [4, 7]. Recently, related problems have been studied in a consultancy for PTT Research. In a queueing system consisting of several single-server queues in parallel, M.B. Combé is studying load balancing rules (allocation of customers to queues), using an analogy to the server routing rules that have been obtained for polling systems.

In the area of *polling analysis*, J.A.C. Resing [20] has shown that the joint queue length process in a large class of polling systems can be viewed as a multitype branching process with immigration. This leads to an important simplification, to some new results and to better insight into the sharp distinction between 'easy' and 'difficult' polling models. Together with Takagi and Takine, O.J. Boxma investigated a work decomposition of the workload in polling systems *with* switchover times into the workload in the same system *without* switchover times, and an additional term [29]. Together with Takagi, he is editing a special issue of Queueing Systems on polling models, to appear in 1992.

A polling-related study [8] of the CRMA protocol in high-speed local and metropolitan area networks has led to the investigation of a basic queueing problem: A single-server queue with dependence between interarrival and service times. For a realistic dependence structure, a detailed analysis of the sojourn time, waiting time and queue length distributions has turned out to be possible [19, 24].

J. van den Berg spent the first six months of 1991 at Cornell, as MSI fellow. With H. Kesten he studied the asymptotic behaviour of travel times in the d-dimensional cubic network with random time coordinates. A paper on the results will be submitted for publication [22]. With J. Steif a model is studied which is known as the 'hard-core lattice gas model' in statistical physics, and which has recently been rediscovered in operations research as a model of a large communication network, where adjacent nodes are not allowed to transmit simultaneously. Several interesting results have been obtained and further progress is expected. The paper 'Probabilistic problems arising from an optimal-path algorithm', which was in preparation last year will be finished in November 1991 with the title 'On the number of non-dominated paths' [23].

In a joint project with PTT Research, J.A.C. Resing investigates the performance of ATM multi-service networks. After having surveyed the relevant literature [27], with special emphasis on the approximation of arrival processes in ATM networks, he studies the evolution of the traffic characteristics of a cell stream that successively visits several nodes of an ATM network, experiencing interference from other streams [28]. Furthermore, a start has been made with a study of the queue lengths and waiting times of the cells at these nodes in tandem.

BS 2.4 Reliability and availability of networks
Project members: Prof.dr.ir. O.J. Boxma, Prof.dr.ir. J.W. Cohen (advisor), Prof.dr. F.A. van der Duyn Schouten (project leader), Dr.ir. P.R. de Waal, Drs. P. Wartenhorst.

F.A. van der Duyn Schouten and S.G. Vanneste (Tilburg University) completed the performance analysis of two easily implementable maintenance strategies for a multi-component system, consisting of a large number of identical components. A start has been made with the analysis of a maintenance optimization model where the maintenance decision not only depends on the current state of a production unit but also on the content of a subsequent buffer.

P. Wartenhorst and F.A. van der Duyn Schouten [13] extended previous results for a two-unit standby system with Markovian degradation and a single repair facility in three directions: preemptive resume policies, state dependent repair time distributions and dynamic control of the speed of repair. A report on this last aspect is in preparation.

P. Wartenhorst spent six months at Koninklijke/Shell-Laboratorium in Amsterdam (KSLA). During his visit he analyzed with W.P. Groenendijk (KSLA) the transient behaviour of the total maintenance load in a complex production unit [30]. The research is part of a manpower planning project within KSLA.

P.R. de Waal finished the analysis of a queueing system with impatient customers; a report is in preparation. In this model the impact is studied of preventive maintenance jobs on the total maintenance workload and on the maintenance backlog. P.R. de Waal also built a general framework model, by which the various maintenance and operation options in a complex production network can be described. The framework will be used as a reference model for various specific maintenance optimization and manpower planning problems.

F.A. van der Duyn Schouten continued his participation in a research project directed to reliability optimization of industrial electricity systems.

PUBLICATIONS 1991

Papers in Journals and Proceedings

1. J. VAN DEN BERG, R.W.J. MEESTER (1991). Stability properties of a flow process in graphs. *Random Structures and Algorithms 2*, 335-341.
2. J.L. VAN DEN BERG, O.J. BOXMA (1991). The M/G/1 queue with processor sharing and its relation to a feedback queue (invited paper). *Queueing Systems 9*, 365-401.
3. O.J. BOXMA, W.P. GROENENDIJK, J.A. WESTSTRATE (1990). A pseudoconservation law for service systems with a polling table. *IEEE Trans. Commun. 38*, 1865-1870.
4. O.J. BOXMA (1991). Analysis and optimization of polling systems. J.W. COHEN, C.D. PACK (eds.). *Queueing, Performance and Control in ATM*, Proc. ITC-13 workshop, North-Holland Publ. Cy., Amsterdam, 173-183.

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6. O.J. BOXMA, G.A.P. KINDERVATER (1991). A queueing network model for analyzing a class of branch-and-bound algorithms on a master-slave architecture. *Oper. Res. 39*, xxx-xxx.
7. O.J. BOXMA, H. LEVY, J.A. WESTSTRATE (1991). Efficient visit frequencies for polling tables: minimization of waiting cost (invited paper). *Queueing Systems 9*, 133-162.
8. O.J. BOXMA, H. LEVY, U. YECHIALI (1991). Cyclic reservation schemes for efficient operation of multiple-queue single-server systems, to appear in *Annals of Operations Research*, Special Issue on Stochastic Modelling of Telecommunication Systems.
9. J.W. COHEN (1991). On the attained waiting time. *Adv. Appl. Probab. 23*, 660-661.
10. J.W. COHEN (1991). On two teletraffic congress programs: Roots and scope. A. JENSEN, V.B. IVERSEN (eds.). *Teletraffic and Datatraffic in a Period of Change*, Proc. ITC 13, North-Holland, Amsterdam, 1059-1065.
11. P.R. DE WAAL, N.M. VAN DIJK (1991). Monotonicity of performance measures in a processor sharing queue. *Performance Evaluation 12*, 5-16.
12. P.R. DE WAAL, N.M. VAN DIJK (1991). Interconnected networks of queues with randomized arrival and departure blocking, to appear in *Annals of Operations Research*, Special Issue on Stochastic Modelling of Telecommunication Systems.
13. P. WARTENHORST, F.A. VAN DER DUYN SCHOUTEN (1991). Availability analysis of a two-unit standby system with preemptive repair. B.R. HAVERKORT, I.G. NIEMEGEERS, N.M. VAN DIJK (eds.). *Proceedings of the First International Workshop on Performability Modelling of Computer and Communication Systems.*

Reports

14. BS-R9003 J.W. COHEN. *The two-dimensional random walk, its hitting process and its classification (revised version).*
15. BS-R9101 J.P.C. BLANC, P.R. DE WAAL, P. NAIN, D. TOWSLEY. *A new device for the synthesis problem of optimal control of admission to an M/M/c queue* (accepted for publication in IEEE Trans. Autom. Control).
16. BS-R9102 O.J. BOXMA. *Analysis and optimization of polling systems.*
17. BS-R9111 O.J. BOXMA, H. LEVY, J.A. WESTSTRATE. *Efficient visit frequencies for polling tables: minimization of waiting cost.*
18. BS-R9114 J.W. COHEN. *Zero drift random walk on NxN with reflection, ergodicity conditions.*
19. BS-R91xx S.C. BORST, O.J. BOXMA, M.B. COMBÉ. *An M/G/1 queue with dependence between interarrival and service times.*
20. BS-R91xx J.A.C. RESING. *Polling systems and multitype branching processes.*

Other publications

21 J. VAN DEN BERG, A. GANDOLFI (1990). *LRU is better than FIFO under the Independent Reference Model.* MSI technical report 90-81, Cornell University (accepted for publication in J. Appl. Probab.).

22. J. VAN DEN BERG, H. KESTEN (1991). *Inequalities for the Time Constant in First-passage Percolation.* Preprint Cornell University, August 1991.

23. J. VAN DEN BERG (1991). *On the Number of Non-dominated Paths.* Preprint, December 1991.

24. S.C. BORST, O.J. BOXMA, M.B. COMBE (1991). Collection of customers - A correlated M/G/1 queue. Accepted for publication in the proceedings of *ACM Sigmetrics/Performance '92.*

25. J.W. COHEN (1991). *Analysis of Random Walks.* Monograph, in preparation.

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27. J.A.C. RESING (1991). *Cell Level Performance Analysis of ATM Multiservice Networks 1: Introduction.* Report PTT Research, March 1991.

28. J.A.C. RESING (1991). *Cell Level Performance Analysis of ATM Multiservice Networks 2: Tandem Queues with Deterministic Service Times.* Report PTT Research, June 1991.

29. H. TAKAGI, T. TAKINE, O.J. BOXMA (1991). *Distribution of the Workload in Multiclass Queueing Systems with Server Vacations.* Report IBM Research, Tokyo Research Laboratory; accepted for publication in Naval Research Logistics.

30. P. WARTENHORST, W.P. GROENENDIJK (1991). *Transient Failure Behaviour of Repairable Systems.* Tech. Report AMER.91.018 Koninklijke/Shell-Laboratorium, Amsterdam.

31. J. VAN DEN BERG, J. STEIF (1991). A uniqueness condition for Gibbs measures, with applications to the 2-dimensional Ising anti-ferromagnet and hard-core gas model. Preprint, December 1991.

RESEARCH GROUP BS 3

TITLE: System and control theory

TITEL: Systeem- en regeltheorie

LIST OF PROJECTS

BS 3.1 Deterministic system theory;
BS 3.2 Stochastic system theory;
BS 3.3 Systems with a generalized state space;
BS 3.4 Control of discrete-event systems;
BS 3.5 Control-theoretic computations for element models.

REPORT ON 1991

BS 3.1 Deterministic system theory
Project member: Prof.dr. J.M. Schumacher.

In the framework of the so-called 'behavioral approach' to linear systems, results have been obtained concerning the development of an equivalence notion for a class of nonstationary stochastic processes. Part of the motivation for the research comes from econometrics, more in particular from the theory of cointegrated time series.

Prof. J.D. Aplevich (University of Waterloo, Canada) visited the department during two months in the summer; his stay was made possible by the Systems and Control Theory Network in The Netherlands. J.M. Schumacher cooperated with him on a general formulation of the linear-quadratic control problem which incorporates both singular cost criteria and singular dynamics. A publication is in preparation.

A new subject of research has been the development of geometric methods for the analysis of the robustness of feedback systems. A first paper on this topic has been accepted for publication in Systems & Control Letters. Further work in this area will be closely connected to the research in project BS 3.5.

Much time has gone into the preparation of notes for the graduate course on linear systems, which J.M. Schumacher teaches together with J.C. Willems (University of Groningen). This course is part of the graduate program organized by the Systems and Control Theory Network in The Netherlands. The notes are intended for eventual publication in book form.

BS 3.2 Stochastic system theory
Project member: Prof.dr.ir. J.H. van Schuppen.

Research on adaptive control was continued. The limitations of the synthesis procedure of selftuning control were investigated by methods of stochastic realization. A paper was completed and submitted. A presentation was held at the First European Control Conference in Grenoble, July 1991.

The joint work with G. Picci (Padova) on the finite stochastic realization problem was continued. The classification of primes in the positive matrices was pursued. A manuscript is in preparation. A short version of this manuscript with preliminary results was submitted for inclusion in the proceedings of the International Symposium MTNS-91.

Dr. A. Gombani (LADSEB and University of Padova, Padova, Italy) is visiting CWI starting April 1991 for possibly a year. His visit is financed by the Italian government through a fellowship from C.N.R. Van Schuppen is cooperating with him on the analysis of scattering systems and the synthesis of inverse scattering algorithms.

The control problem of routing of freeway traffic is slowly gaining importance. Later this decade routing directions will be provided at major freeway intersections in The Netherlands, in major European countries, in the USA, and in Japan. There is a need for routing algorithms which on the basis of actual information on the traffic state of the network decide how to set the routing directions. A study has been started into this problem. A model in the form of a stochastic control system has been defined. Routing problems have been formulated and an algorithm proposed.

Lecture notes were written for a course on *Stochastic control and filtering*. This course is taught jointly with A. Bagchi in the course program of the Systems and Control Theory Network.

BS 3.3 Systems with a generalized state space

Project members: Prof.dr. J.M. Schumacher (project leader), Drs. M. Kuijper.

A characterization of minimality of descriptor representations without direct feedthrough term has been derived. Also, the transformation group has been given for minimal representations of this form. The results have been written down in a report, that will be published in Automatica.

A report has been written on geometric methods for determining the pole/zero structure at infinity of first-order representations with a generalized state space (pencil representation, descriptor representation).

A realization procedure has been derived for the partial fractions of a transfer function with respect to two complementary parts of the extended complex plane, that are given a-priori. Also, a pencil realization procedure has been given for a matrix fractional representation with respect to a subset of the extended complex plane. The relation between the two methods has been clarified. Results have been written down in a report that will be published in *Linear Algebra Appl.*

BS 3.4 Control of discrete-event systems

Project members: Prof.dr.ir. J.H. van Schuppen (project leader), vacancy.

This project has not yet been started because no research assistant (oio) has been made available.

BS 3.5 Control-theoretic computations for element models
Project members: Prof.dr. J.M. Schumacher (project leader) Drs. J. de Does.

Aspects of robust stabilization in the *pointwise-gap metric* have been studied. The relation between robustness analysis and the finite-dimensional geometry of angles of subspaces has been investigated, yielding a very easy proof of the connection of the gap topology with robust stabilization in the standard feedback configuration, and a robustness measure for more general interconnection schemes.

Furthermore, some properties of relevant topologies have been studied, in particular the similarities and differences between the topologies that arise by varying the domain in the complex plane over which the supremum of the pointwise gaps is taken.

PUBLICATIONS 1991

Papers in Journals and Proceedings

1. M. KUIJPER, J.M. SCHUMACHER (1991). Minimality of descriptor representations under external equivalence. *Automatica J. - IFAC* (to appear November 1991).
2. M. KUIJPER, J.M. SCHUMACHER (1991). Realization and partial fractions. *Linear Algebra and Its Applications* (to appear).
3. M. KUIJPER, J.M. SCHUMACHER (1991). State space formulas for transfer poles at infinity. *Proceedings MTNS-91*, Kobe, Japan, June 1991.
4. M. KUIJPER, J.M. SCHUMACHER (1991). Realization of finite and infinite modes. *Proceedings ISIRS Conference*, Warsaw, Poland, July 1991.
5. J.M. SCHUMACHER (1991). A pointwise criterion for controller robustness. *Systems and Control Letters* (to appear).
6. J.M. SCHUMACHER (1991). System-theoretic trends in econometrics. A.C. ANTOULAS (ed.). *Mathematical System Theory: The Influence of R.E. Kalman*, Springer, Berlin, 1991.
7. J.M. SCHUMACHER (1991). Equivalence of representations for a class of nonstationary processes. *Proceedings CDC*, Brighton, England, December 1991.
8. J.H. VAN SCHUPPEN (1991). For which control objectives does tuning hold? G.B. DI MASI, A. GOMBANI, A.B. KURZHANSKY (eds.). *Modeling, Estimation and Control of Systems with Uncertainty*, (Proceedings IIASA Workshop), Progress in Systems and Control Theory, Volume 10, Birkhäuser Boston Inc., Boston, 445-448.
9. J.H. VAN SCHUPPEN (1991). Asymptotic selftuning for Gaussian stochastic control systems. C. COMMAULT et al. (eds.). *Proceedings of the First European Control Conference*, Grenoble, France, 1991, Hermès, Paris, 258-263.
10. J.H. VAN SCHUPPEN (1991). Routing of freeway traffic - A state space model and routing problems. *Proceedings of the 30th Conference on Decision and Control*, IEEE Press, New York, 1991 (to appear).

Reports

11. BS-R9103 M. KUIJPER. *Descriptor representations without direct feedthrough term.*
12. BS-R9108 M. KUIJPER, J.M. SCHUMACHER. *State space formulas for transfer poles at infinity.*
13. BS-R9112 J.M. SCHUMACHER. *A pointwise criterion for controller robustness.*

Other publications

14. J.H. VAN SCHUPPEN (1991). *Tuning of Gaussian Stochastic Control Systems.* Preprint, submitted for publication.
15. J.H. VAN SCHUPPEN (1991). *Stochastic Realization of Finite-Valued Processes and Primes in the Positive Matrices.* Preprint, June, submitted for publication in the Proceedings of the International Symposium MTNS-91, Kobe, Japan.
16. J.H. VAN SCHUPPEN (1991). *Routing of Freeway Traffic - A State Space Model and Routing Problems.* Preprint, March (A short version of this preprint will appear in the proceedings of the CDC91.).

RESEARCH GROUP BS 4

TITLE: Image analysis

TITEL: Beeldanalyse

REPORT ON 1991

The research output of BS 4 continues to grow well. Several activities matured in 1991 (discretization, graph morphology, 3D spatial statistics, software support) and others have also been encouragingly successful (Markov models for object recognition, error metrics, iterative filters). New interests have developed (glance functions, granulometries, discrete scaling).

Mature projects

A.J. Baddeley completed research on spatial statistics for three-dimensional point patterns, including analysis of data from a confocal microscope. The statistical analysis detected a previously unrecognised biological difference between two subspecies of the macaque monkey; this will be studied further at the University of London. It is now planned to collect full three-dimensional images of the same material, and to become involved in recent developments in 3D image processing.

A.J. Baddeley and M.N.M. van Lieshout continued their work on Bayesian/Markov modelling techniques for object recognition problems in image analysis. It has now been shown that many standard object recognition techniques, including the Hough transform, simple erosions, and binning techniques, are special cases of a statistical (maximum likelihood) approach. An analogue of stochastic annealing has also been developed.

A.J. Cabo completed a paper on convex hulls of random point processes with Prof.dr. P. Groeneboom (Delft University of Technology).

H.J.A.M. Heijmans completed two research papers on the discretization of morphological operators and functionals. Heijmans and Dr. L. Vincent (Harvard Robotics Laboratory) continued their work on graph morphology and finished a second paper on this subject. Heijmans and Prof. J. Serra (Centre de Morphologie Mathematique, Ecole des Mines de Paris) completed their work on the construction of morphological filters by iterative techniques.

Considerable software work has been undertaken to implement techniques developed in the research group. Our main support software is the SCILIMAGE package, and we collaborate closely with the developers (Delft University of Technology and University of Amsterdam). However, our own fundamental research requires many unfamiliar low-level image transformations for which special programming techniques are needed. A.G. Steenbeek (programmer, STO) has developed a very successful solution in the form of a C++ library for low-level image programming (CLIP), suitable for use either independently or as an enhancement to SCILIMAGE.

P. Nacken, working in a SION project jointly with the TNO institute for

Perception (Soesterberg) and the Faculty of Mathematics and Computer Science (University of Amsterdam) continued his research on hierarchical graph representation of images and operations on such representations. He finished a paper on the construction of metrics for comparing and clustering line segments.

R. de Groot (Hogeschool Holland, Diemen) finished his undergraduate degree project on the implementation of morphological operators in SCILIMAGE and CLIP. His work will be continued by another student from the Hogeschool Holland, L. van der Kamp.

New developments

Recently A.J. Cabo has obtained interesting results about the relationship between 'glance functions' and covariance functions for convex sets, which may have practical applications to inference for the Boolean model in image processing.

A.J. Baddeley's research on error metrics for images changed direction when it was realised that the problem (of defining metrics on spaces of images) was related to a more abstract problem in the theory of random capacities. Existing work in that field was studied and extended to solve the original problem. The results are now being applied to the practical measurement of errors in binary image processing, specifically in edge detection.

In cooperation with Prof. E. Dougherty (Rochester Institute of Technology), H.J.A.M. Heijmans initiated a study of granulometries for grey-level images. Granulometries are regarded as one of the most powerful tools of image analysis for the description of geometrical structure in materials and biological tissues. For binary images the concept of a granulometry is well understood. For grey-level images, however, there remain many open problems. Heijmans and Dougherty have obtained some interesting preliminary results and their work will continue.

H.J.A.M. Heijmans and P. Nacken became interested in the problem of scaling discrete sets in the plane using convexity notions. So far, their study, which is relevant for the construction of granulometries for discrete images, has raised a number of questions in the context of discrete (distance) geometry.

Currently P. Nacken is working on discrete skeletons based on chamfer metrics and graph representations of binary objects based on such skeletons.

Professional activities

Group members participate in the CWI study group on wavelets and the CWI multidisciplinary research on image processing.

H.J.A.M. Heijmans was invited by Academic Press to write a monograph on theoretical aspects of mathematical morphology. This book, which will probably be finished in 1992, will appear in the supplement series 'Advances of Electronics and Electron Physics'.

A.J. Baddeley is writing a book on stereology for medical researchers (in collaboration with course lecturers in the International Society for Stereology).

Group members have been active in 7 international conferences, including a

large attendance at GEOBILD '91(5th Workshop on Geometrical Problems of Image Processing) in Georgenthal, Germany, in March 1991.

A.J. Baddeley held a course on 'stochastic geometry and the analysis of spatial data' at the Faculty of Mathematics, University of Utrecht.

Spatial stochastic models for patterns of geological faults, and associated image processing techniques, are being investigated by A.J. Baddeley as part of a consulting study for the Australian Coal Industry Research Laboratories (jointly with CSIRO Division of Mathematics and Statistics).

PUBLICATIONS 1991

Papers in Journals and Proceedings

1. H.J.A.M. HEIJMANS (1991). Theoretical aspects of gray-level morphology. *IEEE Trans. PAMI 13*, 568-582.
2. H.J.A.M. HEIJMANS (1991). From binary to grey-level morphology. To appear in R. HARALICK (ed.). *Mathematical Morphology: Theory and Applications*
3. H.J.A.M. HEIJMANS (1991). Morphological discretization. U. ECKHARDT, A. HUBLER, W. NAGEL, G. WERNER (eds). *Proc. of the 5th Workshop on Geometrical Problems of Image Processing*, Georgenthal, Berlin, Akademie Verlag, 99-106.
4. H.J.A.M. HEIJMANS, A. TOET (1991). Morphological sampling. To appear in *Comp. Vis. Graph. Im. Proc.: Image Understanding*.
5. H.J.A.M. HEIJMANS, P. NACKEN, A. TOET, L. VINCENT (1991). Graph morphology. To appear in *J. Vis. Comm. Image Repr.*
6. H.J.A.M. HEIJMANS, J. SERRA (1991). Convergence, continuity and iteration in mathematical morphology. To appear in *J. Vis. Comm. Image Repr.*
7. M.N.M. VAN LIESHOUT (1991). A Bayesian approach to object recognition. U. ECKHARDT, A. HUBLER, W. NAGEL, G. WERNER (eds). *Proc. of the 5th Workshop on Geometrical Problems of Image Processing*, Georgenthal, Berlin, Akademie Verlag, 185-190.
8. R.A. MOYEED, A.J. BADDELEY (1991). Stochastic approximation of the MLE for a spatial point pattern. *Scandinavian Journal of Statistics 18*, 39-50.
9. P. NACKEN (1991). Hierarchical graph representation of image structure based on intensity extrema. U. ECKHARDT, A. HUBLER, W. NAGEL, G. WERNER (eds). *Proc. of the 5th Workshop on Geometrical Problems of Image Processing*, Georgenthal, Berlin, Akademie Verlag, 191-198.
10. R.P.C. RODGERS, A.J. BADDELEY (1991). Monte Carlo study of random packing on the surface of a sphere. *Journal of Applied Probability*, to appear, September.
11. C. RONSE, H.J.A.M. HEIJMANS (1991). The algebraic basis of mathematical morphology. Part II: openings and closings. *comp. Vision, Graphics and image Proc: Image understanding 54*, 74-97.

Reports

12. BS-R9104 H.J.A.M. HEIJMANS, J. SERRA. *Convergence, continuity and iteration in mathematical morphology.*
13. BS-R9109 A.J. BADDELEY, M.N.M. VAN LIESHOUT. *Recognition of overlapping objects using Markov spatial processes.*
14. BS-R9115 A.J. CABO, P. GROENEBOOM. *Limit theorems for functionals of convex hulls.*
15. BS-R91xx *Hausdorff metric for capacities.*
16. BS-R91xx A.J. BADDELEY. *An error metric for binary images.*
17. BS-R91xx A.J. BADDELEY, R.A. MOYEED, C.V. HOWARD, A. BOYDE. *Analysis of a three-dimensional point pattern with replication.*
18. H.J.A.M. HEIJMANS. *Discretization of morphological operators.*
19. BS-R91xx P. NACKEN. *A metric for line segments.*

Other publications

20. A.J. BADDELEY (1991). Stereology. Chapter 10 of *Spatial Statistics and Digital Image Analysis*: a cross-disciplinary report, National Research Council USA (Washington: National Academy of Science Press, 1991).
21. H.J.A.M. HEIJMANS, L. VINCENT (1991). *Graph Morphology in Image Analysis.* Harvard Robotics Laboratory Technical Report 91-11, 1991; to appear in E. DOUGHERTY (ed.). Mathematical Morphology in Image Processing, Marcel Dekker, New York, 1991/1992.

RESEARCH GROUP BS *

TITLE: Statistics and probability theory

TITEL: Statistiek en waarschijnlijkheidsrekening

Formerly Research group BS 5 (the research of this group has been terminated during 1991).

LIST OF PROJECTS

BS 5.1 Stochastic processes;
BS 5.2 Semiparametric inference for filtered experiments;
BS 5.3 Asymptotic methods and resampling techniques;
BS 5.4 Applied statistics and consultation.

REPORT ON 1991

BS 5.1 Stochastic processes
Project members: Dr. H.C.P. Berbee, Dr. J. van den Berg.

J. van den Berg has spent the first six months of 1991 at Cornell University, as MSI fellow. With H. Kesten the asymptotic behaviour of travel times in the d-dimensional cubic network with random time coordinates has been studied. A paper on our results has been submitted for publication.

With J. Steif a model is studied which is known as the 'hard-core lattice gas model' in statistical physics, and which has recently been rediscovered in operations research as a model of a large communication network. Our research has led to interesting combinatorial problems. Some progress has been made and we hope to obtain further results soon. The paper 'Probabilistic problems arising from an optimal-path algorithm', which was in preparation last year will be finished in November 1991 with the title 'On the number of non-dominated paths' [3].

H.C.P. Berbee worked on a problem for Markov respresentation for Ψ-mixing. This problem seemed to have a positive solution, but quite generally an unnatural aspect arose, that is connected with randomization. Unfortunately, progress in this problem has been delayed due to the fact that Berbee has been ill for the larger part of the year.

BS 5.2 Semiparametric inference for filtered experiments
Project member: Dr. K.O. Dzhaparidze.

K.O. Dzhaparidze continued the joint work with P.J.C. Spreij (Free University Amsterdam) started with the CWI Report BS-R9029, a new report *On second order optimality of asymptotically linear estimation* is under preparation. The results were reported at the 19th European Meeting of Statisticians, September 2-6, Barcelona. At the same meeting Dzhaparidze and E. Valkeila presented a lecture on the new version of their joint work *On large deviation*

probabilities for the maximum likelihood estimators, in Prob. Theory and Math. Stat. (B. Grigelionis, ed.), vol. 1, p. 285-292, 1990. The completion of the new version is planned for next year.

K.O. Dzhaparidze worked on time series analysis and econometrics, giving lectures on these subjects in the Catholic University Nijmegen. He has prepared a syllabus on time series analysis and the CWI Report BS-R91xx which together may constitute a considerable part of a textbook on this subject [11, 14]. The methods used here can be extended to random fields - he intends to work on this direction. Dzhaparidze started collaboration in Nijmegen with M. van Zuijlen and J. Kormos (Debrecen, temporarily Catholic University Nijmegen) on statistical inference for almost stationary processes.

K.O. Dzhaparidze and M. van Zuijlen gave lectures on the Option Theory of finances in Budapest to participants of the international 'Tempus' project, as well as to students of the Catholic University Nijmegen. A syllabus is under preparation [15].

BS 5.3 Asymptotic methods and resampling techniques

Project members: Drs. A.L.M. Dekkers, Dr. R. Helmers, Prof.dr. L.F.M. de Haan.

With M. Husková (Charles University, Prague) the asymptotic consistency and the accuracy of the bootstrap approximation for multivariate U-quantiles and related statistics was obtained. These results were presented (by R. Helmers) at the meeting on 'Order Statistics and Non Parametrics: Theory and Applications', September 18-20, 1991, Alexandria, Egypt and reported in CWI Report BS-R91xx [10]. R. Helmers will visit Charles University, Prague, in November 1991 to continue joint research with M. Husková on bootstrap methods.

A revised version of MS-8708 appeared in Ann. Statist. and a revised version of BS-R9021 will appear shortly in '*Exploring the Limits of Bootstrap*' (R. Le Page & L. Billard, eds.) [5]. A paper on bootstrapping empirical U-processes (with application in spatial statistics) is in preparation.

In the first semester a special course 'Bootstrap Approximations and Edgeworth Expansions' for Ph.D. students in probability and statistics was given in Amsterdam (aio-network stochastics).

R. Helmers acted as invited discussiant at the meeting on '*Stochastic Models and Methods for Shale and Sand Formations*', September 12, 1991, ISI meeting, Cairo, Egypt.

A.L.M. Dekkers completed his research in statistical extreme-value theory, under the supervision of L.F.M. de Haan (advisor) towards a Ph.D. thesis. (On November 14, 1991 A.L.M. Dekkers will receive his degree at the Erasmus University Rotterdam; L.F.M. de Haan (promotor), R. Helmers (copromotor)).

BS 5.4 Applied statistics and consultation

Project members: Dr. K.O. Dzhaparidze, Dr. R. Helmers, Prof.dr. L.F.M. de Haan, Drs. M.C.J. van Pul.

The statistical consultation project, joint with RWS and KNMI, was

continued and will shortly be completed. The aim of the study was to determine the heights of safe sea-dikes along the Dutch coast. This work began in 1984; a detailed account of the results will be given in a final report (in preparation). R. Helmers wrote a chapter on the statistical methods used in this study. Theoretical work connected with this project was described in [13].

A course on bootstrap methods for researchers and users of statistics in industry and government was given on May 29, June 5 and 12. The course emphasized general ideas and applications rather than theory. A syllabus 'Bootstrap Methods' was especially written by R. Helmers for the course. The number of participants was 38.

A book 'Bootstrap Approximations' for SIAM's series 'Frontiers in Applied Mathematics' is currently in preparation. A soft deadline for submitting a manuscript is September 1, 1992. The syllabus 'Bootstrap Methods' is viewed as a very preliminary version of the book.

Joint with F.X. Plooy (Paedological Institute, University of Amsterdam), A.J. van Es (Department of Mathematics, University of Amsterdam), and E. Mammen (University of Heidelberg) a statistical analysis of data related to transitions (regressions) in the development of small children was started. The problem can be viewed as one of making inference about the number (and locations) of modi of a density. E.g. we want to assert that the unknown number of modi is at least k, with 95% confidence. It appears that bootstrap methods for kernel density estimators can be used here. (Dr. E. Mammen (Heidelberg) will visit CWI in October).

Joint with K.O. Dzhaparidze, R. Helmers prepared a forthcoming issue of CWI Quarterly on Statistics.

K.O. Dzhaparidze and R. Helmers, together with R. van der Horst (programmer, STO) and a team from NOS, worked on the joint project 4058P 'Study of switching behaviour of TV-viewers'. A detailed account of the results obtained so far can be found in an interim report [16].

K.O. Dzhaparidze worked on the revised version of the CWI Report BS-R9036 on iterative procedures in statistics, with the intention to apply in the near future iterative methods to the problems concerning spatial point patterns mentioned in the CWI Report BS-R8926 by R.A. Moyeed and A.J. Baddeley.

M.C.J. van Pul continued his work (towards a Ph.D. thesis in 1993) on statistical models for software reliability. Several topics were studied. Most of the software reliability models assume perfect repair and constant software size. Both restrictions oversimplify reality in a huge way. A model was developed, that combines imperfect repair and software growth in a natural way. The model has in addition very attractive statistical properties. Results were presented at the INTERFACE'91 conference in April 1991.

The goodness of fit problem in the context of software reliability was also studied. We derived the asymptotic distribution of an analogue of the Kolmogorov-Smirnov test statistic for a special class of counting processes using an idea of Khmaladze. Results are gathered in a private communication. There are, however, still a few open problems. Cooperation with J.A. Wellner

(Seattle) and E.V. Khmaladze (Tbilisi) on this subject should lead to publication in 1992.

In case of the Littlewood model, a criterion which guarantees the existence of a unique solution of the likelihood equations has not been found and probably does not exist. Instead of finding such a criterion, L.G. Barendregt and M.C.J. van Pul developed an algorithm in order to determine the consistent one from a set of solutions of the ML equations. Results will be sent to Statistica Neerlandica for possible publication in 1992. Inspired by Helmers course on Bootstrap methods, we have verified the validity of the parametric bootstrap method in the context of counting processes. Furthermore we constructed bootstrapped confidence intervals and compared them with earlier results.

PUBLICATIONS 1991

Papers in Journals and Proceedings

1. J. VAN DEN BERG, R.W.J. MEESTER (1991). Stability properties of a flow process in graphs. *Random Structures and Algorithms 2*, 335-341.
2. J. VAN DEN BERG, H. KESTEN (1991). *Inequalities for the Time Constant in First-Passage Percolation*, preprint.
3. J. VAN DEN BERG (1991). *On the Number of Non-Dominated Paths*, preprint, expected November 1991.
4. R. HELMERS (1991). On the Edgeworth expansion and the bootstrap approximation for a studentized *U*-statistic. *Annals of Statistics 19*, 470-484.
5. R. HELMERS, P. JANSSEN, N. VERAVERBEKE (1991). Bootstrapping *U*-quantiles. R. LE PAGE, L. BILLARD (eds.). *Exploring the Limits of Bootstrap*, Wiley InterScience, New York (in press).
6. M.C.J. VAN PUL (1991). Statistical models in software reliability. *Proceedings Interface '91*, Seattle, April 22.

Reports

7. BS-R9107 A.L.M. DEKKERS, L. DE HAAN. *Optimal choice of sample fraction in extreme-value estimation.*
8. BS-R9122 M.C.J. VAN PUL. *Simulations on the Jelinski-Moranda model of software reliability.*
9. BS-R9123 M.C.J. VAN PUL. *Software reliability and the bootstrap.*
10. BS-R91xx R. HELMERS, M. HUSKOVÁ. *Bootstrapping multivariate U-quantiles and related statistics.*
11. BS-R91xx K.O. DZHAPARIDZE. *On constructing kernel polynomials of a spectral function: application to ARMA models.*

Other publications

12. J. VAN DEN BERG, A. GANDOLFI (1990). *LRU is better than FIFO under the Independent Reference Model.* MSI Technical Report '90-81, Cornell University, accepted for publication in J. App. Probab.

13. A.L.M. DEKKERS (1991). *On Extreme-Value Estimation*. Ph.D. thesis, Erasmus University Rotterdam.
14. K. DZHAPARIDZE (1991). *Statistics of Stochastic Processes: Applications to Time Series Analysis*, syllabus.
15. K. DZHAPARIDZE, M. VAN ZUIJLEN (1991). *Martingale Methods for Option Pricing*, syllabus under preparation.
16. K. DZHAPARIDZE et al. (1991). *Study of Switching Behaviour of TV-viewers*. Interim Report, 201 p.
17. R. HELMERS (1991). *Bootstrap Methods*. Syllabus, 125 p.
18. R. HELMERS (1991). Discussion of the invited papers of M. Sorensen and of E. Bolviken, J. Helgeland, and G. Storvik in the meeting on 'Statistical Models and Methods for Sand and Shale Formations', ISI meeting, Cairo, Egypt, 2 p, to appear in *Proceedings ISI meeting*.

Department of Numerical Mathematics

HEAD OF DEPARTMENT: Prof.dr. P.J. van der Houwen

LIST OF RESEARCH GROUPS

NW 1 Discretization of evolution problems
NW 2 Boundary-value problems, multigrid and defect correction
NW 3 Large-scale computing

		NW1	NW2	NW3	working	budget	ext.	de-		guests	remarks
					time in fte	time in fte	paid	tached			
appointed											
Houwen, v.d.	head dept.	1.00			1.00	1.00					
Verwer	proj.leader	1.00			1.00	1.00					
Goede, de	researcher	0.17			1.00	0.17	RWS				
Hundsdorfer	researcher	1.00			1.00	1.00					
Sommeijer	researcher	1.00			1.00	1.00					
Blom	sc.programmer	0.53			0.53	0.53					
Lioen	sc.programmer	0.50		0.50	1.00	1.00					
Trompert	jr.researcher	1.00			1.00	1.00	RIVM				
Zegeling	jr.researcher	0.67			1.00	-	STW				
Nguyen Hu C	researcher	0.66			1.00	-				0.66	
Hemker	groupleader		0.95		0.95	0.95					
Wesseling	advisor		pm		pm	-					
Koren	researcher		1.00		1.00	1.00					
Zeeuw, de	sc.programmer		1.00		1.00	1.00					
Maarel, v.d.	jr.researcher		0.90		1.00	1.00					
Molenaar	jr.researcher		0.13		1.00	0.13					
Nooyen, van	jr.researcher		0.13		1.00	0.13	IOP				
Everaars	sc.programmer		1.00		1.00	1.00					
Riele, te	groupleader			1.00	1.00	1.00					
Kok	proj.leader			1.00	1.00	1.00					
Winter	sc.programmer			0.50	1.00	1.00					
Vorst, v.d.	advisor			pm	pm	-					
Lai	guest res.			0.33	1.00	-				0.33	ERCIM
Boender	jr.researcher			0.40	1.00	-		0.40	RUL		
Louter-Nool	sc.programmer			0.60	0.60	0.60					
research time		7.53	5.11	4.33		15.51					
request	jr.researcher	*			1.00						
request	jr.researcher	*			1.00						
request	jr.researcher	*			1.00						
request	jr.researcher	*			1.00						
request	jr.researcher	*			1.00						
request	jr.researcher		*		1.00						
request	sc.programmer		*		1.00						
request	jr.researcher		*		1.00						
request	jr.researcher			*	1.00						
request	jr.researcher			*	1.00						

RESEARCH GROUP NW 1

TITLE: Discretization of evolution problems

TITEL: Discretisatie van evolutieproblemen

LIST OF PROJECTS

NW 1.1 Stability and convergence;
NW 1.2 Method of Lines book;
NW 1.3 Adaptive grid methods (STW);
NW 1.4 Static-regridding methods (RIVM);
NW 1.5 3D Shallow-water equations (follow-up in preparation by Ministry of Public Works);
NW 1.7 Boussinesq model (Delft Hydraulics);
NW 1.8 Parallel initial-value-problem solvers for mechanical problems (UvA-Hanoi);
NW 1.9 Parallel initial-value-problem solvers for circuit analysis (submitted to STW);
NW 1.10 Parallel initial-value-problem solvers for partial differential equations.

PARTICIPATION FROM OTHER GROUPS

Some of the above-listed projects are joint with the research group NW 3. The new project 'Algorithms for mathematical air pollution models' is a joint effort of NW 1 and NW 2.

PROBLEM FORMULATION AND SCIENTIFIC IMPORTANCE

The analysis, development and documentation of algorithms for the numerical solution of evolution problems for differential equations. The research ranges from the very fundamental to utilization or practically oriented. Currently, the research concentrates on both ordinary and partial differential equations. Applications are found in modelling industrial and environmental problems, computational fluid dynamics, engineering and circuit analysis. Needless to say that due to the increasing processing power of modern computers, the scientific and practical importance of large-scale numerical computation is growing steadily.

In 1991 four main subjects were considered: convergence and stability analysis (NW 1.1-1.2), adaptive and moving-grid methods (NW 1.3-1.4), difference schemes for hyperbolic problems (NW 1.5, NW 1.7), and parallel algorithms (NW 1.8-1.10).

The first subject, convergence and stability analysis, is of a fundamental nature. In the whole research group NW 1, fundamental questions, mainly related to convergence and stability theory, need continuous interest in order to build up and maintain a sufficiently high level of theoretical knowledge and

insight. It is stressed that a high level of theoretical knowledge and insight is a prerequisite for the successful application of algorithms to complex practical problems. Unfortunately, in 1991 available research time has been too limited to do substantial work on convergence and stability questions.

The second subject, adaptive and moving-grid methods for time-dependent partial differential equations, is more practically oriented. This type of numerical methods is of great importance for the efficient computation of solutions possessing rapid temporal and spatial transitions. For this subject we currently cooperate with the numerical group of CWM/RIVM in Bilthoven. Both STW and RIVM have supported the research in 1991. For 1992 support has been requested from the 'Cray Research Grant Program' for implementing a locally uniform grid refinement method on the CRAY Y-MP supercomputer. The plan is to apply this software for computationally intensive brine-transport simulations. STW will also give support in 1992, while RIVM support is under request.

The third subject, difference schemes for hyperbolic problems, is also practically oriented. Here the research concentrates on the numerical treatment of the 3D shallow-water equations (a follow-up of the VECPARCOMP project is in preparation by RWS, possibly as part of NOWESP (NOrthWEst European Shell Project) which will be submitted to the EC MAST II program). In this project, there is a close cooperation with engineers and numerical analysts of RWS and Delft Hydraulics. The 3D shallow-water equations project has a strong software component and is partly supported by the Large-Scale-Computing Group NW 3. Finally, the use of vector computers has obtained a firm footing in numerical mathematics. Anticipating on a similar development for parallel computers, the research on parallel algorithms for partial differential equations will be intensified.

The fourth subject currently deals with parallel Runge-Kutta and other block methods for ordinary differential equations, and with parallel fractional step methods for convection-diffusion equations. A joint project with the Universities of Amsterdam and Hanoi was started for the development of parallel methods for the solution of higher-order initial-value problems from mechanics. The group submitted an STW project for the design of parallel algorithms for solving circuit analysis problems and applied for EC support for developing algorithms for delay-differential equations and partial differential equations. The development and implementation of parallel codes based on the methods designed in NW 1.8, NW 1.9 and NW 1.10 will be a joint activity of the Large-Scale-Computing Group NW 3 and the Evolution-Problems Group NW 1.

In preparation are a number of projects falling under CWI's research program 'Environmental Mathematics'. This program is planned to start January 1992. For NW 1 the current plan includes three new projects (i) Numerical analysis of the climate model IMAGE, (ii) Removal of sensitivity to the initial state in climate models, and (iii) Algorithms for mathematical air pollution models.

START AND END OF PROJECTS

Project	Starting date	Expiration date
NW 1.1	--	1995
NW 1.2	--	Project has been deferred
NW 1.3	1988	1992
NW 1.4	1989	1992
NW 1.5	1992	1996 (in preparation by RWS)
NW 1.7	1988	1991
NW 1.8	1989	1994
NW 1.9	1992	1996 (submitted to STW)
NW 1.10	1991	1996

The starting dates of the three above-mentioned projects on environmental mathematics are not yet known.

REPORT ON 1991

NW 1.1 Stability and convergence
Project NW 1.1 is mainly theoretically oriented and concentrates on the analysis of algorithms. Specifically, studies on the fundamental notions of stability and convergence fall under the heading of NW 1.1. Because of a year of leave of Dr. Hundsdorfer to the University of Geneva little research time was left for this project so that it has actually been stopped this year. It will hopefully be continued in 1992. An invited lecture on this project has been presented at the Kolloquium über Angewandte und Numerische Mathematik, ETH Zürich, June 12.

NW 1.2 Method of Lines book
The Method of Lines covers a great variety of numerical ODE methods when applied for the temporal discretization of time-dependent PDEs. The plan was to start writing after the return of Dr. Hundsdorfer in October of this year (intended authors are W.H. Hundsdorfer, J.M. Sanz-Serna and J.G. Verwer). However, it has now been decided to defer the writing due to the necessity of spending the greater part of the available research time on more applied projects for which external funding can be found.

NW 1.3 Adaptive grid methods (STW/KSLA)
Adaptive grid methods are numerical methods which compute numerical solutions on grids dynamically adapted to the solution at hand. These methods are meant for problems involving fine-scale structures that develop, propagate, decay, and/or disappear as the solution evolves. Examples include reaction zones in combustion processes, boundary layers in flow problems, etc. The numerical solution of these problems is difficult because the nature, location and duration of the fine-scale structures are usually not known in advance. Thus, conventional numerical approaches that calculate solutions on a

prescribed (typically uniform) grid readily fail to adequately resolve the fine-scale phenomena at reasonable computational costs.

In this STW project the research concentrates on so-called moving-grid methods where the adaptation is based on a continuous-in-time movement of nodal points, like in classical Lagrangian methods.

In 1991 attention was focussed on three subprojects:

(i) *Revision of a report on the gradient-weighted moving-finite-element method in one space dimension.* A revision of the report (NM-R9006) has been carried out on request of JCP, the Journal of Computational Physics. This has led to some notable improvements in performance. The report will be published by JCP.

(ii) *Application of a moving-grid method to a class of 1D brine-transport problems in porous media.* Jointly with Drs. J.C.H. van Eijkeren and Dr. S.M. Hassanizadeh (RIVM), an investigation has been carried out on using an earlier developed moving-grid finite-difference-method for modelling 1D brine transport. The moving-grid method MFD appears to be highly attractive here for dealing with high-salt concentrations which arise in groundwater flows around salt domes. See [RIVM Report nr. 959101001] and [CWI report NM-R9112].

(iii) *The application of the moving-finite-element method to 2D brine-transport problems in porous media.* The 1D method mentioned under (ii) can not be extended to higher space dimension. Because brine tranport is often advection dominated, the application of the MFE method is natural since this method has good (theoretical) properties for advection problems and can be applied in higher space dimension. The research will be reported in 1992.

NW 1.4 Static-regridding methods (RIVM)

This project is related to the STW project NW 1.3. However, here the research concentrates on static regridding. Unlike Lagrangian-type methods like MFD and MFE, a static-regridding method does not move nodal points in a time continuous way, but it moves points only at discrete time levels. This leads to a completely different numerical problem setting. While Lagrangian-type methods work well in one space dimension, they are believed to be much more difficult to use for multi-dimensional problems. Static-regridding methods where the nodal movement is decoupled from the PDE discretization are simpler to use in more dimensions and more robust.

In 1991 attention was focussed on the RIVM project: '*Adaptive-grid software for partial differential equations in environmental problems*'. Environmental modelling at RIVM frequently leads to systems of ordinary and partial differential equations. This demands support from numerical mathematics and has led to a cooperation with RIVM's department CWM (Center for Mathematical Methods). The goal of the cooperation is the development of advanced, user friendly numerical software for environmental problems of interest to the various research laboratories of RIVM.

Currently, the project concentrates on the numerical modelling of brine transport near and away from underground salt formations, which serve as a possible repository for high-level radioactive wastes. The brine-transport models are

used to assess the risk of potential transport of pollutants to the geosphere by groundwater flow. Recent theoretical and experimental hydrological studies indicate that for such high-concentration situations the involved basic equations of flow and transport need to be modified in order to remain sufficiently realistic (generalized Darcy laws, generalized Fick laws, choice of dispersion operators). This involves a significant effort in numerical modelling, since the evolutionary equations which show up are severely nonlinear and must be solved implicitly over long time intervals in high precision.

From the numerical point of view, an additional difficulty is that the high-salt concentrations appear locally, thus giving rise to steep gradients in the evolving concentration profiles. For reasons of efficiency this impedes the use of adaptive grid techniques using some form of local grid refinement. In 1D the numerical computation of high-salt concentration profiles is well feasible using moving-grid methods. In 2D, and much more so in 3D, this is less clear and here the emphasis is on the application of a static-regridding, local-uniform-grid-refinement method developed at CWI (see reports NM-R9105, 9011, 9022).

The greater part of the CWI research is contract research by order of RIVM. For 1991 financing is provided by a fund of the Dutch Ministry of Economic Affairs. For 1992 funding will be applied for at the same source. In addition, for 1992 a research proposal has been made to the 'Cray Research Grant Program', via NCF (Stichting Nationale Computer Faciliteiten), for support for developing a CRAY Y-MP implementation of the local-uniform-grid-refinement method and for applying this CRAY software to realistic brine-transport models. The existing brine-flow project is planned for 1991-1992. After 1992 the cooperative research will be continued, possibly focussing on a different environmental application.

An invited lecture on this project has been presented at the 14-th Biennial Conference on Numerical Analysis, 25th - 28th June, 1991, Dundee, Scotland. This lecture will appear in the proceedings. A second invited lecture was presented at the meeting 'Ordinary Differential Equations and Their Applications' of the N.F.W.O. - F.N.R.S. Contact Group on Numerical Analysis, Université de Liège, March 8, 1991. A full report on the 1991 research is under preparation and will be published early in 1992.

NW 1.5 3D Shallow-water equations (RWS)

Rand Corporation, Delft Hydraulics, ICIM (Informatics Centre for Civil Engineering and Environment), and computation divisions of the RWS (Ministry of Public Works) cooperate in the design of time-dependent numerical models for simulating three-dimensional water flow in a variety of practical situations. This model aims at the computation of hydrostatic and weakly non-hydrostatic flows and transport processes, leading to a so-called multilayer model. By order of RWS the numerical mathematics department of CWI was asked to develop a computational efficient model on vector and parallel computers.

We concentrated on two subjects:

(i) *An implementation on the CRAY Y-MP4/464.* The numerical model for the 3D equations was implemented on the CRAY Y-MP4/464 which was installed at SARA early 1991. In order to exploit parallelism a domain decomposition approach had to be used. The experiments showed that the CRAY is very suitable for the time-consuming simulation of 3D shallow-water flows [NM-R9106].
(ii) *Continental Shelf model.* A numerical model of the Northwest European Continental shelf was developed. As a test, the tidal elevations and currents during the period 9 to 12 February 1989 were computed on the CRAY Y-MP2E which was installed at ICIM medio 1991. The results were in accordance with data published in the literature (report will appear early 1992).

This research is carried out in consultation with Dr. A.W. Heemink (RWS) and other researchers from RWS and Delft Hydraulics.

NW 1.7 Boussinesq model

This project aims at the design of a numerical, two-dimensional Boussinesq model of at least fourth-order accuracy, both in space and time, for describing fairly long, free surface waves. Starting point is the numerical two-dimensional shallow-water model developed by Wubs in the STW project: 'Evaluation and stabilization of 2D shallow-water solvers' which was carried out by the department in 1983-1987. Boussinesq models are obtained by adding so-called Boussinesq terms to shallow-water models. The major problem in developing reliable Boussinesq models is the requirement that the underlying shallow-water model should be sufficiently accurate, that is, its order of accuracy should be at least four. Since the model of Wubs does have a fourth-order option, it is an ideal starting point for this project.

The project (medio 1988 until 1990) was supported by STW. The final reports were prepared in 1991 and published in the report series of Delft Hydraulics.

NW 1.8 Parallel initial-value-problem solvers for mechanical problems (UvA-Hanoi)

This project started in April 1990 with the University of Amsterdam (UvA) and the University of Hanoi. The project aims at the development and analysis of parallel methods for second and higher-order ODEs. In 1991 the stability of iterated Runge-Kutta-Nyström methods with high stage order was investigated. The iteration parameters were determined such that the iterated method becomes sufficiently stable after a minimal number of iterations and should improve the results reported in [NM-R9103]. The improved results will appear in a report of the University of Hanoi at the end of this year.

NW 1.9 Parallel initial-value-problem solvers for circuit analysis (submitted to STW)

Anticipating the approval of this project, the investigations of parallel, diagonally-implicit iteration of Runge-Kutta methods (PDIRK methods) for solving large systems of stiff equations on parallel computers are continued.

These methods seem to be an excellent starting point for circuit-analysis codes. We focussed on two topics:
(i) *Accuracy of PDIRK methods.* Newton-iterated backward differentiation formulas (BDFs) are mainly used in circuit-analysis codes. However, the higher-order BDFs have limited stability regions. Like the BDFs, PDIRK methods are such that in each step the (sequential) costs consists of solving a number of linear systems with the same matrix of coefficients and with the same dimension as the system of differential equations. Although for PDIRK methods the number of linear systems is usually higher than for Newton iteration of BDFs, the more computational intensive work of computing the matrix of coefficients and its LU decomposition is identical. The advantage of PDIRK methods over Newton-iterated BDFs is their unconditional stability (A-stability for Gauss-based methods and L-stability for Radau-based methods) for any order of accuracy [NM-R9114].
(ii) *Stepsize strategies for PDIRK methods.* In order to use PDIRK methods in production codes, a reliable stepsize strategy should be provided. A start was made to adapt various strategies from the literature for use in PDIRK methods. Invited lectures on this project has been presented at the University of Utrecht, April 17, at the Numerical Analysis Symposium, 20th-21st June, 1991, University of Manchester, at the International Conference on Parallel Methods for Ordinary Differential Equations, 10th-13th September, 1991, University of Triest in Grado (It), at the University of Hanoi, October 25, 28 30 and 31, at the Numerical Analysis Seminar, INRIA Rennes (Fr.), November 8, and at the CNR Institute for Applied Mathematics in Naples, November 26 and 27.

NW 1.10 Parallel initial-value-problem solvers for partial differential equations
In 1991 the group NW 1 started investigations to design numerical methods for partial differential equations that are not based on parallelism across the problem, but methods with intrinsic parallelism (parallelism across the method). The results reported in [NM-R9104] indicate that fractional step methods (operator splitting methods) are candidates for achieving this form of parallelism.

PUBLICATIONS 1991

Papers in Journals and Proceedings

1. J.G. BLOM, H. BRUNNER (1991). Algorithm 689 - Discretized collocation and iterated collocation for nonlinear Volterra integral equations of the second kind. *ACM Trans. Math. Software 17*, 167-177.
2. P.J. VAN DER HOUWEN (1991). Block Runge-Kutta methods. K. STREHMEL (ed.). *Numerical Treatment of Differential Equations*, Proceedings of Fifth International Seminar NUMDIFF-5, Halle, May 22-26, 1989, Teubner-Texte zur Mathematik, Band 121, 68-79.

3. P.J. VAN DER HOUWEN, B.P. SOMMEIJER (1991). Iterated Runge-Kutta methods on parallel computers. *SIAM J. Sci. Stat. Comput. 12*, 1000-1028.
4. P.J. VAN DER HOUWEN, B.P. SOMMEIJER (1991). Block Runge-Kutta methods on parallel computers, to appear in *ZAMM* in 1992.
5. P.J. VAN DER HOUWEN, B.P. SOMMEIJER, NGUYEN HUU CONG (1991). Stability of collocation-based Runge-Kutta-Nyström methods. *BIT 31*, 469-481.
6. W.H. HUNDSDORFER (1991). Local and global order reduction of some LOD schemes. K. STREHMEL (ed.). *Numerical Treatment of Differential Equations*, Proceedings of Fifth International Seminar NUMDIFF-5, Halle, May 22-26, 1989, Teubner-Texte zur Mathematik, Band 121, 225-232.
7. W.H. HUNDSDORFER, B.I. STEININGER (1991). Convergence of linear multistep and one-leg methods for stiff nonlinear initial value problems. *BIT 31*, 124-143.
8. E.D. DE GOEDE (1991). Stabilization of a time integrator for the 3D shallow water equations. *Int. J. Num. Meth. in Fluids 12*, 475-490.
9. E.D. DE GOEDE (1991). A time splitting method for the three-dimensional shallow water equations. *Int. J. Num. Meth. in Fluids 13*, 519-534.
10. E.D. DE GOEDE (1991). 3D shallow water model on the CRAY Y-MP4/464, to appear in the proceedings of the *Sixth Int. Workshop on the Use of Supercomputers in Theoretical Science*, Antwerp.
11. E.D. DE GOEDE (1991). On the numerical treatment of the advective terms in 3D shallow water models. *Proceedings of the 2nd Int. Symposium on High Performance Computing*, Montpellier, 491-502.
12. R.A. TROMPERT, J.G. VERWER (1991). A static-regridding method for two-dimensional parabolic partial differential equations. *Appl. Numer. Math., 8*, 65-90.
13. J.G. VERWER, W.H. HUNDSDORFER, B.P. SOMMEIJER (1991). Convergence properties of the Runge-Kutta-Chebyshev method. K. STREHMEL (ed.). *Numerical Treatment of Differential Equations*, Proceedings of Fifth International Seminar NUMDIFF-5, Halle, May 22-26, 1989, Teubner-Texte zur Mathematik, Band 121, 273-284.

Reports

14. NM-R9101 P.J. VAN DER HOUWEN, B.P. SOMMEIJER, K. STREHMEL. *Smoothed Runge-Kutta methods in the method of lines.*
15. NM-R9103 P.J. VAN DER HOUWEN, B.P. SOMMEIJER, NGUYEN HUU CONG. *Parallel diagonally-implicit Runge-Kutta-Nyström methods.*
16. NM-R9104 P.J. VAN DER HOUWEN, B.P. SOMMEIJER. *Parallel solution of Burgers equation.*
17. NM-R9105 J.G. VERWER, R.A. TROMPERT. *Local uniform grid refinement for time-dependent partial differential equations.*

18. NM-R9106 E.D. DE GOEDE. *3D shallow water model on the CRAY Y-MP4/464.*
19. NM-R9108 A.S. VASUDEVA MURTHY, J.G. VERWER. *Solving parabolic integro-differential equations by an explicit integration method.*
20. NM-R9109 E.D. DE GOEDE. *Numerical methods for the 3D shallow water equations on vector and parallel computers.*
21. NM-R9110 E.D. DE GOEDE. *On the numerical treatment of the advective terms in 3D shallow-water models.*
22. NM-R9112 P.A. ZEGELING, J.G. VERWER, J.C.H. VAN EIJKEREN. *Application of a moving-grid method to a class of 1D brine-transport problems in porous media.*
23. NM-R9114 P.J. VAN DER HOUWEN, B.P. SOMMEIJER. *Analysis of parallel diagonal-implicit iteration of Runge-Kutta methods.*
24. NM-R9116 P.J. VAN DER HOUWEN. *Parallel step-by-step methods.*
25. NM-R9117 B.P. SOMMEIJER. *Parallel-iterated Runge-Kutta methods for stiff ordinary differential equations.*

Other publications

26. J.C.H. VAN EIJKEREN, P.A. ZEGELING, S.M. HASSANIZADEH (1991). *Practical use of SPRINT and a Moving-Grid Interface for a Class of 1D Non-Linear Transport Problems*, RIVM Report nr. 959101001.
27. J. MOOIMAN (1991). *Boussinesq Equations based on Positive Definite Hamiltonian*, Delft Hydraulics Report.
28. J. MOOIMAN (1991). *Comparison between Measurements and a Boussinesq Model for Wave Deformation by a Shoal*, Delft Hydraulics Report.

RESEARCH GROUP NW 2

TITLE: Boundary-value problems, multigrid and defect correction

TITEL: Randwaardeproblemen, multigrid en defectcorrectie

LIST OF PROJECTS

NW 2.1 The analysis of defect correction and adaptive techniques;
NW 2.2 Application of multigrid techniques to fluid dynamics problems (Hermes, BRITE);
NW 2.3 Reliable and efficient methods for the semiconductor device simulation equations (IOP);
NW 2.4 Parameter identification in ordinary differential equations (AKZO).

START AND END OF PROJECTS

Project	Starting date	Expiration date
NW 2.1	1989	1995
NW 2.2	1990	1991
NW 2.3	1988	1992
NW 2.4	1991	1992

REPORT ON 1991

NW 2.1 The analysis of defect correction and adaptive techniques
Project members: Prof.dr. P.W. Hemker, Dr.ir. B. Koren, Drs. P.M. de Zeeuw, Ir. H.T.M. van der Maarel.
In cooperation with P. Thoolen (University of Amsterdam) a study was made of the use of adaptive methods for the discretization of time-dependent hyperbolic discretization laws. The problem was related with a practical problem concerning ion-exchange in a groundwater flow. A method for the n-dimensional homovalent system as described by Rhee, Aris and Amundsen, two approximation methods by Charbeneau and the new adaptive numerical method were compared. This study can be seen as a pilot study for a new time-dependent multigrid method for hyperbolic equations.

In view of possible interference of modern multigrid methods and the modern wavelet techniques, also a study was made of the new wavelet and multiresolution techniques. No direct application was tackled, but the efforts led to cooperation with the department AM and sharing in part of the AM wavelet course.

NW 2.2 Application of multigrid techniques to fluid dynamics problems (Hermes, BRITE)

Project members: Prof.dr. P.W. Hemker, Dr.ir. B. Koren, Ir. H.T.M. van der Maarel, Drs. C.T.H. Everaars.

In 1991, several tasks still arose which were related to research done in the framework of the Hermes project, a project which has been formally terminated at the end of 1990. An invited contribution to a book on hypersonics was written [4], two other papers and one report were prepared on work done in 1990 [5, 6, 15], and still another paper was revised and successfully resubmitted [11]. Further spin-offs of the research done in the framework of the Hermes project were: (i) the organization (in cooperation with P. Wesseling) of a session on multigrid methods for compressible computational fluid dynamics at the Fifth Copper Mountain Conference on Multigrid Methods (Copper Mountain, Colorado, March 31 - April 5, 1991), (ii) invited seminars on computational aerodynamics at the Philips Laboratory (Bedford, Massachusetts) and the Wright Laboratory (Dayton, Ohio) [27], and (iii) an invited lecture at the Seminar Numerieke Advectie, Rijksuniversiteit Utrecht, Instituut voor Meteorologie en Oceanografie [28, 29]. Publications related to research done for Hermes, which were accepted in 1990 or already in 1989 and which appeared in 1991, were: [2, 3, 7, 8, 26].

Concerning the BRITE project, during the first few months of 1991 research was concentrated on an adaptive multigrid method for the steady, 2-dimensional Euler equations for compressible fluid flow. Fluid flow fields, that are computed by a uniform grid, may lack accuracy in small parts of the domain of interest. Therefore, a computational method was developed, which allows high grid densities in such small subdomains in order to improve the accuracy. Nonlinear multigrid is employed for the solution of the related set of discrete equations, both for first-order and for second-order accurate representations.

Based on the work done in 1990, which involved the construction of an adaptive multigrid code, an analysis was made of the consistency of the discretization. The new analysis concentrates on the internal boundary between the coarse and the fine grid. It emphasizes the use of the local truncation error in the refinement criterion. It appears that the flux computation requires a more accurate interpolation along such grid interfaces than in the rest of the domain if we want to retain the same consistency. This research was presented at the Fifth Copper Mountain Conference on Multigrid Methods, April 1991 [10]. A report containing the full analysis is to appear [23]. Further, at the Fourth International Symposium on Computational Fluid Dynamics, September 1991, a paper was presented in which the solution-adaptive multigrid method was applied to the fundamental gas dynamics problem of a shock wave standing normal on convex surface [9].

The larger part of the year was used to develop a similar adaptive multigrid method for the 2D steady Navier-Stokes equations, describing viscous flow. The method for Euler flow computations was extended and now incorporates the terms describing the effect of viscosity in the flow field. The experience

with the development of the Euler method could be used to construct properly the discretization of the viscous terms, when internal grid interfaces are involved.

A report on experiments with the adaptive multigrid method for the steady Navier-Stokes equations is in preparation [22]. It will consider the laminar boundary layer-shock wave interaction problem of Hakkinen et al.. Other reports which are still in preparation in the framework of the BRITE project are: [18-20].

NW 2.3 Reliable and efficient methods for the semiconductor device simulation equations (IOP)

Project members: Prof.dr. P.W. Hemker, Drs. P.M. de Zeeuw, Drs. J. Molenaar, Drs. R.R.P. van Nooyen.

In this project, part of the IOP-IC Technology, mathematical methods for semiconductor simulation are studied. Three main lines can be distinguished in this research. J. Molenaar studied the theoretical and practical aspects of the application of multigrid techniques, in combination with local grid refinement. The research by Van Nooyen aims at a better understanding of the discretizations used, and the derivation of practical a-posteriori error estimates. P.M. de Zeeuw studied the possibilities to improve the efficiency of TRENDY, an integrated programme for IC process and device simulation, developed at the University of Twente.

During the first half of the year the research by J. Molenaar was mainly concentrated on the following two topics: (i) development of an adaptive multigrid method for 2D semiconductor device simulation, and (ii) comparison of cell-centered and vertex-centered multigrid for semiconductor device simulation.

As the semiconductor device equations are singularly perturbed, the dependent variables vary rapidly in small parts of the domain. Therefore it is desirable to have a refined mesh in parts of the domain where large variations of the solution occur. We discretize the equations on an adaptive grid by means of the (hybrid) mixed finite element method. We employ a nonlinear multigrid method to solve the equations and we use the relative truncation error between coarse and fine grids as a refinement criterion for constructing the adaptive grids. Satisfactory results are obtained by this method for a realistic bipolar transistor problem [1], [17].

Both the primal and the dual mixed finite element can be used to discretize the equations. The former can be identified with a vertex-centered box scheme, whereas the latter is equivalent to a cell-centered finite volume discretization. In both cases the system of nonlinear equations obtained after discretization is solved by multigrid. In cell-centered multigrid it is necessary to introduce a local damping of the restricted residual in order to deal with the strong non-linearity of the problem. This can be avoided by using the vertex-centered multigrid algorithm provided that injection is used for the restriction of the residual. Injection is usually too inaccurate a grid transfer operator for second order equations, but by means of a two-grid analysis it is shown that

the choice of a suitable smoothing operator can alleviate this problem. In numerical experiments vertex-centered multigrid appears to be more efficient and robust for the semiconductor equations than cell-centered multigrid. A report on this research is being prepared [21].

The second half of 1991 was used to write a thesis on the research carried out since February 1988. Other publications that appeared this year on the subject are [12], [14].

The research by R.R.P. van Nooyen was devoted to the derivation of a-posteriori error estimators for the discrete continuity equations in the drift diffusion model for semiconductor devices. Two approaches were taken, one based on an estimate of the relative truncation error, the other on a deferred correction scheme. The first approach, based on a method for the Poisson equation derived in 1990, gave reasonably useful results. However, the deferred correction scheme gave much better results, as could be shown both in theory and in practice.

The influence of strong localized electric fields on the discretization error was studied for a one-dimensional problem. The influence was shown to be restricted mainly to the cells where the strong fields occurred. In one dimension this analysis explained the success of a discretization approach used by Brezzi. The second half of this year was used mostly to prepare a thesis based on the research done since February 1988.

P.M. de Zeeuw has studied the possibilities to improve the efficiency of TRENDY. This is an integrated programme for IC process and device simulation, developed by the Integrated Circuits and Electronics group of the University of Twente, The Netherlands. Depending on the problem and the mesh size used in the simulation, TRENDY can be expensive with respect to cpu time and storage requirements. This is due to the algorithm used for the solution of large sparse linear systems. At CWI, first a new direct solver was developed and implemented, especially tailored for the type of problem occurring in TRENDY. This solver showed a reduction of 50% of storage requirements. Next, an iterative solver was developed, based on a stabilized bi-conjugate-gradient method (Bi-CGSTAB), recently developed by Prof.dr. H.A. van der Vorst (University of Utrecht). Further, a robust preconditioner was developed, implemented and tested in order to take part in the Bi-CGSTAB process. Some sensible stopping and restart criterions were developed as well. The resulting solver turns out to be both reliable and efficient. Compared with the solver originally used in TRENDY, it shows essentially less storage and cpu requirements. The present solver can stand competition with all known iterative procedures used for such problems. More comparisons with the methods used at Philips Natlab and at the ETH Zürich would be interesting. Both the direct and the iterative solver have been made available for the ICE group at the University of Twente.

NW 2.4 Parameter identification in ordinary differential equations (AKZO)
Project members: Prof.dr. P.W. Hemker, Drs. J. Kok (NW 3)
In view of interest shown by an industry (AKZO-research) attention is

renewed in parameter estimation problems. Based on research made in the years 1971-1976, contacts with the industrial partner led to a contract for additional research and the construction of a modern implementation of techniques that were developed earlier. It is to be expected that a continued effort in this direction will show new developments and interesting new applications.

PUBLICATIONS 1991

Papers in Journals and Proceedings

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2. B. KOREN (1991). A computational tool for analyzing strong viscous-inviscid interactions in gasdynamics. A.G. TENNER (ed.). *Proceedings of the CP90 Europhysics Conference on Computational Physics*, Amsterdam, 1990, World Scientific, Singapore, 395-399.
3. B. KOREN (1991). Low-diffusion rotated upwind schemes, multigrid and defect correction for steady, multi-dimensional Euler flows. W. HACKBUSCH, U. TROTTENBERG (eds.). *Multigrid Methods III*, International Series of Numerical Mathematics, 98, Birkhäuser Verlag, Basel, 265-276.
4. B. KOREN, P.W. HEMKER (1991). Efficient multigrid computation of steady hypersonic flows. *Computational Methods in Hypersonic Aero-dynamics*, Computational Mechanics Publications, Southampton, in preparation.
5. B. KOREN, P.W. HEMKER (1991). Multi-dimensional upwind schemes, multigrid and defect correction for accurate and efficient Euler flow computations. W. BERRY, B. BATTRICK (eds.). *Aerodynamics for Space Vehicles*, European Space Agency, Noordwijk, 129-134.
6. B. KOREN, P.W. HEMKER (1991). Multi-D upwinding and multigridding for steady Euler flow computations. A. RIZZI, I.L. RYHMING (eds.). *Proceedings of the Ninth GAMM Conference on Numerical Methods in Fluid Mechanics*, Lausanne, Notes on Numerical Methods in Fluid Mechanics, Vieweg, Braunschweig, to appear.
7. B. KOREN, P.W. HEMKER (1991). Damped, direction-dependent multigrid for hypersonic flow computations. *Appl. Numer. Math. 7*, 309-328.
8. B. KOREN, P.W. HEMKER (1991). Defect correction and nonlinear multigrid for steady Euler equations. W.G. HABASHI, M.M. HAFEZ (eds.). *Advances in Computational Fluid Dynamics*, Cambridge University Press, Cambridge.
9. B. KOREN, H.T.M. VAN DER MAAREL (1991). Analysis of transonic shock configurations by a solution-adaptive multigrid technique. *Prel. Proceedings of the Fourth International Symposium on Computational Fluid Dynamics*, Davis, California, 640-645.
10. H. VAN DER MAAREL (1991). Adaptive multigrid for the Euler equations. *Comm. Appl. Num. Methods.*, submitted.

11. H.T.M. VAN DER MAAREL, B. KOREN (1991). Spurious, zeroth-order entropy generation along a kinked wall. *Int. J. Numer. Meth. Fluids 13*, 1113-1129.
12. J. MOLENAAR (1991). A two-grid analysis of the combination of mixed finite elements and Vanka-type relaxation. W. HACKBUSCH, U. TROTTENBERG (eds.). *Multigrid Methods III*, International Series of Numerical Mathematics, 98, Birkhäuser Verlag, Basel.
13. P.M. DE ZEEUW (1991). Nonlinear multigrid applied to a one-dimensional stationary semiconductor model. *SIAM J. Sci. Stat. Comput.*, to appear.

Reports

14. NM-R9102 J. MOLENAAR. *A two-grid analysis of the combination of mixed finite elements and Vanka type relaxation.*
15. NM-R9107 P.W. HEMKER, B. KOREN. *Efficient multi-dimensional upwinding for the steady Euler equations.*
16. NM-R9111 R.R.P. VAN NOOYEN. *An improved accuracy version of the mixed finite element method for a second order elliptic equation.*
17. NM-R9115 J. MOLENAAR. *Adaptive multigrid applied to a bipolar transistor problem.*
18. NM-R91xx B. KOREN. *Monotone, higher-order accurate, multi-dimensional upwinding.*
19. NM-R91xx B. KOREN. *Point relaxation for low Mach number, steady Navier-Stokes flows.*
20. NM-R91xx B. KOREN, H.T.M. VAN DER MAAREL. *On shock waves at continuously curved, convex surfaces.*
21. NM-R91xx J. MOLENAAR. *Multigrid for semiconductor device simulation: cell-centered or vertex-centered multigrid?*
22. NM-R91xx H.T.M. VAN DER MAAREL. *Numerical investigation of laminar boundary layer-shock wave interaction, employing solution-adaptive multigrid.*
23. NM-R91xx H.T.M. VAN DER MAAREL. *A solution-adaptive multigrid method for the steady Euler equations.*
24. NM-R91xx P.M. DE ZEEUW. *Incomplete line-LU for discretized coupled PDEs as preconditioner in Bi-CGSTAB.*

Other publications

25. H. DECONINCK, P.W. HEMKER, CH. HIRSCH, M. NAPOLITANO, P. LARSEN (1991). *Solution Adaptive Navier-Stokes Solvers with Grid Decoupled Upwind Schemes and Multigrid Acceleration.* BRITE/EURAM Progress Report, Von Karman Institute, Rhode St. Genese.
26. B. KOREN (1991). *Multigrid and Defect Correction for the Steady Navier-Stokes Equations, Application to Aerodynamics*, CWI Tract 74, CWI, Amsterdam.
27. NM-N91xx B. KOREN. *Report on a Window-On-Science Trip.*

28. B. KOREN. *Upwind Schemes versus Centered Schemes, a One-Sided View.* Note prepared for Seminar Numerieke Advectie at the Rijksuniversiteit Utrecht, CWI, Amsterdam.
29. B. KOREN. *Extension of a Multi-D Upwind Scheme.* Note prepared for Seminar Numerieke Advectie at the Rijksuniversiteit Utrecht, CWI, Amsterdam.

WORKING PLAN 1992

NW 2.1 The analysis of defect correction and adaptive techniques
The relation between *sparse grids* as introduced by Zenger in 1991 and various multigrid techniques will be investigated. In particular the possibility to apply the sparse grids adaptively. This may lead to a completely new application of multigrid algorithms in the linear case, with additional possibilities to make the algorithms parallel. The situation is still completely opaque for the nonlinear case.

The relation between multigrid approximation and the use of multiresolution techniques used with *wavelets* will be studied further. This may lead to a new approach to handle boundary-value problems with the aid of the new wavelet concepts.

The research started at CWI and the University of Amsterdam in 1991 on the use of adaptive multigrid techniques for time-dependent hyperbolic problems will be continued. In particular the accurate treatment of hyperbolic conservation laws is important, in view of the possible applications. Up to now only applications from ion-exchange in water flow through porous media has been considered. Research will be conducted in the direction of time-dependent, *parabolic multigrid* methods. The first application will be related to thermal flow in an aquifer. The cooperation with the University of Amsterdam will be continued.

With professor G.I. Shishkin (Acad. Sci. USSR, Sverdlovsk) adaptive discretization schemes for *singularly perturbed boundary-value problems* will be studied. Here the combination of analytic techniques together with adaptive multigrid methods may be exploited.

PLAN: Contribution to CWI wavelet course, November 1991.

NW 2.2 Application of multigrid techniques to fluid dynamics problems (BRITE)
The continuation of the BRITE/EURAM project is expected for another two years. This will lead to the extension of the present research on adaptive methods for compressible flow problems in two dimensions to similar problems in three dimensions. This will require - in the first place - extension of the present data-structure to the three-dimensional situations, and a similar adaptation of the CFD-algorithms that are now all two-dimensional.

In cooperation with GMD (G. Lonsdale and K. Stüben) research will be done regarding the implementation of the BRITE/EURAM codes on highly parallel, distributed memory computers.

In cooperation with NW 3 similar research will be done with respect to the CRAY computer (cf NW 3).

In cooperation with GMD (Y. Luh) research will be done on the analysis of a multigrid solution method for the multidimensional upwind discretizations.

An ERCIM (COMETT) course on the use of multigrid for CFD problems is planned in March 1992 in France (A. Dervieux) and in Germany later in 1992.

Research will be started on a numerical method for the three-dimensional Navier-Stokes equations in a rotating frame and in a Lagrangian formulation. Here contact is possible with Dutch wind turbine industries.

Further cooperative research is foreseen in cooperation with the research teams on 'Scientific Visualization' and 'Environmental Mathematics'.

In all above-mentioned research tasks, a major programming support (approximately 2.0 fte) is required to investigate and exploit new methods to visualize the numerical results. A preliminary study on distributed computing, which was started in 1991, will be continued in 1992.

NW 2.3 Reliable and efficient methods for the semiconductor device simulation equations (IOP)

In 1992 the research in this project will be concluded by the publication of two doctoral theses.

NW 2.4 Parameter identification in ordinary differential equations (AKZO)

In view of interest shown by an industry (AKZO-research) renewed attention is devoted to the solution of a special kind of multipoint boundary-value problems. These problems arise from parameter estimation in ordinary differential equations and concern the non-linear least-squares approximation of experimental data by the solution of a system of nonlinear ODEs. This problem has some relation with new interest in the group, started in 1989, on inverse problems.

The first interest in this project is the development of an efficient algorithm for the solution of real-life problems from chemical kinetics. In the year 1992 an application for a new STW-project will be made. The purpose of the STW-project will be to bring the new algorithmic technology in a user-friendly form, applicable directly by the chemical industry.

RESEARCH GROUP NW 3

TITLE: Large-scale computing

TITEL: Grootschalig rekenen

LIST OF PROJECTS

NW 3.1 Development of numerical software in the programming language Ada;
NW 3.2 Parallel numerical algorithms;
NW 3.3 Computational number theory;
NW 3.4 Chebyshev reference software;
NW 3.5 Consultation and supporting projects for NW 1, NW 2, MR 2 and MR 3.

PROBLEM FORMULATION AND SCIENTIFIC RELEVANCE[1]

The computational power and the amount of memory of the fastest available computers has increased dramatically in the past decennia. It is to be expected that this trend will continue in the present decade and that the teraflop computer will be a common device by the end of this century (1 teraflop/s means 10^{12} operations per second). This will provide a potential to simulate reality to a degree of accuracy which was unthinkable until now. Complex and costly experimentations will be replaced to a great extent by computer models which will reveal the finest details beyond the limits of any real experiment. Scientific and societal progress, industrial competitiveness, the understanding and control of environmental factors will be governed by the availability of adequate computing power. In particular, those research and development activities will be affected where both simulation and optimization play a leading role. Chemical, pharmaceutical, aerospace, automotive industries, as well as physics, mathematics and computer science are among the most promising examples. In The Netherlands, the trend to replace or prepare laboratory experiments by accurate computer simulation already becomes clearly visible (WL, NLR, Philips (semiconductor devices), Shell, ...). Computational Science in general, and Computational Physics, Computational Chemistry, etc., have become recognized, full-fledged disciplines. Within these, computer science and numerical mathematics play a central role.

The further increase of computational power of the fastest computers is expected to come mainly from a more intensive exploitation of parallelism. The three main architectural approaches which should be explored in order to progress toward the teraflop/s goal are:

1. Partly based on the recent 'Rubbia-report' (February 1991): *Report of the EEC Working Group on High-Performance Computing* which stresses the importance of Large-scale Computing. Recommendations are made to stimulate European High-Performance Computing industry and related research, in order to form a counterbalance against the American and Japanese competition.

- Tens of very powerful CPUs, shared memory and fast access to it;
- Hundreds of CPUs with local memory and a variety of local networks between them - mainly used as MIMD machines;
- Thousands of relatively cheap CPUs with a combination of shared and distributed memory, mainly used as SIMD machines.

It is unclear yet which of these three approaches will survive eventually, so that experimentation should proceed on all of them. It should be noted in this respect, that several big computer manufacturers belonging to the first category (like Cray and Convex), have announced plans for machines in the massive parallelism category.

Direct consequences of these developments for research and development are a refinement of the mathematical models involved, an increase in scale of the corresponding numerical models, increase of the amount of data, increasing need of parallel numerical algorithms, of standard evaluation techniques for parallel computers, of visualization tools, of network facilities, of tools for the production of efficient software, of parallelizing compilers, better data-organization techniques, etc. All this offers excellent new research opportunities in (numerical) mathematics and computer science.

CWI intends to play an active role in these developments, provided that sufficient qualified manpower will become available.

LIST OF PROJECTS

NW 3.1 Development of numerical software in the programming language Ada
Note: Project NW 3.1 was terminated in 1991. It is mentioned here for completeness.

NW 3.2 Parallel numerical algorithms
Study and optimization of existing algorithms for parallel architectures; development of new algorithms and software interfaces as a tool for improving the ease of programming of parallel architectures.

NW 3.3 Computational number theory
Study of how parallel (vector-) computers may be used in an optimal way to help solve number-theoretical problems with a numerical component and number-theoretical problems which have applications in cryptography.

NW 3.4 Chebyshev reference software
Development of methods for the assessment of geometric form of objects from data gathered by coordinate measurement systems.

NW 3.5 Consultation and supporting projects for NW 1, NW 2, MR 2 and MR 3

START AND END OF PROJECTS

Project	Starting date	Expiration date
NW 3.1	1981	1991
NW 3.2	1984	1996
NW 3.3	1976	1996
NW 3.4	1990	December 1992
NW 3.5	see NW 1, NW 2, MR 2, MR 3	see NW 1, NW 2, MR 2, MR 3

PROJECT NW 3.1

TITLE: Development of numerical software in the programming language Ada

TITEL: Numerieke programmatuur in de programmeertaal Ada

ADDITION TO REPORT ON 1990
(Kok, Winter)
As members of the international *Ada-Europe Numerics Working Group* in cooperation with the American working group *ACM-SIGAda NUM WG*, and by representing the Working Group in the standardization body ISO-IEC/JTC1/SC22/WG9, the project group members observed the progress in the standardization process of the earlier developed proposal on Ada specifications and performance requirements of the elementary mathematical functions, after this proposal had been accepted by WG9 and advanced for international approval.

Report of a study regarding the quality of many Ada compilation systems with respect to the floating-point number representations and related arithmetic will appear in 1991 [1].

PUBLICATIONS 1991

1. D.T. WINTER (1991). Floating-point attributes in Ada. *Ada Letters*, to appear.

PROJECT NW 3.2

TITLE: Parallel numerical algorithms

TITEL: Parallelle numerieke algoritmen

Problem formulation and scientific relevance

Field of study
To investigate parallel (vector-) algorithms for the numerical solution of large-scale parallel computing problems which are of vital interest to scientists and engineers working in the application areas (like physics, chemistry, meteorology, oil exploration, computational fluid dynamics, environmental problems). If sufficient funding is available, the resulting algorithms may be tested and optimized on available parallel (vector-) computers, like the CRAY Y-MP4, the IBM 3090, the NEC SX-3 and the FPS scalar-matrix system (which was installed at CWI in September 1991).

Report on 1991

1. *Parallel Aspects of some Spectral Problems in Linear Algebra* (Malyshev, Louter-Nool, Te Riele)
ERCIM Fellowship A. Malyshev (Dec. '90 - June '91)
The generalized eigenvalue problem $Ax = \lambda Bx$ is central to some important control theory applications, for example, the Lyapunov and the Riccati equations. An algorithm was studied for computing deflating subspaces of the regular linear matrix pencil $\lambda B - A$, and the extent to which this algorithm can be parallelized.
The algorithm was implemented in a portable way suitable for shared memory parallel systems. Timing results were collected for the ALLIANT FX/4 [5].

2. *Parallel block algorithms for Cholesky decomposition* (Louter-Nool)
Terminated; for a final report see [2].

3. *Solving large systems of linear equations* (Lioen, Winter)
Terminated; for a final report see [3].

4. *Influence of memory systems on vector processor performance* (Winter)
Terminated; for a final report see [4].

5. *LAPACK* (Louter-Nool, Winter, Te Riele)
A second release of the LAPACK - library was tested on the IBM 3090 and the ALLIANT FX/4. Terminated.

6. *NUMVEC*. Terminated.

Publications 1991

Papers in Journals and Proceedings

1. H.J.J. te Riele, T.J. Dekker, H.A. van der Vorst (eds.). IMACS Symposia on Parallel Scientific Computing, Amsterdam, The Netherlands. Three Special Issues of the journal *Applied Numerical Mathematics: Vol. 7, Nr. 5*, June 1991; Vol. 8, Nr. 2, September 1991, Vol. 9, Spring 1992.

Contributions from CWI:

2. M. LOUTER-NOOL (1991). Block Cholesky for Parallel processing (in Second Issue);
3. W.M. LIOEN, D.T. WINTER (1991). Solving large dense systems of linear equations on systems with virtual memory and with cache (in Third Issue);
4. D.T. WINTER Influence of memory systems on vector processor performance (in Third Issue);

Reports

5. NM-R9113 A.N. MALYSHEV. *Parallel aspects of some spectral problems in linear algebra.*

WORKING PLAN 1991-1992

1. Cray Research Grant - project *Cray Multigrid Software* (July '91 - June '92)
Construction, analysis and documentation of numerical multigrid software, optimized for the CRAY Y-MP4,

a) for the solution of linear second order elliptic partial differential equations on a rectangular grid, and
b) for the solution of the Euler flow equations on a domain arbitrarily composed of rectangles.

2. ESPRIT III BRA - project *Algorithms for Parallelism and Efficiency*
Application of special programming techniques within the so-called *Bulk Synchronous Paradigm*; contribution from CWI on parallel algorithms for initial-value problems.

3. ESPRIT III project *Evaluation of Parallel Processors*
Benchmarking parallel systems: methodology, prescription, selection, distribution and running of benchmarks.

4. ERCIM Fellowship Lai (September '92 - February '93)
Study of parallel numerical methods for partial differential equations on an SIMD parallel computer with applications in fluid dynamics.

EXTERNAL CONTACTS

Dr. M.J. Daydé (CERFACS, Toulouse, France).
Prof.dr. Th.J. Dekker, Dr. W. Hoffmann, Drs. K. Potma (Univ. of Amsterdam).
Dr. K. Dekker (Delft University of Technology).
Prof.dr. J. Dongarra (Oak Ridge Laboratory, Tennessee, USA).
Prof.dr. W. Jalby, Dr. B. Philippe (IRISA/INRIA Rennes, France).

KNOWLEDGE TRANSFER

1. *ERCIM Course on Large-scale Scientific Parallel Computing* (May '91: INRIA, Rocquencourt; Dec. '91: GMD, Bonn; Sept. '92: RAL, Oxford).
2. *Mini-Symposium on Parallel Aspects of the Generalized Eigenvalue Problem*

(May 24, '91: CWI; speakers were P. van Dooren (Philips Research Laboratory, Louvain-la-Neuve, Belgium), A. Bunse-Gerstner (Univ. Bielefeld, Germany) and A. Malyshev (CWI)).

PROJECT NW 3.3

TITLE: Computational number theory

TITEL: Getaltheorie m.b.v. de computer

PROBLEM FORMULATION AND SCIENTIFIC RELEVANCE

Field of study
Computational Number Theory (CNT) studies problems from elementary, algebraic and analytic number theory which require the help of modern computers, including vector and parallel systems. This, in turn, may enlarge insight and understanding, and lead to mathematical/numerical solution of the problems studied. For this purpose, multi-length integer arithmetic software is indispensable. Applications in Public-Key Cryptography have particularly stimulated the study of the problems of factorization and primality testing. As a consequence, algorithmic and software progress in this area have been enormous in the past two decades.

CWI has played a leading role in the past decade in factorization (particularly on large vector-computers), and in computational aspects of the Riemann hypothesis.

REPORT ON 1991

1. *Stieltjes' work on the Mertens conjecture* (Te Riele)
In 1994 it will be 100 years ago that Thomas J. Stieltjes died. To commemorate that event, the Dutch Mathematical Society is organizing a re-edition of the collected works of Stieltjes, enlarged with several articles on Stieltjes' influence on present-day mathematics. One of these contributions will comment on Stieltjes' work on the function $M(x)\sqrt{x}$ (where $M(x)$ is the sum of the values of the Möbius-function of argument $\leqslant x$), and on the developments in this area after Stieltjes [7].

2. *Factorization of large numbers* (Boender, Lioen, Sellink, Te Riele, Winter)
a. In January 1991, the CWI-MPQS program was optimized for the new CRAY Y-MP4 supercomputer, installed at SARA in December 1990. With that program a 101-decimal digit number was factorized on one processor of the Y-MP4 in about 475 hours of CPU- time. This was the first time a number of more than 100 decimal digits was factorized on a single computer by means of the Multiple Polynomial Quadratic Sieve. This method is the best one known to handle numbers which are the product of two large, approximately equal prime factors. These numbers are being used in cryptography as keys in public-key cryptosystems [4].
b. The contribution to the table of prime factors of numbers of the form

$a^n \pm 1$, for $13 \leqslant a \leqslant 100$, was continued. Many numbers in the 65 - 78 digit range were factorized with help of MPQS on SGI- workstations, on the NEC SX-2 and on the CRAY Y-MP4. This is a joint project with R.P. Brent of the Australian National University.
c. As part of their work for a Master's Degree at the University of Leiden, H. Boender and A. Sellink studied and implemented a version of the Multiple Polynomial Quadratic Sieve factorization method, where the coefficient of the second degree term of the quadratic polynomials is the product of *three*, rather than (the usual) *two* primes. The three-primes version was compared with the two-primes version on an SGI workstation [8].

3. *The Diophantine equation* $x^3+y^3+z^3=k$, k *given* (Lioen, Te Riele)
The report on the implementation on the CYBER 205 of the new algorithm of Heath-Brown for the solution of the Diophantine equation $x^3+y^3+z^3=k$ was finished [6].

4. *Amicable numbers* (Te Riele)
The study (started in 1990) of the new amicable pair algorithm which is based on finding as many solutions as possible of the equation $\sigma(x)=n$, was completed. A run of about 40 hours on an SGI - workstation produced about 30 new amicable pairs. A report is in preparation.

5. *Sums of Farey-series related to the Riemann hypothesis* (Te Riele)
An experimental study was started of a function of the Farey series which has implications for the Riemann hypothesis (based on work of Franel, Landau, Mikolas and Sato). This is joint work with K. Sato (Nihon University, Koriyama, Japan).

PUBLICATIONS 1991

Papers in Journals and Proceedings

1. A. IVIĆ, H.J.J. TE RIELE (1991). On the zeros of the error term for the mean square of $|\zeta(\frac{1}{2}+it)|$. *Math. Comp. 56*, 303-328.
2. H.J.J. TE RIELE (1991). A new lower bound for the de Bruijn-Newman constant. *Numer. Math. 58*, 661-667.
3. H.J.J. TE RIELE (1990). Rekenen aan de Riemann hypothese. F. VAN DER BLIJ e.a. (red.). *Kaleidoscoop van de wiskunde 1, Van priemgetal tot populatiegenetica*, Epsilon Uitgaven, Utrecht, 181-192.
4. H.J.J. TE RIELE, W.M. LIOEN, D.T. WINTER (1991). Factorization beyond the Googol with MPQS on a Single Computer. *CWI Quarterly, vol. 4, nr. 1*, 69-72.
5. R.P. BRENT, G.L. COHEN, H.J.J. TE RIELE (1991). Improved techniques for lower bounds for odd perfect numbers. *Math. Comp. 57*, 857-868.

Reports

6. NM-R91xx D.R. Heath-Brown, W.M. Lioen, H.J.J. te Riele. *On solving the Diophantine equation* $x^3+y^3+z^3=k$ *on a vector computer.*
7. NM-R91xx H.J.J. te Riele. *On the history of the function* $M(x)\sqrt{x}$ *since Stieltjes.*

Other publications

8. H. Boender, M.P.A. Sellink (1991). *De Multi-polynomiale Kwadratische Zeefmethode*, afstudeerscriptie, CWI, Amsterdam.

Working plan 1991-1992

1. Cray Research Grant - project *Cray integer arithmetic Software* (July '91 - June '92)
Construction, analysis and documentation of a multiprecise integer arithmetic software package optimized for the CRAY Y-MP4.

2. *Factorization of large numbers with the Number Field Sieve* (this is a multi-annual project with RU Leiden)

a. Investigation of the Number Field Sieve- factorization method for a class of integers which is as large as possible (possibly for any given integer). Development of a portable, machine-independent implementation of this method, and adaptation and optimization of this for parallel supercomputers (like the CRAY Y-MP4 and the NEC SX-3). Study and, if possible, increase of the practical usefulness of the NFS- method. Comparison with the so far best known general method (MPQS) and experimental determination of the range where NFS beats MPQS.
b. Investigation and implementation on the CRAY Y-MP4 of the self-initialization version of MPQS as proposed by Pomerance.
c. Further improvement of the CWI - MPQS- program by implementation of the so-called 'Two-primes variation' and of 'Structured Gaussian Elimination' (according to Odlyzko).

3. *Sums of Farey-series related to the Riemann hypothesis*
Continuation of the experimental work started in 1991. Analysis of the results and derivation of theoretical results.

External contacts

Prof.dr. R.P. Brent (The Australian National University).
Prof.dr. R. Heath-Brown (Oxford University, UK).
Prof.dr. A. Ivić (Univ. of Belgrade, Jugoslavia).
Dr. A.M. Odlyzko (ATT Bell Labs, Murray Hill, USA).
Prof.dr. K. Sato (Nihon University, Koriyama, Japan).
Prof.dr. R. Tijdeman (University of Leiden).
Prof.dr. R.S. Varga (Institute for Computational Mathematics, Kent State University, USA).

KNOWLEDGE TRANSFER
1. Seminar (1992) at Leiden University on factorization of large numbers.

PROJECT NW 3.4

TITLE: Chebyshev reference software

TITEL: Chebyshev reference software

PROBLEM FORMULATION AND SCIENTIFIC RELEVANCE
As part of automated manufacturing processes, coordinate measuring systems (CMSs) are used to acquire and analyze coordinates on the surface of a workpiece. Both the processes of data acquisition and data analysis techniques are under computer control. This project is concerned with the data analysis techniques in cases where the workpiece is to be assessed for departure from fundamental geometric form. The forms considered are line and circle in a specified plane, and line, circle, plane, sphere, cylinder and cone in 3-space. These forms are basic to metrology; other more complicated shapes are often compositions of these basic forms

The technical problem is to devise the appropriate mathematics for Chebyshev and one-sided assessment of geometric form. It relates to the measurement of manufactured components for quality assurance and tolerancing purposes. The results will be of benefit to manufacturing industry, particularly mechanical engineering.

The results of this project are algorithms and software that can be used in practice or for comparison/validation of subsequent commercial products. This will particularly benefit those companies not large enough to support the personnel required to produce such software or to benchmark bought-in software.

REPORT ON 1990 AND 1991
(Kok, Winter) In the initial phase of the project in 1990, attention was focussed on the mathematical aspects of surface fitting for the different geometric forms treated by the project. During 1991, several draft implementations produced by the project partners for various geometric forms were extensively tested and commented upon, while contributions were made to the approaches under investigation.

WORKING PLAN 1992
Final year of the project in which a testing strategy will have been developed and all software will be thoroughly tested.

EXTERNAL CONTACTS
National Physical Laboratory (Teddington).
Physikalisch-Technische Bundesanstalt (Braunschweig).

KNOWLEDGE TRANSFER AND RELEVANCE
There is a small but distinct users community for the products developed in this project.

PROJECT NW 3.5

TITLE: Consultation and supporting projects for NW 1, NW 2, MR 2 and MR 3

TITEL: Consultatie en ondersteunende projecten bij NW 1, NW 2, MR 2 en MR 3

REPORT ON 1991
1. *Computation of the position of a trailing suction pipe* (Kok, Te Riele)
By order of 'Baggermaatschappij Boskalis' a study was made of the problem of the computation of the position of a trailing suction pipe. This is based on the lengths and the mutual angles of the composing pipe parts. Two angles are measured by a gravitation pendulum and a bias caused by the oblique position of some pipe parts had to be taken into account. As an illustration, a realization in software of the derived formulas was appended.

2. *Multimedia* (Winter)
See Report on 1991 of MR 2.

WORKING PLAN 1992
For information about these projects, see the programs of NW 1, NW 2, MR 2 and MR 3
1. Parallel solution of ODEs (NW 1, SCIENCE).
2. Circuit Analysis and Control Engineering (NW 1, STW).
3. Climate simulation and massively parallel computing (NW 1, MR 3, NOP).
4. Parameter identification for reaction kinetics (NW 2, AKZO).
5. Multimedia (MR 2).

Department of Software Technology

HEAD OF DEPARTMENT: Prof.dr. J.W. de Bakker

LIST OF RESEARCH GROUPS

AP 1 Semantics
AP 2 Concurrency and real time systems
AP 3 Extensible programming environments
AP 4 Algebraic and syntactic methods
AP 5 Logic and Language

		AP1	AP2	AP3	AP4	AP5	working	budget	ext.	de-		guests	remarks
							time in fte	time in fte	paid	tached			
appointed													
Bakker, de	head dept.	0.80					0.80	0.80					
Rutten	researcher	1.00					1.00	1.00					
Turi	jr.researcher	1.00					1.00	-		1.00	SION		
Bonsagne	guest research	0.75					1.00	-				0.75	
Baeten	researcher		0.20				0.20	-		0.20			
Bergstra	advisor		pm				pm	-					
Bergstra	researcher		0.20				0.20	-					0.2RUU
Fokkink	jr. researcher		1.00				1.00	1.00					
Groote	jr.researcher		0.13				1.00	0.13					
Klusener	jr.researcher		0.41				1.00	0.42					
Korver	jr.researcher		1.00				1.00	1.00					
Ponse	jr.researcher		1.00				1.00	1.00					
Klint	group leader			0.60			0.60	0.60					
Heering	researcher			1.00			1.00	1.00					
Rekers	jr.researcher			0.83			1.00	0.83					
Deursen, van	jr.researcher			1.00			1.00	1.00					
Kamperman	jr.researcher			1.00			1.00	1.00					
Meulen, v.d.	jr.researcher			0.25			1.00	1.00					
Tip	jr. researcher			1.00			1.00	1.00					
Walters	jr.researcher			0.80			0.80	0.80					
Eker	researcher			0.50			1.00	-					
Klop	group leader				0.70		0.70	0.70					
Apt	group leader					0.80	0.80	0.80					
Eyck, van	researcher					0.80	1.00	1.00		-0.20			
Moortgat	researcher					0.20	0.20	-		0.20	RUU		
Fernando	jr.researcher					1.00	1.00	-		1.00	NFI		
Meijer Viol	jr.researcher					1.00	1.00	-		1.00	OTS		
research time		3.55	3.94	6.98	0.70	3.80		15.08					
request	jr.researcher	*					1.00						
request	jr.researcher	*					1.00						
request	group leader		*				1.00						
request	jr.researcher		*				1.00						
request	jr.researcher		*				1.00						
request	jr.researcher		*				1.00						
request	researcher			*			1.00						
request	researcher			*			1.00						
request	jr.researcher			*			1.00						
request	jr.researcher			*			1.00						
request	jr.researcher				*		1.00						
request	jr.researcher				*		1.00						
request	jr.researcher				*		1.00						
request	jr.researcher				*		1.00						
request	jr.researcher				*		1.00						
request	jr.researcher					*	1.00						
request	jr.researcher					*	1.00						
request	jr.researcher					*	1.00						
request	jr.researcher					*	1.00						
request	coordinator					*	0.50						
request	jr.researcher					*	1.00						

RESEARCH GROUP AP 1

TITLE: Semantics

TITEL: Semantiek

REPORT ON 1991

Main subthemes of AP 1's research during the indicated period have been:

a. Foundations for semantics and comparative issues: the development of the metric semantics machinery, with contrasting themes such as uniform/nonuniform languages, linear time/branching time models, and operational/denotational semantics; moreover, non-wellfounded sets (which may be used as domains where metric spaces do not work), general properties of transition systems.
b. Semantics for parallel object-oriented languages (process creation, rendezvous, dynamically evolving process structures), in particular POOL.
c. Proof theory for POOL.
d. Semantics for nondeterministic dataflow.
e. Semantics of a large variety of concurrent logic languages, including Horn Clause Logic, PARLOG, Concurrent PROLOG, GHC, versions of contextual LP and constraint LP.
f. Integration of LP and OO.
g. Full abstractness issues.
h. (Interleaving vs.) true concurrency.
i. Exploration of the relationship between (the category of) metric spaces, other topological spaces, cpo's and nonwellfounded sets.
j. (At a limited scale) relations between AP 1's methodology and questions in process algebra (e.g. the determination of representatives of weak bisimulation equivalence classes).
k. Several edited collections of results obtained by AP 1, ESPRIT 415, LPC, REX, or conferences/workshops around their themes.

PUBLICATIONS 1991

Papers in Journals and Proceedings

1. P. AMERICA, J.J.M.M. RUTTEN (1991). A layered semantics for a parallel object-oriented language. J.W. DE BAKKER, W.P. DE ROEVER, G. ROZENBERG (eds.). *Proceedings REX/FOOL Workshop on the Foundations of Object-Oriented Languages*, 91-123 (also to appear in FAC).
2. J.W. DE BAKKER (1991). Comparative semantics for flow of control in logic programming without logic. *Information and Computation, Vol. 94*, 123-179.
3. J.W. DE BAKKER, J.J.M.M. RUTTEN (1991). Concurrency semantics based on metric domain equations. G.M. REED, A.W. ROSCOE, R.F. WACHTER (eds.). *Topology and Computation,* Oxford University Press (to appear).

4. J.W. DE BAKKER, E.P. DE VINK (1991). CCS for LP and OO. S. ABRAMSKY, T.S.E. MAIBAUM (eds.). *Proceedings TAPSOFT 1991*, LNCS 494, Springer-Verlag, 1-28.
5. J.W. DE BAKKER, E.P. DE VINK (1991). Rendez-vous with metric semantics. E.H.L. AARTS, J. VAN LEEUWEN, M. REM (eds.). *Proceedings PARLE91*, LNCS 506, Springer-Verlag, 27-57.
6. J.W. DE BAKKER, J.H.A. WARMERDAM (1991). Four domains for concurrency. D. BJØRNER, V.E. KOTOV (eds.). *Ershov Memorial Images of Programming*, North-Holland, to appear (also to appear in TCS).
7. J.W. DE BAKKER, J.H.A. WARMERDAM (1991). Metric pomset semantics for a concurrent language with recursion. I. GUESSARIAN (ed.). *Proceedings Semantics of Systems of Concurrent Processes*, LNCS 469, Springer-Verlag, 21-49.
8. F.S. DE BOER, J.N. KOK, C. PALAMIDESSI, J.J.M.M. RUTTEN (1991). From Failure to Success: Comparing a Denotational and a Declarative Semantics for Horn Clause Logic, to appear in *Theoretical Computer Science*.
9. F.S. DE BOER, J.N. KOK, C. PALAMIDESSI, J.J.M.M. RUTTEN (1991). The failure of failures: towards a paradigm for asynchronous communication. J.C.M. BAETEN, J.F. GROOTE (eds.). *Proceedings CONCUR '91*, LNCS 527, Springer-Verlag, 111-126.
10. F.S. DE BOER, J.N. KOK, C. PALAMIDESSI, J.J.M.M. RUTTEN (1991). Semantics for Concurrent Logic Programming Languages. *Theoretical Computer Science 86*, 3-34.
11. F.S. DE BOER, C. PALAMIDESSI (1991). A fully abstract model for concurrent constraint programming. S. ABRAMSKY, T.S.E. MAIBAUM (eds.). *Proceedings TAPSOFT 1991*, LNCS 494, Springer-Verlag, 296-319.
12. F.S. DE BOER, C. PALAMIDESSI (1991). Embedding as a tool for language comparison: on the CSP hierarchy. J.C.M. BAETEN, J.F. GROOTE (eds.). *Proceedings CONCUR '91*, LNCS 527, Springer-Verlag, 127-141.
13. J.M. JACQUET (1991). Negation in Conclog. *Proceedings 1st ACPC Conference*, LNCS, Springer-Verlag, to appear.
14. J.M. JACQUET, L. MONTEIRO (1991). Comparative semantics of generalized Horn clauses. *Proceedings of 10th Japanese Conference on Logic Programming*, to appear.
15. J.M. JACQUET, L. MONTEIRO (1991). Extended Horn clauses: the framework and some semantics. J.C.M. BAETEN, J.F. GROOTE (eds.). *Proceedings CONCUR '91*, LNCS 527, Springer-Verlag, 281-297.
16. J.J.M.M. RUTTEN (1991). Non wellfounded sets and programming language semantics. *Proceedings of Mathematical Foundations of Programming Semantics*, Pittsburgh, LNCS, Springer-Verlag, to appear.

Reports

17. CS-R9135 J.W. DE BAKKER, E.P. DE VINK. *Rendez-vous with metric semantics.*
18. CS-R9136 J.W. DE BAKKER, E.P. DE VINK. *CCS for OO and LP.*

19. CS-R9148 J.J.M.M. RUTTEN. *Hereditarily-finite sets and complete metric spaces.*
20. CS-R91xx J.M. JACQUET, L. MONTEIRO. *Communicating clauses; towards synchronous communication in contextual logic programming.*

Other publications

21. J.W. DE BAKKER, W.P. DE ROEVER, G. ROZENBERG (eds.) (1991). *Proceedings REX School/Workshop on Foundations of Object-Oriented Languages*, Noordwijkerhout, May/June 1990, LNCS 489, Springer, 442 p.
22. J.W. BAKKER, W.P. DE ROEVER, G. ROZENBERG (1991). Real-time theory in practice. *Proceedings REX Workshop*, Plasmolen, June 1991, LNCS, Springer-Verlag, to appear.
23. J.W. DE BAKKER, J.J.M.M. RUTTEN (eds.) (1991). *Studies in Concurrency Semantics: Selected Papers of the Amsterdam Concurrency Group*, World Scientific Publishers, to appear.
24. J.W. DE BAKKER, J.J.M.M. RUTTEN (eds.) (1991). *Deliverables Second Year and Periodic Progress Report*, ESPRIT Basic Research Action Integration, June.
25. F.S. DE BOER (1991). *Reasoning about Dynamically Evolving Process Structures: a Proof Theory for the Object-Oriented Language POOL.* Ph.D. thesis, Free University Amsterdam.
26. A. ELIËNS (1991). *DLP: a Language for Distributed Logic Programming.* Ph.D. thesis, University of Amsterdam [jointly with AP 3].

RESEARCH GROUP AP 2

TITLE: Concurrency and real time systems

TITEL: Concurrency en real time systemen

LIST OF PROJECTS

AP 2.1 CONCUR;
AP 2.2 SPECS;
AP 2.3 ATMOSPHERE;
AP 2.4 TRANSFER;
AP 2.5 Longer Term Fundamental Research.

REPORT ON 1991

Our work on algebraic concurrency theory (process algebra), coming into full power in the context of the ESPRIT project METEOR, has put us among the most important groups worldwide, together with the CCS-group in Edinburgh with e.g. and the CSP-group in Oxford. A sign of this is the coordination of the current ESPRIT BRA CONCUR, the proposed ESPRIT BRA ACE and the proposed Concurrency Network. This work has culminated in two books that appeared at Cambridge University Press. At the moment, extensions with real time aspects and probabilities receive most attention.

Our work on specification languages started with cooperation with AP 3 on the algebraic specification language ASF and modularization concepts in general (module algebra). In METEOR and currently in ATMOSPHERE, we work on the Philips wide spectrum language COLD. In VIP, we worked on the specification language VVSL. In SPECS, we designed the specification language CRL (Common Representation Language), that incorporates process algebra, and can be used to translate high level specifications in SDL or LOTOS into, and in turn derived representations, tools and in the end product quality code can be derived from CRL. Version 3.0 is due at the end of SPECS (end 1992).

We are also involved with the development of the process specification language PSF at the University of Amsterdam. Apart from these two main lines of research, we also have some research on term rewriting systems (in cooperation with AP 4), as applications are found in proving results about process algebra, and t.r.s. are also very important in the implementation (or prototyping) of specification languages.

PUBLICATIONS 1991

Papers in Journals and Proceedings

1. J.C.M. BAETEN, J.A. BERGSTRA (1991). Recursive process definitions with state operator. *Theoretical Computing Science 82 (2)*, 285-302.
2. J.C.M. BAETEN, J.A. BERGSTRA (1991). Design of a specification language by abstract syntax engineering. L. FEIJS, J.A. BERGSTRA (eds.). *Proceedings METEOR Workshop Methods based on Formal Specifications*, LNCS 490, Springer-Verlag, 363-395.
3. J.C.M. BAETEN, J.A. BERGSTRA (1991). *Real time process algebra*, Extended abstract in Proc. CSN 91; also in Formal Aspects of Computing, 3, 142-188.
4. J.C.M. BAETEN, J.A. BERGSTRA (1991). Real space process algebra. J.C.M. BAETEN, J.F. GROOTE (eds.). *Proceedings CONCUR'91*, LNCS 527, Springer-Verlag, 96-110; to appear in FACS.
5. J.C.M. BAETEN, J.A. BERGSTRA (1991). Process algebra with signals and conditions. M. BROY (ed.). *Proceedings NATO Summer School*, Marktoberdorf 1990, Springer-Verlag, to appear.
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7. J.C.M. BAETEN, J.A. BERGSTRA (1991). Asynchronous communication in real space process algebra. *Proceedings Chalmers Workshop on Concurrency*, Båstad 1991, to appear.
8. J.C.M. BAETEN, J.A. BERGSTRA, J.W. KLOP (1991). Decidability of bisimulation equivalence for process generating context-free lan. to appear in *Journal of the ACM*.
9. J.C.M. BAETEN, J.A. BERGSTRA, S. MAUW, G.J. VELTINK (1991). A process specification formalism based on static COLD. L. FEIJS, J.A. BERGSTRA (eds.). *Proceedings METEOR Workshop Methods based on Formal Specifications*, LNCS 490, Springer-Verlag, 303-335.
10. J.C.M. BAETEN, F.W. VAANDRAGER (1991). An algebra for process creation, to appear in *Acta Informatica*.
11. R.N. BOL, J.F. GROOTE (1991). The meaning of negative premises in transition systems specifications. J. LEACH ALBERT, B. MONIEN, M. RODRIGUEZ ARTALEJO (eds.). *Proceedings ICALP 91*, Madrid, LNCS 510, Springer-Verlag, 481-494.
12. J.F. GROOTE, A. PONSE (1991). μCRL: a base for analysing processes with data. E. BEST, G. ROZENBERG (eds.). *Proceedings 3rd Workshop on Concurrency and Compositionality*, Goslar, GMD-studien 191 & Hildesheimer Informatik-Bericht 6/91, 125-130.
13. J.F. GROOTE, A. PONSE (1991). Process algebra with guards (combining Hoare logic with process algebra). J.C.M. BAETEN, J.F. GROOTE (eds.). *Proceedings CONCUR'91*, LNCS 527, Springer-Verlag, 235-249.
14. J.F. GROOTE, F.W. VAANDRAGER (1991). Structured operational semantics and bisimulation as a congruence. *Information and Computing*.

15. A.S. KLUSENER (1991). Completeness in real time process algebra. J.C.M. BAETEN, J.F. GROOTE (eds.). *Proceedings CONCUR'91,* LNCS 527, Springer-Verlag, 376-392.
16. H. KORVER (1991). Computing distinguishing formulas for branching bisimulation. K.G. LARSEN, A. SKOU (eds.). *Proceedings 3rd CAV 1991,* Aalborg, report IR91-4/5, Aalborg University, 376-392.
17. A. PONSE (1991). Process expressions and Hoare's logic. *Information and Computing.*
18 F.W. VAANDRAGER (1991). Determinism (event structure isomorphism = step sequence equivalence), to appear in *Theoretical Computer Science.*

Reports
19. CS-R9106 A.S. KLUSENER. *Completeness in real time process algebra.*
20. CS-R9121 H.P. KORVER. *Computing distinguishing formulas for branching bisimulation.*
21. CS-R9130 G.J. AKKERMAN, J.C.M. BAETEN. *Term rewriting analysis in process algebra.*
22. CS-R9131 J.C.M. BAETEN, J.A. BERGSTRA. *Real space process algebra.*

Other publications
23. J.C.M. BAETEN, J.A. BERGSTRA (1991). *The State Operator in Real Time Process Algebra.* Progr. report P9104, University of Amsterdam.
24. J.C.M. BAETEN, J.A. BERGSTRA (1991). *Asynchronous Communication in Real Space Process Algebra.* Progr. report P9106, University of Amsterdam.
25. J.C.M. BAETEN, J.F. GROOTE (eds.) (1991). *Proceedings CONCUR'91,* LNCS 527, Springer-Verlag.
26. J.F. GROOTE (1991). *Process Algebra and Structured Operational Semantics.* Ph.D. thesis, University of Amsterdam.
27. H.P. KORVER (1991). *The Current State of Bisimulation Tools.* Progr. report P9101, University of Amsterdam.
28. H. KORVER (1991). *An Algorithm to Produce Distinguishing Formulas for Branching Bisimulation.* Progr. report P9103, University of Amsterdam.

RESEARCH GROUP AP 3

TITLE: Extensible programming environments

TITEL: Uitbreidbare programmeeromgevingen

REPORT ON 1991

The group participates in GIPE II (Generation of Interactive Programming Environments - ESPRIT II project 2177) and COMPARE (Compiler Generation for Parallel Machines - ESPRIT II project 5399). The latter project is a new one started in the beginning of 1991. In addition to CWI, it involves the Dutch software company ACE (which is the main contractor), the University of Amsterdam, GMD Karlsruhe, the English software house Harlequin, INRIA Rocquencourt, and the French software company Steria. Its aim is the development of generic compilers and related techniques for current and emerging parallel machine architectures.

We will apply the formal specification tools developed earlier for GIPE in a number of areas of COMPARE:

- Concise and unambiguous definition of functional interfaces. This is of special importance when the design and development of many components rely on such interfaces.
- Prototyping of compiler components and tools. For example, testing compiler components which specifically aim at, or rely on state of the art hardware.
- Development of front-ends for specification languages needed in the generation process of compilers.
- Design and implementation of generators of compiler components.

In this initial period of COMPARE, our work concentrated on the intermediate representations to be used in the (generic) compilers. Requirements to be imposed on such representations have been formulated, based on conventional compiler components and on the (tentative) design that is being developed within COMPARE. Using these requirements, designs and prototype implementations are being developed by means of the ASF+SDF environment, which is borrowed from GIPE.

The second area where research was done is that of generic debuggers. The notion of 'origins' of program fragments is being investigated, which is used for sophisticated (generic) error messages for debugging and animation of execution.

In order to support macros and other syntax modifying features that are present in many programming languages, work was started on extending the expressive power of SDF, which is the syntax definition subformalism of ASF+SDF. In addition to this, attempts were made to raise its expressive power as far as lexical scanning is concerned. The model that was tried allows a pseudo-parallel scanner to explore alternative lexical parses in cooperation with the parser. The results obtained are as yet inconclusive.

The ASF+SDF language definition environment, which is the ongoing concern of GIPE, was improved in many respects. An interactive debugger, an on-line documentation facility, and a prettyprinter for ASF+SDF specifications were added, error handling was improved, and a better (lazier) rewrite strategy was implemented. Furthermore, hybrid data type specifications written in a mixture of SDF and Lisp are now supported by the system. A prototype of an incremental evaluation scheme for both the static and dynamic semantics of languages was implemented, but is not yet part of the system.

Finally, work was started to increase the expressive power of ASF, which is the algebraic/semantic part of ASF+SDF. Use of default equations, matching in context, and global variables promises very compact specifications. We are also considering higher-order algebraic specifications, in which both the signature and the equations are allowed to be higher-order. These constitute a natural integration of first-order algebraic specifications and functional programs.

PUBLICATIONS 1991

Papers in Journals and Proceedings

1. A. VAN DEURSEN (1991). An algebraic specification of the static semantics of Pascal. *Proceedings of Computing Science in the Netherlands*, SION 150-164.
2. P. KLINT (1991). A meta-environment for generating programming environments. J.A. BERGSTRA, L.M.G. FEIJS (eds.). *Algebraic Methods II: Theory, Tools and Applications,* Lecture Notes in Computer Science, Springer-Verlag, 105-124.
3. E.A. VAN DER MEULEN (1991). Deriving incremental implementations from algebraic specifications. *Second International Conference on Algebraic Methodology and Software Technology*, (AMAST), Ohio, USA, May 22-25.
4. J. REKERS, J.W.C. KOORN (1991). Substring parsing for arbitrary context-free grammars. *SIGPLAN Notices, vol. 26, nr. 5,* 59-66 (also appeared in *Proceedings of the Second International Workshop on Parsing Technologies, Association for Computational Linguistics*, 218-224).

Reports

5. CS-R9124 J. HEERING, P. KLINT, J. REKERS. *Lazy and incremental program generation* (revised version).
6. CS-R9129 A. VAN DEURSEN. *An algebraic specification of the static semantics of Pascal.*
7. CS-R9150 J. HEERING. *Implementing higher-order algebraic specifications.*
8. CS-R9158 P. KLINT. *Lazy scanner generation for modular lexical grammars.*

9. CS-R9159 E.A. VAN DER MEULEN. *Fine-grain incremental implementation of algebraic specifications.*

Other publications

10. A. ATIE, I. ATTALI, J. CHAZARAIN, D. CLEMENT, D. DARDAILLER, M.H.H. VAN DIJK, M.C. GIBOULOT, L. HASCOET, P.R.H. HENDRIKS, P. DE JAGER, W. JONKER, P. KLINT, J.W.C. KOORN, A. LE HORS, F. MONTAGNAC, E.A. VAN DER MEULEN, G. POPOVITCH, V. PRUNET, J. REKERS, F. THOMASSET, H. WALTERS, A. WAMMES, J. WESTER (1991). *Third Review Report of ESPRIT Project 2177 (GIPE II)*, January.
11. M. ALT, U. ASSMANN, J. VAN BRUMMEN, A. DESPLAND, D. DETERDING, H. EMMELMANN, C. FERDINAND, R. FORTIER, V. GOETCHERIAN, N. HAINES, M. JOURDAN, J. KAMPERMAN, P. KLINT, C. KOUTSOUMALIS, M. MAZAUD, C. MELDRUM, T. MUELLER, N. ROQUES, G. SANDER, M. SCHOOREL, A. SIZER, F. THOMASSET, F. TIP, W. WAKKER, H. WALTERS, R. WILHELM (1991). *First Review Report of ESPRIT Project 5399 (COMPARE).*
12. P.R.H. HENDRIKS (1991). *Implementation of Modular Algebraic Specifications.* Ph.D. thesis, Programming Research Group, University of Amsterdam.

RESEARCH GROUP AP 4

TITLE: Algebraic and syntactic methods

TITEL: Algebraïsche en syntactische methoden

LIST OF PROJECTS

AP 4.1 INTEGRATION;
AP 4.2 SEMAGRAPH;
AP 4.3 CONCUR.

REPORT ON 1991

Background

The objective of AP 4 is to perform foundational research in the field of (primarily but not exclusively) term rewriting systems. This extends to theoretical applications in the field of process algebra (in cooperation with AP 2, Concurrency and Real Time Systems), as well as in logic programming (in cooperation with AP 5, Logic and Language). The primary theme of AP 4, term rewriting systems (TRSs), and the secondary themes, process algebra and logic programming, are not unrelated. Investigations in all subjects strictly adhere to the algebraic-axiomatic methodology. Just as TRSs are nothing else than equational axiom systems with oriented equations, the core of process algebra consists of a family of (mainly) equational axiom systems, which have been explicitly designed to be amenable for a term rewriting analysis. This ensures both the possibility for rigorous proofs of consistency of axiomatizations and the possibility - in principle - of a further development towards executability (and thus, in the long run, towards mechanical tools assisting in manipulating process expressions and system specifications).

We now discuss in more detail the scientific relevance of the theme of term rewriting systems.

a. TRSs are a theoretical tool to analyze abstract data type specifications or algebraic specifications (consistency properties, computability theory, decidability of word problems, theorem proving).
b. TRSs provide the foundation for functional programming. Historically, the paradigm TRSs Combinatory Logic and Lambda Calculus served to formalize the concept of computable or recursive number theoretic function; especially the Lambda Calculus has been viewed as a rudimentary functional programming language. Several functional programming languages have been based on Lambda Calculus or Combinatory Logic, starting with LISP and recently Miranda. Theory about TRSs, concerning for instance evaluation strategies, has proved to be of direct relevance in a proper understanding of existing functional language features as well as in the design of new functional languages; especially the relation between

term rewriting and 'term graph rewriting' is of importance here (this is the substance of BRA project SEMAGRAPH, see below).

c. Recently, there is a surge of interest in combining the functional programming style and the logic programming style. Various proposals are being developed at many research sites for integrating the concepts of term rewriting and 'resolution', the main derivation method in logic programming. An important link between term rewriting and logic programming is given by conditional TRSs. A conditional TRS can be viewed as a logic program defining an equality relation, which can serve as the underlying equality of some other logic program. (This is the substance of part of the BRA project INTEGRATION, see below).

Research results

We now present a short report of the work done by AP 4 in each of the three BRA projects.

INTEGRATION

Participation by AP 4 follows two main lines. Together with K.R. Apt (AP 5) and C. Palamidessi (guest researcher in AP 5) the present research group, in particular Klop and Middeldorp, endeavours to compose an extensive survey and systematization of numerous known results in the area of 'Equational Logic Programming'. ELP is a framework that aims at an integration of (the foundations of) functional programming and logic programming; with respect to the component of functional programming it turns out that conditional term rewriting systems play a key role. This last fact leads to the second and more specific main line of investigation, with A. Middeldorp as primary researcher: the study of modular properties of term rewriting systems, in particular conditional ones. A key result here is Middeldorp's generalization of Toyama's classical theorem stating that confluence is a modular property for (unconditional) term rewrite systems, to the larger class of conditional term rewrite systems (CS-R8944). Other related results by Middeldorp have been reported in CS-R8959 and CS-R9003. Middeldorp's research is collected in his Ph.D. thesis (November 1990).

SEMAGRAPH

The task of AP 4 is to study to what extent the existing body of theory about term rewrite systems can be generalized or adapted to term graph rewriting. Term graph rewriting is a technique involving sharing of subterms that is of major importance for implementations of functional program languages for reasons of efficiency and feasibility of computations. Also, term graph rewriting introduces infinite terms, as unwindings of cyclic term graphs. A start was made with a study of infinitary term rewriting (where rewrite sequences may have as length an arbitrary ordinal) and infinitary normal forms. Infinitary normal forms arise naturally as the output of programs in a functional programming language. In this study AP 4 cooperates with the University of East-Anglia (Norwich), where the initiator and project manager of

SEMAGRAPH, Prof. M.R. Sleep, is located. A surprising discovery of this research was that confluence for orthogonal term rewrite systems does not generalize to the transfinite setting, although the normal form property does generalize. Subsequently it was found that the failure of infinitary confluence for orthogonal rewriting is only marginal, and can be located to a small class of 'bad' terms.

CONCUR
The only participant of AP 4 in this project is J.W. Klop (0.1 part time), who acted as Program Committee Chairman for the international conference CONCUR 90, at the end of year 1 (August 1990), with theme: 'Theories of Concurrency: Unification and Extension'. Together with Baeten (AP 2, general project manager of CONCUR) conference proceedings have been edited.

Other work (not in ESPRIT BRA framework)
Dr. F.J. de Vries has performed together with Prof. D.J.N. van Eijck (AP 5, Logic and Language) a study aiming at the application of process algebra techniques in order to formulate a semantical theory for natural languages. More about this work can be found in the analogous document of AP 5. This work is another example of a fruitful interaction between the various research groups in our department AP.

PUBLICATIONS 1991

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2. J. VAN EIJCK, F.J. DE VRIES (1991). Dynamic interpretation and Hoare deduction. G. CHIERCHIA (ed.). *Proceedings of SALT I, conference on Semantics and Linguistic Theory*, Cornell Univ. to appear.
3. J.R. KENNAWAY, J.W. KLOP, M.R. SLEEP, F.J. DE VRIES (1991). Transfinite reductions in orthogonal term rewriting systems. R.V. BOOK (ed.). *Proceedings of 4th Intern. Conf. RTA-91 (Rewriting Techniques and Applications)*, Como, Italy, April 1991, LNCS 488, Springer-Verlag, 1-12.
4. J.W. KLOP, A. MIDDELDORP (1991). Strong sequentiality in orthogonal term rewriting systems. *Journal of Symbolic Computation*, to appear.
5. J.W. KLOP, R.C. DE VRIJER (1991). Extended term rewriting systems. M. OKADA (ed.). *Proceedings of the 2nd Workshop on Conditional and Typed Rewrite Systems*, LNCS, Springer-Verlag, to appear.
6. A. MIDDELDORP (1991). Modular properties of conditional term rewriting systems, to appear in *Information and Computation*.
7. A. MIDDELDORP (1991). Confluence of the disjoint union of conditional term rewriting systems. M. OKADA (ed.). *Proceedings of the 2nd*

Workshop on Conditional an Typed Rewrite Systems, LNCS, Springer-Verlag, to appear.

8. A. MIDDELDORP, Y. TOYAMA (1991). Completeness of combinations of constructor systems. R.V. BOOK (ed.). *Proceedings of 4th Intern. Conf. RTA-91 (Rewriting Techniques and Applications)*, Como, Italy, April 1991, LNCS 488, Springer-Verlag, 188-199.

Reports

9. CS-R9105 A. MIDDELDORP. *Modular properties of conditional term rewriting systems.*
10. CS-R9107 J.W. KLOP, R.C. DE VRIJER. *Extended term rewriting systems.*
11. CS-R9115 D.J.N. VAN EIJCK, F.-J. DE VRIES. *Dynamic interpretation and Hoare deduction.*

Other publications

12. J.W. KLOP (1991). Term rewriting systems. ABRAMSKY, MAIBAUM, GABBAY (eds.). *Handbook of Logic in Computer Science, vol. 2*, Oxford University Press, to appear.

RESEARCH GROUP AP 5

TITLE: Logic and language

TITEL: Logica en taal

REPORT ON 1991

Logic programming
The main thrust of our research since 1989 was the study of termination of logic and Prolog programs. First, we investigated which natural conditions imposed on logic programs and goals ensure termination. To this end in total four classes of logic programs were investigated by Apt, Bezem, and Pedreschi (University of Pisa):

- those which terminate for all ground goals for all selection rules;
- those which terminate for all ground goals for the Prolog selection rule and two corresponding classes of programs allowing negative literals in the bodies. For each class of programs a simple and complete method of proving termination was provided and illustrated by some natural examples. It was argued these classes of programs comprise most natural logic and pure Prolog programs. Also it was investigated how infinite derivations can be stopped by modifying the underlying interpreter of logic programs. Apt, Bol and Klop (AP 4) made in 1988 and 1989 a systematic study of a number of natural loop checking mechanisms was made concentrating on the subject of their soundness (no solution is lost), completeness (all infinite derivations are pruned), relative strength and related properties. Once the basic definitions of loop checking were firmly set, Bol studied in 1990 and 1991 generalizations, alternative applications and implementation issues of loop checking mechanisms.
- Bezem, Bagai and Van Emden (University of Victoria, Canada) studied downward closure ordinals of logic programs; Apt wrote a systematic introduction to logic programming which recently appeared in the Handbook of Theoretical Computer Science;
- Turi proposed in 1990 a new type of semantics for general logic programs based on the use of non-ground atoms.

Deductive databases
Two forms of computing which are used in deductive databases (DDB in short) - top down and bottom up computing were studied in detail. An implementation of top down computing formed one of the motivations for the above reported work on loop checking. Also Apt systematically derived best known algorithms for the bottom computing.

Non-monotonic reasoning
Apt and Blair (University of Syracuse) studied the arithmetical complexity of the perfect model of stratified logic programs and various known formalisms for non-monotonic reasoning. Apt and Bezem applied their study of the terminating general logic programs to formalize temporal reasoning, a special form of non-monotonic reasoning exemplified by the so-called Yale Shooting Problem, by means of logic programming.

Program verification
Apt, Francez and Katz (Technion, Haifa) provided a systematic study of the notion of fairness for various models of distributed computing. Apt and Olderog (University of Oldenburg) finished their book on program verification. It treats in a uniform framework both sequential and concurrent programs. A large portion of the material is entirely new, in particular the use of program transformations for program verification. In the book they systematically discuss deterministic and nondeterministic programs, parallel programs with shared variables, and distributed programs with message passing, concentrating in each case on operational semantics, syntax-directed assertional proof systems and their soundness proofs, program transformations and their correctness proofs, and a correctness proof of a substantial example. In particular, solutions to the classical problems of consumer/producer, mutual exclusion and distributed termination are discussed and proved correct.

Natural language processing
In April 1989, work on natural language understanding has started. The focus of attention of work of a guest researcher H. Walinska was the study of verb formation of so-called 'zero-headed' English verbs and an extensive comparison of English and Slavic verbal prefixation. In 1989 and 1990 the focus of the work of Van Eijck has been on the semantics of quantification in natural language. Several overview papers on quantifiers and determiners were completed; research on quantifiers in partial models and on dynamic aspects of quantification was started. In particular Van Eijck and De Vries (AP 4) proposed a Hoare style proof system allowing us to reason about sentences involving dynamic interaction of quantification and description. The focus of the work of Moortgat has been the development of categorial grammar formalisms, with prototype implementations in Prolog. Relations between categorial systems and substructural logics (linear logic, relevance logic) were studied. Polymorphic type inference mechanisms were devised to handle underspecified typing in categorial grammars.

PUBLICATIONS 1991

Papers in Journals and Proceedings
1. K.R. APT, M. BEZEM (1991). Acyclic programs. *New Generation Computing*, to appear.
2. K.R. APT, E.R. OLDEROG (1991). Introduction to program verification.

E. NEUHOLD, M. PAUL (eds.). State of the Art. Book. *Formal Description of Programming Concepts,* Springer-Verlag (to appear).
3. K.R. APT, E.R. OLDEROG (1991). Using transformations to verify parallel programs. *Algebraic Methods II: Theory, Tools and Applications,* LNCS, Springer-Verlag, 55-81.
4. K.R. APT, D. PEDRESCHI (1991). Proving termination of general Prolog programs. *Proceedings International Conference on Theoretical Aspects of Computer Software,* LNCS, Springer-Verlag, to appear.
5. R.N. BOL (1991). Generalizing completeness results for loop checks. *Theoretical Computer Science,* to appear.
6. R.N. BOL (1991). Loop checking and negation. J. VAN EIJCK (ed.). *Logic in AI,* LNCS 478, Springer-Verlag, 121-138.
7. R.N. BOL, K.R. APT, J.W. KLOP (1991). An analysis of loop checking mechanisms for logic programs. *Theoretical Computer Science,* in press.
8. (1991). *Aspects of Computer Software,* Senday, Japan, to appear.
9. R.N. BOL, J.F. GROOTE (1991). The meaning of negative premises in transition system specifications. *Proceedings ICALP '91,* Springer-Verlag, to appear.
10. J. VAN EIJCK (1991). Quantification. A. VON STECHOW, D. WUNDERLICH (eds.). *Handbook of Semantics,* in press.

Reports

11. CS-R9115 D.J.N. VAN EIJCK, F.-J. DE VRIES. *Dynamic interpretation and Hoare deduction,* submitted for publication.

Other publications

12. K.R. APT, E.-R. OLDEROG (1991). *Verification of Sequential and Concurrent Programs,* Texts and Monographs in Computer Science, Springer-Verlag, 441+xvi pages.
13. R.N. BOL (1991). *Loop Checking in Logic Programming.* Ph.D. thesis, University of Amsterdam, 199+viii pages.

Department of Algorithmics and Architecture

HEAD OF DEPARTMENT: Prof. L.G.L.T. Meertens

LIST OF RESEARCH GROUPS

AA 1 Algorithms and complexity
AA 2 Cryptology
AA * Computer systems and ergonomics
AA 4 Databases
AA 5 Constructive algorithmics

		AA1	AA2	AA4	AA5	not yet	working	budget	ext.	de-		guests	remarks
						decided	time in fte	time in fte	paid	tached			
appointed													
Meertens	head dept.				0.60		0.60	0.60					
Vitanyi	group leader	0.80					0.80	0.80					
Tromp	jr.researcher	1.00					1.00	1.00					
Chaum	group leader		0.60				0.60	0.60					
Heijst, van	jr.researcher		0.42				1.00	0.42					
Ham, van	jr.researcher		0.50				1.00	0.50					
Kersten	group leader			0.80			0.80	0.80					
Berg,C.A.v.d.	researcher			1.00			1.00	1.00	SION				
Siebes	proj. leader			1.00			1.00	1.00					
Elshoff	researcher			0.38			1.00	-		1.00	NFI		
Thieme	jr.researcher			0.58			1.00	0.58	NFI				
vd Voort	jr.researcher			1.00			1.00	1.00					
Plomp	jr.researcher			1.00			1.00	-		1.00	SION		
Woude,v.d.	researcher				0.75		1.00	-		1.00	NFI		
Pemberton	group leader					1.00	1.00	1.00	0.4SERC				
Barfield	researcher					1.00	1.00	1.00	0.4SERC				
Bordegoni	researcher					0.60	1.00	-					
Boeve	jr.researcher					0.20	1.00	0.20					
van Dijk	sc.programmer					1.00	1.00	1.00					
research time		1.80	1.52	5.76	1.35	3.80		11.50					
request	jr. researcher	•					1.00						
request	researcher	•					1.00						
request	proj. leader	•					1.00						
request	researcher	•					1.00						
request	researcher	•					1.00						
request	researcher	•					1.00						
request	jr. researcher	•					1.00						
request	jr. researcher		•				1.00						
request	jr. researcher		•				1.00						
request	jr.researcher		•				1.00						
request	jr.researcher		•				1.00						
request	coordinator		•				1.00						
request	proj. administr		•				0.50						
request	jr. researcher			•			1.00						
request	jr. researcher			•			1.00						
request	jr. researcher			•			1.00						
request	jr. researcher			•			1.00						
request	jr. researcher			•			1.00						
request	jr. researcher			•			1.00						
request	jr. researcher			•			0.50						
request	jr. researcher			•			1.00						
request	researcher				•		1.00						

RESEARCH GROUP AA 1

TITLE: Algorithms and complexity

TITEL: Algoritmiek en complexiteit

REPORT ON 1991

Distributed Computing
A general theorem expressing the total interconnect (wire) length of physical embeddings of computation networks in d-dimensional Euclidean space ($d=1,2,3$) which is technology independent, and the proof that this lower bound is optimal within a factor 10 for n-cube, cube-connected cycles, mesh, and so on (SICOMP88 Vitányi).

A first direct solution of constructing multi-user wait-free atomic variables from single reader single writer atomic variables. A special case is the construction of multireader variables which is optimal and simpler than existing constructions. Another special case is the construction of multiwriter variables from multireader variables, of which the complexity improves orders of magnitudes over all other known (none of them earlier) solutions. This one is much more simple than other solutions as well (ICALP89 Li-Vitányi, JACM under revision Li-Tromp-Vitányi).

General lower bounds, which are often optimal, on the message complexity of the 'Distributed Match-Making Problem' as a theoretical paradigm for nameserver, mutual exclusion, distributed routing (Algorithmica88, Mullender-Vitányi, Math. Syst. Th., Kranakis-Vitányi).

Computational machine learning
Valiant's seminal model of distribution-free pac (probably approximately correct) learning has started the field of computational learning theory. Yet it turns out that classes of concepts which should intuitively be learnable in this sense are NP-complete to learn. Hence certain investigations have focussed on learning under specific distributions, like the uniform distribution, to increase the number of learnable concept classes. Yet this approach is too restrictive for a viable theory. In practice we do not meet such a specific distribution. There arises the problem of finding a class of distributions which is large enough to be significant, and small enough to enhance learnability. Li-Vitányi have identified the class of 'simple' distributions, which include all computable and enumerable distributions (hence anything with rational parameters which has ever been used or has a name). We show completeness results both for discrete sample spaces and continuous sample spaces. A discrete concept class is polynomial pac leearnable under all simple distibutions iff it is polynomial pac learnable under one specific distribution: the universal distribution $m(x)=2^{-K(x)}$, where $K(x)$ is the length of the shortest effective binary

description of x (its Kolmogorov complexity) - provided we draw examples according to $m(x)$ in the learning phase. A continuous concept class is pac learnable under all simple measures if its is learnable under the universal measure $M(x)$ - the continuous analogue of $m(x)$. Several classes are shown to be learnable under the new model which were not known to be learnable under the old (Valiant's) model, or which were known to NP-complete (in the discrete case) to learn or unlearnable (in the continuous case) in the old model. We also introduce the idea that learning syntactically described classes of concepts (like all finite automata) is not reasonable. In practice, we only want to learn 'simple' concepts, like finite automata which recognize parity rather than a long random string. We formulate this idea precisely and prove several results. We also bring the model in the feasible (polynomial time computable universal distribution) domain. See FOCS89, COLT89, AAAI90, SICOMP91.

Kolmogorov complexity
Li-Vitányi solved a well-known 20 year old problem in time complexity of Turing machine computations (1-work tape versus k work tape computation time from Hopcroft & Ullman 69) and related problems involving pushdown stores and queues (INFO&COMP88, STRUCTURES86, SICOMP with L. Longpré). Li-Vitányi have given the authoritative survey on Kolmogorov complexity and its applications (STRUCTURES88; USPEKHI MAT. NAUK89; Complexity Theory Retrospective, Springer; Chapter 4 in Handbook of Theoretical Computer Science, Part A, 1990). We gave a new approach to formal language theory using Kolmogorov complexity, replacing the classic 'pumping lemma's' by stronger Kolmogorov complexity characterizations and lemmas, which are far more intuitive and easy to use, both replacing existing theorems and providing new results (ICALP89, JACM). We have analyzed the relation between Solomonoff's inductive inference and induction principles in recursion theory (Gold's paradigm) and statistics (Fisher's Maximum Likelihood, Rissanen's Minimum Description Length, Yaynes' Maximum Entropy), and connected it with distribution-free learning (STRUCTURES89, JCSS). We have found a new Kolmogorov complexity method in combinatorial theory and applied it to prove results earlier proven by the probabilistic method (in Erdoes and Spencer's book), and by information theoretic (second moment) methods by Pippenger (STUCTURES91). Work is in full progress on the comprehensive textbook M. Li and P.M.B. Vitányi, 'Introduction to Kolmogorov Complexity and Its Applications', Addison-Wesley, to appear.

PUBLICATIONS 1991

Papers in Journals and Proceedings
1. A. BLUM, T. JIANG, M. LI, J. TROMP, M. YANNAKAKIS (1991). Linear approximation of shortest superstrings. *Proceedings 23rd ACM Symp. Theory of Computing*, New Orleans, 328-336.
2. P. CLOTE, E. KRANAKIS (1991). Boolean functions, invariance groups and parallel complexity. *SIAM Journal on Computing, 20:3.*

3. G. KISSIN (1991). Upper and lower bounds on switching energy in VLSI. *J. Assoc. Comp. Mach., 38,* 222-254.
4. E. KRANAKIS, P.M.B. VITÁNYI (1991). Weighted distributed matchmaking. *Mathematical Systems Theory,* to appear.
5. M. LI, J. TROMP, P.M.B. VITÁNYI (1991). How to share concurrent wait-free variables. *J. Assoc. Comp. Mach.,* under revision.
6. M. LI, P.M.B. VITÁNYI (1991). A new approach to formal language theory by Kolmogorov complexity. *J. Assoc. Comp. Mach.,* to appear/revision.
7. M. LI, P.M.B. VITÁNYI (1991). Inductive reasoning and Kolmogorov complexity. *J. Comp. System Sciences,* to appear.
8. M. LI, P.M.B. VITÁNYI (1991). Learning simple concepts under simple distributions. *SIAM J. Comput, 20:5.*
9. M. LI, P.M.B. VITÁNYI (1991). Combinatorics and Kolmogorov complexity. *Proceedings 6th IEEE Structures in Complexity Theory Conference,* Chicago.
10. L. LONGPRE, M. LI, P.M.B. VITÁNYI (1991). On the power of the queue. *SIAM J. Comput.,* to appear.
11. J.T. TROMP (1991). How to construct an atomic variable. *Distributed Computing,* under revision.

Reports

12. CS-R9101 G. KISSIN, J. TROMP. *The energy complexity of threshold and other functions.*
13. CS-R9113 J. TROMP, P.M.B. VITÁNYI. *Randomized wait-free test-and-set.*
14. CS-R9125 M. LI, P.M.B. VITÁNYI. *Combinatorics and Kolmogorov complexity.*
15 CS-R9126 A. BLUM, T. JIANG, J.T. TROMP, M. JANNAKAKIS. *Linear approximation of shortest superstrings.*
16. CS-R9128 M. LI, P.M.B. VITÁNYI. *Optimality of wait-free atomic multi-writer variables.*
17. M. LI, P.M.B. VITÁNYI. *Kolmogorov Complexity Arguments in Combinatorics.* ITLI Prep. Series, Computation and Complexity Theory, Techn. Rept. CT-91-01, University of Amsterdam.
18. M. LI, J. TROMP, P.M.B. VITÁNYI. *How to Share Concurrent Wait-Free Variables (revised).* ITLI Prep. Series, Computation and Complexity Theory, Techn. Rept. CT-91-02, University of Amsterdam.
19. M. LI, P.M.B. VITÁNYI. *Average Case Complexity under the Universal Distribution Equals Worst Case Complexity.* ITLI Prep. Series, Computation and Complexity Theory, Techn. Rept. CT-91-03, University of Amsterdam.

Other publications

20. P. CLOTE, E. KRANAKIS (1991). *Boolean Functions, Parallel Computation and Proof Systems,* ca 400 pp. (to appear 1992).
21. E. KRANAKIS (1991). *Primality and Cryptography,* Wiley-Teubner Series in

Computer Science, B.G. Teubner (Stuttgard) and John Wiley and Sons (Chichester), 1986, 235+xv pp.

22. M. Li, P.M.B. Vitányi (1991). *Introduction to Kolmogorov Complexity and Its Applications,* Addison-Wesley, ca. 400 pp. (to appear 1992).

RESEARCH GROUP AA 2

TITLE: Cryptology

TITEL: Cryptografie

REPORT ON 1991

The field of open research in modern (i.e. not paper and pencil or electro-mechanical machine based) cryptography emerged in about 1976. The first conferences occurred in 1981, both in Europe and in the U.S., each attended by some 75 or so participants. The following year the International Association for Cryptologic Research was founded during the launch of what remains an unbroken series of international conferences, 'Crypto' in Santa Barbara California each August and 'Eurocrypt' held somewhere in Europe each Spring. Attendance at the conferences has grown surprisingly steadily to about 250 or 300, with over 100 papers submitted, and about 30 presented. These remain the only regular international conferences devoted to the theme, although the association has sponsored one in Australia and another in Japan. The association has also launched a journal a few years back, which like the conference proceedings is published by Springer-Verlag.

The research of the Crypto Group during the last five years can best be described separately for each of the four main research project themes.

Theoretical results

A line of development can be traced through a series of significant results by the Crypto Group in this area, although there were also some scattered other results (see list of publications section I: 1, 2, 7, 8, 11, 25, 28 & section II: 2, 4, 5) in this area. This line began with publication 19, which was first presented at a conference at which a 'dual' result was first presented by a team of researchers from M.I.T. The results show that Alice can give exponentially high certainty to Bob that she knows a satisfying assignment of some predicate, without helping Bob learn the assignment. The model we used allows Alice to protect her secret from Bob even if he has infinite computing power (and thus he may find all instances but still will not know which one Alice had) called 'unconditional privacy', whereas their model was that Bob had polynomially bounded resources, called 'computational privacy'. These results were elaborated and made accessible to the generally interested reader in the invited section II.14 also listed as 8.1.

The next step in this line, reference 16, extended the results to multiple parties, each having their own secrets, and each wishing to participate in an agreed computation that takes the secrets as input, and where the output of the computation will become known to all parties. Again there was a related independent result by the same team. Their model was the same as in their original paper, ours included theirs as a special case, but also allowed for one distinguished participant to have unconditional privacy. Next 17 appeared at the

same conference as an almost identical independent result by a partly overlapping Israeli team. This showed that if two-thirds of the participants are honest, then all you need is secure channels between every pair of participants to do a multiparty computation. (17 was invited to JCSS, and is also shown as 8.2.) Subsequently, using the distinguished participant of 16, together with an extension of 17 improving it to the optimal one-half honest participants, we have been able to achieve in 24 strongest result in a natural model to date, which in essence says constructively that privacy can be protected unconditionally if a majority do not conspire, and even if they do they will have to break the underlying cryptosystem in order to learn secrets of the others.

Conventional cryptography
The area of conventional cryptography is typified by the well known and somewhat controversial DES (U.S. Data Encryption Standard). The cipher is composed of sixteen iterations, each of the same basic structure. In a paper presented in 1986, we showed how to break a cipher made up of seven of these iterations, while the most that had previously been achieved was the more or less trivial four. In 13 we propose a generalization of our attack which includes several other attacks and observations in the literature. Last year at Crypto Biham and Shamir, in a seventy page quite technical paper, were able to break eight iterations. A Japanese alternative to DES, which was submitted to ISO and received some significant attention, was completely broken by us in 6.

Untraceable transactions
A comprehensive approach to secure consumer transactions allowing individuals maximum privacy was proposed and surveyed in 21, several translations of which were invited and others of which have appeared in the last five years. These results were in three parts: untraceable communication (see invited paper 23); untraceable payments (see 3, 4, 9 10, 12, 18, 19, 27); and a way for people to maintain the database about themselves while allowing them to prove that queries to it are answered correctly, called credential mechanisms (see 22 and section.II.3). Although we have played a major role in launching this area of investigation, there are a number of sites around the world which have published related theoretical as well as practical results.

New kinds of cryptographic primitives
Apart from the cryptographic primitives needed for untraceable transactions, we have created some additional novel ones that have also received some attention. One of the main ideas that perhaps catalyzed the field of modern cryptography was Whitfield Diffies notion of 'digital signature'. We have proposed an alternative to this, which has arguable advantages in many applications. A digital signature is self-authenticating, in the sense that anyone can verify it using only the public key identifying the signer and the message claimed to have been signed. With our 'undeniable' signatures, cooperation of the signer is needed each time the signature is verified; if the signer refuses to allow, say, a judge to verify the signature, the signer can be asked to use the

protocol that lets him show that the alleged signature is not his, without revealing anything more. Since this notion first appeared in 26, we have improved it in 29, extended it in 5, and currently have submitted a survey on the topic, which has attracted a number of other researchers to the extent that it occupied its own seesion at the last Eurocrypt conference.

Another new cryptographic primitive just introduced in 30 called 'group signatures', lets any member of a group form a signature (either self-authenticating or undeniable) that can only be traced to the particular member by some action such as cooperation of a majority of other group members.

PUBLICATIONS 1991

Papers in Journals and Proceedings

1. D. CHAUM, (1991). Zero-knowledge undeniable signatures. I.B. DAMGÅRD (ed.). *Advances in Cryptology, EUROCRYPT '90,* Springer-Verlag, 458-464.
2. D. CHAUM (1991). Can numbers be a better form of cash than paper? *Proceedings of the Second SmartCard 2000,* North-Holland, to appear.
3. D. CHAUM I.B. DAMGÅRD, T. PEDERSEN (1991). Convertible undeniable signatures. *Advances in Cryptology, CRYPTO '90,* Springer-Verlag, to appear.
4. D. CHAUM, S. ROIJAKKERS (1991). Unconditionally-secure digital signatures. *Advances in Cryptology, CRYPTO '90,* Springer-Verlag, to appear.
5. J.-H. EVERTSE, E. VAN HEYST (1991). Which new RSA signatures can be computed from some given RSA signatures? I.B. DAMGÅRD (ed.). *Advances in Cryptology, EUROCRYPT '90,* Springer-Verlag, 83-97.
6. E. VAN HEYST, D. CHAUM (1991). Group signatures. *Advances in Cryptology, EUROCRYPT '91,* Springer-Verlag, to appear.
7. T. OKAMOTO, K. OHTA, D. CHAUM (1991). Direct zero knowledge proofs of computational power in five rounds. *Advances in Cryptology, EUROCRYPT '91,* Springer-Verlag, to appear.
   (a) Security Without Identification: Transaction Systems to Make Big Brother Obsolete, *Communications of the ACM, vol. 28 no. 10,* October 1985, 1030-1044 (invited); (b) Revised version (in Dutch) *Informatie,* pp. 213, 1987. (c) Extended and revised version: Subtitled 'Card Computers to Make Big Brother Obsolete' (in German), *Informatik-Spektrum, vol. 10,* 262-277, 1987; & *Datenschutz und Datensicherung, no. 1,* 1988, 26-41.

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8. B. DEN BOER, D. CHAUM (1991). *Combining Secrets in Most Concealing Ways: Dynamic Graphs for Restricted Choices in Hidden Key Transformations,* to appear.
9. D. CHAUM, B. DEN BOER (1991). *Zero Information Circuits with DES,* to appear.
10. D. CHAUM, J.H. EVERTSE (1991). *An Efficient Credential Mechanism Allowing an Unlimited Number of Credential Types,* to appear.

11. J.-H. EVERTSE, E. VAN HEYST (1991). *Which New RSA Signatures can be Computed from Some Given RSA Signatures?* Report W91-06, Mathematical Institute, University of Leiden.

Other publications

12. D. CHAUM (ed.) (1991). *Proceedings of the Second SmartCard 2000,* North-Holland, to appear.

RESEARCH GROUP AA *

TITLE: Computer systems and ergonomics

TITEL: Computersystemen en ergonomie
Formely Research group AA 3 (the research of this group has been terminated during 1991).

REPORT ON 1991
The most important result of the ABC sub-project was the release of 4 implementations of the language (described below), and a book published by Prentice Hall. ABC is a language that is extremely easy to learn - someone who knows Pascal or C can learn it in an hour or two: we have observed a teenager, armed with only a quick-reference card and no other knowledge of the language, sit down at a terminal and start to program. Despite this ease of learning, the language is very powerful, and typical ABC programs are a quarter or a fifth the length of equivalent Pascal or C programs. ABC is used by number theorists, cryptographers, teachers, and hobbyists alike. While there are areas for further work, such as graphics and system programming, all recent work in the system has been on maintainance and promulgation, and attention focussed on Views, in itself a generalization of the precepts discovered in the ABC research. The initial research into Views was to find a user model of computer interaction that would encompass all possible applications. This was done via a number of experimental systems, such as editors and mail-readers (described below). This led to our TAXATA model of interaction: all information is presented to the user as documents which are in principle editable, all actions are accomplished by editing documents, and what is presented on the screen is precisely the state of things (Things are exactly as they appear - a stronger version of WYSIWYG, what you see is what you get). More details of this approach can be found in the included article on Views.

This model led to the development of an implementation model for the system, and a test implementation of Views. Based on the success of this pilot, SERC, the Software Engineering Research Centre in Utrecht, joined with us, and widened the research into multi-user authoring using Views, widening the system from single-user to multi-user. In this context we have developed (but not yet tested in practice) a simple model for safeguarding consistency on concurrent access of an object by different users, as well as a model for a user-accessible representation of the current state of progress in a cooperative design process. Current research is in the graphics model of the system, the extension of the model to low-level interaction tools, the application specification language, the persistent object world model (in cooperation with AA 4), the maintenance of consistency of the system through use of a network of invariants between objects, and user-transparent object locking during sharing.

PUBLICATIONS 1991

Papers in Journals and Proceedings

1. LON BARFIELD, EDDY BOEVE, STEVEN PEMBERTON (1991). The Views user interface system. *Proceedings of the 1991 Computer Human Interaction Conference (CHI '91)*, ACM Press.
2. STEVEN PEMBERTON (1991). A short introduction to the ABC language. *SIGPLAN Notices, Vol 26, No. 2*, Feb 1991.
3. STEVEN PEMBERTON (1991). Position paper: 'object-centred open user interfaces'. *Second Eurographics Workshop on Object Oriented Graphics.*
4. STEVEN PEMBERTON (1991). Action through editing: uniform user interfaces. *First Moscow Workshop on Human Computer Interfaces.*

RESEARCH GROUP AA 4

TITLE: Databases

TITEL: Databases

REPORT ON 1991

Research in this period centered around several projects: PRISMA, Floc, Tropics, ISDF, and ECOS. They are discussed briefly below. The PRISMA project (1986-1990) was a large-scale research effort (30 persons) in the design and implementation of a highly parallel machine for data and knowledge processing. It was organized as a nationwide Dutch research activity with combined forces from four universities, a governmental research institute, and Philips Research Laboratories. During these years considerable effort was spent by our members in the PRISMA team on the design and prototyping of the database system, which resulted in ca. 45K lines of documented POOL code, developed together with our partners at Twente University. By the end of 1988 a stable interpreter for the programming language POOL became available, which was used to finalize the prototype PRISMA/DB in the spring of 1989. This first implementation round was finished with a two-day workshop to evaluate the code produced and to assess future enhancements.

Awaiting the delivery of the POOL compiler for the multi-processor machine, we spent our time on research issues related to the PRISMA database system, such as an evaluation of the programming language POOL for its expressiveness of relational database concepts at the level of the One-fragment manager, database recovery, and the semantics of nested queries in SQL. In 1990, we had to rework major portions to make the system run on the 100-node multiprocessor.

The Ph.D. project Floc ran from 1985 till 1989. It aimed at the formalization of object oriented datamodels, in particular the structural parts of these models. Moreover, a design theory for this formalism was developed. As category theory is the mathematical theory of structures, it was chosen as vehicle for the development of the formalism called Floc. During the course of this project, category theory proved to be more than adequate to formalize both the static and the dynamic structure, including constraints, of object oriented datamodels. Moreover, it allowed for the inclusion of negative and disjunctive information as well as the development of a, deductive, query language for Floc. The main theme for the design theory was on structural equivalence, for which category theory proved to be, again, indispensable. Briefly, this allows a database designer to switch between alternative, but equivalent, models of the same Universe of Discourse. For example, it was shown that traditional constraints such as functional, multivalued and join-dependencies can also be modelled by a suitable type construction and a (simple) dynamic constraint.

The Esprit-II project TROPICS ran from 1989 till June 1990. One of the major themes in this project was to enhance the PRISMA database system to

become a viable platform for carthographic and office systems. Therefore, our group has developed an extended version of SQL and implemented a prototype for feasibility studies. After termination of this project, we refocussed our effort on active databases.

The Integrated Systems Design Framework (ISDF) project (1990-1993) is a research collaboration between several Dutch universities. The overall goal of this project is the development of an integrated framework for the description of information systems and the analysis of information systems descriptions within this framework. The importance of such a framework lies in the outlook it offers for the development of truly integrated information systems design methodologies, which apply hitherto largely unused mathematical theories for the analysis of their design. In particular, it provides a sound theoretical basis for such methodologies to formulate requirements and logical designs, and it forms a reference point for the accompanying software development tools. The task of our group is, in close collaboration with Twente University, to develop a formalism which is suitable for both:

- the expression of the design concepts within the framework, such as specialization and generalization;
- the analysis of a design with regard to structure, dynamics and constraints, for problems such as structure equivalences, lifeness/deadlock and consistency, as well as the interaction between these three areas.

The activities undertaken are an extension of our earlier research in Floc. In the past year, structure equivalence has, again, been a major theme. In particular, a sound and complete axiom system for structural equivalence for a large collection of type-systems has been developed. Moreover, a Datalog-variant for deduction over databases with complex objects and subtyping has been defined. The semantics of this language have been defined using category theory. Finally, the design-theory for object oriented databases is now focussed on the normalization of class-hierarchies.

The ECOS project (1990-1993) aims at the design of the nucleus of a new generation DBMS, which provides the user a model and query language to describe and manipulate graph-like objects. The task of such an object server is to efficiently implement the model on a (distributed) computing system, shielding the complexity of maintaining the fragmented representation through clustering, indexing, and query-evaluation strategies.

The research actions within our group focus on the software architecture of an extensible complex object server (ECOS) with an emphasis on active database support and dynamic distributed query processing. An active database system is characterized by a set of event-condition-action pairs, which describe actions to be taken upon encountering an event in a particular database state. In a dynamic query processing scheme one considers query processing in a distribute setting as a scheduling and load balancing problem. The expectation is to achieve better system utilization (and response time) compared to traditional approaches (such as PRISMA).

PUBLICATIONS 1991

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8. A.P.J.M. SIEBES (1991). EG, integration of the object-oriented and the deductive database paradigms. *CWI Quarterly, Vol. 4, no. 4.*
9. A.P.J.M. SIEBES, M.H. VAN DER VOORT, M.L. KERSTEN (1991). A framework for the formalisation of active objects. *Proceedings CSN '91,* November 1991.

Reports

10. CS-R9112 C.A. VAN DEN BERG, M.L. KERSTEN, S. SHAIR-ALI. *Dynamic parallel query processing.*
11. CS-R9122 M.H. VAN DER VOORT, M.L. KERSTEN. *Facets of database triggers.*
12. CS-R91xx S. PLOMP. *Lock latency in distributed systems.*
13. CS-R91xx A.P.J.M. SIEBES, M.H. VAN DER VOORT, M.L. KERSTEN. *A framework for the formalisation of active objects.*

RESEARCH GROUP AA 5

TITLE: Constructive algorithmics

TITEL: Constructieve algoritmiek

REPORT ON 1991

Most of the results that have been obtained to date are characterized by taking an algebraic view on certain important data types and considering homomorphisms on the algebraic structures obtained. From a theoretical perspective this is nothing new; the novelty of the approach lies in the development of notation that makes it possible to express this in a way that is suitable for calculation. This approach, which was developed in collaboration with Richard Bird (Programming Research Group, University of Oxford), has proven surprisingly fruitful. Many important 'program transformations' turn then out to be special cases of general and simple algebraic identities. By using initiality of the algebra, and therefore the unique property of homomorphisms (usually in the form of so-called 'promotion properties'), induction proofs can be replaced by calculation using equational reasoning. An important impulse to the research was given by the work of Grant Malcolm (then at Groningen), who showed how to formulate various results 'generically', that is, independent of a specific data type, by using a categorical approach.

This productive approach has by no means been exhausted, and extensions in several directions have been explored: to infinite structures, which correspond to a final rather than an initial algebra, to categories of continuous algebras, and to categories (or 'almost' categories) in which the morphisms are relations rather than functions. In all these cases it is possible to use a calculational style of program derivation. An important recent result is the discovery by Fokkinga of a very elegant category-theoretical formulation of the notion of 'law' imposed on a data-type, which abstracts from the algebraic signature by using instead its encapsulation as an endofunctor. The work on relations was initiated by Roland Backhouse (first at Groningen, now at Eindhoven). In the context of VLSI design, methods that are closely related in spirit and contents have been developed and used by Mary Sheeran (Glasgow) and Geraint Jones and Wayne Luk (Oxford) for the synthesis of essentially systolic algorithms.

Part of the research approach is an emphasis on theory development that is example-driven, by focussing each time on a specific problem or class of problems (and methods). Jeuring has given calculational derivations of (in some cases well-known) algorithms for a diversity of classes of problems on sequences, and of new algorithms for such problems on other data types, such as binary labelled trees and multi-dimensional arrays. The general method is the systematic derivation, by calculation, of conditions under which the efficient computation of an optimal 'disposition' (for sequences, e.g a segment, subsequence, partition or permutation) is possible, which are then applied to specific problems, like sorting, pattern matching, or the 0-1 knapsack problem.

Recently, the synthesis of programs involving asynchronously communicating processes has begun to appear to yield to a relational approach, but much remains to be done there (work in cooperation with Morgan, Oxford).

Next to the development of theory, some attention has been paid to design requirements for tools providing mechanical assistance in creating and manipulating program derivations. This is done in the context of the STOP project (see below).

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3. M.M. FOKKINGA (1991). An exercise in transformational programming—backtracking and branch-and-bound. *Science of Computer Programming, Vol. 16, Number 1*, 19-48.
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8. J.T. JEURING (editor-in-chief) (1991). *The Squiggolist, Vol. 2, Number 1*, CWI.
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16. J.C.S.P. VAN DER WOUDE (1991). Atoms and extensionality, what's the point? *Notes EURICS Workshop on Calculational Theories of Program Structure*, Hollum-Ameland.
17. J.C.S.P. VAN DER WOUDE (1991). C4, general manipulative nonsense. *Notes EURICS Workshop on Calculational Theories of Program Structure*, Hollum-Ameland.

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18. CS-R9104 M.M. FOKKINGA, E. MEIJER. *Program calculation properties of continuous algebras.*
19. CS-R9132 M.M. FOKKINGA. *Calculate categorically!*
20. CS-R9133 M.M. FOKKINGA. *Datatype laws without signatures.*
21. CS-R91xx J.T. JEURING. *Incremental algorithms on lists.*
22. CS-R91xx E. VOERMANS, J. VAN DER WOUDE. *Relational tupling.*

Department of Interactive Systems

HEAD OF DEPARTMENT: Drs. P.J.W. ten Hagen

LIST OF RESEARCH GROUPS

IS 1 Computer Graphics
IS 2 Interaction
IS 3 Intelligent CAD systems

		IS1	IS2	IS3	IS 4	working	budget	ext.	de-		guests	remarks
						time in fte	time in fte	paid	tached			
appointed												
Hagen,ten	head.dept		0.50	0.50	pm	1.00	1.00					
Kuyk	group leader	1.00				1.00	1.00					
Liere,van	sc.programmer	0.92				1.00	0.92					
Blake	researcher	0.25				1.00	-		0.25	STW		
Guravage	sc.programmer	0.25				1.00	-		1.00	STW		
Burger	sc.programmer	1.00				1.00	1.00					
Herman	group leader		1.00			1.00	1.00					
Blom	researcher		1.00			1.00	1.00					
Ruiter,de	researcher		1.00			1.00	1.00					
Soede	researcher		1.00			1.00	1.00					
Rutten	guest res.		0.20			1.00	-				0.20	ERCIM
Vegt,van der	jr.researcher		0.20			0.80	0.26					
Arbab	group leader			1.00		1.00						
Rogier	researcher			1.00		1.00	-		1.00	NFI		NFI
Veerkamp	researcher			1.00		1.00	1.00	NFI				
Spilling	jr.researcher			1.00		1.00	1.00	NFI				
Veltkamp	jr.researcher			1.00		1.00	1.00	NFI				
Smit	jr.researcher			1.00		1.00	-			NFI		
Noot	sc.programmer			1.00		1.00	1.00					
research time		3.42	4.90	5.50	0.00		11.18					
vacancy CWI	researcher	0.08				1.00						
vacancy	researcher	*				1.00						
vacancy	researcher	*				1.00		STW		STW		
vacancy	programm.	0.75				1.00		STW		STW		
vacancy	researcher	*				1.00						
vacancy	researcher	*				1.00						
vacancy	researcher	*				1.00						
vacancy	researcher		*			1.00						
vacancy	researcher		*			1.00						
vacancy CWI	jr.researcher		*			1.00						
vacancy	guest research		0.50			1.00					0.50	
vacancy	jr.researcher		*			1.00						
vacancy	jr.researcher		*			1.00						
vacancy CWI	jr.researcher			*		1.00						
vacancy	jr.researcher			*		1.00						
vacancy	jr.researcher			*		1.00						
vacancy	jr.researcher			*		1.00						
vacancy	researcher				*	1.00						
vacancy	researcher				*	1.00						
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vacancy	jr.researcher				*	1.00						
vacancy	jr.researcher				*	1.00						

RESEARCH GROUP IS 1

TITLE: Computer graphics

TITEL: Computergrafiek

REPORT ON 1991

The research involved the design of an interaction based graphics workstation. This work was initiated by a study on interaction aspects which formed the basis of the design of a non-conventional architecture. The feasibility of this design was shown by actual implementation on VLSI of some of the critical modules in the architecture. With these modules a complete prototype will be assembled by the end of 1991. The feasibility study included development of new shading algorithms, optimized for the specific hardware configuration. These algorithms turned out to be generally applicable and are competitive to existing efficient algorithms. To support the design effort, a graphics hardware simulator has been implemented. The modularity of this simulator makes it suitable to implement a layered set of simulators, needed for design validation on different abstraction levels.

Besides this, the research between 1987 and 1990 involved the development and completion of the dialogue cell system. The dialogue cell system has been used in house as a tool for the development of user interfaces. More recently, it has been used by an external software house. From 1990 onwards, this research has been directed towards the specification of highly configurable graphics subsystems. To gain insight in this type of systems, research has been done in spatial subdivisioning techniques for a class of radiosity algorithms.

In 1991, work is being done on identifying research areas for the CWI multidisciplinary research on Scientific Visualization. This new research theme is scheduled to start in 1992.

PUBLICATIONS 1991

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3. D.C.A. BULTERMAN, G. VAN ROSSUM, R. VAN LIERE (1991). A structure for transportable, dynamic multimedia systems. *Usenix Summer Conference 1991*, Nashville.
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15. A.A.M. KUIJK (ed.) (1991). *Advances in Computer Graphics Hardware III,* EurographicSeminars, Springer-Verlag, Berlin.

RESEARCH GROUP IS 2

TITLE: Interaction

TITEL: Interactie

REPORT ON 1991

In the past year, the group, which is only one year old, has actively taken part in the specification and the implementation work of the Manifold system, aspects of its visual programming. As a first larger example (and related also to the NEW API activities), the GKS Input Model has been fully described with the help of the Manifold computing model; this has proven the feasibility of this model to be used for future generation interactive graphics standard (the paper resulting from that work has been offered for publication lately).

PUBLICATIONS 1991

Papers in Journals and Proceedings

1. F. ARBAB, I. HERMAN (1991). MANIFOLD: A Language for Specification of Inter-process communication. *Proceedings of the EurOpen Autumn Conference*, Budapest (†).
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6. CS-R9127 D. SOEDE, F. ARBAB, I. HERMAN, P.J.W. TEN HAGEN (1991). *The GKS input model in Manifold.*
7. CS-R9142 F. ARBAB, I. HERMAN, P. SPILLING. *An overview of Manifold and its implementation.*

RESEARCH GROUP IS 3

TITLE: Intelligent CAD systems

TITLE: Intelligente CAD-systemen

REPORT ON 1991

Our research activity in this group can be roughly divided into three areas.

1. *Design knowledge representation.* This effort is primarily focussed on a design theory suitable for intelligent CAD, its implication on design knowledge representation, and the use of AI techniques for its implementation. The language ADDL (formerly called IDDL) was designed for this purpose. It is based on object-oriented and logic programming paradigms. The ADDL system has a two-level architecture with meta-level and object-level scenarios. Each level has its own interpreter for its scenarios, which are sets of if-then rules. Architectural design has been the test-bed of the ideas and tools developed in this effort. Control architectures for coordination of dynamic and interactive tasks, which frequently arise in design, is another focus of research. Closely related issues involving incomplete information and belief revision are also being studied.
2. *Design object representation.* The primary focus of this effort is on design object modelling and its representation. An important aspect of a design object in most design applications is its geometric shape. The field of geometric modelling has by now matured to the point that efficient representation and manipulation of the nominal geometries of solids and surfaces are commercial reality. In the context of intelligent CAD, this ability is far from sufficient. Using incomplete geometric information, reasoning with the high-level semantics of geometric entities and relationships, and dealing with geometric constraints are vital necessities. Our experiments with some of the issues in design object representation produced a language (Oar) that combines the power of logic programming for expressing declarative facts about objects and their interrelationships, with the concept of message passing as the mechanism for triggering the imperative knowledge associated with objects. Oar is being used elsewhere to implement a system for incremental satisfaction of geometric constraints in the context of a small two-dimensional drafting application. Further development and extension of this work will continue under this effort. Efficient storage, manipulation, and retrieval of large amounts of information define a different focus of activity in this effort. There are significant differences between the requirements of Intelligent CAD systems and the premises of conventional database systems. Consequently, contemporary databases do not provide adequate solutions for the problems of information management in Intelligent CAD. Nevertheless, many of the traditional concerns in the field of databases are still valid and relevant in this domain, e.g. management of large volumes of persistent

data, security, concurrent multiple access, updates and coherence, locking etc. Furthermore, some of the major requirements of Intelligent CAD systems point in the same direction as some of the current trends in databases research. These include object-oriented-ness, dynamism, evolution, heterogeneity, deductive databases, distributed databases, versions, etc.

3. *Communication and interaction.* The focus of this effort is on communication and interaction between processes. This is a fundamental area of research with applications in a wide range of seemingly different problems. Among them, programming of massively parallel systems, coordination of multiple agents in distributed problem solving, and flexible user interface management systems. Our ideas in this area have culminated in a new language for coordination of the interaction between independent processes, called Manifold. Manifold is a language for defining dynamic interaction among a set of processes. A manifold definition coordinates the communication between a number of independent processes to perform a higher level task. Manifolds are themselves processes and can cooperate with other processes to perform still higher level functions. The novelty of Manifold is that unlike many other multi-process languages and systems, the primary focus of attention in Manifold is the interaction among the processes, not the processes themselves. A special, but important, case is when one of the processes involved in a system is a person. The proper interface to such a process is quite different from that for other processes: it involves some degree of graphics (ranging from simple character shapes, to two-dimensional graphics, to three-dimensional visualizations), special timing constraints, various presentation filters, and multi-media formats. In addition to our work on Manifold, advanced AI techniques and context-dependent anticipation of user actions are among the issues being studied in the area of intelligent user interfaces. The paradigm of event-driven cooperation among independent agents that is supported by Manifold seems to provide an appropriate high-level control in complex open systems. Specifically, it seems to be applicable to intelligent CAD system architecture. Much of a designer's activities involves manipulating a representation of a design object by adding new information, changing, and inspecting. Except for the simplest examples, this manipulation is quite complex because it involves multiple aspects of the design objects and implies different interpretations of its representation. The most natural architecture to accommodate such an activity is that of multiple cooperating expert agents. In an intelligent CAD system, the context in which such agents cooperate may change in time. Even the exact purpose of the activity of an agent may be initially unspecified: it may, for instance, discover its exact purpose in time by inspecting the status and the contents of the design object representation.

PUBLICATIONS 1991

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14. CS-R9141 R.C. VELTKAMP, F. ARBAB. *Geometric constraint satisfaction.*

15. CS-R9142 F. ARBAB, I. HERMAN, P. SPILLING. *An overview of Manifold and its implementation.*

Other publications

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17. H. YOSHIKAWA, F. ARBAB (eds.) (1991). *Intelligent CAD III: Selected Contributions from the Third IFIP WG5.2 Workshop on Intelligent CAD,* Osaka, Japan, Elsevier Science Publishers.

Department of Computer Systems and Telematics

HEAD OF DEPARTMENT: Dr. D.C.A. Bulterman

LIST OF RESEARCH GROUPS

CS 1 Multimedia kernel systems
CS 2 Silicon protocols and operating systems

		CS1	CS2	CS3	working	budget	ext.	de-		guests	remarks
					time in fte	time in fte	paid	tached			
appointed											
Bulterman	head dept.	0.50	0.50	pm	1.00	1.00					
Rossum,van	researcher	1.00			1.00	1.00					
Jansen	sc.programmer	1.00			1.00	1.00					
Mullender	sc.programmer	0.50			1.00	1.00					
Winter	sc.programmer	0.50			1.00	-		0.50	NW		
vd Horst	sc.programmer	0.50			1.00	-		0.50	BS		
Hardman	programmer	0.25			1.00	-		0.25	OWL		
Bührman	jr. researcher	0.95			1.00	-		0.95	SOZA		
research time		5.20	0.50	0.00		4.00					
request	jr. researcher	•			1.00						
request	jr. researcher	•			1.00						
request	jr. researcher	•			1.00						
request	jr. researcher		•		1.00						
request	jr. researcher		•		1.00						
request	jr. researcher			•	1.00						
request	jr. researcher			•	1.00						

RESEARCH GROUP CS 1

TITLE: Multimedia kernel systems

TITEL: Multimedia kernel systemen

LIST OF PROJECTS

CS 1.1 Operating systems evaluation;
CS 1.2 Systems aspects of user interface support.

REPORT ON 1991

At present, we have investigated two key areas of systems-level multimedia support: the adaptation of existing distributed operating systems for multimedia work (project CS 1.1) and the investigation of the systems-interface aspects of multimedia user interfaces (CS 1.2). The current status of both of these projects will be briefly outlined below.

CS 1.1 Operating systems evaluation

The goal of this work is to select an operating systems base for future experimentation. At present, we have had a group porting the Amoeba operating system to our multimedia platform (a Silicon Graphics 4D25G); this work is expected to be completed by September, 1991. Use of Amoeba has several advantages for our work: first, it is a system that is still evolving in functionality, meaning that (in coordination with researchers at the Free University in Amsterdam) we can propose extensions that are not limited by broad compatibility concerns. It is also an operating system with excellent communication performance characteristics (a key ingredient for multimedia applications). While these reasons have provided the motivation for the use of Amoeba, the final choice of this system will depend on its perceived robustness and the degree to which constructive partnerships can be made with other groups using this system (most notably at the Free University Amsterdam). Other operating systems that are being investigated for consideration are CMU's Mach-3 kernel and the OSF/1 kernel. If we decide to use Amoeba, then we will also work together with the group of Mullender at the University of Twente (who is planning to base his research on the Mach-3 kernel) in order to insure the inter-operability of our results. Our present work has resulted in one conference paper, to be presented at the EurOpen Fall Technical Conference in Budapest.

CS 1.2 Systems aspects of user interface support

The first-year goals of this project are to develop a deeper understanding of the problems associated with providing operating systems support for higher-level interface functions. As an initial project, we developed a document structure that could be used to encode representation-independent (and target-system independent) encoding of multimedia documents. The emphasis of this

structure was to partition the general processing pipeline in such a way documents could be defined for a heterogeneous environment while retaining basic document synchronization and presentation information. As a follow-up to this work, we will investigate specific representations for particular applications and target platforms. This research will be done in coordination with a number of other projects at CWI, notably AA 3 (Computer Systems and Ergonomics), AA 4 (Databases), BS 4 (Image Analysis) and IS 2 (Interaction). The initial focus of this work will be to investigate document manipulation primitives for creating, recalling and transferring multimedia data among heterogeneous hosts, with later work in the year aimed at developing a proof-of-concept demonstration system for the initial stages of our multimedia work. Our present work has resulted in one conference paper, presented in June 1991 at the USENIX Multimedia Research and Systems Conference in Nashville, TN (USA). The basic aspects of the operating systems work on CS 1 have their roots in the Amoeba project.

PUBLICATIONS 1991

Other publications

1. D.C.A. BULTERMAN, G. VAN ROSSUM, R. VAN LIERE (1991). A Structure for Transportable, Dynamic Multimedia Documents. *USENIX Summer Technical Conference on Multimedia,* June 1991.
2. D.C.A. BULTERMAN, D.T. WINTER, G. VAN ROSSUM (1991). Multimedia Synchronization and UNIX—or—If Multimedia is the Problem, Is UNIX the Solution? Preprint of *Proceedings, EurOpen Fall Technical Conference,* Budapest, September 1991.

RESEARCH GROUP CS 2

TITLE: Silicon protocols and operating systems

START OF RESEARCH GROUP: foreseen in 1992

Multidisciplinary Research

LIST OF RESEARCH THEMES

MR 3 Environmental research
MR 4 Computational geometry
MR 5 Scientific visualization

MULTIDISCIPLINARY RESEARCH MR 3

TITLE: Environmental research

TITEL: Wiskunde en milieu

INTRODUCTION

The term 'environmental research' covers a wide range of scientific activities in many natural sciences. Environmental research is often multidisciplinary and involves the interfacing of sciences like meteorology, oceanography, hydrology, geology, biology, physics, chemistry and mathematics. Mathematics is vital since it is an essential resource for setting up theories and models for a wide diversity of problems. Mathematics provides a universal language for modelling purposes in the natural sciences and disciplines from industry and engineering.

We use the term 'environmental mathematics' for denoting all activities concerned with mathematical modelling and computer simulation in the environmental sciences. These activities may concern theory, algorithms, computer implementation, and may interface with virtually any mathematical and computational discipline. For instance, modelling based on differential equations and numerical mathematics (computational fluid dynamics), image reconstruction, inverse methods and parameter estimation, dynamical system theory and chaos, statistics, operations research, optimization and optimal control, large-scale modelling using super and parallel computers together with visualization and massive-data handling, biomathematics, etc.

FIELD OF STUDY

Science and technology have benefitted greatly from the systematic use of mathematics. As a result, there exists nowadays a unanimous opinion that mathematics is increasingly vital to science and technology, and therefore to society itself. In line with this positive development, the aim of the research program 'Environmental Mathematics' is

- The development of advanced mathematics for the environmental sciences.
- Contributing to strategic and applied multidisciplinary environmental research.
- Transfer of knowledge and interaction and communication with the environmental science community.

POLICY

This special program will combine all CWI research projects with applications to the environmental sciences and forms part of the research program of the institute. In due time the program is expected to get input and staff from many CWI research groups. This implies that particular projects should also fit in the research programs of the involved CWI departments. Of course, in the

selection of projects the aim of this special program should be put in the foreground. The policy for entering CWI projects is based on three main criteria:

1. To safeguard the aim of promoting and developing advanced mathematics in environmental research, projects should not be carried out in isolation from real applications. Various ways of relating a proposed project with applications are conceivable (contract research, joint work with environmental scientists, concrete applications discussed in environmental literature). A minimum requirement is that environmental scientists show a distinct interest in the project.
2. To capitalize on past successful CWI research, as well as to maintain a high scientific quality, projects should fit sufficiently well in existing research programs of the scientific departments. A sufficient degree of in-house expertise should be available, either from existing CWI staff, or from long-term visiting researchers. In case of important projects experienced long-term visitors should be recruited, if necessary.
3. To promote transfer of knowledge, preference should be given to projects that also serve an educational purpose and involve or lead to Ph.D. or post-doc research. This is an important requirement since there is a growing need for young, skilled scientists in multidisciplinary environmental research.

Funding

Apart from these general criteria, we should also mention the issue of funding. Externally funded projects are attractive, as CWI has to earn about 30% of its own budget. However, there should be enough room for projects for which external funding is not directly available. This is of importance in view of the long-term strategic goal of the program which necessitates a good balance between theory and practice.

Computer simulation and scientific computing

New projects should also be judged on their own merits in relation to important scientific developments. A development which cannot be ignored is the rapidly increasing significance of computer simulation and scientific computing, as recently brought up in the Rubia report. From this report we quote, 'The field of computing is on the verge of a new revolution. During recent years the amount of computational power at the disposal of scientists and engineers (super and parallel computers) has increased dramatically. This has enabled them to envisage approaches that will revolutionize all fields of science, as has already taken place in the structural analysis of astronautical and other more mundane engineering systems'. Another interesting quotation from this report reads, 'Scientific and societal progress, industrial competitiveness, the understanding and control of environmental factors necessary to human well-being will be governed by the availability of adequate computing power'. The Rubia report emphasizes the importance of high-performance computing for Europe and also explicitly mentions subjects of direct relevance to this research program.

LIST OF PROJECTS

MR 3.1 Adaptive-grid software for partial differential equations in environmental problems;
MR 3.2 Mathematical techniques for the study of the population biology of infections;
MR 3.3 Numerical simulation of brine flow for predicting the potential transport of radioactive pollutants, an environmental study using a CRAY supercomputer;
MR 3.4 System theoretic and stochastic properties of the climate model IMAGE;
MR 3.5 Numerical analysis of the climate model IMAGE;
MR 3.6 Removal of sensitivity to the initial state in climate models;
MR 3.7 Algorithms for mathematical air pollution models;
MR 3.8 A massive parallel air pollution model, an environmental study on a Connection Machine supercomputer;
MR 3.9 Pollution by sediment transport in shallow waters;
MR 3.10 Mathematical and numerical modelling of soil transport processes in the root zone.

PROJECT MR 3.1

TITLE: Adaptive-grid software for partial differential equations in environmental problems

Environmental modelling frequently leads to systems of ordinary and partial differential equations for which numerical techniques have to be used. The computer implementation of these techniques becomes more and more involved and the environmental scientists should be supported here. To ensure progress and to cope with the growing complexity of environmental modelling, the environmental scientists should be able to concentrate on their problem formulation and validation, and not be hindered by numerical intricacies. The above considerations have led to a cooperation between RIVM's department CWM (Center for Mathematical Methods) and CWI's numerical mathematics department. The goal of the cooperation is the development of advanced, user friendly numerical software for environmental problems of interest to the various research laboratories of RIVM. Currently the project concentrates on the numerical modelling of brine transport near and away from underground salt formations, which serve as a possible repository for high-level radioactive wastes. The brine-transport models are used to assess the risk of potential transport of pollutants to the geosphere by groundwater flow.

STARTING DATE: January 1991.

PROJECT MR 3.2

TITLE: Mathematical techniques for the study of the population biology of infections

Veterinary epidemiology is the study of the spread, in space and time, of diseases in animal populations, with the objective to trace factors that are responsible for or contribute to the occurrence of a disease. Mathematical models can enhance the understanding of the causal relationship between phenonema at the population level and mechanisms which act in and between individuals and, moreover, they are helpful in evaluating the possible effect of control measures. The cooperation between CDI and CWI aims at the operationalization of recent abstract mathematical results concerning the basic reproduction ratio R_0 in the context of specific animal diseases, in particular Aujeszky's disease.

STARTING DATE: September 1, 1990.

PROJECT MR 3.3

TITLE: Numerical simulation of brine flow for predicting the potential transport of radioactive pollutants, an environmental study using a CRAY supercomputer

This project is related to project MR 3.1 and focusses on large-scale numerical brine-flow computations for which supercomputers like the CRAY Y-MP should be used. In one space dimension (1D) the numerical computation of high-salt concentration profiles is well feasible on workstations like SUNs and SGIs or mini-supercomputers like the ALLIANT. However, in 2D, and of course in 3D, the anticipated runtime and memory use may become so large that access to supercomputers becomes vital.

STARTING DATE: January 1992.

PROJECT MR 3.4

TITLE: System theoretic and stochastic properties of the climate model IMAGE

IMAGE, developed at RIVM by Rotmans, is an integrated model aiming at providing a better understanding of greenhouse phenomena. Within IMAGE the greenhouse problem is modelled as a dynamic system composed of a great variety of submodels, called modules. These modules are based on mathematical models describing, e.g., physical-chemical processes in the Earth's

atmosphere relevant to the greenhouse effect. This project serves to examine the system theoretic and probabilistic properties of the current set of modules. System theory is the study of dynamical systems as mathematical models of dynamic behaviour. The predictions of a model may be poor if the model does not satisfy certain system theoretic properties. Further, at present the modules do not contain stochastic elements, though it appears that probabilistic modelling of certain aspects of these submodels would be very natural and worthwhile.

STARTING DATE: as early as possible after acceptance by NOP.

PROJECT MR 3.5

TITLE: Numerical analysis of the climate model IMAGE

IMAGE, developed at RIVM by Rotmans, is an integrated model aiming at providing a better understanding of greenhouse phenomena. Within IMAGE the greenhouse problem is modelled as a dynamic system composed of a great variety of submodels, called modules. These modules are based on mathematical models describing, e.g., physical-chemical processes in the Earth's atmosphere relevant to the greenhouse effect. The mathematical models need to be refined in order to aid to a better understanding of the interaction of the various processes and to enhance the reliability of IMAGE as a prediction tool. This subproject serves to provide the required research support on all involved aspects of numerical mathematics. Numerical mathematics is concerned with the construction, analysis and computer implementation of approximative methods for solving mathematical problems. It plays a crucial role in IMAGE because the mathematical equations encountered (nonlinear ordinary and partial differential equations) must be treated by numerical methods. The research will focus on implementing in the IMAGE model recent advanced numerical methods as used for instance in modern CFD (computational fluids dynamics) applications.

STARTING DATE: as early as possible after acceptance by NOP.

PROJECT MR 3.6

TITLE: Removal of sensitivity to the initial state in climate models

Models for nonlinear physical and ecological phenomena may exhibit growth of error due to sensitive dependence upon incomplete or wrong initial data. This growth may mask other uncertainties in the model output due to poorly estimated parameters, physical effects, and numerical errors which show up when models are implemented on the computer. The problem is to control the wrong initial data effect so that the need of a better parameter estimation, etc.

can be detected. Finding solutions to this control problem has important applications for climate modelling. An example is provided by the baroclinic model of the currents in the southern parts of the oceans which are important for the heat balance in the southern hemisphere. One of the main aims of this project is to study and adapt the sentinel method of Professor Lions (Paris) for climate modelling. This method is new and highly promising and up to now it is used only in a small circle of applied mathematicians. Both analytical and numerical aspects will be taken up.

STARTING DATE: as soon as possible after acceptance by NOP.

PROJECT MR 3.7

TITLE: Algorithms for mathematical air pollution models

Air pollution caused by industrial emissions of toxic chemical substances is a major environmental problem in most countries of the world. The transport of substances by air is mathematically modelled by so-called LRTAP (Long-Range Transport of Air Pollution) models. Advanced LRTAP's should couple advection (the most important transport mode) to diffusion and to chemical reaction phenomena. Also phenomena like radiation, precipitation, emission, deposition, etc. should be modelled. Most importantly, due to the appearance of more and more chemical species in industry, biochemistry, etc., they further should take into account as many (polluting) substances as there are active in the atmosphere. Altogether this implies that advanced LRTAP models belong to the computationally most expensive models in computational environmental research (and computional fluid dynamics). The aim of this project is to contribute to the development of advanced numerical methods for LRTAP modelling.

STARTING DATE: January 1992.

PROJECT MR 3.8

TITLE: A massive parallel air pollution model, an environmental study on a Connection Machine supercomputer

This project should serve as a demonstration project to enlighten the role modern large-scale scientific computing can play for environmental problems. The plan is to build this project around a highly sophisticated, massive-parallel computer. A good candidate is the Connection Machine supercomputer which has as many as 64.000 processors. A plan will be developed when project MR 3.7 is well underway.

PROJECT MR 3.9

TITLE: Pollution by sediment transport in shallow waters

This project is in preparation and planned to be a continuation of the existing cooperation between NW, CWI's numerical mathematics department, and DGW, the Tidal Waters Division of RWS (Rijkswaterstaat), on the design of three-dimensional numerical models for simulating water flows in a variety of practical situations.

PROJECT MR 3.10

TITLE: Mathematical and numerical modelling of soil transport processes in the root zone

Transport models have traditionally played an important role in soil physics. In the Netherlands these models are studied at the Institute for Soil Fertility Research (IB-DLO). A particular question of interest is to explain how geometric properties of the soil influence the transport processes. Concepts from fractal geometry are just beginning to be used in describing soil structures like micropores or capillary networks created by plant roots and soil organisms. Difficulties arise if one tries to connect the physical properties of the soil to the biological processes of uptake of water, nutrients and gases by plant roots, in particular when trying to predict the transport of chemical pollutants in the soil and their uptake by the plants. The first objective of this project is to formulate a mathematical description of the diffusion process and to compute the solution numerically in order to test existing analytic approximations. At a later stage more intricate situations will be handled for which no analytic solutions are available. A second objective is to use computerized image analysis to obtain the required distance distributions directly from images of the soil structures.

STARTING DATE: as soon as possible in 1992.

MULTIDISCIPLINARY RESEARCH MR 4

TITLE: Computational geometry

TITEL: Computationele meetkunde

GENERAL POLICY

Computational geometry designs and analyzes algorithms for geometric problems, usually in low-dimensional (two- or three-dimensional) euclidean spaces. Typical examples are determining the convex hull of a given set of points, finding a shortest path between given points avoiding certain obstacles, determining a Voronoi-diagram or a triangulation, art gallerey and visibility problems, and polygon decomposition.

The novelty of the field comes from the current demand to solve geometric problems in practice very fast, viz. instantly. This is essential e.g. at steering a robot or implementing computer graphics. Many of the algorithms presently available generally are too slow for these purposes. One needs algorithms that run in at most about linear time.

This makes the field of interest to several research fields. There is a mathematical component (discrete geometry), an operations research component (combinatorial optimization), a theoretical computer science component (algorithmics), and a practical computer science component (implementation).

Short-term and current activities:

- research in routing problems for large-scale networks, in particular finding fast ($n \cdot \log n$) algorithms, with application to the design of chips;
- research in visualization problems;
- running the seminar 'Combinatorics, Algorithms, and Geometry' that deals mainly with discrete and computational geometry, in particular the complexity aspects of geometric problems;
- training of Ph.D. students in computational geometry;
- strengthening the cooperation between the different research groups at CWI relating to computational geometry.

Long-term activities:

- smoothening the line from conception to implementation of computational geometry algorithms, possibly by establishing a computational geometry laboratory;
- strengthening and enlarging the cooperation with research groups on computational geometry at other institutions, also by joint research projects (sponsored possibly by international agencies);
- organizing Workshops and Special Years on (topics in) computational geometry and related fields.

MULTIDISCIPLINARY RESEARCH MR 5

TITLE: Scientific visualization

TITEL: Wetenschappelijke visualisatie

LIST OF PROJECTS

MR 5.1 Computational steering;
MR 5.2 Distributed Visualization;
MR 5.3 Three dimensional imagery.

INTRODUCTION

Scientific visualization is an emerging field at the borders of computer science, numerical mathematics and modern statistics. It has been defined as 'both a tool for interpreting image data fed into a computer, and for generating visual images from complex multi-dimensional data'. Its purpose is to facilitate direct visual communication and interaction between the computer and the (scientific) user. Key concepts are **visual information** and **interaction**. Existing scientific methods are enhanced by increasing the user's ability to see results, interrogate and navigate through datasets, and to supervise and dynamically control the computational processes. Research in scientific visualization is inherently multidisciplinary and has many interrelations with existing research interests at CWI.

RESEARCH AREA

A landmark report commissioned by the US National Science Foundation, defined scientific visualization as *'a tool both for interpreting image data fed into a computer, and for generating images from complex multi-dimensional data sets. It studies those mechanisms in humans and computers which allow them in concert to perceive, use and communicate visual information'*. The key ideas for us are the concept of **visual information** and the need for direct **interaction** between the computer and the user.

Visual information embraces 'real' visual scenes (such as digital images), mapped data (weather maps, geographical data) visual presentations of numerical data (plots, dynamic graphics, color coded image displays) and visual methods of communication between computer and user.

For centuries scientists and mathematicians have searched for methods of presenting data in ways that communicate essential information and lend insight into the underlying scientific or computational process. This need has become increasingly urgent since the computer 'data explosion'. Visualization of data is the obvious solution, because of the unique talents of the human visual system.

The purpose of *scientific* visualization is thus to enhance existing scientific and numerical methods by increasing the scientist's ability to see data and

understand the results of computations, to interrogate and navigate through datasets, and to supervise and dynamically control the computational processes.

The perceived importance of scientific visualization can be judged from the explosive growth of national and international scientific visualization support centers. The idea of these centers is to provide the necessary know-how for scientists to visualize and interpret their results. These visualization centers are often equipped with powerful hardware and a large number of specialized software packages.

Visualization has become technically possible through the rapid development of computer hardware: high-resolution image displays, graphics hardware, memory devices, workstations and supercomputers. Yet this new hardware has stimulated even greater demand for visualization techniques, because one can now capture and compute huge multidimensional datasets.

The ability to capture digital images and complex signal data, and to perform near-realistic simulations or computations, has expanded the horizons of fields such as genetics, fluid dynamics, civil engineering and biomathematics, and has created whole new disciplines such as computational chemistry. New mathematical research fields have been stimulated by the ability to study fractals, chaotic attractors, higher-dimensional euclidean geometry, stochastic simulations and combinatorial optimizations.

Interaction means that the user can control the computational processes generating the display, with immediate and direct effect. Direct interaction enhances realism (for example, the user can 'move' through a scene). More importantly, interaction is communication in the reverse direction, user to computer. User control over the parameters of a simulation or complex computation can greatly improve our insight into these processes. Ultimately we can envisage physical processes being controlled by a user through a visualization pipeline, for example, controlling a microscope stage or a biotechnology process.

Modern interactive statistical graphics, form an important class of visualization techniques. These are descendants of classical mathematical plotting techniques, but their novelty lies in the interaction with the user. For example, MacSpin and similar packages allow a set of several hundred multidimensional data points to be presented as a point cloud in three dimensional space, which can then be rotated under the control of the user (with the mouse) to search for interesting views (projections) of the data. Brushing and multiple-plot techniques allow the user to select and examine individual elements of the display, and to see the correspondence between different views of the selected items.

Long term goals

The aim of the research theme on scientific visualization is to trigger the following long term activities :

- *to encourage interdisciplinary mathematics, computer science and ergonomics research in the field of scientific visualization.*

  The research activities will be centered around a small number of carefully

selected projects. Due to the nature of scientific visualization these projects will have a strong commitment towards applications.
The results of each project must be evaluated both on research quality and on the effectiveness of the interdisciplinary work that the project envisioned.

- *to expose other research groups within the CWI to the merits of modern visualization methods and techniques.*
  The goal of this activity is to provide other CWI researchers with the knowledge of modern visualization techniques and the application of these to their own research. This type of support is very difficult to place in existing CWI support departments due to the very specific and detailed character of visualization techniques.
- *to act as a central meeting place for national and international scientific visualization researchers.*
  This activity is aimed at making the CWI an outstanding and well known center for research on scientific visualization. Well known visualization researchers must have the opportunity to visit and exchange information with other researchers in the field. Seminars, workshops and visualization courses must be organized to meet this aim.

SHORT TERM RESEARCH ACTIVITIES

The first Common Research Area that has been selected is *the role of interaction in the visualization cycle*. Each project will result in novel visualization paradigms and formalisms in the the area of interactive visualization.

The following is a list of the initial research projects:

MR 5.1 Computational steering

The goal of computational steering, a central theme in current visualization research, is to provide users with techniques that allow information to be gathered and interpreted from a simulation while the simulation is still progressing. It has been shown that these techniques will greatly shorten the modeling/simulation/interpretation life cycle.

The application area for this research will be an environment which models, computes and visualizes the Navier-Stokes equations.

This research will be a joint activity of at least NW 2 and IS 1. It is envisioned that many project groups in the CWI will profit from the results of this study.

MR 5.2 Distributed Visualization

It is quite clear that parallel and distributed processing will play a major role in interactive visualization systems. This project aims at researching the effect that distributed computing will have on the visualization process as a whole.

We propose to research distributed visualization techniques by applying these to a particular class of volume rendering algorithms. The problem of sampling and reconstructing the three-dimensional structure of a complex

object is pervasive in many areas of visualization and computer vision research.

Close collaboration with other CWI research groups is also expected, in particular, the multimedia and database research groups (AA). In the later stages of the project, the optimization group (BS) is also expected to get involved.

MR 5.3 Three dimensional imagery

This project will study the computational efficiency and visual effect of algorithms for the display of 3D images. It will also examine basic 3D image processing algorithms, including spatial filtering, deconvolution, and three-dimensional morphology.

The application area for this research will be *confocal microscopy* where several participants already have challenging problems (soft tissue imaging, VLSI chip inspection, bone microstructural imaging).

Personnel currently involved: Roerdink (AM \ DLO-Institute for Soil Fertility Research), Heijmans, Baddeley (BS), Van Liere (IS).

WORKING PLAN 1992

The activities in 1992 will focus on:

- *build up of the research group*
  Allocate and train personnel for the three research projects.
- *build up of the supporting infrastructure*
  Central to the software supporting infrastructure is the availability of these tools for other project groups within the CWI. An easy to use, yet powerful, software environment is essential. This strategy will allow researchers within the visualization group to easily share the aquired expertise with others.
  The initial hardware infrastructure will concentrate on high-bandwidth connectivity between a number of workstations and the central compute server. The build up of such a hardware infrastructure can be combined with the hardware environment envisioned by the multimedia research group.
- *knowledge transfer*
  Initiate a national seminar series on scientific visualization. The series will focus on applications of scientific visualization techniques in the sciences. The intended audience are scientists from other national research institutes.
  To give two courses on scientific visualization. The first course will be given in February with the University of Amsterdam as a course of the Academia van Informatica.
  Strengthen the collaboration with other ERCIM institutes.