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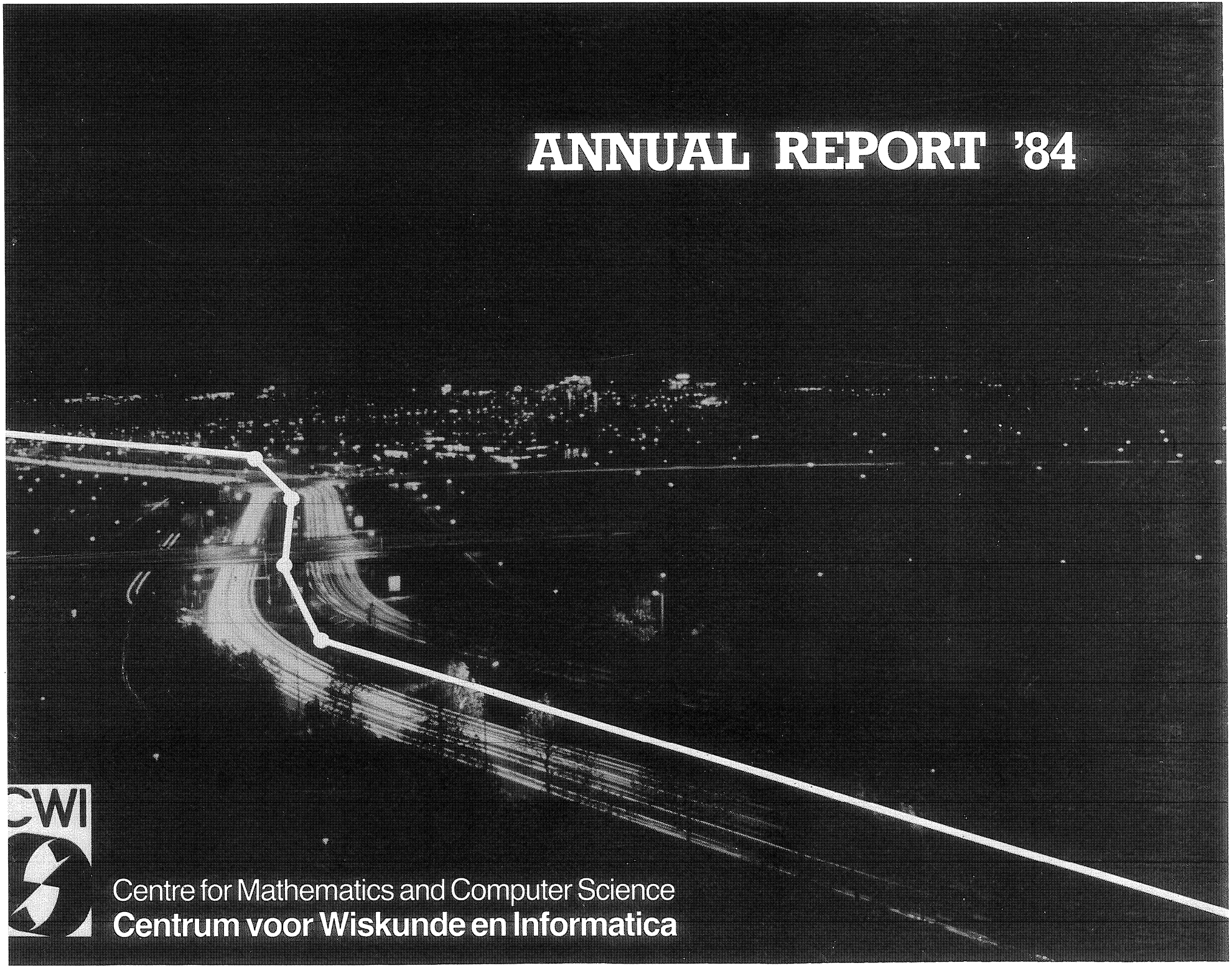

CWI

Centre for Mathematics and Computer Science

Centrum voor Wiskunde en Informatica

The cover is an illustration of the STW sponsored projects on statistical analysis of traffic flows and on vehicle routing.

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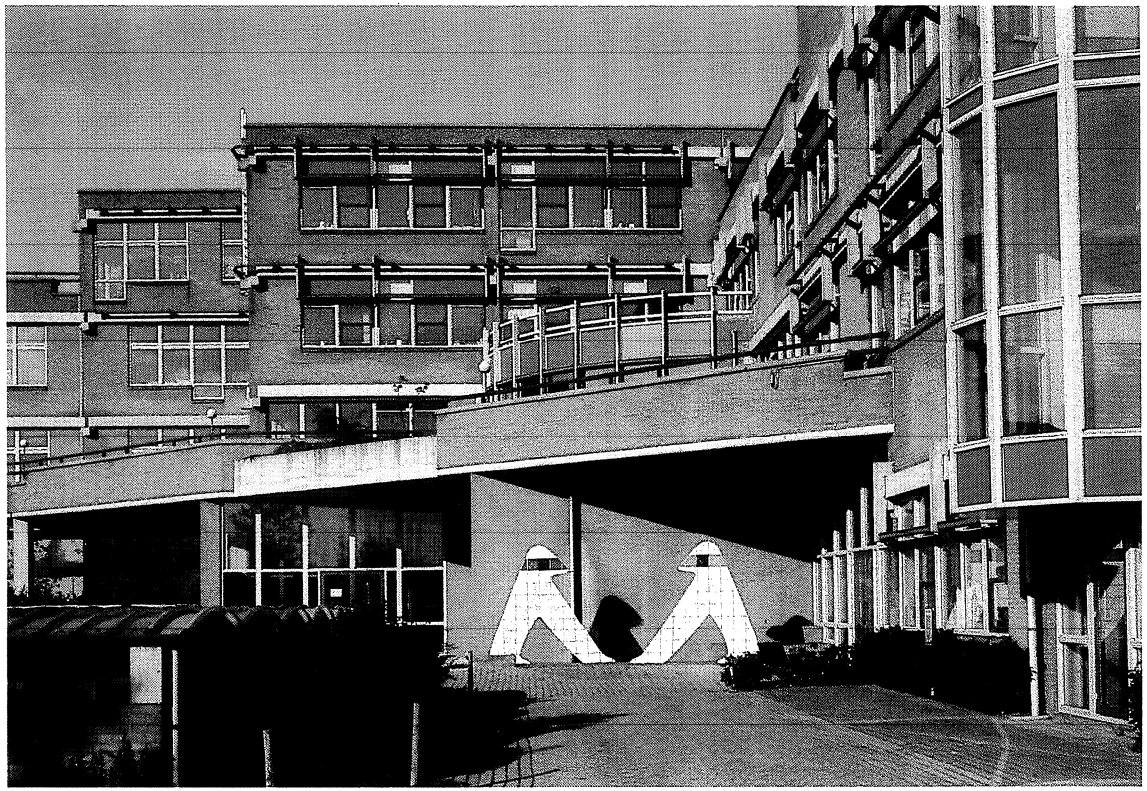

The Mathematical Centre, founded 11 February 1946, is a non-profit institution for the promotion of pure and applied mathematics and computer science. It is sponsored by the Netherlands Government through the Netherlands Organization for the Advancement of Pure Research (ZWO).

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CONTENTS

Introduction

The Centre for Mathematics and Computer Science (CWI) is the research institute of the Foundation Mathematical Centre (SMC), which was founded on 11 February 1946. Until September 1983 the institute bore the same name as the foundation, but it has since been changed so as to give a more precise description of the actual disciplines covered by the institute.

The aims of the foundation reach farther than the maintenance of a research institute, though naturally such an institute is a very important aspect of the realization of its goals. According to the statutes of the foundation, its purpose is 'to foster the systematic pursuit of pure and applied mathematics in the Netherlands'. SMC tries to achieve this on the one hand by stimulating national and international contacts, not only between mathematicians but also between mathematicians and practitioners of disciplines to which mathematics can make relevant contributions; on the other hand, by doing mathematical research and directing the research of young mathematicians, by pursuing an active publications policy, organizing courses, colloquia, and lectures, carrying out consultation projects, making available computing facilities, etc.

SMC is sponsored by the Netherlands Organization for the Advancement of Pure Research (ZWO). The Dutch universities and research institutes may apply to ZWO for the financing of research projects. As of 1981, ZWO has delegated part of this task to SMC: those research projects concerning mathematics which used to be submitted to ZWO for evaluation and financing, are now handled by SMC, which is also responsible for the supervision of financed projects. As part of this new function, SMC governs seven national working communities, viz. concerning Numerical Mathematics, Stochastics, Discrete Mathematics, Operations Research and System Theory, Analysis, Algebra and Geometry, and Logic and Foundations of Mathematics.

From the very first, computer science has been a major concern of SMC. The first computer in the Netherlands was constructed at its institute. Closely related to this was the pioneer work of the Mathematical Centre in program development and schooling in the fields of hard- and software. Due to its (partially) self-developed computer systems, the Mathematical Centre was for a long time able to supply the computer facilities needed by the two universities in Amsterdam. Eventually, however, the need grew to such an extent that in cooperation with both universities a joint computer centre was founded (SARA, 1971). CWI continues to develop new applications which are then made available through SARA.

At the time of SMC's foundation, computer science was still innocently viewed as a branch of mathematics. It has since grown into a discipline of its own right. Therefore Dutch computer scientists felt the need of an independent research organization for computer science in the Netherlands (SION, 1982), which is similar to SMC in that it is an organization of ZWO, and sponsors research in the Netherlands. SION governs six working communities, viz. on Theoretical Computer Science; Software and Architecture; Pattern Recognition and Artificial Intelligence; Interactive Systems; Performance Evaluation, Modelling and Simulation; and Management of Computing and Information Systems. SION shares its bureau with SMC at CWI.

Organization SMC

SMC is administered by a Board of Trustees, in which the Minister of Education and Science is represented. The actual administration has been delegated to the Board of Directors of SMC, which is also in charge of its institute CWI. A Scientific Advisory Committee supports the Board of Trustees and Directors in developing the research policy of the foundation. This committee is formed by members of the National Working Communities, of CWI, and others selected by the Board of Trustees. Regarding CWI, the Boards of Trustees and Directors are supported by a general Advisory Council and by a Policy Advisory Council. There are, moreover, a number of Advisory Committees for the specific disciplines, which recommend and supervise the research of CWI's scientific departments.

CWI

The goal of CWI is to do fundamental and

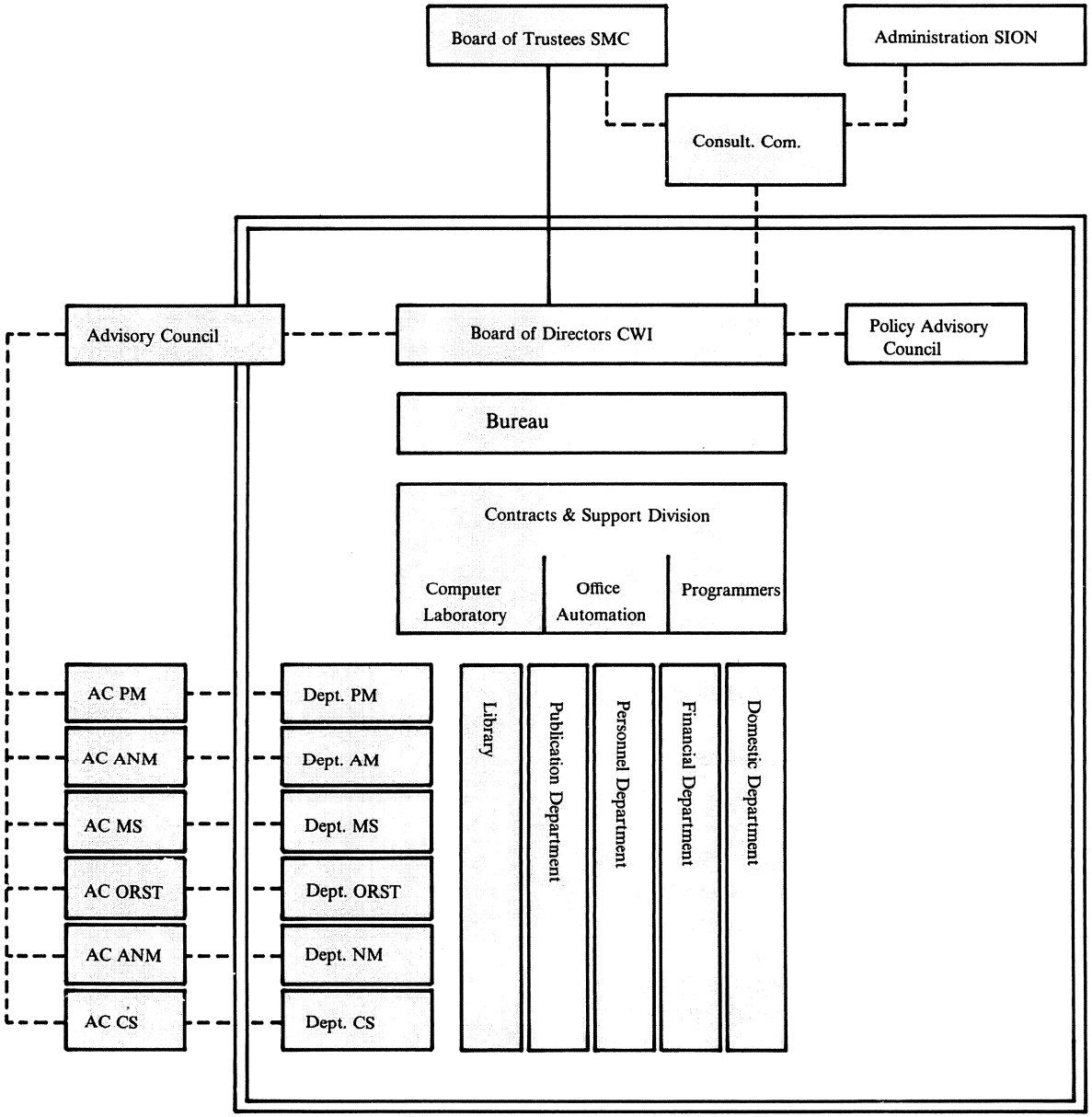


Fig. 1 The Centre for Mathematics and Computer Science

advanced research in mathematics and computer science, with special attention to those areas to which the research may have relevant applications. The research is fundamental in that it is mainly concerned with those problems for which there are as yet no standard methods of solution. It is advanced in that CWI aims at research work which is of a high level both nationally and internationnally. Preference is given to those subjects which, from an international point of view, look likely to have interesting developments.

The research at CWI is organized in six scientific departments:

- Pure Mathematics;
- Applied Mathematics;
- Mathematical Statistics;
- Operations Research and System Theory;
- Numerical Mathematics;
- Computer Science.

There are, moreover, a number of supporting service departments; besides the Personnel and Financial Departments, there are the Contracts and Support Division, the Publication Department, and the Library.

The subdivision of the research into six departments is less rigid than it appears, for there exists considerable collaboration between the departments. This is a matter of deliberate policy, not only in the selection of research topics, but also in the selection of the permanent scientific staff.

Research Programs

During the last decade, a change has been perceptible in the nature of the research carried out in mathematics and computer science. After a long period of increasing specialization, with a strong emphasis on pure mathematics, it seems that now the time has come to reap the fruits of the (abstract) theories and techniques developed then, and to apply them successfully, sometimes quite unexpectedly, in varied fields of knowledge. Disciplines which had grown apart are interacting once more, thus stimulating new developments, witness the renewed contacts with physics and chemistry, and such new areas of application as mathematical system theory, the information sciences, mathematical biology, and mathematical economics. Especially remarkable are the applications of what is traditionally called pure mathematics. Within CWI, this greater emphasis on applications may be illustrated by the assignment of various projects to our institute not only by the Foundation for the Technical Sciences (STW), but also by the European Community as part of its ESPRIT program, the European Strategic Program of Research and Development in Information Technology.
In the light of these national and international developments, CWI's research program for the next few years has been a subject of intensive debate. Great consideration is now given to a closer collaboration of the various scientific departments within CWI, and interdepartmental research projects are encouraged. In figure 2 a number of such projects are indicated.

World-wide research in computer science has shown so rapid a progress that a revision of our policy was deemed necessary. The need to strengthen and widen the field of research was felt by many, both within CWI and outside. The Dutch government has acknowledged this by the publication, in January 1984, of its policy intentions to promote computer science and information technology in the Netherlands, and to stimulate education in computer science, making funds available to this end. In close cooperation with SION, SMC has therefore revised the research program for CWI's activities in the field of computer science. In the proposed research program, it is suggested that CWI will concentrate its research on a limited number of projects in the following research areas:

- Computer systems and technology (esp. networks);
- Software and artificial intelligence;
- Information systems.

Even more than in the past, CWI should become a transfer centre for know-how in computer science, to the benefit of the scientific community, government, and industry. Though the main interest of CWI will always be pure scientific research, part of its activities should be devoted to development, such as is, for example, carried out in the various ESPRIT projects.

According to international standards, CWI is a relatively small research institute, and hardly capable of participating in all important developments in mathematics and computer science. By its very nature, however, it is especially adapted to the dynamic and interdisciplinary character of present-day research, for it can provide closely collaborating research units, supported by excellent computer facilities and a well-stocked library.

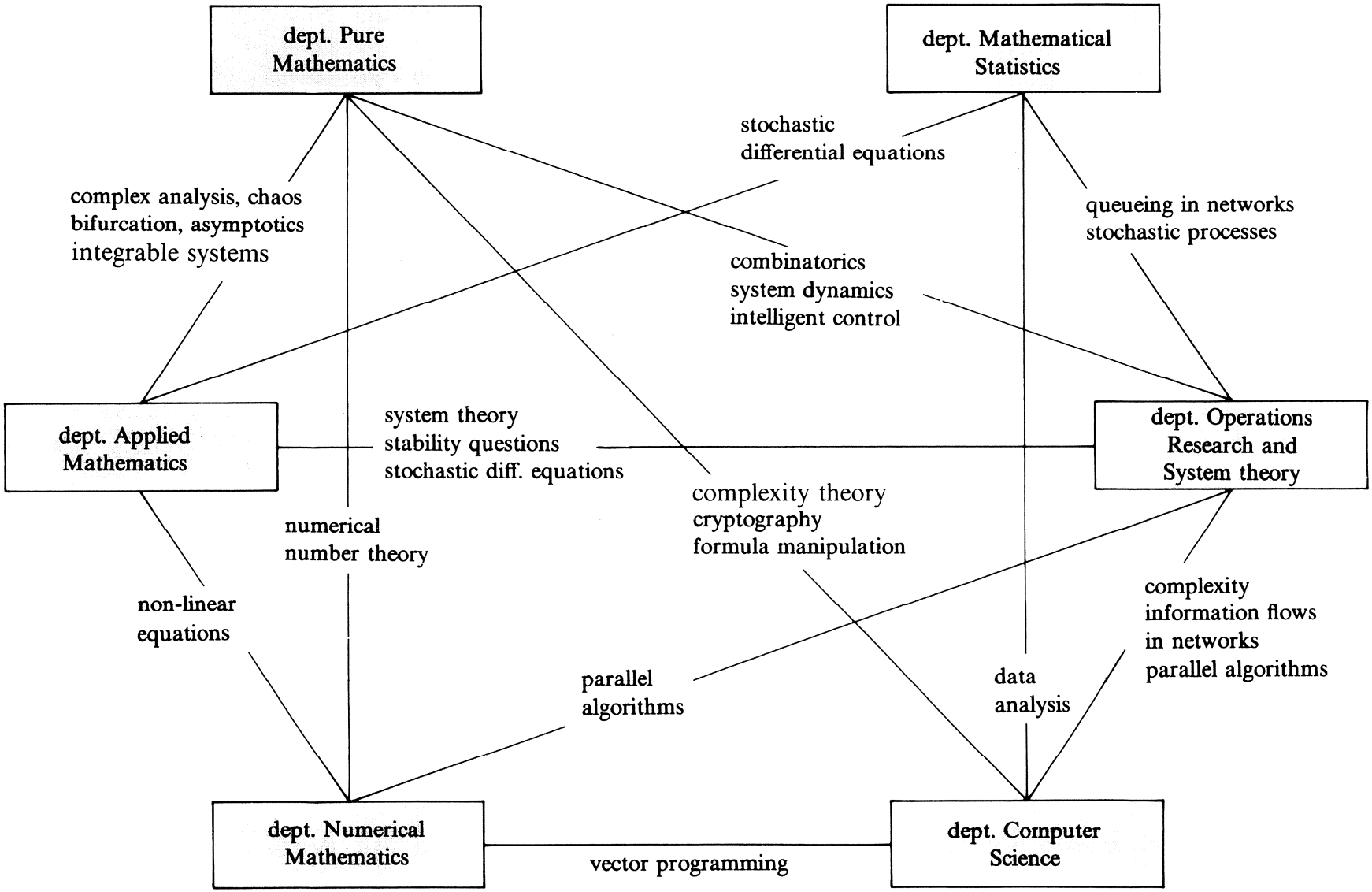


Fig. 2 Interdepartmental research projects

Department of Pure Mathematics

Prof.Dr. M. Hazewinkel (head of department)

Dr. E.P. van den Ban
Dr. A. Blokhuis
Dr. A.E. Brouwer
Dr. A.M. Cohen
Dr. J.H. Evertse
Drs. A.G. Helminck
Dr. G.F. Helminck
Drs. J.M. Jansen
Dr. T.H. Koornwinder
Dr. J. van de Lune
Drs. S.M. Verduyn Lunel
Dr. J. de Vries

As has been pointed out above, one of the most remarkable developments of the last few years has been the growing involvement of pure mathematics in applications. Such areas as number theory, partially ordered sets, logic, algebraic geometry, several complex variables, and differential topology have now found (real) applications; their influence is not limited to the field of (applied) mathematics, but is also felt in other branches of science. Mathematical system theory, for example, originally part of electrical engineering, now uses ideas from algebraic geometry and topology, algebraic K-theory and interpolation theory (for linear systems), and from differential topology, Lie algebras and Lie groups, functional analysis on manifolds, and differential geometry (for non-linear systems). Applications of functional analysis in numerical mathematics have given this discipline a more solid foundation, so that now assurances can be given as to the reliability of results.

The policy of the Pure Mathematics department during the last few years has been to concentrate research on those aspects of (pure) mathematics of which it may be expected that CWI can make an independent contribution, without duplicating research done elsewhere in the Netherlands.

Currently, there are the following research projects:

- Discrete mathematics;
- Analysis on Lie groups;
- Algebra;
- Theta functions;
- Analysis and number theory;
- Topology and analysis.

Discrete Mathematics

In this project, carried out by Brouwer, Blokhuis, and Cohen, a combinatorial investigation of finite and infinite mathematical structures is made. An important aspect of combinatorics is the investigation of finite configurations of great regularity, e.g., t-designs, transversal designs, strongly regular graphs, codes, and association schemes. One of the first questions that arises is whether such configurations with prescribed values of their parameters exist. As many of them are direct generalizations of situations and concepts that occur in projective spaces over a finite field, algebraic and geometric methods are extremely useful in the construction of such designs. Work on this project is therefore supported by the algebra project discussed below.

In particular, finite incidence structures are investigated. Most of this research was discussed in the weekly seminar on Algebra and Geometry, which is visited by members of Technological University Eindhoven, State University Groningen, State University Utrecht, and CWI. New results have been gained in the field of Lie-type geometries and distance-regular graphs. Much effort has been put in the collecting, expanding, and writing down of results concerning distance-regular graphs, with a view to a monograph by Brouwer, Cohen, and A. Neumaier (Univ. Freiburg). Further research was concerned with locally isohedral graphs (carried out in cooperation with D. Buset of Univ. Libre de Bruxelles), blocking sets, and NP-completeness of contractibility problems (done in cooperation with H.J. Veldman of Techn. Univ. Twente). Furthermore, Brouwer contributed a chapter to a book on Latin squares, edited by A.D. Keedwell.

Blokhuis, Brouwer, D. Chaum (Univ. of California, Santa Barbara), and Evertse are engaged in research on cryptography. Cryptography is concerned with the formulation of

mathematical systems which make it possible to encode (and decode) confidential information in such a way that it may be passed through an unsafe channel, or stored safely in databases. Several cryptographic techniques for the protection of privacy in payment systems, as developed by Chaum, have been further investigated.

Analysis on Lie groups

This is a joint project of State University Leiden and CWI. For CWI, Van den Ban, A.G. Helminck, and Koornwinder are taking part in it. Their research topic is harmonic analysis on (pseudo-)Riemannian symmetric spaces, the study of special functions and their group-theoretic interpretation, besides research in classical function theory and analytic number theory.

Van den Ban's research dealt with invariant differential operators on non-Riemannian symmetric spaces. He also investigated the properties of matrix coefficients of representations related to such spaces, and gave a generalization of Kostant's convexity theorem.

For the Seminar on Analysis on Lie groups, Koornwinder gave a course on the spherical Fourier transformation for semi-simple Lie groups. He supervises the thesis research of Drs. R. Beerends (State Univ. Leiden) on inversion of the spherical Abel transformation on semi-simple Lie groups. Furthermore, Koornwinder investigated the relation between Jacobi functions and hypergeometric orthogonal (e.g., Wilson) polynomials, and their group-theoretical interpretation. A refinement was given of De Brange's recent proof of the Bieberbach conjecture.

Algebra

The aim of this project is to give algebraic support to the projects on Discrete Mathematics and on Analysis on Lie groups, discussed above, besides doing independent algebraic research.

Cohen's research concerned the more algebraic aspects, and was largely carried out during his visit to the University of California at Santa Cruz, where he continued his cooperation with B. Cooperstein. The groups of Lie type E_6 have been investigated in their 27-dimensional representation, and a start has been made with a study of subgroups of the finite groups $E_6(q)$. Concerning the geometry of Tits systems, an investigation has been made of Coxeter groups.

Cohen and A.G. Helminck did research on Lie groups and algebras. A study of generalized symmetric spaces that are defined by pairs of commuting involutions of a reductive algebraic group led to a classification of these spaces; these results will be published in Helminck's doctoral thesis.

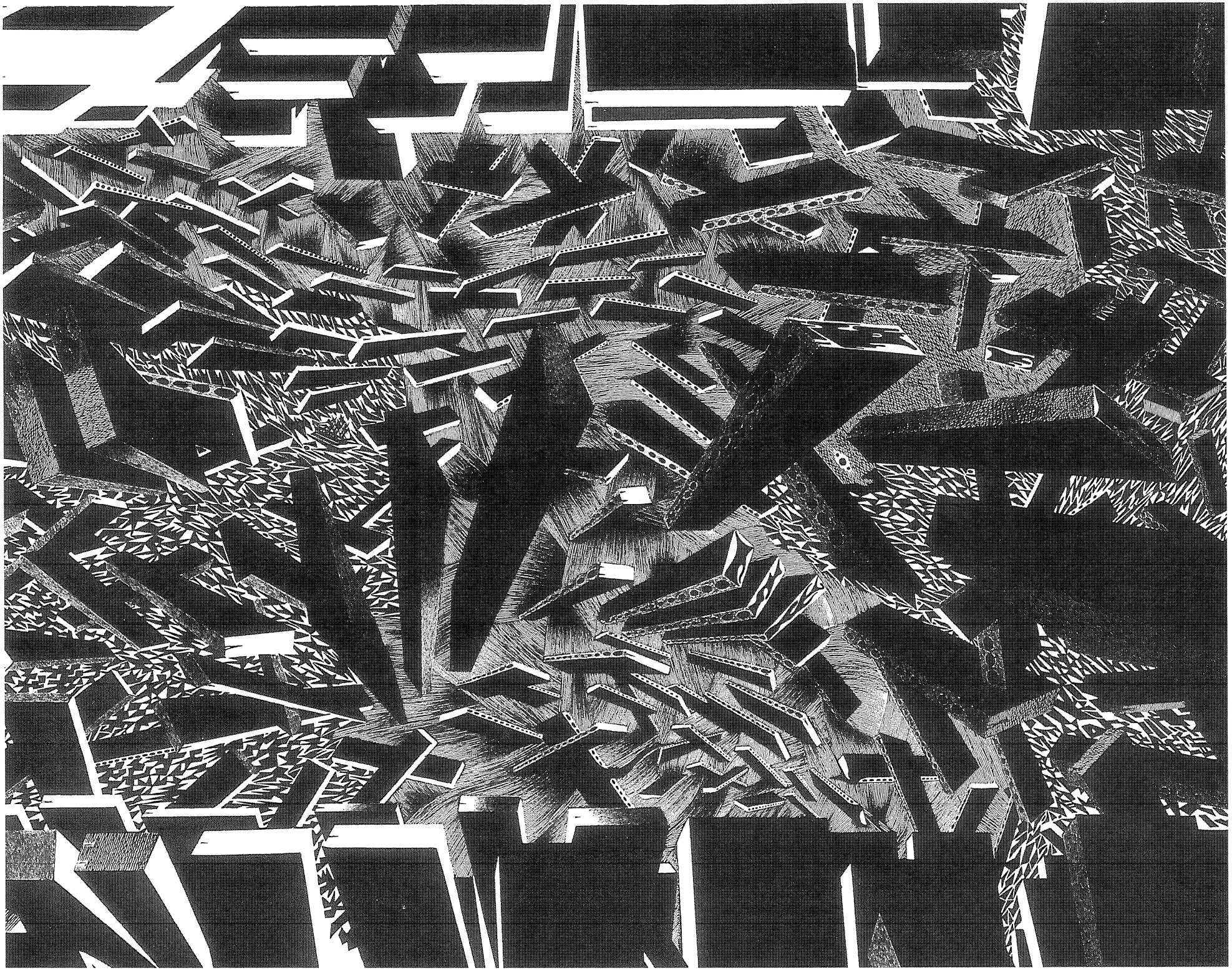
Theta functions

Hazewinkel, G.F. Helminck, and Verduyn Lunel are studying the various relations between theta functions, (inverse) scattering, completely integrable and holonomic systems, in order to use the knowledge acquired in the course of their investigation for applications. The following topics are considered especially important: the relation between Lax-Phillips. scattering and stochastic realization theory; the relations between functional integration (the Feynman-Kac formula), stochastic flows, heat kernels (heat equations), and theta functions; analysis on the Heisenberg group; and relations between completely integrable systems, such as the Toda lattice and representation theory of Lie groups.

Verduyn Lunel's research on symmetries and conservation laws for completely integrable systems was broken off prematurely, as he left CWI. Helminck rounded off his research on the τ-function, which plays an important part in the work of Sato, Miwa, and Jimbo on completely integrable evolution equations. Starting with a Grassman variety of a certain Banach space, a procedure was evolved to find the solutions of a class of partial differential equations (the so-called Kadomtsev-Petviashvili hierarchy). Results will be published in 1985.

Analysis and number theory

The research on this project was carried out by Jansen and Van de Lune, and concerned a number of more or less related topics from classical analysis and number theory. Results were published in Van de Lune's doctoral dissertation. Besides, a number of various problems were investigated, such as computa-



tions concerning the distributions of numbers in continued fractions expansions. This was done in cooperation with P. Hoogendoorn (Ministry of Defence), and was used to compare the processing speeds of different computers.

In cooperation with Te Riele and Winter of the Numerical Mathematics department, the research on the numerical verification of the Riemann hypothesis was continued.

Topology and analysis

In cooperation with J.C.S.P. van der Woude, De Vries is working on a book on topological dynamics. De Vries's research project on topological transformation groups was mainly concerned with keeping up to date with the literature on equivariant topology, most of which is published in Russian. Some additions were made to earlier results on G-compactifications of products.

Working stochastic process (Anatoli Fomenko, Moscow)

Department of Applied Mathematics

Prof.Dr. H.A. Lauwerier (head of department)
F. van den Bosch
Dr. O. Diekmann
Drs. B. Dijkhuis
Dr.Ir. J. Grasman
Ir. H.J.A.M. Heijmans
Drs. J.V. Lankelma
T.J.H. Smit
Drs. H.E. de Swart
Dr. N.M. Temme
L.L.M. van der Wegen

In the first half of this century, linear analysis and related disciplines grew into an impressive and useful tool. Nowadays, however, there are problems in mathematics, chemistry, biology, etc., for which linear approximations are no longer sufficient. During the last few years, therefore, interest has been focused on nonlinear problems, and our understanding of these problems has grown accordingly. Both mathematicians and theoretical physicists have made important contributions to the rapid development of nonlinear analysis. Remarkable, too, are the efforts to acquire a better understanding of perturbations. The study of deformations, perturbations, and imperfect bifurcation is evidence that the field of interest is not limited to isolated mathematical objects, but includes related disciplines.

The object of the Applied Mathematics department is to concentrate research on those areas which receive a great deal of attention internationally, but insufficiently so in the Netherlands. This is true both of biomathematics, surely one of the fastest growing fields in mathematics, and of nonlinear analysis, two disciplines that are closely related. Besides, research is carried out in topics from mathematical physics, to safeguard and develop knowledge which otherwise would not be (sufficiently) present in our country.
The research is divided into the following projects:

- Nonlinear analysis and biomathematics;
- Dynamical systems with stochastic perturbations;
- Asymptotics and applied analysis;

Nonlinear analysis and biomathematics

The aim of this project is on the one hand the study and construction of models of biological phenomena, and on the other the use and development of techniques from nonlinear analysis.

Dr. J.A.J. Metz (State Univ. Leiden, adviser of the department), Diekmann, and Heijmans have been working on a book that besides contributions by biologists will also contain a systematic exposition underlying the theory of the construction of structured population models and their mathematical analysis. Research on the stable-size distribution of cell populations was continued. Heijmans's research dealt with fission into unequal daughters and with the case in which the chance of fission depends on age. Diekmann, Heijmans, and H.R. Thieme (Univ. Heidelberg, temporarily CWI) used the theory of positive operators to analyse equations with periodic coefficients. In cooperation with J.J. Tyson (Virginia Polytechnic Institute and State Univ. Blacksburg) the practical usefulness of the abstract results was considerably enhanced by a further elaboration into explicit formulae.

M.A. Gyllenberg (Helsinki Univ. of Technology, temporarily CWI) succeeded in giving a complete analysis of a complex realistic model for the yeast *Saccharomyces cerevisiae* which exhibits asymmetric fission. In cooperation with Heijmans, he also dealt with the partial functional differential equation with delay, which arises by introducing into the model a fixed finite time for the fission procedure.

As an alternative to Holling's 'hungry mantid' simulation model, Metz constructed an analytic model. In cooperation with F.H.D. van Batenburg (State Univ. Leiden) this model was further investigated. On the basis of their research, Heijmans has shown by functional analytic means that for a large number of their results an exact mathematical proof can be given.

Together with R.M. Nisbet and W.S.C. Gurney (Univ. of Strathclyde, UK), Diekmann and Van den Bosch have been working on models for predator-prey interaction in which the prey is vulnerable to the predator for a very short period of its life only (e.g., as egg or larva).

Thieme is analysing a complex realistic model for the growth of waterflea populations, and has dealt with problems of existence, uniqueness, and stability. Diekmann has also been working on the predator-prey-patch problem. In cooperation with M.W. Sabelis (first Agricultural Univ. Wageningen, now State Univ. Leiden), he has constructed models for the growth of spider and predator mite populations on vegetables, in order to gain a better insight in certain aspects of biological control.

Heijmans is studying an existing model for the production of red blood cells, in order to investigate which mechanism causes a number of observed phenomena.

In cooperation with S.N. Chow (Michigan State Univ.) and J. Mallet-Paret (Brown Univ.), Diekmann worked on the stability, multiplicity, and global continuation of symmetric periodic solutions of a nonlinear Volterra integral equation.

Dynamical systems with stochastic perturbations

In order to trace the origin of stochastic behaviour in biological and physical systems,

In the celebrated paper 'The functional response of invertebrate predators to prey density' (Mem. Ent. Soc. Canada 48, 1966), *the entomologist C.S. Holling describes the results of experiments on the predatory behaviour of the praying mantid* Hierodula Crassa, *together with a rather complicated semi-stochastic simulation model. Starting from Holling's work an analytical model was recently formulated by the theoretical biologist J.A.J. Metz (Rijksuniversiteit Leiden, advisor of the Department of Applied Mathematics of CWI) and studied by him, F.H.D. van Batenburg and H.J.A.M. Heijmans. The results of this study, such as approximation for the functional response (i.e. the number of prey caught per unit of time per predator) as a function of prey density, are described in the* Springer Lecture Notes in Biomathematics 54: *Mathematical Ecology, S.A. Levin & T.G. Hallam (eds.), 29-41, 1984) and in three papers which have appeared in the* Journal of Mathematical Biology *(vol 22 (1985), 209-238, 239-257 and vol 21 (1984), 115-143).*

a mathematical investigation must be made both of the dynamics of deterministic systems with complex behaviour and of systems with stochastic perturbations. Bifurcation theory, analysis of ordinary and partial differential equations, and the theory of stochastic processes are the tools which should help us find solutions to these problems.

The research of Grasman and Lankelma is in the field of stochastic population dynamics. They investigated the influence of stochastic perturbations on generalized Volterra-Lotka systems. The state variables of such a system represent the densities of a biological species. The expected extinction time of a species owing to stochastic perturbations was investigated.

De Swart studied spectral and atmospherical models, a research project that is sponsored by STW and is carried out in cooperation with the Royal Netherlands Meteorological Institute. He has constructed a model to describe large-scale motions in the atmosphere.

Asymptotics and applied analysis

For many physical or biological problems, asymptotic methods are an important means to gain qualitative information on solutions of equations or to find approximations for solutions. In the last few years, the department has acquired great expertise in dealing with asymptotic problems. This has made many, both within CWI and outside, turn to CWI with problems in the fields of complex analysis, integrals, and differential equations.

Temme wrote a survey article on uniform asymptotics of integrals, to appear as a chapter of volume 1 in the CWI Monograph series. He investigated a class of polynomials related to Laguerre polynomials, which play an important part in asymptotics. At the conference held on the occasion of the 150th anniversary of Laguerre, he read a paper on this topic.

Van der Wegen's research dealt with remainder estimation for uniform asymptotic expansions for a class of Bessel functions. Asymptotic expansions derived formally by Luke in 1975 by means of a differential equation were provided with numerical estimations for the remainders, with integrals as a starting point.

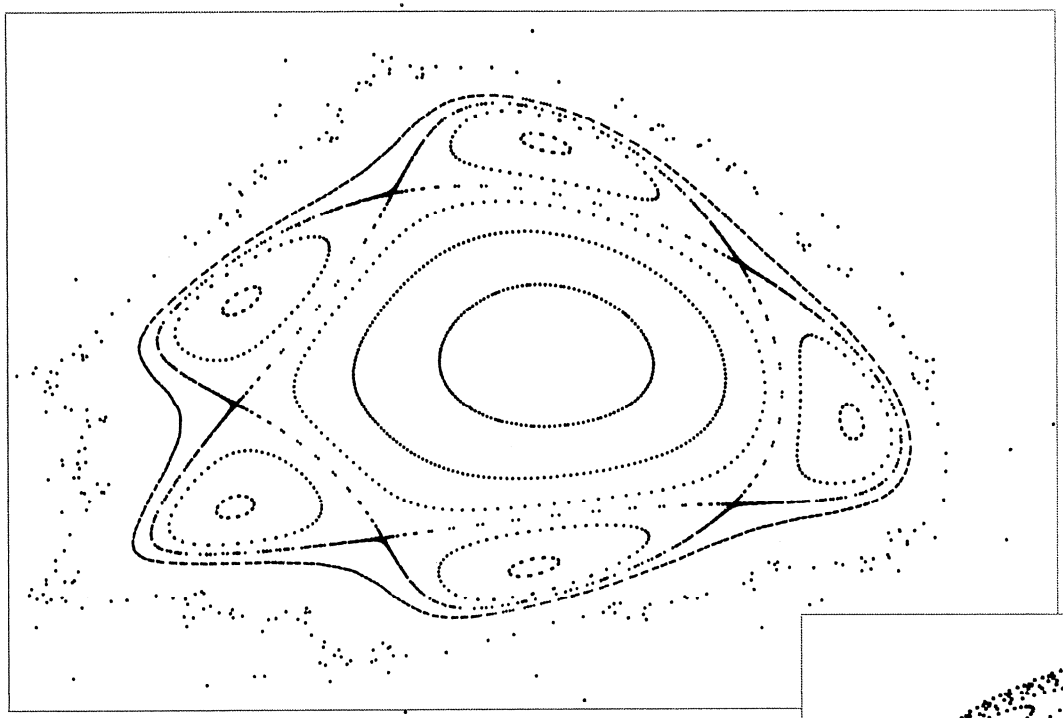
In cooperation with Groeneboom of the Mathematical Statistics department, Temme solved an integral equation that is important in the theory of the estimation of monotone densities, by means of the Laplace transformation technique. In cooperation with Prof.Dr. J.T.F. Zimmerman (Netherlands Institute for Sea Research), he investigated residual currents in tidal areas. By means of shallow water equations a description was given of the evolution of the vorticity as a result of the bottom topography.

Grasman continued his work on a monograph on the asymptotics of nonlinear oscillations.

In order to gain better insight in the processes described by discrete dynamical systems, Lauwerier investigated several actual problems with the help of a personal computer. It was found that in many cases a mathematical analysis can give an explanation of phenomena obtained during the interplay of researcher and computer.

Dijkhuis continued his research on the localizability in quantum mechanics. It was proved that in a one-particle quantum mechanical system, perturbations are propagated with the velocity of light. In systems of two or more particles superluminal velocities are possible in principle. An example was found of a two-particle system that appeared to spread at a superluminal velocity. Closer analysis has shown that in this case perturbator and detector are of infinite size, but tuned in such a way that a finite perturbation is recorded. It has not yet been determined whether superluminal propagation speeds actually do occur.

The research of Smit deals with the construction of gauge theories on the basis of supersymmetries, a recent concept of great importance in theoretical physics. The structure of a graded Lie algebra was derived on the basis of space-time symmetries.

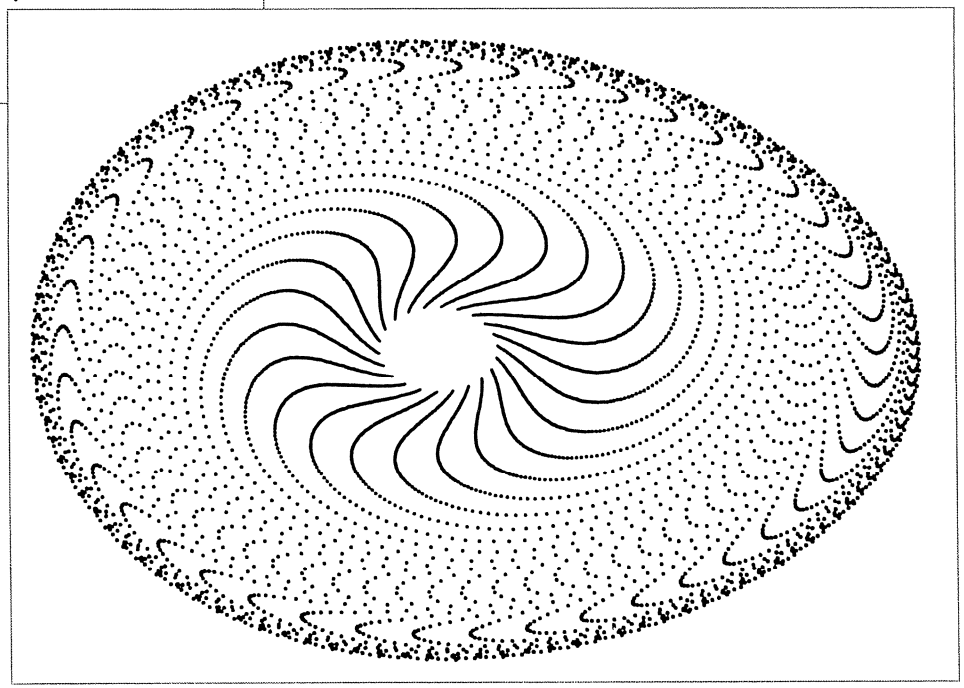


Hénon's quadratic map

$$x_{n+1} = x_n \cos\alpha - y_n \sin\alpha + x_n^2 \sin\alpha,$$

$$y_{n+1} = x_n \sin\alpha + y_n \cos\alpha - x_n^2 \cos\alpha,$$

shows up in the discretized version of the differential equation $\ddot{x} = 1 - x^2$. *The picture gives the map for* $\cos\alpha = 0.24$.



The same differential equation discretized using a Runge-Kutta scheme generates the map

$$x_{n+1} = x_n + hy_n + \tfrac{1}{2}h^2(1 - x_n^2),$$

$$y_{n+1} = y_n + h(1 - x_n^2) - h^2 x_n y_n - \tfrac{1}{2}h^3 y_n^3.$$

The picture shows 5000 (odd) points of orbit starting from $x = 1, y = 0.1$ *with* $h = 0.2$

Department of Mathematical Statistics

Dr. R.D. Gill (head of department)
Drs. A.W. Ambergen
Dr. H.C.P. Berbee
A.L.M. Dekkers
Dr. K.O. Dzhaparidze
Drs. A.J. van Es
Drs. S. van de Geer
Dr. P. Groeneboom
Dr. R. Helmers
Drs. A.J. Koning
J. Nool
R. in 't Veld
M.M. Voors

The process of a new synthesis between theory and applications that is taking place in mathematics in general can also be observed in mathematical statistics, resulting in vigorous new activity. The greater complexity of data available in all fields of scientific, industrial, or social enquiry and the possibilities of modern information technology have led to a much broader approach, with emphasis on dependent stochastic processes, estimation of 'abstract' parameters such as curves or surfaces, and with as much attention being paid to the process of hypothesis forming and model building as to the activities which take place within an already precisely formulated model. This is reflected in the research and consultation of the department in such areas as bootstrap methods, semiparametric models, and density estimation. New areas of application of statistics have even led to the introduction of new principles of statistical inference, e.g., for dealing with the only partially specified models used in the analysis of clinical cancer trials.

Much of mathematical statistics is built on probabilistic techniques and ideas. This originated in the use of probabilistic models to represent the physical process of random sampling and poorly understood 'measurement error', as well as to represent uncertain knowledge. However, a striking feature of modern mathematics and physics is the deep penetration of probability theory, so that in more and more situations stochastic models are appropriate. This is especially apparent in operations research and system theory, but is even visible in such fields as number theory and differential equations. Conversely, in order to solve the present day problems of mathematical statistics and probability theory, methods from all branches of pure and applied mathematics are needed.

The research of the department is organized in three main projects:

- Semiparametric statistics;
- Stochastic processes;
- Applied statistics.

Semiparametric statistics

Semiparametric models, i.e., models which are partly parametric and partly nonparametric in character, have become very popular in various fields of applications, e.g., biometry. Up till now, there have been very few contributions towards a general theory on the basis of which estimators for specific models can be constructed. The aim of this research project is to construct statistical procedures and to derive their properties for semiparametric models, as well as to apply techniques from parametric statistics in nonparametric models, in particular estimation theory.

Dzhaparidze and Gill are doing research in semiparametric estimation theory. Gill investigated the possible use of the theory of Von Mises derivatives for non- and semiparametric models, coming up with a new (and useful) definition of maximum-likelihood estimators for such models.

In cooperation with J.A. Wellner (Univ. of Washington, Seattle), Gill investigated a number of specific semiparametric models, in particular some models of Vardi for stratified systematic sampling problems.

An important part of Dzhaparidze's research was devoted to a concrete semiparametric model which is a generalization of the Cox regression model. Investigation of this model in the light of the general asymptotic theory has led to a better understanding of the asymptotic behaviour of the generalized Cox estimator.

For the Proceedings of the CWI Symposium

on Mathematics and Computer Science, held in 1983, Groeneboom has written an article on current developments in density estimation which discusses the relation between minimal risk of density estimators and ϵ-entropy of the collection of densities considered.

In cooperation with Temme of the Applied Mathematics department and Sommeijer of the Numerical Mathematics department a program was developed to give a numerical solution of an integral equation derived from a revised version of Groeneboom's contribution to the Neyman-Kiefer Conference (Berkeley, 1983). This integral equation describes the asymptotic behaviour of the L_1-distance of the (Grenander) maximum-likelihood estimator of a monotone density to the estimated density.

The relation between Airy functions and the asymptotic distribution theory was derived from characteristics of Brownian motion. By means of Airy functions the solution of a heat equation was characterized analytically. This heat equation occurs in the analysis of various models, e.g., in the description of the maximum number of those infected by an epidemic or the strength of a fibre bundle.

A problem with classical histogram and kernel estimators of a density is that a so-called smoothing parameter has to be chosen. Since 1974 a number of data adaptive methods have been proposed, for most of which only consistency results are known. Van Es has begun research on this topic in order to find a method by which more detailed results may be gained.

Gill continued his cooperation with Drs. N. Keilman and Dr. F. Willekens of the Netherlands Interuniversity Demographic Institute to investigate the usefulness of recent developments in the theory of stochastic censoring, such as counting processes models, the semiparametric Cox regression model, etc. One specific activity was the application of fixed-point theory to solve problems arising with a certain kind of aggregate data, called 'occurrences but no exposures'.

Helmers continued his research on the precision of bootstrap estimators for the distribution of statistical quantities. For Hoeffding's class of U-statistics it was shown that the bootstrap approach is in a certain sense superior to the classical approach. With Dr. P. Janssen (Limburgs Universitair Centrum, Belgium) and Prof. R.J. Serfling (Johns Hopkins Univ.), Helmers continued the research on asymptotic properties of generalized L-statistics. The cooperation with Dr. R.J.M.M. Does (State Univ. Limburg) and Dr. C.A.J. Klaassen (State Univ. Leiden), concerning Edgeworth expansions for functions of uniform spacings, was concluded with two publications. Together with Prof. D.M. Mason (Munich) Helmers is writing an extensive survey article on the asymptotic theory for linear combinations of order statistics.

Van Es rounded off his investigation of the weak limit distributions of elementary symmetric polynomials of independent and identically distributed stochastic quantities with a publication of results.

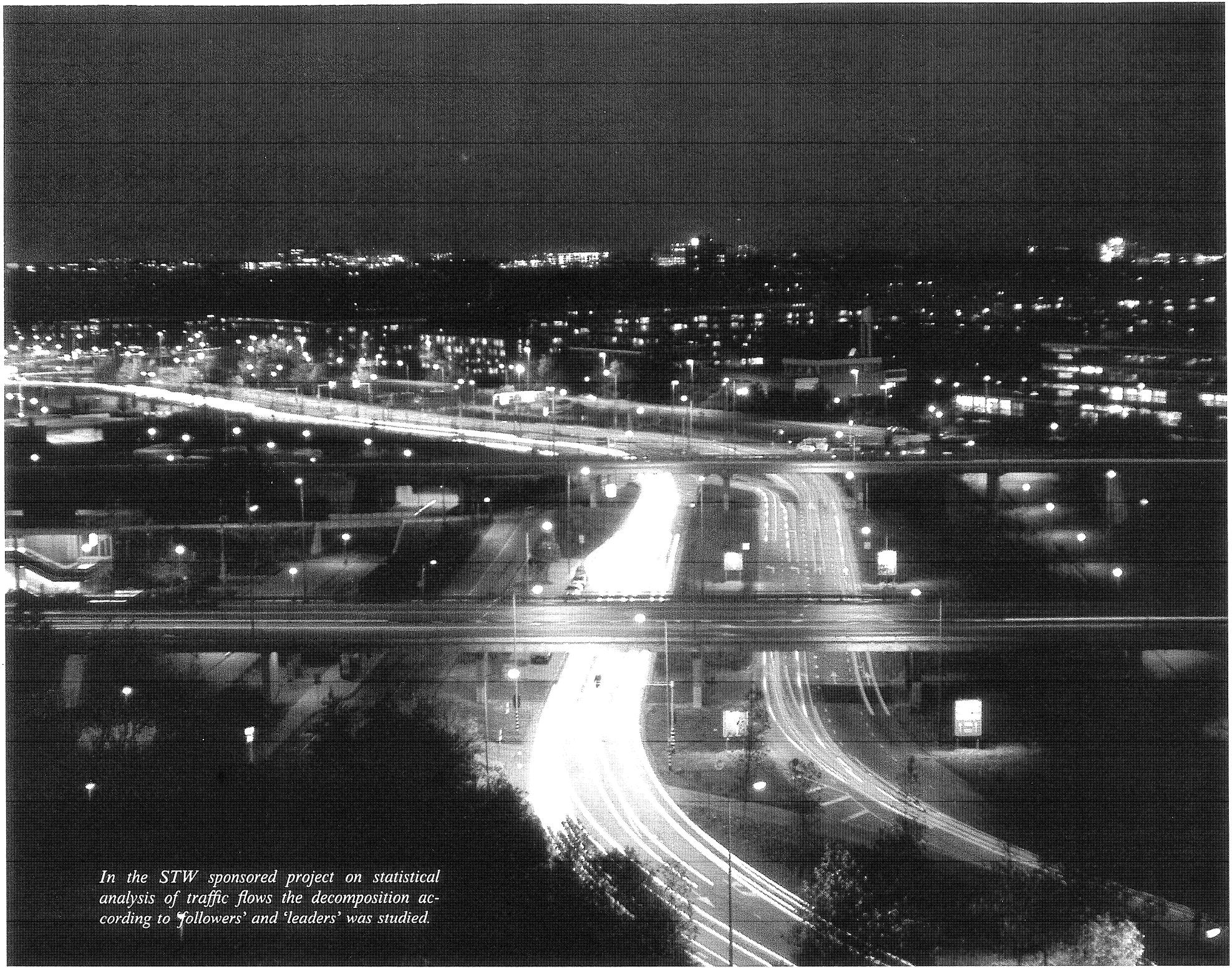
Stochastic processes

The aim of this research project is to study stochastic processes with special emphasis on processes in space and time, and to investigate the statistical analysis of particular stochastic processes.

Berbee is investigating stochastic processes with applications to physics. A Markov representation was found for chains with infinite connections, which makes it easier to understand the structure of such chains. Properties of this representation are now investigated. An article was written on the speed of convergence for averaging stochastic sequences.

Dzhaparidze prepared a new edition of his book *Parameter estimation and hypothesis testing in spectral analysis of stationary time series,* to be published by Springer-Verlag in 1985. This book is based on an earlier Russian edition, and partly on a course given by the author in 1981. It will contain recent results in the field of time series analysis.

In September, Koning started work on the STW sponsored project whose aim is to develop methods for the statistical analysis of traffic flows. In close cooperation with



In the STW sponsored project on statistical analysis of traffic flows the decomposition according to 'followers' and 'leaders' was studied.

Rijkswaterstaat (Public Works), known stochastic models for traffic flows will be further developed, in particular with a view to the reliability of the resulting parameter estimators. This research also draws on the activities of the department in semiparametric statistics and Berbee's work on phase-change in stochastic processes (the sudden formation of a traffic-jam!).

Applied statistics

The aim of this project is to enrich mathematical statistics through new impulses from practical problems, and conversely to make the results of theoretical research available to users of statistics in other areas.

Ambergen gained some important results in the field of discriminant analysis, a multivariate statistical technique used to decide to which of several populations a new observation belongs. For models with both continuous and discrete variables asymptotic distributions were determined of estimators for the posterior probability that an object originates from a certain population. The research was done in cooperation with Prof.Dr. W. Schaafsma (State Univ. Groningen). The newly developed theory was implemented in the computer program POSCON (Posterior Confidence interval) by Drs. D.M. van der Sluis (State Univ. Groningen).

Van de Geer's research is concerned with break-point methods for statistical models with abrupt changes in the parameters. She continued her investigation of the two-phase regression model. The multidimensional analogue of break-point regression has led to applications of interesting new theories about empirical processes. The results of the current research concern the asymptotic properties of least squares estimators. By means of the theory of empirical processes very general results may be deduced for any regression model, thus numerous known special models are fitted into one theory. This research originated from a consultation project on the accelerated life-testing of plastic pipes, in which some very unexpected problems were encountered.

Further research concerned an extension of the two-random sample problem, in which it is unknown which observations are from which sample. The aim is to design a statistical procedure to check whether there really have been two random samples or only one. This research is done in cooperation with P. Haccou and Prof.Dr. W.R. van Zwet (both of State Univ. Leiden).

Consultation

This year the consultation activities of the department were in a stage of transition, with a number of old projects drawing to a close and new ones starting up. In particular Helmers, Van Es, and Dzhaparidze started work on two large projects with Rijkswaterstaat (Public Works) concerning the probability of extreme water levels at the North Sea coast and in the IJsselmeer. For these projects Prof.Dr. L. de Haan (Erasmus Univ. Rotterdam; an authority on extreme-value theory) will be acting as advisor to the department.

Consultation projects also started on the automatic segmentation into phonemes of spoken language (here the break-point methods studied by Van de Geer may perhaps come in useful), and on a very large sample survey concerning company tax, for which techniques of multivariate exploratory data analysis will be applied (Ambergen).

Department of Operations Research and System Theory

Prof.Dr. J.K. Lenstra (head of department)
J.M. Anthonisse
Dr. J.P.C. Blanc
Dr.Ir. E.A. van Doorn
Drs. G.A.P. Kindervater
Drs. B.J. Lageweg
Drs. J.W. Polderman
Drs. M.W.P. Savelsbergh
Prof.Dr. A. Schrijver
Dr. J.M. Schumacher
Dr.Ir. J.H. van Schuppen
Drs. P.J.C. Spreij
Ir. S.A. Smulders
Drs. L. Stougie
H.M.C.A. Hop (trainee)

The name of the department, Operations Research and System Theory, covers a variety of subjects, ranging from complexity theory and combinatorics to probability theory and differential geometry. The unifying element is to be found outside of mathematics, in the applicability of the research in decision situations. Problems were originally supplied by economics and industrial engineering, where the need for optimal action in decision situations was first felt, but nowadays they also come from communications and control, and even from the political and social sciences. Though by the very nature of its subject, the emphasis of the research would seem to be on applications, the department has always been interested in the development of the underlying mathematical theory. It is felt that the department has found a fruitful balance between pure scientific research and an involvement in practical projects. There are the following research projects:

- Combinatorial optimization;
- Analysis and control of information flows in networks;
- System and control theory.

Combinatorial optimization

Combinatorial optimization is concerned with the investigation of problems that require the determination of an optimal ordering, choice, or assignment of a finite number of objects, such as the determination of distribution systems, depot locations, timetables, production plans, etc. It uses results from discrete mathematics, probability theory, and computer science, and researchers from these fields take an active part in the development of combinatorial optimization.

Analysis of the complexity of problems in this field has led to an overall distinction between problems that are solvable within polynomial time and NP-complete problems, for which it is unlikely that such algorithms will be found. For the solution of NP-complete problems, one can choose between enumeration methods, which eventually result in an optimal solution but often only after exponential computing time, or approximation algorithms, which are fast but do not guarantee an optimal solution. The research within the department covers all of these aspects.

The aim of the research is the design and analysis of combinatorial algorithms. Specific research projects include the investigation of hierarchical planning systems for production and distribution problems, the study of parallel architectures and algorithms, and the development and implementation of vehicle routing algorithms.

The research of Anthonisse, Lageweg, Lenstra, and Stougie is concerned with the design and analysis of algorithms. Lenstra finished his editorial work on the following books: *The traveling salesman problem,* in cooperation with E.L. Lawler (Univ. of California, Berkeley), A.H.G. Rinnooy Kan (Erasmus Univ. Rotterdam), and D.B. Shmoys (Harvard Univ.), and *Combinatorial optimization: an annotated bibliography,* with M. O'hEigeartaigh (Dublin) and Rinnooy Kan, both to be published by Wiley in 1985.

The well-known Dorhout-Tomizawa algorithm for the linear assignment problem was expanded by Lageweg to the linear transport problem. Lageweg, Lenstra, Stougie, and J.B. Orlin (MIT) investigated approximation and optimization algorithms to find a minimal set of characteristics by which a given number of persons can be distinguished. Anthonisse developed a method for two-dimensional proportional representation.

Lenstra and Rinnooy Kan have published a survey of the latest developments on machine scheduling problems. J. Han (Beijing, tem-

porarily CWI) published a number of results for the flowshop problem. For a notorious unsolved job-shop problem Lageweg improved the interval which contains the optimal solution value.

In the field of linear programming the members of the group investigated the algorithm of Kamarkar as a preparation to the implementation of this new method.

Schrijver continued his research on polyhedral and polynomial methods. In cooperation with A.M.H. Gerards (Catholic Univ. Tilburg), matrices with the Edmonds-Johnson characteristic were investigated, resulting in a new class of t-perfect graphs. The cooperation with M. Götschel (Univ. Augsburg) and L. Lovász (L. Eötvös Univ., Budapest) was continued. For their book on *The ellipsoid method and combinatorial optimization,* they worked on combinatorial applications. Schrijver's book, *The theory of linear and integer programming,* is nearing completion.

The research on hierarchical planning models was continued by Lenstra and Stougie. Stougie and Rinnooy Kan wrote a general article about stochastic integer programming, to be published in *Stochastic programming: numerical methods and applications,* edited by Y. Ermoliev and R.J.B. Wets. Another chapter on the use of dynamic programming as an optimization technique for stochastic integer programming problems is in preparation. In cooperation with M. Meanti, C. Vercelli (both of Univ. of Milan), and Rinnooy Kan, Stougie investigated multi-knapsack problems. Stougie is rounding off his research at CWI by writing a doctoral dissertation on hierarchical planning models.

Anthonisse, Kindervater, Lageweg, Lenstra, and Savelsbergh continued the research (partly sponsored by STW) on the development and implementation of algorithms for vehicle routing. This research is aimed at the interactive use of optimization algorithms for the determination of distribution systems. By using the C implementation of the Graphical Kernel System, a first implementation was made of the user interface for CAR (Computer Aided Routing).

Analysis and control of information flows in networks

Over the last few years, the need has grown for the mathematical modelling and analysis of information flows and control structures in communication networks, such as we find in computer networks, telecommunication systems, and networks of queues. Problems that are characteristic of this field of research are for example: the allocation of the various units within a computer to users, and the decision of job priority; the control of information flows between computers in so-called computer networks; the routing and control of communication networks, e.g., between groundstations and satellites; the control of information and production flows within an organization. Until recently, the way these problems were dealt with was hardly systematic. The more extensive applications of computer networks and their increased complexity now require a more fundamental analytic approach.

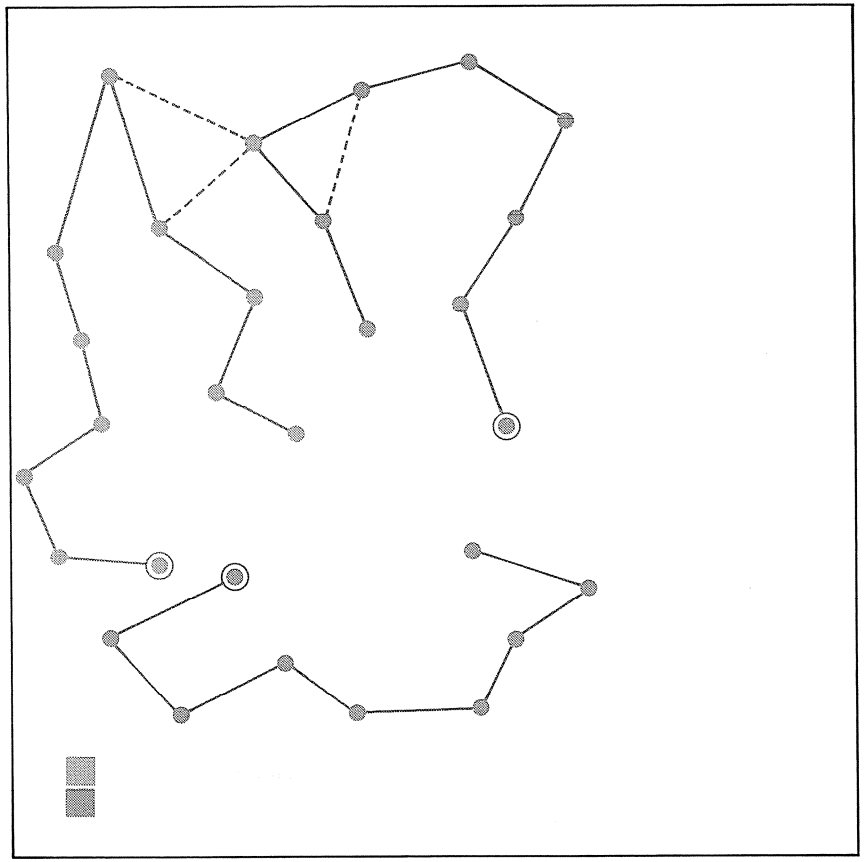
Blanc, Van Doorn and Hop, in cooperation with Berbee from the Mathematical Statistics department, continued their research on relaxation times for queueing systems.

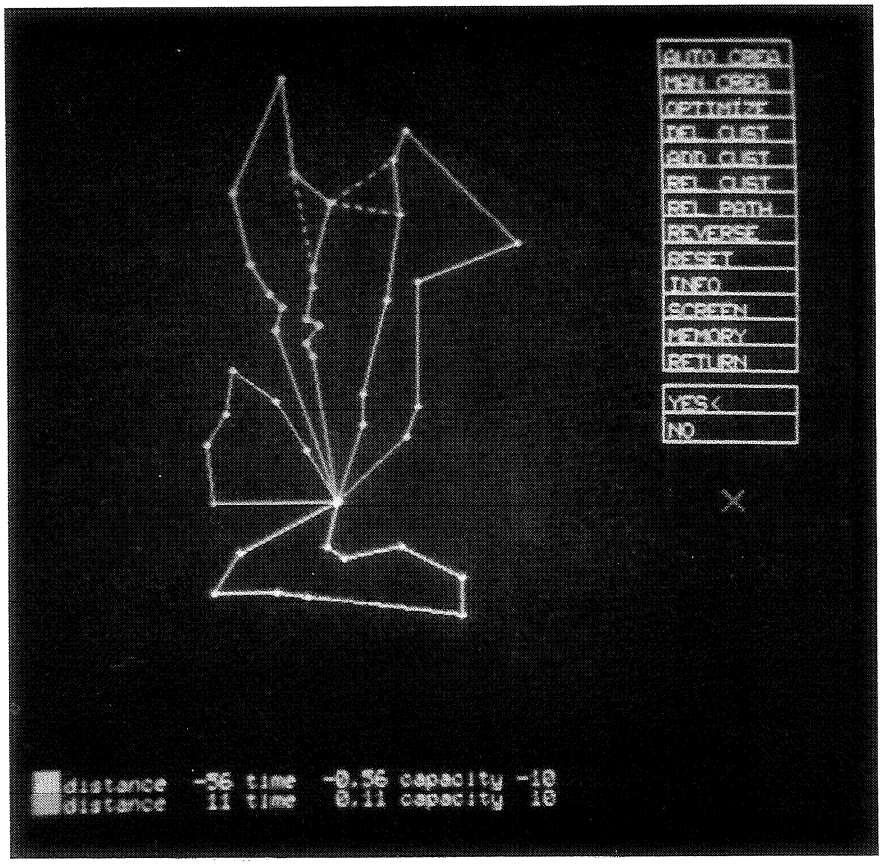
In cooperation with the Dr. Neher Laboratory of PTT, Blanc and Van Doorn investigated dimensioning techniques for telephone networks. Furthermore, aspects of the equivalent random method were studied.

Van Doorn has begun research on a performance evaluation of computer systems. At the request of the Computer Science department some stochastic aspects of process scheduling were analysed.

System and control theory

System theory is concerned with the study of dynamic phenomena. Its approach differs from that of classical applied analysis in the emphasis it puts on the concept of a dynamic system, and on the interaction of a dynamic system with its environment. Besides, the aspect of synthesis is emphasized, and special attention is paid to the design of filters for dynamic systems. Practical problems that motivated research in this field are to be found in the control of airplanes, satellites, chemical processes, etc.

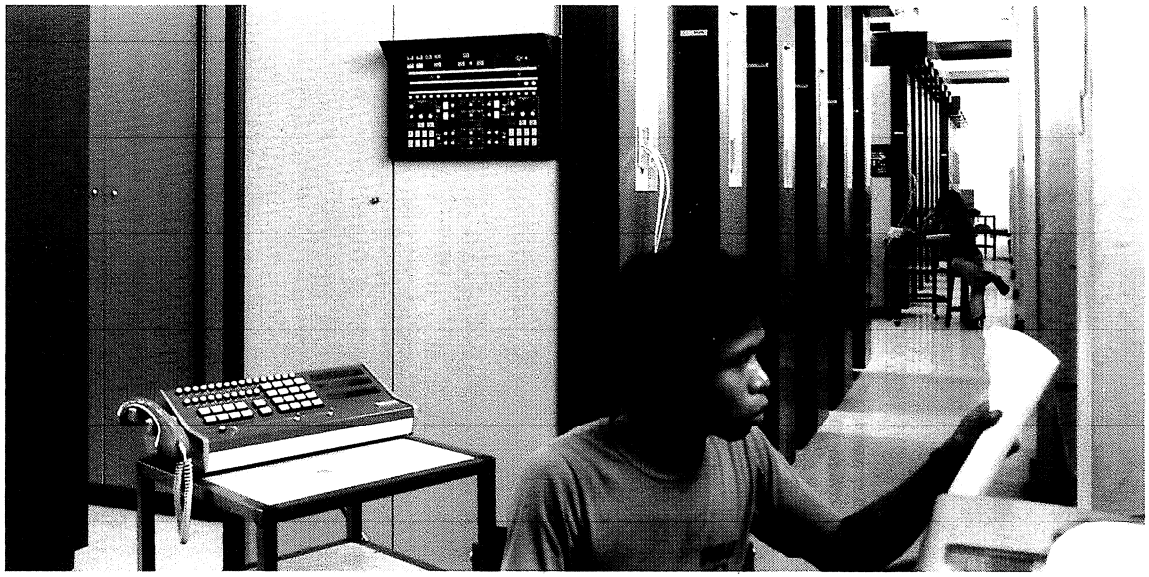




In July, Schumacher started his research at CWI in the field of deterministic system theory. Polderman continued an investigation of the literature on adaptive control. His research is concerned with the structure of an adaptive control system. Point process systems are the subject of Spreij's research, in particular recursive parameter estimation problems for systems with point process observations.

In cooperation with G. Picci (Padua), Van Schuppen continued research on the weak stochastic realization problem for processes on finite spaces. The classification of prime matrices was investigated with a view to the

The planner evaluates the relocation of customer k from the left route into the right route. The information at the bottom shows that for the left route distance and travel time are decreased whereas for the right route they are increased. The net result is profitable so the planner will probably accept the relocations by indicating 'yes' in the menu.



Overload control of telephone exchanges is a problem for which system and control theory is useful

minimal factorization of positive matrices. The research on overload control of communication systems was continued, for which alternative models were studied. This research was done in cooperation with F.C. Schoute (PTT Hilversum). A selection problem, arising from the definition of an efficient access protocol for multi-access broadcasting channels, which are used in local computer networks such as Ethernet, was formulated as a stochastic control problem.

For the adaptive filter and control problem, models were developed for time-varying parameters. Algorithms for such problems were investigated, in cooperation with Ir. A.W. Heemink (Rijkswaterstaat, Rijswijk) and Ir. T. Schilperoort (Hydraulics Laboratory, Emmeloord).

For the STW sponsored project on prediction and control problems for motorways, Smulders made an investigation of the literature on traffic modelling. He is working on the construction of a model and on the derivation of a prediction algorithm.

Consultation

As in preceding years, the department was involved in a number of consultation projects, a few of which are mentioned here.

As a continuation of the analysis of relations between advisory bodies of the central government, a similar analysis was made of the system of inter-departmental committees. Relations between such committees as well as relations between the departments of their main divisions were studied.

For the public transportation service of a major Dutch city the optimal allocation of trams to depots was analysed. This was part of a study to determine the locations and capacities of those depots.

For a financial concern, planning to adapt a new method of processing certain transactions (over 6 million each month), a heuristic method was developed to determine for each of its 1000 major clients their month of entrance to the new method. The number of transactions due to a client followed a specific seasonal pattern. The capacity of the new method would gradually grow, at three sites, until after 18 months all transactions could be processed. The clients were eager to switch to the new method, but care had to be taken that the capacity was never exceeded.

Department of Numerical Mathematics

Prof.Dr. P.J. van der Houwen (head of department)

Dr. P.W. Hemker	Ir. J.H.M. ten Thije Boonkkamp	B.P. Sommeijer
Dr. W.H. Hundsdorfer	Dr. J.G. Verwer	D.T. Winter
Drs. J. Kok	Drs. M. Visman	Drs. P.M. de Zeeuw
Ir. B. Koren	Ir. F.W. Wubs	*trainees*
Drs. R. Kroezen	*programmers*:	E. de Goede
Dr.Ir. H.J.J. te Riele	Drs. J.G. Blom	J.J. Rusch
Ir. S.P. Spekreijse	Drs. M. Louter-Nool	T. de Vries

Numerical mathematics is concerned with the design, analysis, and implementation of numerical algorithms for a computer-aided solution of problems from the (technical) sciences. The possibilities opened up by the new generation of (super)computers have important consequences for many disciplines, but in particular for numerical mathematics. Modern vector computers now allow reasonable computing times for really gigantic calculations. The combination of numerical techniques and fast computers has provided a powerful tool to attack problems that before had to be left unsolved because the calculations involved were simply too large to be carried out.

The main fields of interest of the department have always been differential and integral equations, numerical software, and numerical number theory. In the last few years, however, there has been a change in the nature of the research: if, in the past, the emphasis was on the development of methods, now the research has gradually become more problem-oriented, and is directed rather towards a purely theoretical analysis of numerical methods.

The research is organized in the following projects:

- Discretization of initial value problems;
- Multigrid techniques for boundary value problems;
- Computer-assisted number theory;
- Numerical software in Ada;
- Volterra integral equations;
- Software for vector computers;
- Shallow water equations;
- Euler equations.

Discretization of initial value problems

The aim of the research is the development, analysis, and documentation of algorithms for the numerical solution of initial boundary value problems for differential equations. The Applied Mathematics department is interested in analytical aspects of differential equations. Often their results suggest a good approach for the analysis of numerical algorithms, so as to acquire insight into the stability of the algorithm and into the precision of the solution. As for numerical stability, great progress has been made in the field of linear differential equations. Nonlinear stability, however, proved to be a far more intractable subject, and it is only since a revolutionary paper by Dahlquist in 1975 that research in nonlinear differential equations has become rewarding.

Dekker and Verwer completed their monograph on the *Stability of Runge-Kutta methods for stiff nonlinear differential equations,* in which recent developments in the field of nonlinear stability of Runge-Kutta methods are discussed. It was published by North-Holland Publishing Co. in the CWI Monographs series.

In cooperation with J.M. Sanz-Serna (Univ. de Valladolid, Spain), Verwer has made a convergence analysis for the full discretization error of method of lines approximations. An evaluation was made of five integration techniques for the nonlinear Schrödinger equation. In cooperation with A.O.H. Axelsson (Catholic Univ. Nijmegen), Verwer investigated the backward-beam method, which led to a number of interesting conclusions about the crucial role of the spectral stiff parameter.

In September, Ten Thije Boonkkamp started research on the incompressible Navier-Stokes equation.

Van der Houwen en Sommeijer continued their research on initial value problems with periodic solutions. Special symmetric linear multistep methods were constructed for the accurate numerical integration of oscillating solutions of second order initial value problems in which the first derivative is missing. They are cooperating with Dr. B. Neta (Naval Postgraduate School, Monterey).

For the research project on shallow water equations, Van der Houwen, De Vries, and Sommeijer are investigating the dispersive behaviour of various methods for hyperbolic differential equations.

Van der Houwen and Sommeijer continued their research on differential-difference equations. In cooperation with Dr. H. Arndt (Univ. Bonn), linear multistep methods for first and second order differential-difference equations were developed. The research on stabilized predictor-corrector methods, carried out in cooperation with Dr. C.T.H. Baker (Univ. of Manchester), was concluded with an application to parabolic delay differential equations.

Multigrid techniques for boundary value problems

Research in numerical analysis of boundary value problems is concerned with the development and evaluation of methods for the numerical solution of elliptic partial differential equations and of integral equations. Both types of equation often occur in technical applications. Numerical methods are the most important tool to obtain quantitative information on the solution of these equations. Boundary value problems form such a wide field of research, that of necessity this research project is limited to certain aspects only, in particular to multigrid techniques.

In 1978, the possible value of multigrid methods for the solution of stiff boundary value problems was recognized. It turned out that the numerical methods for the solution of certain integral equations were substantially improved by this new technique. Especially interesting are the results of using multigrid methods on vector computers.

Hemker continued his investigation of the defect correction principle and its theoretical background. In cooperation with Prof.Dr. K. Böhmer (Univ. Marburg) and Prof.Dr. H. Stetter (Techn. Univ. Wien), a survey article was published. The mixed defect correction iteration method was successfully applied to a two-dimensional convection-diffusion problem. Other applications of this technique are now being considered.
Hemker and De Zeeuw investigated the Petrov-Galerkin finite element method of Hughes-Brooks as to its precision and stability. In particular they studied the relation between the use of asymmetric prolongations and restrictions in the multigrid method for elliptic equations.

In cooperation with P. Sonneveld and Prof.Dr.Ir. P. Wesseling (both of Techn. Univ. Delft), De Zeeuw is evaluating the efficiency of solution methods for certain large linear systems. A paper on multigrid and conjugate gradient methods as convergence acceleration techniques will be published in the proceedings of a course on multigrid methods (Bristol, Sep. 1983).

Hemker and Spekreijse are investigating whether the multigrid method can be applied to hyperbolic equations. After having evaluated various discretization methods, they have focused the research on completely conservative upwind schemes, and on approximate Riemann solvers in particular. They have, moreover, studied the use of the FMG-FAS multigrid method for solving discretized steady Euler equations.

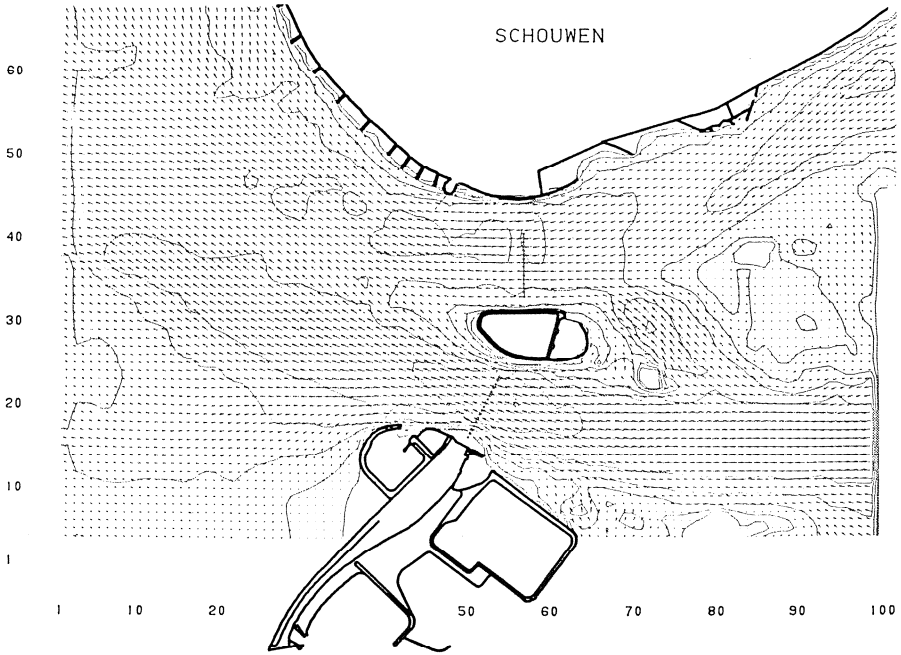
Hemker and De Zeeuw investigated the use of the Newton process for solving discretized Euler equations. They were particularly interested in the efficient solution of linear systems by means of the CS multigrid method, and various linear relaxations were implemented.

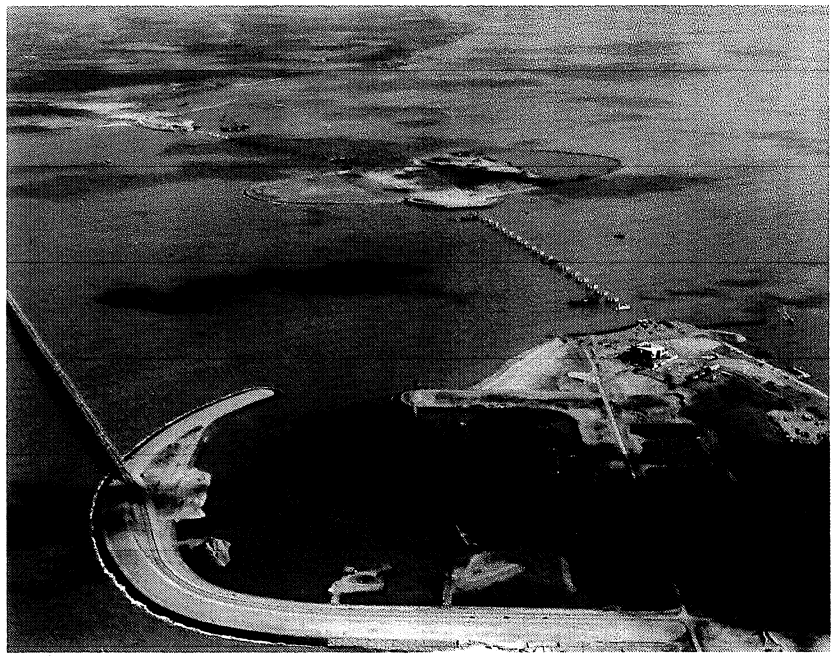
Computer-assisted number theory

The work on this project is carried out by Te Riele and Winter, in cooperation with J. van

de Lune of the Pure Mathematics department. Their aim is to approach certain problems in number theory, some of which are of very long standing, with the help of a computer. With the arrival of the CYBER 205 computer at SARA, computations concerning the zeros of the Riemann zeta function were considerably speeded up. By vectorizing the program, a speed-up with a factor of ca. 7 was achieved compared to the fastest CYBER 750 version. By means of this program the region between zeros with numbers 4.15×10^8 and 14.5×10^8 was checked with respect to the correctness of the Riemann hypothesis. The amount of computations carried out on the CYBER 205, was a multiple of the total number of computations made for this project on the CYBER 750 in the period 1981-1983.

Aerial picture (in N.E. direction) of the Oosterschelde estuary, with the dam under construction. Underneath a map of currents of the same area, calculated with the help of a computer. The computation of such maps takes a great deal of time (and money!). At the Numerical Mathematics Department a program is being developed to have such computations executed on SARA's supercomputer CYBER 205 within fifteen minutes.





Te Riele continued his research on amicable pairs of numbers. An efficient algorithm was developed to compute all pairs of amicable numbers in a given region. All (1427) amicable pairs lower than 10^{10} were computed, including over 800 new ones. Various tables provide new insight in the structure and distribution of these numbers, which have been studied since antiquity. Since 1983, CWI has been the 'Centre for Amicable Pairs', where all new pairs are collected and registered. In 1985 a survey will be published of all known pairs (now over 8000).

In response to the many questions about the

disproof of the Mertens conjecture, Te Riele published a report on the historical background, the electronic communications between Bell Labs and CWI, and the publicity concerning the disproof.

Numerical software in Ada

The new programming language Ada has been designed primarily for the programming of software for real-time applications. It is expected, however, that it will also be widely used in large-scale scientific computations. Therefore it is necessary that large basic software libraries for numerical computation in Ada are made available.
The investigation into the (new) possibilities for the implementation of existing and new methods in Ada was concluded with a paper, read at the Ada-Europe/AdaTec Conference in Brussels, in which recommendations were given as to the solution of problems that may occur, if Ada is to be used for the creation of large software libraries. This project was carried out by Kok, Winter, Kroezen, and Visman, with Dr. G.T. Symm and Dr. B.A. Wichmann (both of National Physical Laboratory, Teddington).

As part of a group of numerical mathematicians, led by Dr. B. Ford (NAG, Oxford), Kok and Winter are engaged in the design and construction of an Ada software library for large-scale scientific computations, for which they are investigating the implementability of mathematical methods in portable modules.

Volterra integral equations

In the last few years, problems have arisen in many of the physical sciences (e.g., nuclear reactor kinetics, population dynamics, etc.), that give (a system of) integral equations of Volterra type. In connection with the project on Biomathematics of the Applied Mathematics department, biomathematical problems are investigated. Van der Houwen continued his cooperation with Prof. H. Brunner (Univ. de Fribourg) for the monograph on *Numerical methods for Volterra equations.* With the help of Blom the stability criteria, developed in 1983, were amply tested, and a start was made with the development of a FORTRAN program, based on iterated collocation, for the solution of second kind Volterra equations.

Software for vectorcomputers

The object of this new project is the study of existing and the development of new numerical algorithms in order to exploit the special features of vectorcomputers, such as the CYBER 205 and the CRAY 1. Numerical software for vectorcomputers will be developed and made available. Te Riele made a preliminary investigation into the possibility of vectorizing and parallelizing existing numerical algorithms.

Shallow water equations

Shallow water equations consist of three linked partial differential equations; two momentum equations and a continuity equation. The problem is to calculate the velocities and waterlevels as functions of time and place for any configuration of bottom profile and coasts, and for any given external forces, such as wind, tide, Coriolis forces, etc. The aim of this STW sponsored project is to be able to calculate the flow of the water in a large variety of situations, without having to design a new method of computation for each new situation.

Wubs, Van der Houwen, Sommeijer, and Verwer made a survey of time integrators for shallow water equations. Wubs wrote a special program for the CYBER 205, which makes an optimal use of the possibilities of this computer. The new program turned out to be 10 times faster than an already existing program. Furthermore, Wubs developed a new stabilization technique for explicit methods.

Euler equations

The aim of this STW sponsored project is to develop efficient numerical methods for flows described by the steady Euler equations. Koren, Hemker, and Prof.Dr.Ir. P. Wesseling (Techn. Univ. Delft, and adviser of the department) have tested software, developed as part of the project on multigrid techniques, on transsonic and supersonic channel flows. The software, which is written in ALGOL 68, will be implemented in FORTRAN, so as to be more suitable for intensive computations.

Department of Computer Science

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Dr. J.A. Bergstra
Drs. C.L. Blom
Ir. J.C. Ebergen
Drs. R.J. van Glabbeek
Drs. P.J.W. ten Hagen
Drs. A. Janssen
Dr. P. Klint
Dr. J.W. Klop
Drs. J.N. Kok
Drs. A.A.M. Kuijk
Ir. E.A. Kuypers
Dr. A.K. Lenstra
Prof. L.G.L.T. Meertens
Drs. S.J. Mullender
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Drs. F. van Dijk
L.J.M. Geurts
J. Heering
Drs. T.J.G. Krijnen

trainees:
S. Bekius
J.A.M. van de Graaf
H.F. Moll
S.J. van Veen
E.P. de Vink

Progress in computer science has been extremely rapid during the last few years. Its impact is widely felt, since research in this field is closely bound up with social and technological developments in information processing and telecommunications. Cheap computing facilities are now more readily available, and personal computers have become a common feature of modern society. Besides the advances in microcomputers, there is the development of very large computer systems and supercomputers. All this has stimulated research in networks, VLSI design, operating systems, and distributed systems; at the same time, there is a growing need for software, which in turn has stimulated research in software engineering, integrated programming environments, language design, etc.

In its Computer Science Stimulation Program the Dutch government has stressed the importance of research in this field. In the Program the central position of CWI is pointed out, and it is suggested that CWI should grow into a *centre d'excellence* in the field of computer science, to which end funds will be made available. For the next few years research will be focused on the following areas, the first three of which are a further development of traditional research areas of the Computer Science department, the last concerns mainly new research in a field which up till now has received too little attention in the Netherlands:

- Architecture;
- Software;
- Interaction;
- Artificial intelligence.

Architecture
The research of the department in this field is divided in three projects:

- complexity and algorithms;
- distributed systems and networks;
- VLSI design.

Complexity and algorithms
Algorithms are at the heart of computer science. During the last two decades, complexity theory and the related theory of the systematic design of computer algorithms have become increasingly important. As larger problems are being dealt with, and systems of greater complexity used, there is a growing need for more efficient algorithms.

Vitányi's research is concerned with various aspects of sequential algorithms. He continued his cooperation with J. Seiferas (Univ. of Rochester) on efficient counter implementations. In the field of real-time computations, he developed a meta-argument which supersedes a great number of separate known proofs that computing power in real-time can be improved by means of additional memory elements; at the same time this meta-argument proves that this also holds for types of memory elements for which it was not yet known. He continued his research on real-time simulation of Augmented Counter Machines. For oblivious one-tape machines he improved the lower bound for simulation time. In the Spring, W. Maass (Univ. of Cali-

fornia at Berkeley), M. Li (Cornell Univ.), and Vitányi proved independently of each other that for the simulation of a two-tape machine by a one-tape machine the optimal simulation time is n^2, and similarly for the simulation of machines with more tapes.

Mullender and Vitányi are doing research on distributed algorithms. Vitányi developed a robust time-independent algorithm for the distributed election of a leader in a ring network. This algorithm proved to be more efficient in messages and bits than any known algorithm, both for asynchronous and for synchronous networks. As part of their research on distributed coupling of processes in computer networks, Mullender and Vitányi developed new methods for locating processes that are cheaper than so-called broadcasting.

Vitányi continued his research on the complexity of 'fast' chips where the signal propagation delay is sublinear in the traversed wire length. He showed that the global complexity of such a VLSI circuit depends on the layout of the circuit to a larger extent than was generally assumed. He also investigated the effect on various circuit topologies of sublinear delay. He showed that a simple lattice network topology, as chip implementation of a dictionary machine, is more efficient than a tree layout in layout area under logarithmic delays. Similar results were gained for a lattice network implementation for the fast Fourier transform, compared to the cube-connected cycles.

Lenstra continued his work on the factorization of polynomials and on primality. Results were published in his doctoral dissertation. New results were presented at various international conferences.

Distributed systems and networks

This research project of Mullender is carried out in close cooperation with the research group of Prof.Dr. A.S. Tanenbaum at the Free University of Amsterdam. Its aim is the design and implementation of a distributed operating system. At the Free University the Amoeba system is being implemented. Mullender and R. van Renesse (Free Univ. Amsterdam) are investigating communication protocols. Very fast protocols were developed, based on the remote procedure call model.

Furthermore, Mullender is doing research on stochastic scheduling in a distributed system. If the probability distribution of process execution times is known, it is possible to make forecasts about the remaining execution time of the job at hand, on the basis of the time used so far. The probability distribution function for the execution time of processes has been measured in the UNIX operating system. Results have been used for the design of a scheduling algorithm, which will be further developed and experimented with in Amoeba.

VLSI design

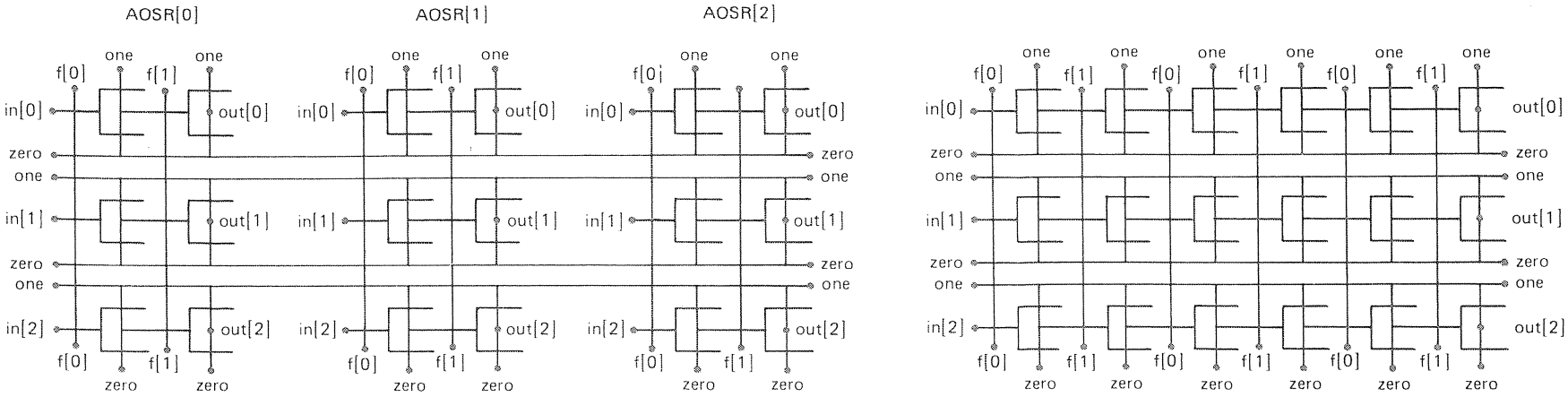
With the advance of micro-electronics, and VLSI in particular, it has become possible to realize parallel computations directly in hardware as an integrated circuit. The aim of this research project is to acquire a better understanding of the possibilities and problems presented by such computations, so as eventually to be able to construct a silicon compiler, i.e., a program that, without the aid or intervention of the designer, translates programs into layouts of VLSI circuits. In a silicon foundry chips could be produced from these layouts. A silicon compiler would make it possible to design chips that are not only more reliable, but also cheaper.

Ebergen and Prof.Dr. M. Rem (Techn. Univ. Eindhoven, adviser of the department) described a method by which a compiler for a component can be derived from a specification. This compiler can be used for the design of the layout of a delay-insensitive circuit. The formalism of trace theory plays an important part in this method. The importance of trace theory for the design of parallel programs and of delay-insensitive circuits will be further investigated.

Veen continued the research on an imperative language for dataflow machines. The code generator for the translation of Summer programs to programs for the Manchester Dataflow Machine was completed and amply tested. Results are described in Veen's doctoral dissertation.

Software

There are four research projects in this field:



A systematically designed layout of an array of shiftregisters

- concurrency;
- software technology, specification languages;
- extensible programming environments;
- the *B* project.

Concurrency

In the seventies, distributed data processing became central to theoretical (and applied) computer science. New developments in the architecture of computer systems have been of great importance in this respect. The research is concentrated on programming concepts for concurrency. Mathematical modelling for concurrent programming concepts is, in fact, far more complex than for sequential programming.

This project is carried out by De Bakker, Kok, Van Veen, and De Vink, in close cooperation with Drs. J.J.C. Meyer (Free Univ. Amsterdam), Dr. E.-R. Olderog (Univ. Kiel), and Prof.Dr. J.I. Zucker (SUNY at Buffalo). The research is focused on imperative and applicative concurrency. A survey article on imperative concurrency is in preparation. An evaluation was made of operational and denotational semantics of uniform concurrency. The research now aims at giving a further refinement of the analysis of operational semantics for guarded recursion with merge. The connection between infinite streams and finite observations, in the semantics of uniform concurrency, has been clarified. Results will be published in 1985.

In the field of applicative concurrency, Kok continued his work on the topological treatment of streams in functional programming. A satisfactory denotational model for non-deterministic dataflow was developed on the basis of a system for the colouring of data, inspired by a similar architectural technique. This research is sponsored by SION. Van Veen and De Vink are studying semantic aspects of logic programming, with special attention to parallel variants.

Some of the above mentioned research was done as part of the National Project on Concurrency, supported by SION and directed by De Bakker in cooperation with Prof.Dr. W.P. de Roever (Catholic Univ. Nijmegen) and Prof.Dr. G. Rozenberg (State Univ. Leiden).

Further research concerned CWI's participation in the ESPRIT project on Parallel Architectures and Languages for AIP: a VLSI directed approach. The role of the Concurrency project in this is on the one hand to direct the Working Group on Semantics,

belonging to the ESPRIT project, and on the other hand to design a semantic model for the language POOL (Parallel Object Oriented Language), developed by Philips Research Laboratory.

Software technology, specification languages
One of the central problems in the development of software is the control of complexity, both of the problems to be solved and of the tools used. As the problems one is faced with in automation projects are usually very large, a systematic approach is of prime importance. In developing software, the following stages may be distinguished: problem analysis, design, specification, implementation, and testing. The research project is concerned, in various degrees, with all of these aspects.

Baeten, Bergstra, Klop, and Van Glabbeek are doing research on specification techniques, in particular on process algebra. The research is focused on verification, specification, and design of distributed systems, until September as part of the pilot ESPRIT project FAST, and from October as part of the ESPRIT project METEOR. So far no model has been designed which gives a description of all of the various features concerning distributed software. The aim of this research project is to design an extensive (and coherent) family of axiom systems, in which each system embodies a combination of features. At the same time research is aimed at proving the consistency of all axiom systems by constructing a model. A third activity is concerned with the analysis of various simple case studies.

Extensible programming environments
Research, carried out by Heering, Klint, and Kuijpers is focused on the algebraic specification method, and is profiting from the theoretical work of Bergstra and Klop. In order to gain insight into the possibilities and restrictions of the algebraic method it was decided to produce a number of sample specifications.
Bergstra, Klint and Heering have worked on an algebraic specification of a simple programming language and on the development of tools for checking such a specification. Since November this work is continued as part of the ESPRIT project 'Generation of Interactive Programming Environments'. Furthermore, Heering has investigated the partial evaluation method from an algebraic point of view. Results will be published in 1985.
Bekius made a new version of the SUMMER compiler which can compile procedures and class definitions separately.

The B project
Work on this project is done by Van Dijk, Geurts, Van de Graaf, Krijnen, Meertens, Moll, Pemberton, and Van Rossum. *B* is designed as a programming language that is suitable for structured programming, and is yet both easy to learn and to use. During this year various improvements in its design and implementation were introduced. An important aim of the implementation activity is to develop versions of the *B* system for personal computer systems. To this end an IBM-PC was made available by IBM Nederland. On the VAX computer the *B* system is running under UNIX; in order to facilitate its distribution, the IBM-PC version is being developed under MS-DOS.

Meertens continued the research on Abstracto, a language designed to facilitate the mathematical activity involved in the specification and systematic development of algorithms. A (modest) system was developed in the language *B* for the interpretative execution of algorithmic expressions.

Interaction

The exchange of information between man and machine or between two machines, when it occurs at program execution times, is termed interaction. Cheap computing facilities allow for dedicated interaction processors to exchange complex information structures (involving pictures) in real time. The research is currently centred on the design and implementation of far more complex interactive systems and on the interactive process itself.

There are four research projects:

- dialogue programming;
- computer graphcis;
- workstations for interaction;
- computer-integrated manufacturing.

Dialogue programming
One of the most important aspects of the interactive process is the dialogue, i.e., the form in which the interaction takes place. By dialogue programming is meant the specification of all possible questions and answers, as well as the state of the (visible) interface at each stage of the dialogue. A method has been developed to specify the dialogue part of an interactive program as an independent module. Ten Hagen is doing research on these so-called dialogue cells.

In cooperation with J. Derksen and R. van Liere (Institute for Building Materials and Structures of the Netherlands Organization for Applied Scientific Research) and J. Ero and H. Hoffman (Philips-ISA), a generator was written for incremental, real-time dialogue compilers, which can accept and parse parallel input. Input schedules and the resource manager of the run-time system were designed, both of which contain new algorithms for the allocation in real-time of the resources of an advanced interactive workstation to those processes that according to the state of the dialogue are most entitled to it. This is a first and important step towards the realization of intelligent workstations.

Computer graphics
Ten Hagen and De Ruiter, together with Bakker, Rauwhorst, and Burger of the Contracts and Support Division are developing graphics standards. In cooperation with L.R.A. Kessener (Techn. Univ. Eindhoven), a proposal was made for a 3D extension of the Graphical Kernel System (GKS), which was accepted by ISO as a Draft Proposal. CWI was also involved in the design and implementation of a FORTRAN 77 implementation of GKS level 2b. Work on this project is done in cooperation with various institutes and industries.

Ten Hagen and De Ruiter continued their research on language primitives for raster graphics, sponsored by STW, and carried out in cooperation with Prof.Dr. J. van den Bos (State Univ. Leiden, formerly Catholic Univ. Nijmegen) and L.R.A. Kessener and M. van Lierop (Techn. Univ. Eindhoven). Two sets of pattern primitives were defined, one for two-dimensional raster primitives, and one for raster images of three-dimensional objects. Further research concerned the derivation of the hierarchical data structure, needed for the pattern graphs, from PHIGS (the Programmers Hierarchical Interface to Graphics Systems).

Workstations for interaction
This new project is carried out by Blom, Ten Hagen, Janssen, Kuijk, and Troiani (Contracts and Support Division). Its aim is to develop advanced interactive workstations. Work on this project is done in collaboration with industry, which provides the hardware and gives important information about application characteristics, especially from the world of CAD. The task of CWI is to design the architecture of such workstations and to see to their programmability. The real end of this project is to develop a fifth generation (intelligent) workstation with a built-in mechanism to support the interactive dialogue.

Computer-Integrated Manufacturing
This was a pilot ESPRIT project of the European Community. For CWI Blom, Ten Hagen, Janssen, Kuijk, and Van Waning took part in it. The research was done in cooperation with ISTEL Inc. (formerly British Leyland Systems Inc., Redditch, UK) as prime contractor, and with the Computer Science department of the University of Amsterdam and the National Aerospace Laboratory as subcontractors of CWI. CWI's contribution was a proposal for a strategy for computer processing and communication in CIM.

Supporting Services

Contracts and Support Division

From its foundation, one of the aims of SMC has been to make the research done at its institute applicable for government institutions and industry. To this end, there is a separate service for handling work on commissions, the Contracts and Support division. It supports the scientific departments, especially with respect to the automation of data handling. It also accepts commissions directly, enlisting the expertise present in the scientific departments where necessary. In accepting projects, the following guidelines are employed by CWI: the methods of solution are generally known, but the problem is so complicated and requires contributions from such varied disciplines that a solution could not be expected from an organization with fewer facilities; the method of solution is known only in scientific circles and has seldom or never been applied in a practical problem; there is no known method of solution. In some cases a solution can be linked to current research or existing knowledge, in other cases the solution of a practical problem may lead to a new area of research, resulting in a mutual enrichment of science and practice.

Some interesting commissions in 1984 were: the development of device drivers for the C version of GKS, in cooperation with the Computer Science department; the implementation of a standardized package for electronic mail; the design and implementation of a statistical package for hospital facilities.

The supporting function of this division is not restricted to the scientific departments, for it also sees to the needs of the administrative departments, where automation is required, as is, for example, by the financial department, the publication department, and the library.

The Computer Laboratory of the Contracts and Support division looks after CWI's computing facilities, in particular a Local Area Network based on Ethernet. An important part of the task of the Computer Lab is the management of EUNET, the European Wide Area Network of UNIX UNIX.† CWI acts as the main 'gateway' between Europe and North America for EUNET/USENET. This year, the network was extended with several gateways to the United States, so that now computer science departments of many universities and research institutes all over the world are connected. CWI is the UNIX representative in Europe.

Library and Information Service

CWI is fortunate in its excellent library, whose collection is in fact of national importance. It has an extensive collection of journals (1000 current subscriptions), ca. 30.000 books, and a large collection of research reports (ca. 45.000). It publishes a national catalogue of journals held by the Institutes of Mathematics and Computer Science of the Dutch universities. At the request of the European Mathematical Council, it collects preprints, research reports, etc., published in Europe, and regularly distributes lists with bibliographic data, so as to provide a current awareness service of 'grey literature'.

For its on-line information retrieval service, the library has access to large international databases on mathematics and computer science.

Publication Department

Of great importance to any scientific institute is its publication department. At CWI phototypesetting facilities are available. The publication department looks after the production of the various reports series of the scientific departments and CWI's books series, CWI Tracts and CWI Syllabi. A good deal of work is carried out for others as well. The series CWI Monographs is produced in cooperation with the commercial publisher North-Holland Publishing Company.

† UNIX is a Trademark of Bell Laboratories.

Computer Equipment

The computer equipment of CWI is managed by the Computer Laboratory of the Contracts and Support Division. The interrelation between the various components is indicated in fig. 3. The computer equipment is largely from Digital Equipment Corporation (DEC). Each computer has a network name by which it can be identified by users or other computer systems.

VAX 11/780 (boring)
This system is used for the research done by the Computer Science department.

VAX 11/750 (turing)
This machine is used for preview facilities for typesetting, for advanced text processing, and for research done by some of the departments. It is also used for administrative purposes.

VAX 11/750 (haring)
This machine is made available to CWI by DEC for the UNIX network, it supplies the gateway function for Europe (200 connections). It is also used by the Computer Lab for system development.

PDP 11/45 (daring)
Access to this machine is limited to the Computer Lab, which uses it as a hardware testbed for new equipment.

PDP 11/34 (mcpdp34)
Used by the Data Entry department and the Library for data entry.

SUN workstation (sering)
This machine is available to all users as a test workstation. The operating system is Berkeley 4.2BSD UNIX. Via Ethernet it is also linked with the VAX computers.

Ethernet
Most of the computers are connected to the CWI Ethernet LAN. An Ethernet cable has been installed throughout the CWI premises. It is expected that in 1985 more workstations, computers, and laser printer stations will have been connected to the Ethernet. It is also expected that in 1985 the WCW-LAN will become operative, connecting all five institutes in the science park WCW in which CWI is located.

Micom
The Intelligent Port Selector (or 'telephone exchange' for data connections) is the pivot of all computer connections, and therefore installed twice, with one of the Selectors as stand-by. From a terminal one can select the computer one wants to work with (VAX, PDP, or SARA's IPS), or peripherals such as the Auto Call Unit, printers, phototypesetter, etc.

Peripherals
Each computer has access to almost all of the peripheral devices, so that these can be used easily and efficiently. Without changes in the lay-out, for example, texts can be sent from any machine to any output devices, according to the quality of the output required (line printer, daisy wheel printer, matrix printer, rasterplotter, or phototypesetter Harris).

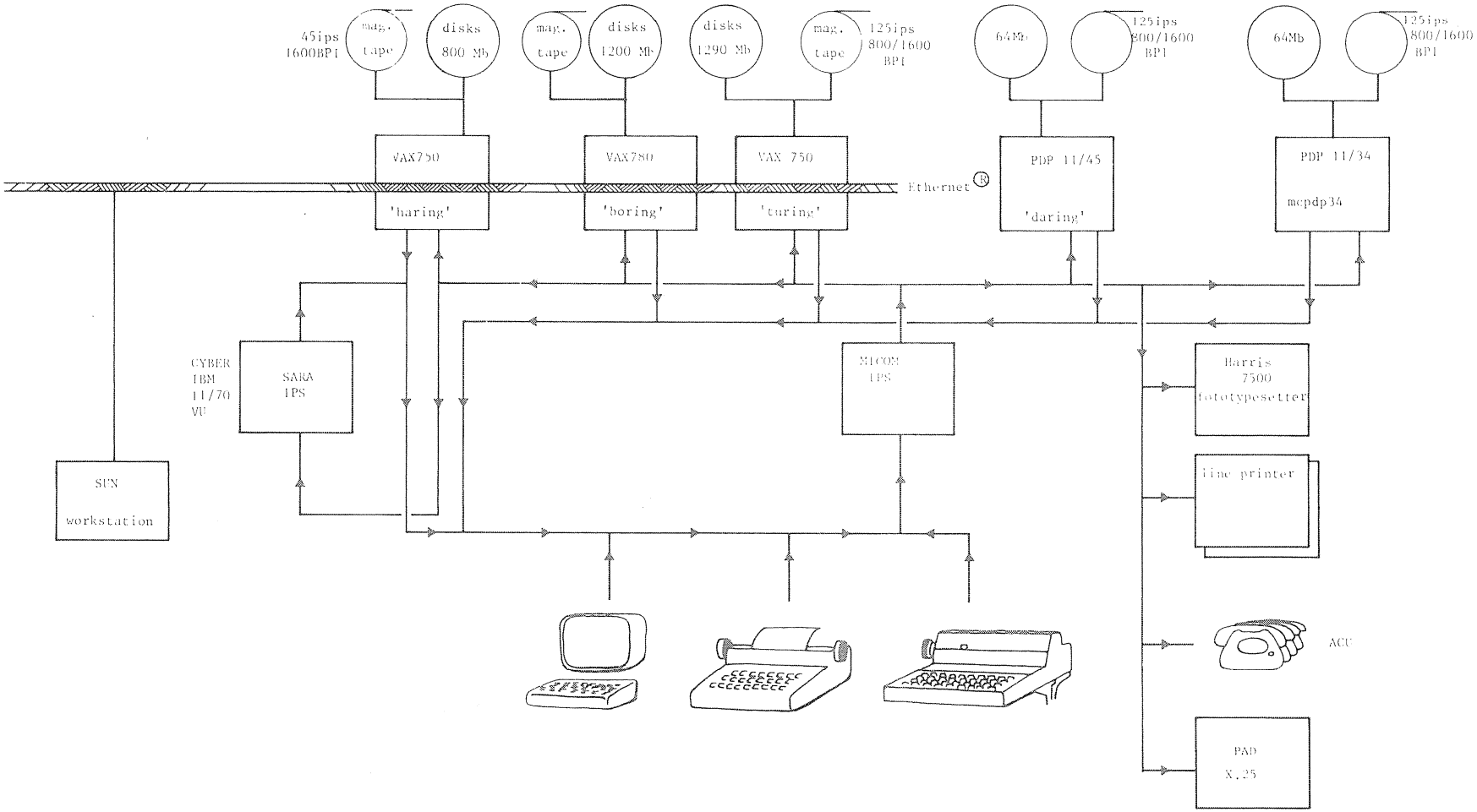


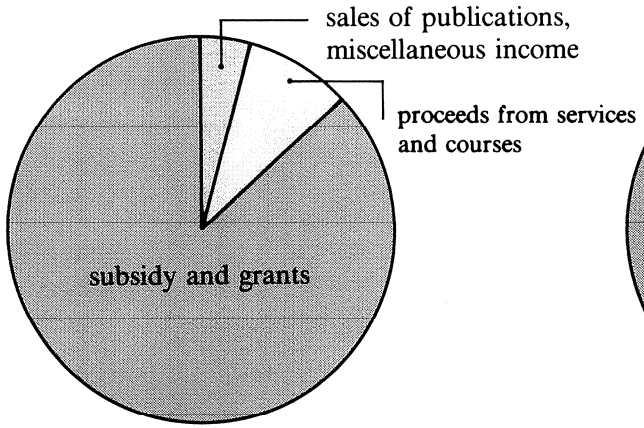
Fig. 3 Computer configuration at CWI (1984)

Finances

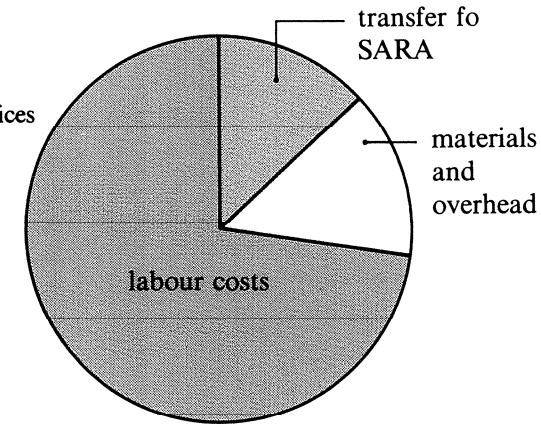
In 1984, SMC spent nearly Dfl. 15 million, of which about Dfl. 1.6 million was allocated to research by the national working communities and over Dfl. 13 million to CWI.
The expenses were covered by a subsidy from ZWO (Dfl. 12.4 million), from SION (Dfl. 0.06 million), from the Free University of Amsterdam (Dfl. 0.1 million) and a grant of nearly Dfl. 0.6 million from the European Community for its ESPRIT-projects. Finally, an amount of about Dfl. 1.7 million was obtained as revenues out of third-party-services, courses and other sources.

	national working communities	*CWI*	*SMC*
	× *Dfl.* 1000		
income			
subsidy and grants	1631	11578	13209
proceeds from services and courses	-	1183	1183
sales of publications	-	157	157
miscellaneous income	-	389	389
	1631	13307	14938
expenses			
labour costs	1618	9690	11308
materials and overhead	13	1894	1907
transfer to SARA	-	1723	1723
	1631	13307	14938
origin of subsidy and grants			
ZWO	1631	10803	12434
SION	-	60	60
VU	-	100	100
ESPRIT	-	615	615
	1631	11578	1309

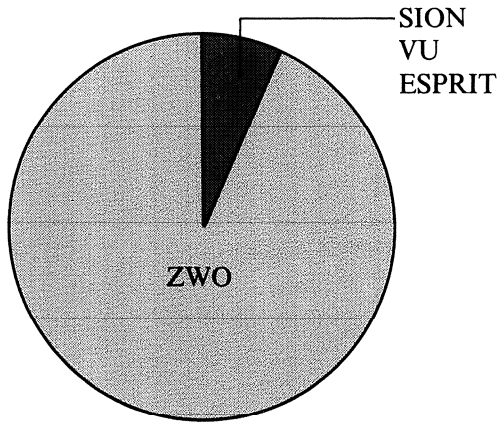
income CWI



expenses CWI



origin of subsidy and grants CWI



Foreign Visitors

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J. Adams (USA)
R.D. Anderson (USA)
E. Badertscher (Switzerland)
A.A. Bruen (Canada)
F. Calogero (Italy)
N. Cutland (UK)
C.F. Dunkl (USA)
R.L. Griess (USA)
J. Grizzle (USA, temp. France)
He Shi (People's Republic of China, temp. France)
O. Hijab (USA)
A. del Junco (Canada)
N.H. Kuiper (France)
B. Kuperschmidt (USA)
C. Meaney (Australia, temp. Italy)
A. Neumaier (FRG)
A. Odlyzko (USA)
D.K. Ray Chaudhuri (USA)
J. Saxl (UK)
B. Schmitt (France)
J. Sekiguchi (Japan)
A. Strasburger (Poland, temp. FRG)
D.A. Vogan (USA, temp. France)

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Jiang Furu (People's Republic of China)
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B. Schmitt (France)
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E.-R. Olderog (FRG)
A. Pnueli (Israel)
C. Smith (USA)
J. Tiuryn (Poland)

List of Publications

Department of Pure Mathematics

Report series

PM-R8401 A. BLOKHUIS, A.E. BROUWER. *Locally 4-by-4 Grid Graphs.*

PM-R8402 A.M. COHEN, A.G. HELMINCK. *Trilinear Alternating Forms on a Vector Space of Dimension 7.*

PM-R8403 J. de VRIES, J.C.S.P. VAN DER WOUDE. *Invariant Measures and the Equicontinuous Structure Relation I.*

PM-R8404 J. dE VRIES, J.C.S.P. VAN DER WOUDE. *Invariant Measures and the Equicontinuous Structure Relation II: the Relative Case.*

PM-R8405 J. dE VRIES. *A Note on the G-space Version of Glicksberg's Theorem.*

PM-R8406 C.F. DUNKL. *Orthogonal Polynomials and a Dirichlet Problem Related to the Hilbert Transform.*

PM-R8407 M. HAZEWINKEL. *On Positive Vectors, Positive Matrices and the Specialization Ordering.*

PM-R8408 A. dEL JUNCO, D.J. RUDOLPH. *On Ergodic Actions whose Self-joinings are Graphs.*

PM-R8409 E.P. VAN DEN BAN. *Invariant Differential Operators on a Semisimple Symmetric Space and Finite Multiplicities in a Plancherel Formula.*

PM-R8410 E.P. VAN DEN BAN. *Asymptotic Behaviour of Matrix Coefficients Related to Reductive Symmetric Spaces.*

PM-R8411 M. HAZEWINKEL. *Experimental Mathematics.*

PM-R8412 T.H. KOORNWINDER. *Squares of Gegenbauer Polynomials and Milin Type Inequalities.*

PM-R8413 E. BADERTSCHER. *Harmonic Analysis and Radon Transforms on Pencils of Geodesics.*

PM-R8414 E.P. VAN DEN BAN. *A Convexity Theorem for Semisimple symmetric Spaces.*

PM-R8415 A.M. COHEN. *Point-line Characterizations of Buildings.*

PM-N8401 M. HAZEWINKEL. *Notes on (the Philosophy of) Linearization.*

PM-N8402 M. HAZEWINKEL. *On Mathematical Control Engineering.*

Publications in journals, proceedings, etc.

Z 1 A. BLOKHUIS, C.W.H. LAM (1984). More coverings by rook domains. *J. Combinatorial Theory Ser. A. 36,* 240-244.

Z 2 A.E. BROUWER (1984). Distance regular graphs of diameter 3 and strongly regular graphs. *Discrete Math. 49,* 101-103.

Z 3 A.E. BROUWER (1984). Four MOLS of order 10 with a hole of order 2. *J. Statist. Planning and Inference 10,* 203-205.

Z 4 A.E. BROUWER, H.A. WILBRINK (1984). A symmetric design with parameters 2-(49,16,5). *J. Combinatorial Theory Ser. A. 37,* 193-194.

Z 5 R. BRUMMELHUIS, T.H. KOORNWINDER (1983). The generalized Abel transform for $SL(2,\mathbb{C})$. *Topics in Modern Harmonic Analysis. Vol. I,* Istituto Nazionale di Alta Mathematica Francesco Severi, Roma, 405-444.

Z 6 A.M. COHEN, B.N. COOPERSTEIN (1983). A characterization of some geometries of exceptional Lie type. *Geom. Dedicata 15,* 73-105.

Z 7 M. HAZEWINKEL (1984). Vezelbundels en natuurkunde. *Ned. Tijdschrift v. Nat. B 50,* 81-84.

Z 8 M. HAZEWINKEL (1984). Symmetry in physics and system theory. An introduction to past, present and future possibilities. *Proc. 23rd IEEE Conference on Data and Control.*

Z 9 M. HAZEWINKEL, T.J. TARN (1984). Quantum mechanical system theory. *Proc. 23rd IEEE Conference on Data and Control.*

Z 10 M. HAZEWINKEL, P.S. KRISHNAPRASAD, S.I. MARCUS (1983). Current algebras and the identification problem. *Stochastics 11,* 65-101.

Z 11 M. HAZEWINKEL, C.F. MARTINI (1984). On decentralization, symmetry and special structure in linear systems. *Lecture Notes in Control and Information Sciences 58,* 437-440.

Z 12 M. HAZEWINKEL, S.I. MARCUS, H.J. SUSSMANN (1984). Nonexistence of finite dimensional filters for conditional densities of the cubic sensor. *Lecture Notes in Control and Information Sciences 61,* 76-103.

Z 13 M. HAZEWINKEL (1984). The linear systems Lie algebra, the Segal-Shale-Weil representation and all Kalman-Bucy filters. *LN Control and Inf. Sci. 58,* 433-436.

Z 14 T.H. KOORNWINDER (1984). Orthogonal polynomials with weight function $(1-x)^{\alpha}(1+x)^{\beta}+M\delta(x+1)+N\delta(x-1)$. *Canad. Math. Bull. 27,* 205-214.

Z 15 T.H. KOORNWINDER (1984). Jacobi functions and analysis on noncompact semisimple Lie groups. R. ASKEY, T.H. KOORNWINDER, W. SCHEMPP (eds.). *Special Functions: Group Theoretical Aspects and Applications,* Reidel, Dordrecht, 1-85.

Z 16 T.H. KOORNWINDER, J.J. LODDER (1984). Generalised functions

as linear functionals on generalized functions. P.L. BUTZER, R.L. STENS, B. Sz.-NAGY (eds.). *Anniversary Volume on Approximation Theory and Functional Analysis,* Birkhäuser, Basel, 151-163.

Z 17 J. DE VRIES (1984). On the G-compactification of products. *Pacific J. Math. 110,* 447-470.

Z 18 J. DE VRIES (1984). Two applications of topological dynamics in combinatorial number theory. *CWI Newsletter 2,* 2-17.

Other publications

Z 19 A. BLOKHUIS. On subsets of $GF(q^2)$ with square differences; presented for publication.

Z 20 A. BLOKHUIS, J.J. SEIDEL. Remarks on Wielandt's visibility theorem; presented for publication.

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