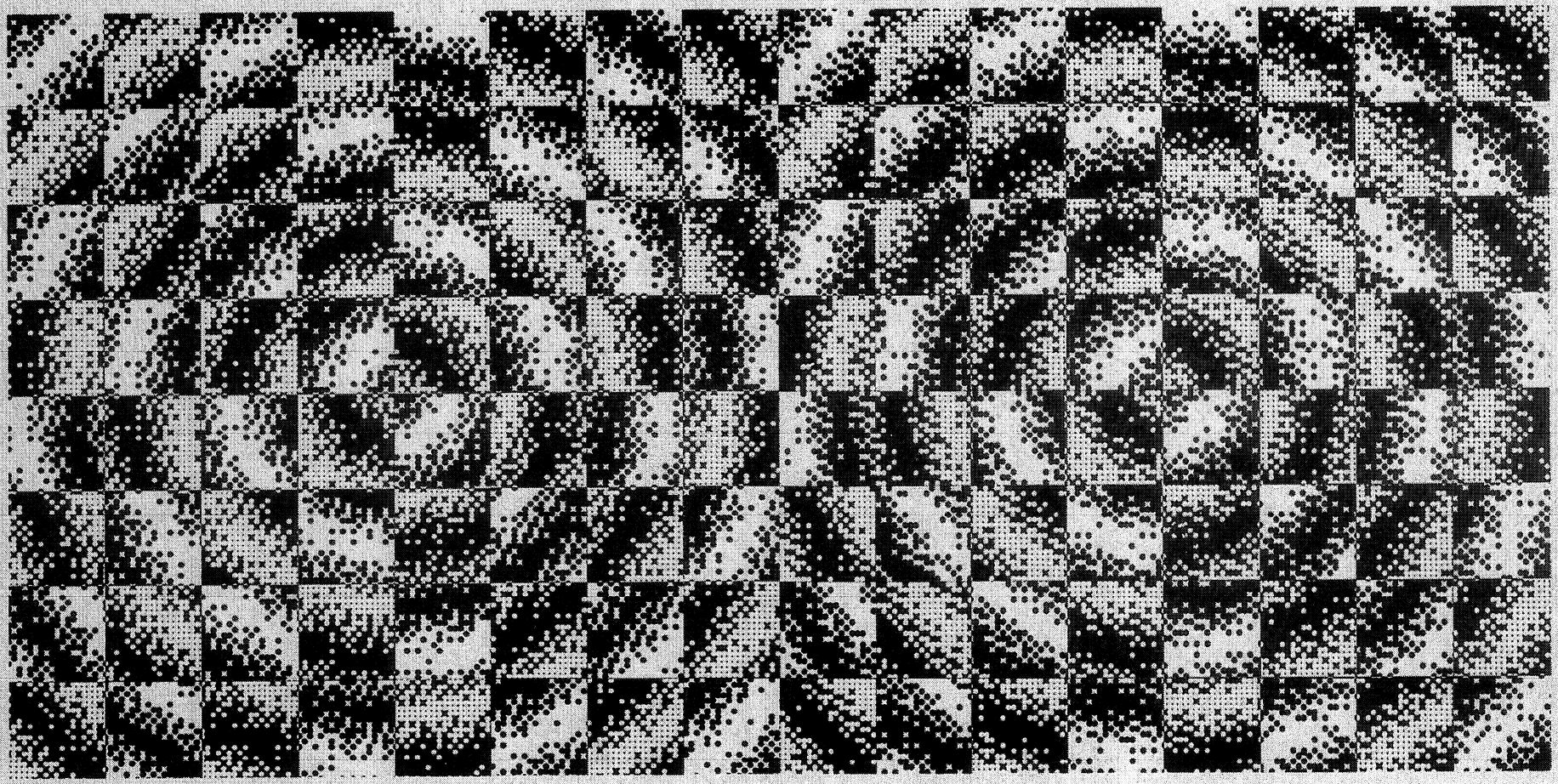
Centrum voor Wiskunde en Informatica
Centre for Mathematics and Computer Science

CWI

ANNUAL REPORT 83



Contents

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).

Board of Directors

prof.dr. P.C. Baayen (scientific director)

drs. J. Nuis (management director)

drs. F.J.M. Barning (assistant director)

Centre for Mathematics and Computer Science

Kruislaan 413
1098 SJ Amsterdam
The Netherlands

P.O. Box 4079
1009 AB Amsterdam
The Netherlands

Centrum voor Wiskunde en Informatica
Centre for Mathematics and Computer Science

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 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.

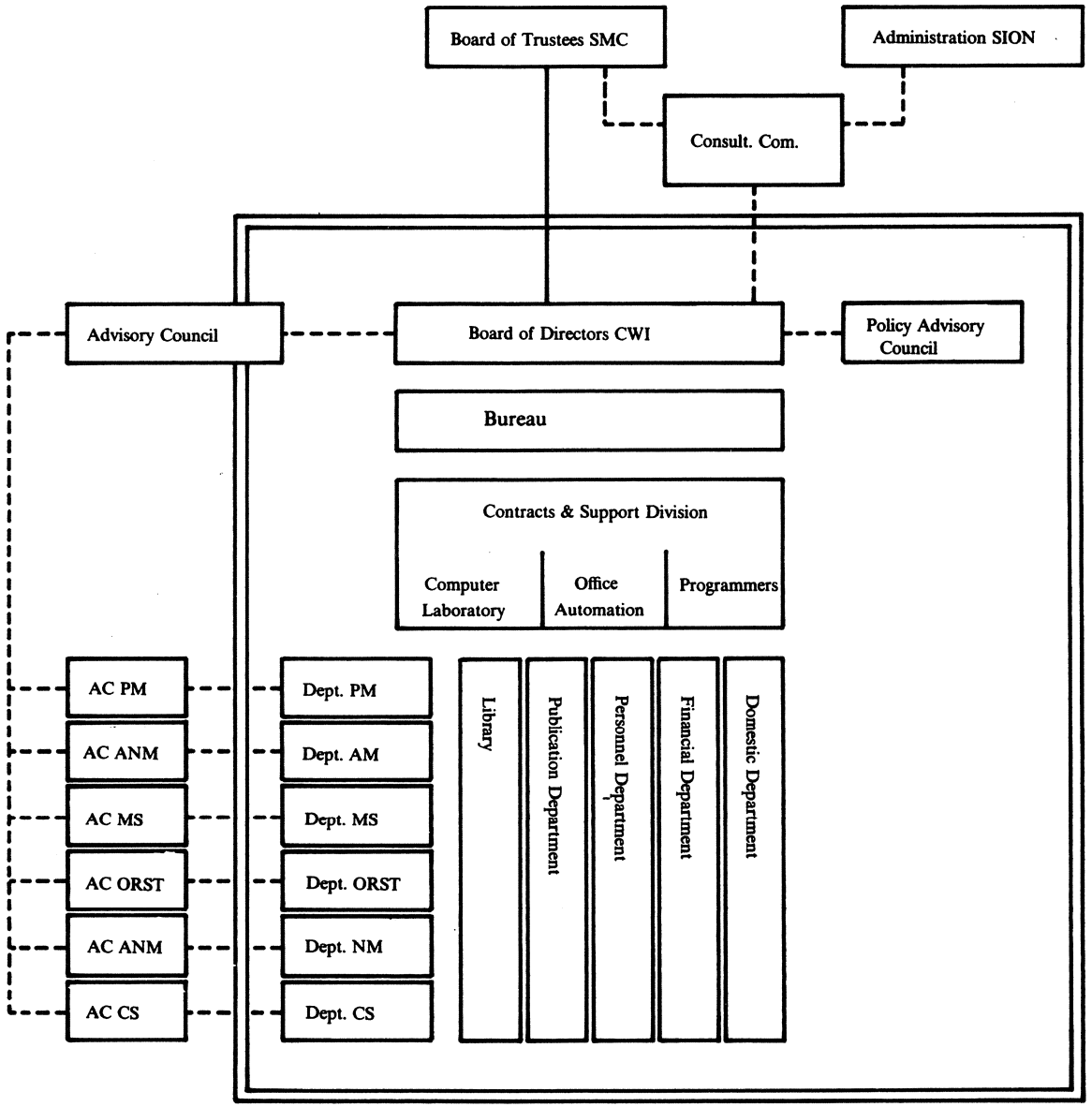


Fig. 1 The Centre for Mathematics and Computer Science

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 in 1983. Great consideration is now given to a closer collaboration of the various scientific departments within CWI, and interdepartmental research projects are encouraged (see fig. 2). In the following figure 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 cooperation with various industries for the ESPRIT projects on formal specification and systematic program development and on design rules for CIM (computer integrated manufacturing) systems.

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. The collaboration between computer scientists and mathematicians, in particular, has always received great attention within the Centre, a fact that was underlined in 1983 by the change of name, from Mathematical Centre to Centre for Mathematics and Computer Science.

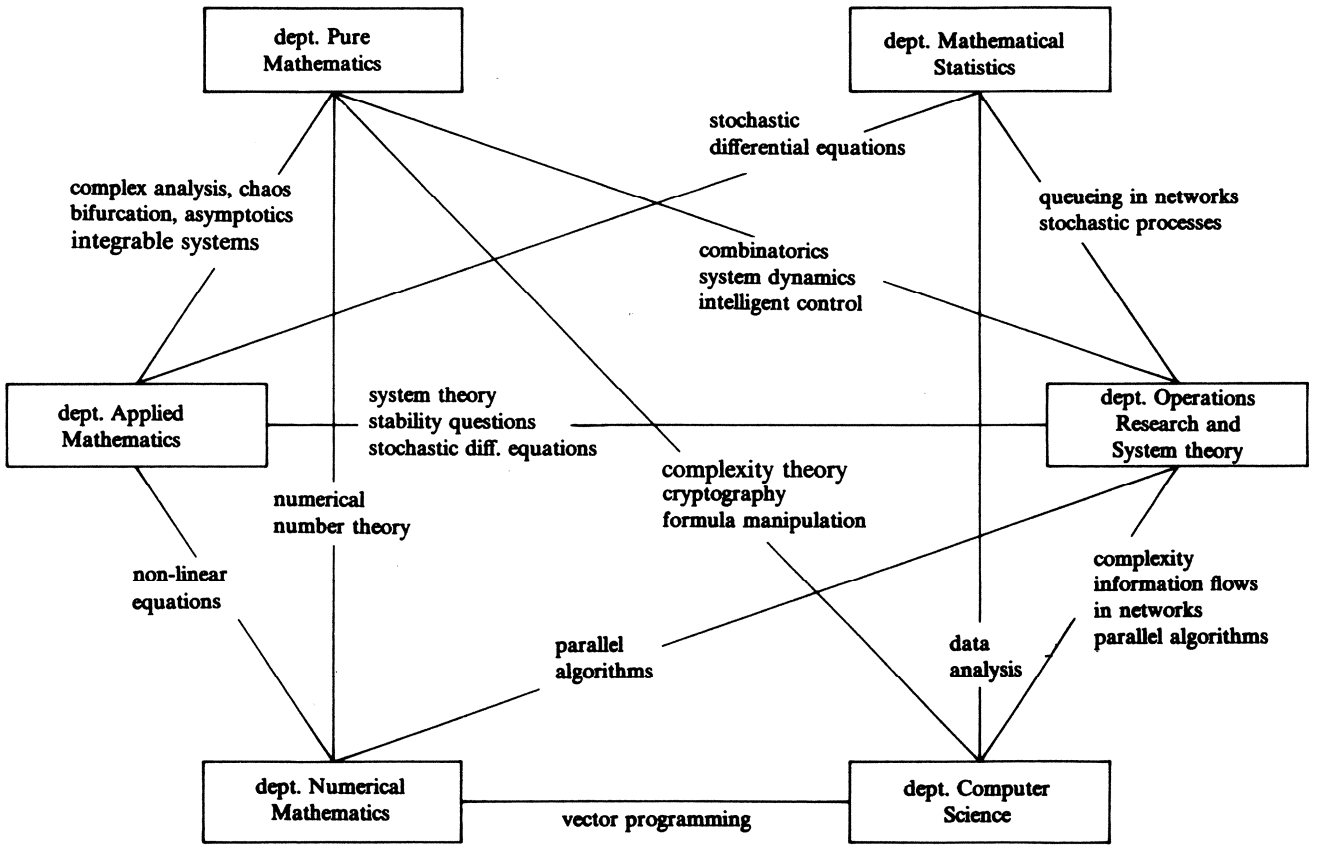


Fig. 2 Interdepartmental research projects

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
drs. A.G. Helminck
dr. G.F. Helminck
dr. B. Hoogenboom
J.M. Jansen
dr. T.H. Koornwinder
drs. S. Lipnisky
J. van de Lune, Ph.D.
drs. S.M. Verduyn Lunel
dr. J. de Vries
dr. J.C.S.P. van der Woude

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 systems 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 nonlinear 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 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. The 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 the Technological University of Eindhoven, the State University of Groningen, and CWI. The study of Lie-type geometries and their graphs was continued. In cooperation with H.A. Wilbrink (TU Eindhoven), the research on near-polygons was carried on. Brouwer continued his work on a book about strongly-regular graphs that he is writing with Wilbrink and J.H. van Lint (also from TU Eindhoven); in the course of this work, a new class of strongly regular graphs with a difference set was found. With A. Neumaier (Freiburg), Brouwer and Cohen have made a survey of all known distance-regular graphs. Given their parameters, a great many graphs were proved to be unique; moreover, some new graphs were found. The existence or non-existence of some distance-regular graphs could be established by relating them to strongly regular graphs.

Another aspect of the discrete mathematics project was the investigation, made by Brouwer and Blokhuis, of the literature on cryptography. Cryptography is concerned with the formulation of mathematical systems, in such a way that confidential information may be passed through an unsafe channel, or stored safely in databases. Special attention was paid to public-key cryptosystems, i.e., systems in which every user has two keys, one of which is made public. On the basis of this known key, information is coded in such a way that without knowledge of the secret

key, decoding will be impossible. Obviously, there are links with coding theory, complexity theory, number theory, and computer science.

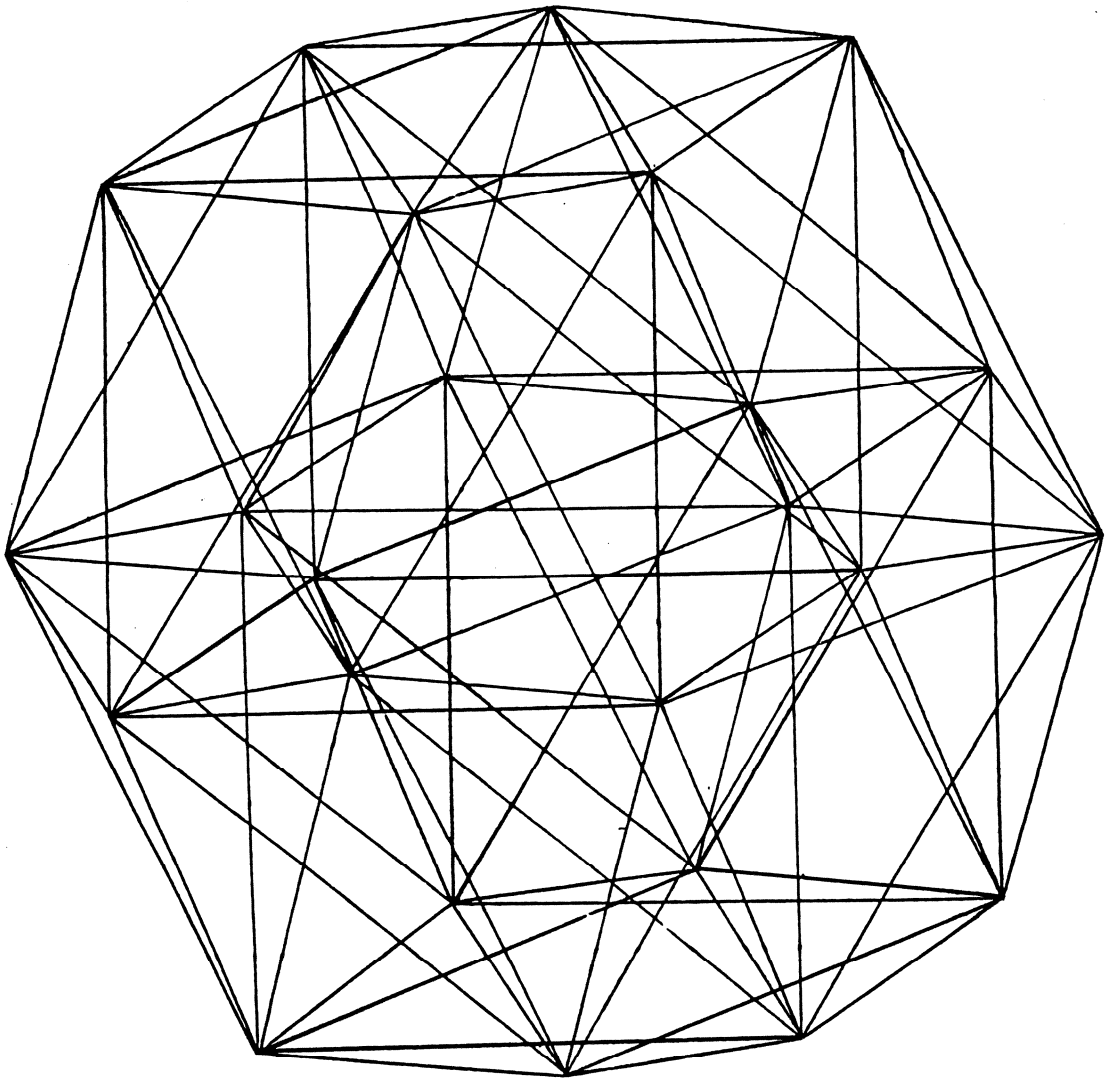
Analysis on Lie groups

This is a joint project of the State University of Leiden and CWI. For CWI, Van den Ban, A.G. Helminck, Hoogenboom, and Koornwinder are taking part in it. Their research topic is the harmonic analysis on (pseudo)Riemannian symmetric spaces and a group-theoretical interpretation of special functions. Let G be a real semi-simple Lie group, and $X := G / H$ a related symmetric space. Harmonic analysis is applied to X, so as to determine and study spherical functions and distributions and their Fourier analysis, G-invariant differential operators and their eigendistributions, etc.

Hoogenboom's investigation into intertwining functions on compact Lie groups resulted in a doctoral dissertation. Further results were produced by him, in cooperation with Koornwinder, concerning the structure of rootsystems with two involutions. In the follow-up of this research, Helminck is also involved.

Van den Ban's research was concerned with the analysis on semi-simple symmetric spaces. He investigated whether the methods developed in his doctoral dissertation could be applied to symmetric spaces G / K_ϵ defined by a signature ϵ. This proved to be possible, as were applications to more general semi-simple symmetric spaces.

In cooperation with P.C. Greiner (Univ. of Toronto), Koornwinder wrote a paper about the Dirichlet problem on the Heisenberg ball. With J.J. Lodder (Institute for Plasma Physics, Nieuwegein), he is working out a rigorous mathematical foundation for Lodder's new type of generalized functions. And in cooperation with



The 4-dimensional polytope corresponding to the 'smallest' geometry of Lie type F_4

R. Askey (Univ. of Wisconsin, Madison) and M. Rahman (Carleton Univ., Ottawa), results were gained concerning an integral involving a system of orthogonal polynomials p_n and the associated functions q_n of the second kind.

For the Oberwolfach conference on Special Functions and Group Theory, a survey article was written by Koornwinder on Jacobi functions and their group-theoretical interpretations.

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.

For the project on discrete mathematics, knowledge of finite algebraic structures, such as permutation groups (often as automorphism groups of graphs and geometries), and of fields and polynomial rings over these, is indispensable. Work on this was carried out by Cohen, Brouwer, and Lipnisky. Most of the results were again discussed in the seminar on Algebra and Geometry.

A start was made with the investigation of the problem of the local recognition of graphs that are related to the geometries of Lie types. In order to get a better understanding of the problems that arose in the course of this study, models have been described, on the basis of the existing literature, of geometries of Lie types G_2, ${}^3D_4$, F_4, E_6 and E_7.

Cohen gave a presentation for some finite quaternion reflection groups, in which the generators are reflections, and in which the relations can be partially read from a diagram. Some results were gained with the help of the computer program CAYLEY, developed by J.J. Cannon (Univ. of Sydney).

Lipnisky investigated which finite solvable subgroups of the symplectic group have a transitive permutation representation on a parabolic subgroup.

Algebraic aspects of the research in analysis on Lie groups are, for example, matrix representations, Lie groups and algebras, and special functions on finite groups. A.G. Helminck has made a start with a classification of paths of pairs of commuting involutive automorphisms of a semi-simple algebraic group. His aim is to give a classification of affine symmetric spaces.

Besides this support given to other projects within the department, the algebra group is investigating (finite) groups of automorphisms of algebraic structures, a more precise definition of the structure of real semi-simple Lie algebras and Lie groups, and the geometry of Tits systems.

In cooperation with E.J. Ditters (Free University, Amsterdam) and members of the Economics department of Erasmus University, Rotterdam, Hazewinkel is doing research on cohomology, Witt vectors, Hopf algebras and representations.

Theta functions

Hazewinkel en G.F. Helminck 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.

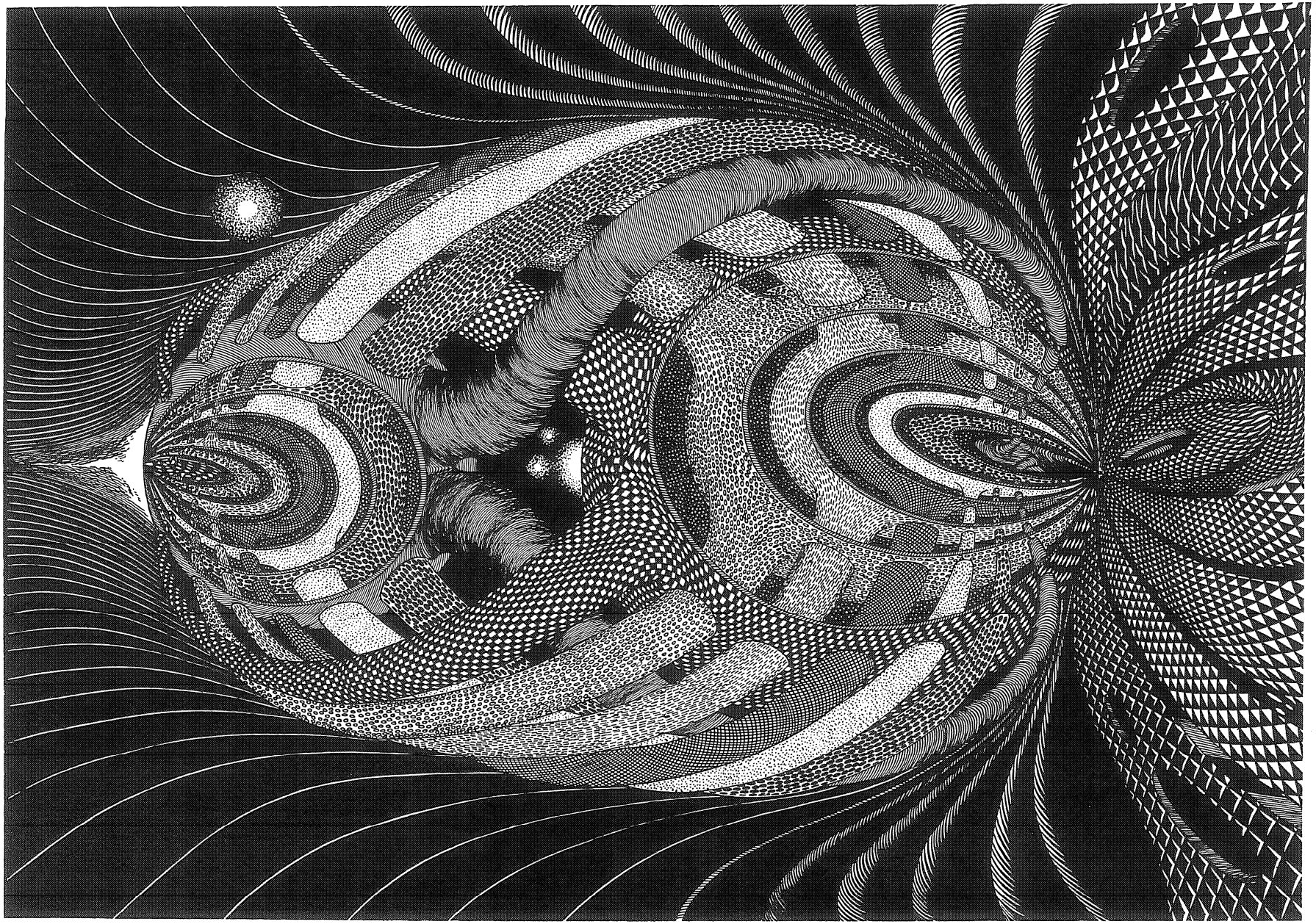
For the seminar on Theta Functions, a thorough investigation of the literature on this topic was made. Helminck investigated the role of the Heisenberg group, the metaplectic group, and the Weil representation in the problems indicated above. The research on the τ function, which is important in the work of Sato, Miwa, and Jimbo on completely integrable evolution equations, was continued. It is now clear that this τ function is a generalization of the theta function. For this research, the approximation of Segal and Wilson of these equations, using the Grassmann manifold, is very important, as is Malgrange's work about universal isomonodromy deformations.

Topology and analysis

In this project, groups and semigroups of topological (continuous) mappings are studied, as well as their applications in topology and analysis. Van der Woude's research was in the field of topological dynamics, while the research of De Vries was concentrated on topological transformation groups. He studied various aspects of what might be called equivariant topology, viz., the adaptation of results from (general) topology to theorems about transformation groups and equivariant mappings. Antonyan's generalization of Tychonov's theorem for G-spaces was refined. On the basis of a refinement of some earlier

Analysis and number theory

An important aspect of this research by Van de Lune (assisted by Jansen) is to acquire know-how in the use of fast computers for the study of problems in analysis and number theory. Examples of such use may be found in the investigation into the location and distribution of zeros of certain analytic functions and related discrete arithmetic functions that occur in several problems in number theory and (classical) analysis.



The deformation of an algebraic surface in $\mathbb{C}^2(Z,w)$. *The case of degree seven. (Anatoli Fomenko, Moscow)*

DEPARTMENT OF APPLIED MATHEMATICS

prof.dr. H.A. Lauwerier (head of department)

dr. O. Diekmann
drs. B. Dijkhuis
drs. S.A. van Gils
dr.ir. J. Grasman
ir. H.J.A.M. Heijmans
drs. J.V. Lankelma
drs. J.J.E van der Meer
drs. H.E. de Swart
dr. N.M. Temme
L.L.M. van der Wegen
drs. S.M. Verduyn Lunel

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;
- Stochastic aspects of dynamical systems;
- Asymptotics and applied analysis;
- Analysis of spectral atmospherical models.

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. This year, a colloquium was held on the dynamics of structured populations. Special attention is paid to the equations that assess growth, aging, death, and birth, while each of these processes may be influenced both by the population itself (e.g., cannibalism) and by other populations. The relevant equations are first order partial differential equations with coefficients and boundary conditions that may be functionals of the solution. Because of these functionals and transformed arguments (e.g., in the case of reproduction by fission), the eqations differ distinctly from the laws of preservation that occur in physics. The mathematical theory of this type of equations is still in its infancy.

Metz, adviser of the Applied Mathematics department, and F.H.D. van Batenburg (both of the Institute for Theoretical Biology of the State University of Leiden) studied Holling's 'hungry mantid' model. They have proposed an analytic model to replace Holling's simulation model for mantid predatory behaviour. From their model relevant parameters, such as functional response and variance of the total catch, can be calculated.

Diekmann, Lauwerier, T. Aldenberg (National Institute for Water Supply, Leidschendam), and Metz formulated and analysed a model for the growth of a size-structured population of individuals (cells) that reproduce by fission into two identical parts. The emphasis of the research was on the influence of changing conditions, such as the availability of nutrients. They showed that the asymptotic behaviour of the total size of the population can be described by a nonlinear ordinary differential equation, while the size distribution becomes stationary. Diekmann also gave some examples of populations with a physiological structure. Heymans, A.R. Thieme (Heidelberg), and Diekmann formulated a model for the growth of a size-structured population of cells that reproduce by binary fission into two identical daughters.

Van der Meer studied the effects of a geographical barrier on the genetic structure of a population. Heymans formulated a model that describes the dynamics of a cell population in which the individuals are characterized by their size. Reproduction is by fission into two (not necessarily identical) parts. It is supposed that the growth of

an individual is in proportion to its size, and thus dependent on the concentration of a nutrient, which may vary in time. Using techniques from dynamical systems theory, Heymans proved that there is a stable equilibrium.

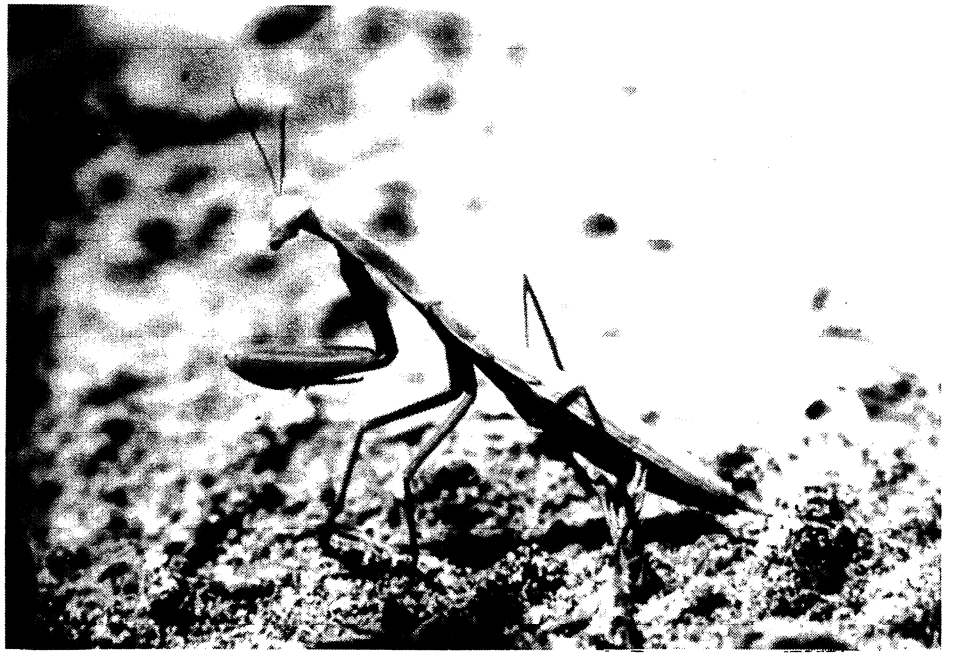
Van Gils studied linear Volterra convolution equations, in particular the semigroup acting on forcing functions and the semigroup acting on initial functions. He also investigated the Hopf bifurcation in the presence of O(2) symmetry.

Verduyn Lunel's research dealt with the rapidly decreasing solutions of autonomous linear functional differential equations. After being reformulated into the functional-analytical language of semigroup operators, the results of his investigation give an answer to some open questions in the existing literature. These results will be published in 1984.

Stochastic aspects of dynamical systems

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

This project is carried out by Lankelma and Grasman. They concentrated their research on the so-called hypercycle of Eigen and Schuster, a special deterministic dynamical system with a cyclic structure. The stability of a stochastic version of this system was investigated. Kolmogorov's exit problems were solved, and numerically an asymptotic estimate of the exit time was given with the help of the WKB-method.



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 the CWI) and studied by him, F.H.D. van Batenburg and H.J.A.M. Heijmans. The results of this study, such as approximation formulas 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 report TW 233/83 (which has meanwhile appeared in the* Springer Lecture Notes in Biomathematics 54: *Mathematical Ecology, S.A. Levin & T.G. Hallam (eds.), p. 29-41, 1984) and AM-R8407 (which will appear in* J. Math. Biol.) *and in two more forthcoming reports.*

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, especially those concerning the investigation of large or small parameters. This has made many, both within CWI and outside, turn to CWI with problems in the fields of complex analysis, integrals, and differential equations.

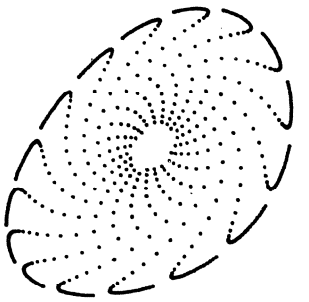
Temme worked on a class of Laplace integrals. Before an asymptotic development is given, the integral should be transformed to a standard expression. Attention is paid to rigorous estimates of the remainder in the asymptotic development, and applications for some special functions are dealt with. Together with P. Groeneboom of the Mathematical Statistics department, Temme analysed an integral equation, the solution of which is relevant to the estimation of monotonous densities.

Grasman has begun work on a monograph on the asymptotics of nonlinear oscillations. Besides giving a survey of the existing literature, the book will contain a revision of his own publications since 1970. It will deal with autonomous oscillators, with weakly coupled oscillators with applications in biology, and with the Van der Pol oscillator with a sinusoidal forcing term.

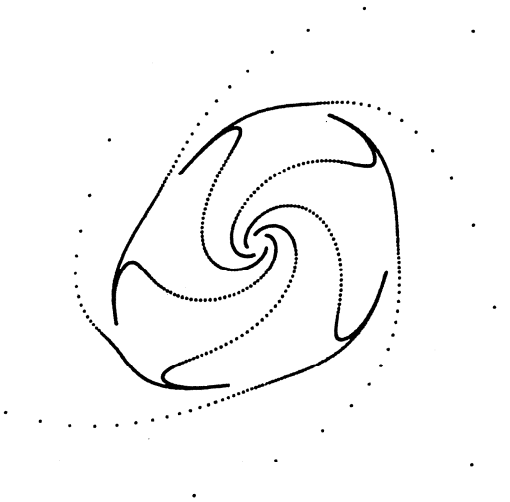
Modern mathematical techniques from functional analysis and function theory of several complex variables are used to gain a better understanding of the nature of such physical problems as translations in time and space in quantum mechanics. The research of Dijkhuis dealt with localizability in quantum mechanics. It was proved that in a relativistic quantum mechanic system, perturbations are propagated with a velocity that equals or exceeds the velocity of light. In this, the quantum mechanical theory obviously differs from classical relativity theory, which does not allow of velocities greater than the velocity of light. In fact, an example was constructed of a quantum mechanic perturbation which at the time of its origin can still be localized in a bounded region, but is at once spread over the whole space.

Lauwerier's work is on the asymptotics of nonlinear discrete dynamical systems. He considered some planar maps for which there exists an unstable invariant manifold, originating from a saddle fixed point. Their parameters are determined with the help of easily computable analytic functions. For his research on chaos and order, Lauwerier investigated the apparently stochastic behaviour of deterministic dynamical systems, such as, for example, a system of ordinary differential equations. During the last decade, research on this topic has been explosive. By means of computer experiments important results have been obtained both by mathematicians and physicists. Furthermore, Lauwerier investigated the bifurcation of a map at resonance 1:4. The maps considered, find their origin in a discrete model of logistic population dynamics. The main purpose is to gain full understanding of the various computer plots in the case that the multipliers of the equilibrium state are almost equal to $+i$ or $-i$. Lauwerier has shown how the theory of normal forms can be applied.

Analysis of spectral atmospherical models
For the STW (Foundation for the Technical Sciences) sponsored project, carried out in cooperation with the Royal Netherlands Meteorological Institute, De Swart is investigating spectral models of the large-scale atmospherical flow which describe medium range weather conditions. Especially the quantitative aspects are studied.



Hopf bifurcation; a single orbit of a planar map seems to converge to a stable 16-cycle



Weak resonance; two orbits are shown perhaps converging to a stable 5-cycle

DEPARTMENT OF MATHEMATICAL STATISTICS

prof.dr. J. Hemelrijk (head of department till April 1st)
dr. R.D. Gill (head of department as from April 1st)

drs. A.W. Ambergen
dr. H.C.P. Berbee
drs. A.J. van Es
dr. P. Groeneboom
drs. S. van de Geer
dr. R. Helmers
J.W. Nool
R. in 't Veld

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 led to the introduction of new principles of statistical inference, e.g., in censored data.

Much of mathematical statistics is built on probabilistic techniques and ideas. Formerly this came mainly from 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 four main projects:

- Distribution theory;
- Stochastic censoring;
- Stochastic processes and applications;
- Applied statistics.

Distribution theory

This project comprises research activities in the field of theoretical statistics.

Helmers is working on second order asymptotics. During the last decade, second order limit theorems have received a great deal of attention. In cooperation with M. Husková (Charles University, Prague), Helmers investigated the possibility of a Berry-Esseen theorem for linear combinations of order statistics. With P. Janssen (Limburgs Universitair Centrum, Diepenbeek, Belgium) and R.J. Serfling (Johns Hopkins University, Baltimore), the asymptotic properties of L-statistics were studied. Strong limit laws and a Berry-Esseen theorem for generalized L-statistics were proved. On the basis of these results, the asymptotic validity of the bootstrap approach was shown for generalized L-statistics. R.J.M.M. Does (State University of Limburg) and C.A.J Klaassen (State University of Leiden) cooperated with him on the investigation of Edgeworth expansions for functions of uniform spacings. In his invited paper for the *Third Prague Symposium on Asymptotic Statistics,* Helmers gave a survey of recent results in the field of second order asympotics.

During his stay at the Mathematical Sciences Research Insitute at Berkeley, Groeneboom wrote a paper with D.R. Truax in which a monotonicity property of the power function of a class of multivariate tests is proved.

In the biweekly seminar on semiparametric estimation theory, Van Es, Gill, Groeneboom, and Helmers, together with members of the two Amsterdam universities and of the University of Leiden, made a thorough investigation of the literature. Semiparametric models have become very popular in various fields of applications, e.g., in biometry. Up till now, there have been very few contributions towards a general theory of semiparametric estimation. The object of this research is to develop a general theory on the

basis of which estimators for specific models can be constructed. In particular it is important to map out the area of applicability of the maximum likelihood principle.

Stochastic censoring

Stochastic censoring is the phenomenon that often occurs in measuring life times or survival times, viz., that for some objects only a lower bound can be given for the relevant time interval. During the last twenty years, this subject has shown remarkable progress, especially because of the increasing interest in large-scale clinical trials to compare different treatments in cancer research, and in the testing of new products on carcinogeneity. Also in industrial life-testing censoring often occurs. Many new statistical techniques have been worked out, and useful new principles have even been developed for statistical inference.

The study of semiparametric estimation theory within the department has stimulated further research by Van Es and Gill in the following two aspects of stochastic censoring.

In case of the k-sample problem with censored data, it is possible, under certain conditions, to construct tests that are optimal when the censoring in the k samples tests is equal. By a semiparametric approach with a nonparametric nuisance parameter new insights have been obtained into the efficiency of k-random tests with unequal censoring.

One of the best-known semiparametric models is the Cox regression model. A study of this model, in cooperation with K. Dzhaparidze (ZWO), has led to general results concerning asymptotic efficiency problems relevant to this and related models. On these and related problems, Gill and Van Es work with P.K. Andersen and N. Keiding (Statistical Research Unit, Copenhagen), Ø. Borgan (University of Oslo), and M. Schumacher (University of Heidelberg), among others.

A regular contact has been established with members of the Netherlands Interuniversity Demographic Institute in order to investigate the applicability of methods for counting processes in demography. This year, an inventory was made of interesting problems.

Some nice applications of new methods for stochastic censoring were found in several cases in which CWI had been applied to for advice, both for scientific and for industrial purposes.

Stochastic processes and applications

In this project, stationary processes are investigated, as well as continuous-time Markov processes.

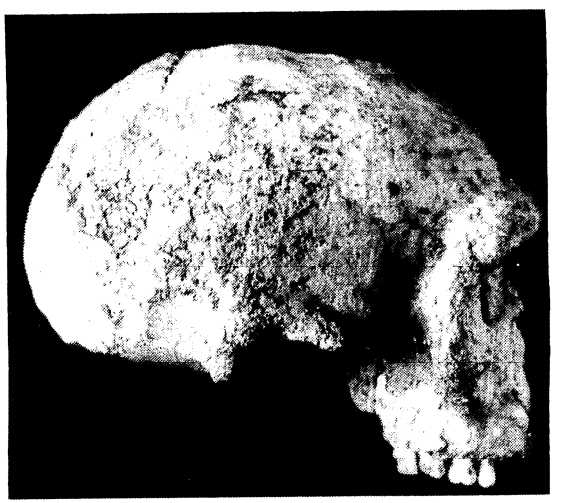
Profiting from R.C. Bradley's work (Indiana University, Bloomington), Berbee wrote a paper on 0-1 laws in stationary processes. The results suggest that, from a certain point of view, renewal theory for stationary processes is closely connected to the theory of random walks and, it is expected, also to isomorphism theory for dynamical systems. Berbee is also working on Markov representations; he tries to describe chains with infinite connections as a functional on a Markov chain.

As for his research on excursion theory, Groeneboom obtained some results concerning the behaviour of the concave majorant of the empirical process and Brownian motion and the Brownian bridge. This year, the research was gradually directed towards estimation theory, in particular the estimation of densities. Results concerning the local and global behaviour of the (Grenander) maximum likelihood estimator of a monotone density were deduced from properties of certain jump processes that are generated by Brownian motion.

With N. Troiani and F.J. Burger from the Contracts & Support Division, a simulation was made to acquire a better understanding of the relevance of the asymptotic results for random samples of moderate size. B.P. Sommeyer (Numerical Mathematics department) and J.W. Nool wrote computer programs for the numerical solution of certain heat equations that characterize the limit distributions of the investigated stochastic variable. The analytical properties of these heat equations were further investigated in cooperation with Nico Temme of the Applied Mathematics department.

Applied statistics

In the social sciences it often occurs that, for instance by using opinion polls, there are large collections of data, consisting of the reactions to many different questions. Prof. J. de Leeuw et al. (State University of Leiden) developed methods and computer programs for the explorative data analysis of such data sets. The aim of the research done at CWI is to investigate the mathematical



Discriminant analysis is a multivariate statistical technique that is used in the classification of fossil human skull fragments (STEINHEIM *skull, 200.000 - 300.000 years old)*

foundations of these methods and to find points of contact with traditional mathematical statistics, as well as to propagate the correct use of these methods.

This year, Gill and Schriever concentrated their research on the asymptotic properties of a number of tests for independence in contingency tables, with particular reference to alternatives that show ordinal dependence. The tests developed last year proved to have some drawbacks. A number of other tests have now been constructed that are without these unsatisfactory qualities. These newer tests have great discriminatory power for alternatives with ordinal dependence.

The research of Ambergen is in the field of discriminant analysis. Discriminant analysis is a multivariate statistical technique that is used to decide to which of several populations a new observation belongs (e.g., medical diagnosis; classification of fossil human skull fragments). The research is concerned with the situation in which, on the basis of posterior probabilities, individuals have to be assigned to one of the populations. Usually only training samples are available from the populations, and therefore sample variability has to be taken into account. The aim of the research is to develop methods to assess and take account of these inaccuracies in such a way that a more reliable assignment to populations is possible. Results were obtained for multivariate normal classification models. This research was done in cooperation with W. Schaafsma (State University of Groningen).

Van de Geer started her work on the statistical analysis of compartment models. A compartment system consists of a number of homogeneous subsystems (compartments) that exchange matter between one another. Especially in pharmacokinetics, compartment analysis is a valuable tool for the investigation of absorption, distribution, and excretion of medicines, but it is also used in other fields, e.g., for the study of metabolic systems or chemical reactions. Van der Geer's research was mainly concerned with the stochastic structure of compartment models. She also considered the case in which the parameters of a compartment model vary between different subjects, to be applied to the investigation of the metabolism of rats, a subject of Dr. E. Wattel (Free University, Amsterdam). The stochastic behaviour of time-dependent parameters allows interesting applications of the theory of stochastic differential equations, to be studied later.

Consultation

Statistical consultation is an integral part of the activities of the department. Through it, the fruits of recent research are applied in practice and become more widely known and available, while conversely the demands of new types of application stimulate new research. As usual, consultation took place during the year on an exceedingly wide range of topics; here we only mention two.

A numismatist studying medieval coinage wished to know the amount of money minted in the reign of Floris V of Holland in order to determine the size of the economy. His data consisted of precisely four numbers: of 175 known coins of a certain type, 126 were each struck by a different die, 40 came in pairs from the same dies, 9 came as triplets. From an unknown number of dies no coins were available. On the basis of plausible assumptions as to how many coins were typically struck with one die, it was determined that the total number of coins struck lay between 8,000,000 and 15,000,000 with 90% confidence.

While construction was in progress on the East-Schelde part of the Delta plan, it was found that gravel used in the foundation of the dam was being carried away by the strong currents at a far greater rate than was expected. Using a physical model for gravel transport and a stochastic process model for variations in the current, calculations were made (at very short notice) on the amount of extra gravel which was needed in the construction.

Some coins (13mm across) minted in the reign of Floris V of Holland

DEPARTMENT OF OPERATIONS RESEARCH AND SYSTEM THEORY

prof.dr. G. de Leve (head of department till September 1st)
prof.dr. J.K. Lenstra (head of department as from September 1st)

J.M. Anthonisse
dr. J.P.C. Blanc
dr. J.C.P. Bus
dr.ir. E.A. van Doorn
drs. G.A.P. Kindervater
drs. B.J. Lageweg
drs. L. Stougie
prof.dr. A. Schrijver
dr.ir. J.H. van Schuppen
dr. H. Nijmeijer
drs. J.W. Polderman
drs. M.W.P. Savelsbergh
drs. P.J.C. Spreij

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 members of this group are involved in 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.

In cooperation with E.L. Lawler and D.B. Shmoys (University of California in Berkeley), and A.H.G. Rinnooy Kan (Erasmus University Rotterdam), Lenstra is working on a book about the travelling salesman problem. For the proceedings of the *Summer School on Combinatorial Optimisation* in Dublin, Lenstra and Rinnooy Kan made an annotated bibliography of recent results in machine scheduling problems. During his stay at CWI, Han Jiye (Academia Sinica, People's Republic of China) made an investigation of some algorithmic results for the flow shop problem, which will be published in 1984.

The research on hierarchical planning models is carried out by Stougie and Lenstra. These models are relevant to problems that are characterized by a sequential decision process, for which in successive stages more and more detailed decisions have to be made. At each stage, the decisions are based on a deterministic model of the present stage and on probabilistic assumptions about the later stages. Its aim is to minimize present cost plus the expected cost in later stages. Stougie and Lenstra wrote an article in which a heuristic is given for a certain hierarchical machine scheduling problem. They also provided a general framework for the probabilistic analysis of approxima-

tion algorithms for hierarchical planning models, being an approach they have frequently used in their research.

The emphasis of Kindervater's research is on parallel algorithms. Within the field of computer science, there have been some remarkable developments concerning parallel algorithms. It is to be expected that soon machines with parallel processors will be available for automatic information processing. Up till now there has been very little research into the applications of such machines for purposes of operations research. Kindervater and Lenstra made an annotated bibliography of the results in this field, and they gave an introductory survey of this topic for the Colloquium on Parallel Computers and Computations, held by the State University of Utrecht and CWI. Further research is directed towards the parallelization of enumerative methods, such as dynamic programming and branch-and-bound.

In a project sponsored by STW, carried out in cooperation with other members of the department, Savelsbergh is working on the development and implementation of algorithms for vehicle routing. For this project, which was started in July, contacts have been made with Van Gend & Loos, the largest road transportation concern in the Netherlands, for whom the routing system is to be developed in the first place.

Schrijver is working on polyhedral and polynomial methods. In cooperation with M. Grötschel (Augsburg) and L. Lovász (Budapest), he is writing a book on *The Ellipsoid Method and Combinatorial Optimization.* Schrijver is also working on books on linear programming and polyhedral combinatorics.

Availability of software is of great importance, both to the scientific research of the department and to its consultation projects. It should enable the researcher to make new programs from available standard algorithms, e.g., for elementary operations such as sorting and merging, and for basic operations research algorithms in the areas of location, distribution, and scheduling. This year, the in- and output system for linear programming was improved, and now includes a more advanced construction of a matrix generator. To the OPERAL library was added NETGEN, a standard generator of network problems (Klingman, Napier & Stutz, Austin, USA).

Van Gend & Loos, the largest road transportation concern in the Netherlands, for whom a vehicle routing system is to be developed

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, for example, 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 and Van Doorn investigated the transient behaviour of networks of queues. They have written a survey article about relaxation times for queueing systems. Furthermore, they obtained some results in their research of simple Jackson networks. An investigation was made of the literature on networks of queues. Two lectures were given on this topic for the Colloquium on Stochastic Analysis of Models for Computer Networks. Their study of the literature had moreover aroused their interest in telecommunication networks, resulting in a number of articles.

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.

Bus expanded his characterization in differential geometric terms of solutions for finite-horizon optimal control problems to problems of infinite horizon. He also obtained some results that related the normality of optimal control problems to first-order controllability of the associated nonlinear system.

Nijmeijer completed his research on problems in differential geometric systems theory with the publication of his doctoral dissertation. In September, Polderman began an investigation of the literature on adaptive control, and earlier in the year Spreij started his research of on-line algorithms for parameter estimation in point process systems.

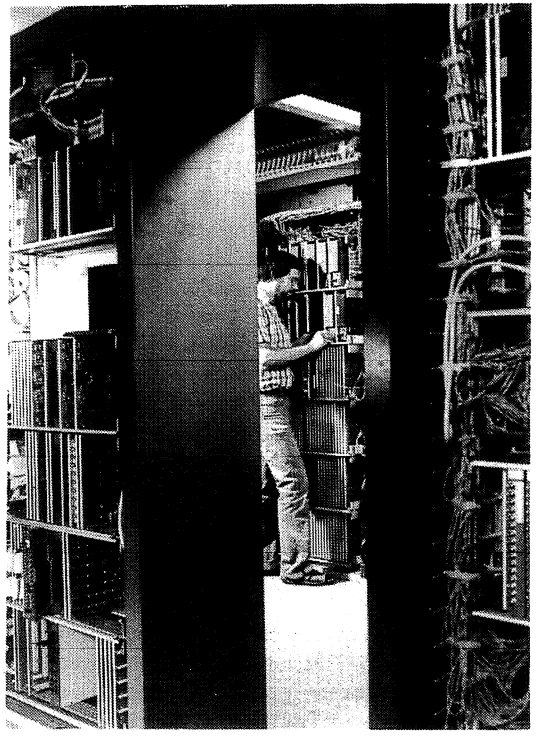
Together with G. Picci (Padua, Italy), Van Schuppen continued his research of weak stochastic realization problems for processes on finite spaces. Great attention was paid to a related problem, the minimal factorization of nonnegative matrices. Concerning adaptive stochastic filtering problems, with regard to recursive identification algorithms were investigated on recursive maximum probability. With A. Bensoussan (INRIA), he solved the stochastic control problem for Gaussian systems on an exponential-quadratric cost functional.

Hazewinkel, from the Pure Mathematics department, is also involved in research in system theory. He investigated the structure of Lie algebras for nonlinear filtering problems for parameter estimation in linear systems. Besides, he investigated symmetries and other structures of linear systems.

Consultation

As in preceding years, the department was involved in a number of consultation projects, ranging over a wide variety of research topics, only a few of which are mentioned here.

An analysis was made of the various relations between the advisory bodies of the central government. The results of this analysis were used in the reorganization of the existing structure. For a large steel industry, a production planning problem with assignment and sequencing aspects was studied. The sequencing part was formulated as a travelling salesman problem with time windows. An algorithm, as well as a computer program was developed. For medical purposes a mathematical model of the alpha rhythm of the heart was evaluated and a filtering problem was solved. Some advice was given for a system identification of a physiological model of the respiratory system.



Advisory work was done on overload control for telephone exchanges

DEPARTMENT OF NUMERICAL MATHEMATICS

prof.dr. P.J. van der Houwen (head of department)

drs. E.J. van Asselt
dr. K. Dekker
dr. P.W. Hemker
drs. J. Kok
R. Kroezen
W. Lioen
dr.ir. H.J.J. te Riele
P. Schroevers
ir. S.P. Spekreijse
dr. J.G. Verwer
M. Visman
ir. H.B. de Vries
ir. F.W. Wubs

programmers:
drs. JG. Blom
drs. M. Louter-Nool
B.P. Sommeijer
D.T. Winter
drs. P.M. de Zeeuw

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 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 equations;
- Shallow water equations.

Discretization of initial value problems

The aim of the research is the development, analysis, and documentation of algorithms for numerical solutions 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 are continuing their work on a monograph on the *Stability of Runge-Kutta methods for stiff nonlinear differential equations.* In this book, all recent developments in the field of nonlinear stability of Runge-Kutta methods will be discussed. They are further investigating the numerical stability in the time-integration of nonlinear initial boundary value problems, in order to show the close connections between stiff problems and partial equations as far as numerical stability is concerned. Verwer and De Vries are working on the numerical solution of multi-space dimensional parabolic partial differential equations by means of splitting methods. Their aim is to ascertain in how far global Richardson extrapolation will be useful to improve the precision of the LOD-method.

Van der Houwen and Sommeijer are investigating initial value problems with periodic solutions. Most methods for the integration of ordinary differential equations regard the problem as a standard problem, without taking into consideration any specific properties the solution may have. In this project, however, initial value problems are studied of which it is known that the solution will have an oscillatory behaviour, and accordingly integration formulas of linear multistep type are developed for it. As part of the research on multigrid methods, Sommeijer and Van der Houwen are developing software for the time-integration of a certain system of differential equations, originating from semi-discretization of a general nonlinear parabolic differential equation. A FORTRAN program was implemented, based on the efficient algorithms developed. De Vries also investigated the numerical solution of nonlinear time-dependent parabolic differential equations, and developed a new technique of integration.

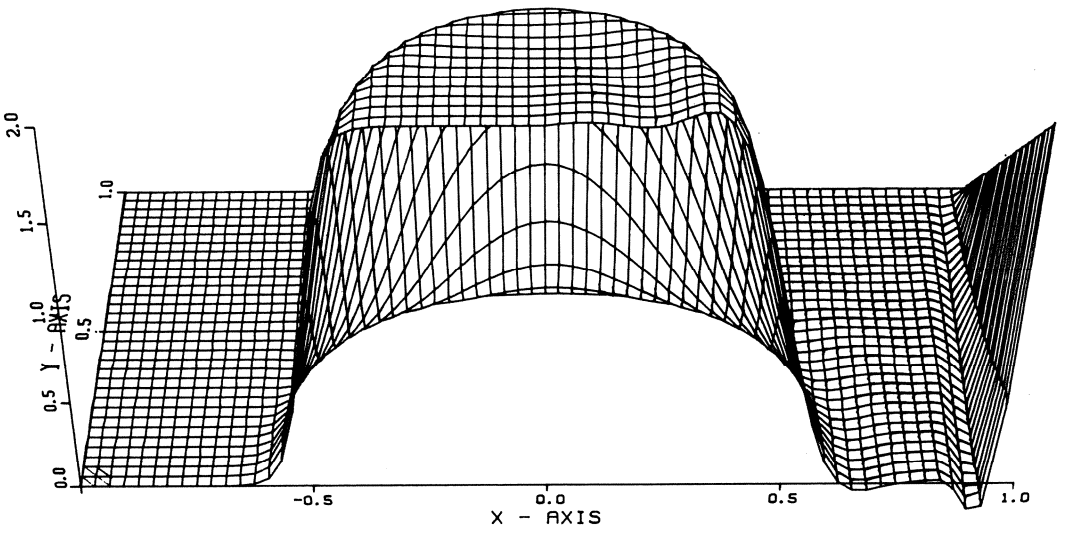
In the field of differential-difference equations, Van der Houwen and Sommeijer are working on linear multistep methods for pure delay differential equations. In cooperation with C.T.H. Baker (University of Manchester), predictor-corrector methods for parabolic differential-difference equations are developed.

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 will be the results of using multigrid methods on vector computers.

Hemker and De Zeeuw are investigating defect correction and its theoretical background. In cooperation with prof.dr. P. Wesseling (Technological University Delft) and ir. R. Kettler (Royal Shell, Rijswijk), software was developed for the solution of discretized linear elliptic partial differential equations by means of multigrid methods. Their aim was to develop software that could be used in the same way as the usual standard software packages for the solution of linear sytems.



Solution of a partial differential equation (problem with interior and boundary layer) computed by means of a multigrid flow

For the solution of nonlinear problems, Van Asselt investigated FMG (Full Multi Grid) methods in which each nonlinear discrete system is solved by Newton iteration. Some termination strategies were evaluated. He also studied globally convergent nonlinear relaxation methods for the solution of a class of nonlinear boundary value problems, where the discretization results in continuous M-functions.

Hemker is doing research on singularly perturbed boundary value problems. He investigated the solution, by means of multigrid methods, of elliptic partial differential equations when the coefficient of the highest derivative contains a small parameter, in particular the anisotropic diffusion equation and the convection diffusion equation were studied.

Hemker, Wesseling, and De Zeeuw implemented two multigrid algorithms, of which the software is made up of autonomous modules. It was constructed specially to be used on scalar and on vector computers. The programs were run on a CYBER 170, an IBM 3081K, a CRAY 1, and a CYBER 205.

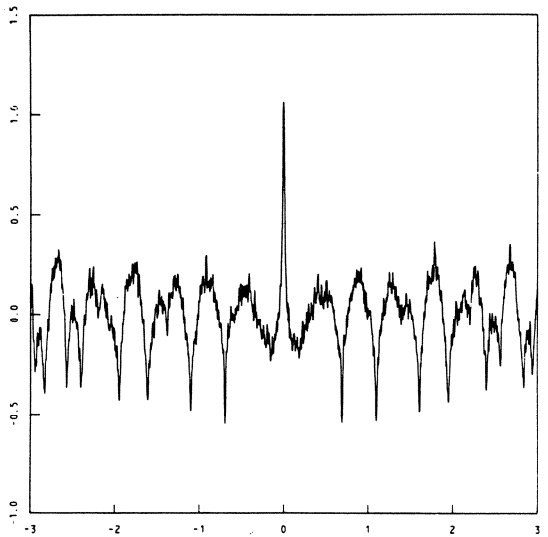
De Zeeuw and Lioen vectorized several multigrid codes for the solution of a discretized elliptic partial differential equation in two dimensions, in order to investigate how efficiently such algorithms may be implemented.

Computer-assisted number theory

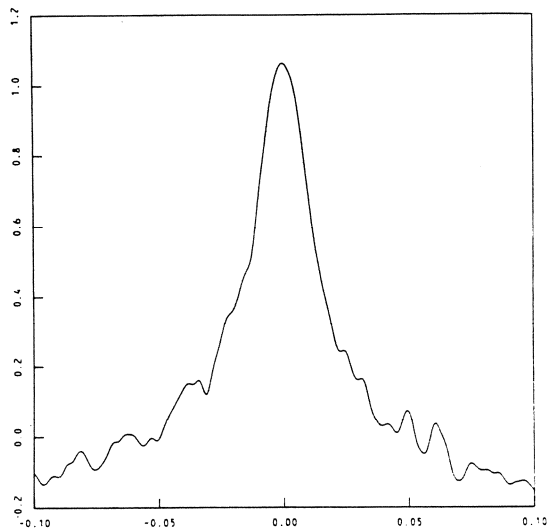
The work on this project is carried out by Te Riele and Winter, in cooperation with J. van de Lune of the Pure Mathematics department. Their aim is to approach certain problems in number theory, some of which are of very long standing, with the help of a computer. Very large computations were made which show that the first 400,000,000 zeros of the Riemann zeta function in the critical strip are simple and lie on the line $Re(s) = 1/2$. Some experiments were made with the existing software on a CRAY 1 and on a CYBER 205 supercomputer, so as to see how much speed-up can be obtained with these supercomputers. The best result was obtained on the CYBER 205, which was three times as fast as SARA's CYBER 750 computer, but, admittedly, great programming efforts were necessary to obtain this result.

Using techniques that were developed in 1982 to generate amicable pairs of numbers from given amicable pairs of numbers, Te Riele computed some new pairs, which were so large as to be a new record. For this, it was necessary to use a program written by A.K. Lenstra of the Computer Science department to prove the primality of some very large primes.

Since better methods and faster computers are now available, Te Riele took up his work on Mertens' conjecture again, which he had been working on in the seventies. In close cooperation with A. Odlyzko (Bell Labs, Murray Hill), Mertens' conjecture, which would have implied the Riemann hypothesis, was disproved with the help of the so-called lattice basis reduction algorithm of A.K. Lenstra, H.W. Lenstra Jr., and L. Lovász. A publication is in preparation.



Graph of the function whose peak value > 1 shows that the Mertens conjecture is false



Enlargement of the central part of the figure above

Numerical software in Ada

The collection of a numerical software library has always been a major concern of the department. A recent development in the field of programming is the language Ada, which many consider as the Esperanto of programming languages. As it is expected that in the future Ada will be widely used, and as numerical computations occur in many scientific and technical computer applications, the necessity of a numerical software library in Ada is obvious. With the available know-how in the department, acquired in the seventies during the development of NUMAL, the first complete numerical software library, CWI felt well equipped to undertake the NUMADA project in cooperation with the National Physical Laboratory (Teddington). To this end the possibilities of Ada for portable numerical software libraries are investigated. The research is focused on the recognition of problems that are linked up with the global design and implementation of such libraries in Ada, and suggestions as to their solution are given. The research was done in cooperation with dr. G.T. Symm and dr. B.A. Wichmann of NPL.

In connection with this project, Kroezen and Visman investigated whether Ada is a user friendly language for scientific computations. On the basis of an existing multigrid program in Algol 68, they checked if certain design principles of Ada, such as data abstraction and method abstraction, held good for the implementation of this program.

Volterra 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. Together with Prof. H. Brunner (Université de Fribourg, Switzerland), Van der Houwen is working on a monograph on discrete Volterra equations. For this, a survey was made of stability criteria that hold for a large class of linear methods.

Shallow water equations

Shallow water equations consist of three linked partial differential equations for the velocity vector and the rise of waterlevel under influence of the tide or winds. The problem is to calculate the velocity vector and rise of waterlevel as functions of time and place for any configuration of coasts, floor profile, or any other obstacle, and for any given external forces, such as wind, friction, Coriolis forces, etc. The aim of this STW sponsored project is to be able to calculate the flow of the water in a great many different of situations, without having to design a new method of computation for each new situation. Besides making an investigation of the literature, Wubs, Van der Houwen, and Sommeijer are evaluating a number of time integrators for hyperbolic differential equations, and a start was made with the development of a multigrid algorithm for hyperbolic equations, the results of which are encouraging.

DEPARTMENT OF COMPUTER SCIENCE

prof.dr. J.W. de Bakker (head of department)

dr. J.A. Bergstra	drs. A.K. Lenstra
drs. C.L. Blom	L.G.L.T. Meertens
ir. J. Ebergen	S. Pemberton
drs. P.J.W. ten Hagen	drs. G. van Rossum
drs. A. Janssen	drs. M.M. de Ruiter
dr. P. Klint	A.H. Veen, M.Sc.
dr. J.W. Klop	dr. P.M.B. Vitányi
A.A.M. Kuyk	dr. J.C. van Vliet
ir. E.A. Kuijpers	drs. W.E. van Waning
programmers:	
drs. F. van Dijk	J. Heering
L.J.M. Geurts	drs. T.J.G. Krijnen
trainees:	
R. van den Born	J.M. Kok
J.A.M. van de Graaf	A.J.C. Nienhuys
F.A.H. van Harmelen	H.D.A. Tan

Progress in computer science has been extremely rapid during the last few years. Its impact is widely felt, for 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 gained great popularity. 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.

The research policy of the department is to divide its attention equally between theoretical and applied computer science. Where possible, the department takes part in international organizations and activities, such as those of the International Federation for Information Processing, the European Association for Theoretical Computer Science, the European Association for Computer Graphics, and the ISO working group for the development of computer graphics standards.

The department has five main research projects:

- Complexity and algorithms;
- Concurrency/specification methods;
- Software;
- Architecture;
- Interaction.

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. The research of the department in this field is concentrated on machine complexity and on the design of efficient algorithms for the factorization of polynomials and for primality tests.

Vitányi investigated real-time simulation of Augmented Counter Machines and multitape Turing machines by an oblivious one-head tape unit. He published several papers on this topic, improving known results. He also investigated in how far many storage heads can be simulated by a single one without loss of time, generalizing the lower bound known for oblivious implementation. Furthermore, he did research on distributed algorithms. A publication concerning VLSI complexity is in preparation.

Lenstra continued his work on the factorization of polynomials and on primality. He gave a number of generalizations of the algorithm developed in 1982. For polynomials in one variable with rational coefficients, he developed a factoring algorithm that uses complex approximation of zeros, instead of the more usual p-adic factorization. The results of this research will be published as a doctoral dissertation in 1984.

The primality test developed in 1982 was implemented on a CRAY 1, and also on a CDC 205. A report on the results was sent to the national working committee on supercomputers. The primality of a great number of 'pseudoprimes' was proved, amongst which many of the primes of the Cunningham Project Tables.

Vitányi and Meertens made an inventory of the various uses of order of magnitude symbols.

Concurrency/specification methods

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 com-

plex than for sequential programming. Revolutionary studies were Hoare's *Communicating Sequential Processes* and Milner's *Calculus for Communicating Systems,* both of which introduced some fundamental concepts in this field. For example, the design of the programming language Ada was greatly influenced by Hoare's CSP.

The research is focused on the use of topological and algebraic techniques. Partly in cooperation with J.I. Zucker (State University of New York at Buffalo), De Bakker continued his investigation into the use of topological and sequential techniques in denotational semantics, in particular with reference to concurrency. A paper was published on compactness in semantics for merge and fair merge. In cooperation with E. Best (Gesellschaft für Mathematik und Datenverarbeitung), a study was made of programs as predicate transformers. Kok began work on a topological treatment of functional programming.

Bergstra and Klop wrote a number of papers on the development of various aspects of process algebras, in particular on communication, abstraction of internal steps, process specification by means of abstract data types and fixed point equations. For their research on VLSI semantics, they gave a proof rule for restoring logic circuits. As an application, the Mullender C-circuit was analysed. In cooperation with J.C.M. Baeten (Technological University Delft), they are working on priority rewrite systems.

As part of the ESPRIT project on Formal Approach to Software Technology, they are cooperating with Philips, CGE, and COPS on the methodological foundations for the design and implementation of software for industries.

Software

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. In principle, a software engineering environment contains the tools to support all of these stages; in a programming environment, one is concerned with the tools for implementation and testing. An obvious approach is to build up an environment out of independent modules. Many systems for personal computers have such an integrated programming environment, ususally constructed around a simple programming language. The research project is concerned, in various degrees, with all of these aspects.

Heering, Klint, and Kuijpers are doing research on extensible programming environments. They have made an evaluation of various editors/pretty printers, developed outside CWI. Klint's visit to INRIA (Rocquencourt), in order to establish contact between researchers in this field, resulted in an evaluation of three language-independent programming environments. The cooperation will be continued, and on further research will be reported in 1984.

Meertens spent a year at the Courant Institute for Mathematical Sciences (New York University). There he continued his work on Abstracto, a language for the specification and systematic development of algorithms. From algorithmic transformations, the interest has gradually shifted to pre-algorithmic transformations, and from there to an all-embracing system which has a single algebraic framework for both specifications and algorithms.

The programming language B was further developed. B is designed as a language that is not only suitable for structured programming, but also, by its very simplicity, both easy to learn and to use. A draft was made for an extended, dedicated programming environment. Furthermore, a tree structure was designed for the internal representation of B programs; a parser was developed to construct such a tree, and an interpreter to execute it. As a preparation for static type checking, a start was made with the implementation of an earlier developed unification algorithm for the B data types. In order to give greater publicity to the language, a smaller version of it was produced, suitable for minicomput-

B

```
PUT 0 IN size
FOR line IN document:
    PUT size+#line IN size
WRITE size
```

PASCAL

```
program count(document, output);
var document: text;
    c: char;
    size: integer;
begin
     reset(document);
     size := 0;
     while not eof(document)
     do begin
             while not eoln(document)
             do begin
                     read(document, c);
                     size := size + 1
                end;
             readln(document)
        end;
     write(size)
end.
```

Compare the two programs above in B and Pasal for counting the number of characters in a text file. These two programs illustrate clearly how compact B programs turn out to be.

ers such as the PDP 11/34. It was ported to an MC-68000 system, which was kindly made available by the firms Manudax and ACE, so as to gain experience with its portability. As part of IBM's support program for universities and research institutes, an IBM personal computer was made available for this project, to which the implementation will also be ported. The Mark 0 system was made available to a number of academic institutes. For the Mark 1 distribution of B, a more efficient syntax-directed editor was implemented. The first issue of the *B Newsletter* was published.

CWI's concern with software engineering was limited to a postgraduate course, given by Bergstra and Van Vliet. On the basis of his extensive lecture notes, the latter is writing a coursebook on the subject.

Architecture

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.

This year, Ebergen and prof.dr. M. Rem (Technological University Eindhoven, and adviser of CWI's computer science department) have reconnoitred the field of VLSI design, in close cooperation with the VLSI club of TU Eindhoven. The interest was focused on the development of a method to design programs for VLSI implementation. For this, the trace method developed by Rem and dr. J.A.J. Snepscheut was used. Quite unexpectedly, it resulted in a method by which new and more efficient programs could be developed for various data structures. These results will be published in 1984.

Van den Born, Van Dijk, Van Veen, and Veldkamp (the latter of the Contracts and Support division) continued their work on an imperative language for data flow machines. For practical reasons, it was decided to restrict the class of programs that is accepted by the compiler, so that the implementation of the data-flow analysis algorithm is now more or less complete. The implementation and application of the algorithm to static type checking was the subject of Van Dijk and Veldkamp's Master's thesis. Van den Born completed the design of a flow analyser for micro-code programs.

Interaction

The process between man and machine, or between two machines, is indicated by the term interaction. Interest in the interactive use of computers grew as time-sharing became more common in the sixties, but the greatest impetus to research in this field has been the rise of microprocessors and the availability of cheap computing facilities. The research is now centred on the design and implementation of far more complex interactive systems and on the interactive process itself.

One of the most important aspects is the dialogue, the form in which the interaction usually 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 the Institute for Building Materials and Structures of the Netherlands Organization for Applied Scientific Research, and also with Philips, the semantics of dialogue cells have now been defined at a sufficiently specific level to allow an implementation. The most important results of the research were communicated in a *Eurographics Tutorial* in Zagreb.

For a project sponsored by STW, Ten Hagen and De Ruiter are cooperating with J. van den Bos and W. Theunissen (Catholic University Nijmegen) on language primitives for raster graphics. After completion by De Ruiter of a basic system for raster graphics, based on the Graphical Kernel System, a start was made with the design and definition of the underlying structures and their language primitives. A test implementation was made.

In September, the European Community assigned a pilot ESPRIT project on Computer Integrated Manufacturing to British Leyland Systems Inc. (Redditch, UK) and CWI, with Trinity College (Dublin) and the Computer Science department of the University of Amsterdam as subcontractors. The aim of this project is to analyse the technological problems that arise at the introduction of computers for purposes of design and manufacturing, possibly including the implementation of a fully integrated CAD/CAM system, in order to define a number of design rules for information technology strategies for processing, communication, and control.

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 commmissions directly, enlisting the expertise present in the scientific departments where necesary. 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 1983 were: the analysis of stress rupture data for an industrial firm, carried out in cooperation with the department of mathematical statistics; a FORTRAN implementation of the Graphical Kernel System, in cooperation with the computer science department and a national working community; the implementation of a EUNET-EIES gateway, so that the ESPRIT Information Exchange System is connected to the UNIX† network; the calculation of a continuous sterilizer for tin cans.

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 Lab 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, for which CWI is the backbone centre. 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

CWI is fortunate in its excellent library, whose collection is in fact of national importance. It has an extensive collection of journals (950 current subscriptions), ca. 30.000 books, and a large collection of research reports (ca. 40.000). 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 now available. The publication department looks after the production of the various reports series of the scientific departments and CWI's books series, MC Tracts and MC Syllabi (as from 1984 these series are continued as CWI Tracts and CWI Syllabi). A good deal of work is carried out for others as well. The new 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).

VAX 11/780
This system is used for the research done by the Computer Science department, and to a lesser extent for research by the departments of Pure Mathematics, Operations Research and System Theory, and Numerical Mathematics. Furthermore, it supplies preview facilities for typesetting. It is this computer, moreover, that provides the gateway for the European UNIX network (140 connections).

VAX 11/750
This machine is supplied on loan by DEC to support the UNIX network. It is also used by the Computer Lab for system development.

PDP 11/45
This computer is used for text processing, with special software for layout, typesetting, spelling and text analysis.

PDP 11/34
The PDP 11/34 is used by the supporting services, for administrative purposes by the personnel and financial departments, and for data input by the library, publication department, and Data Entry.

Ethernet
The VAX 11/780 and the VAX 11/750 are connected via Ethernet. In the Fall of 1983 the experiment with the Local Area Network was rounded off. An Ethernet cable has been installed throughout the CWI premises, and it is expected that by the summer of 1984 five machines will have been connected via Ethernet.

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).

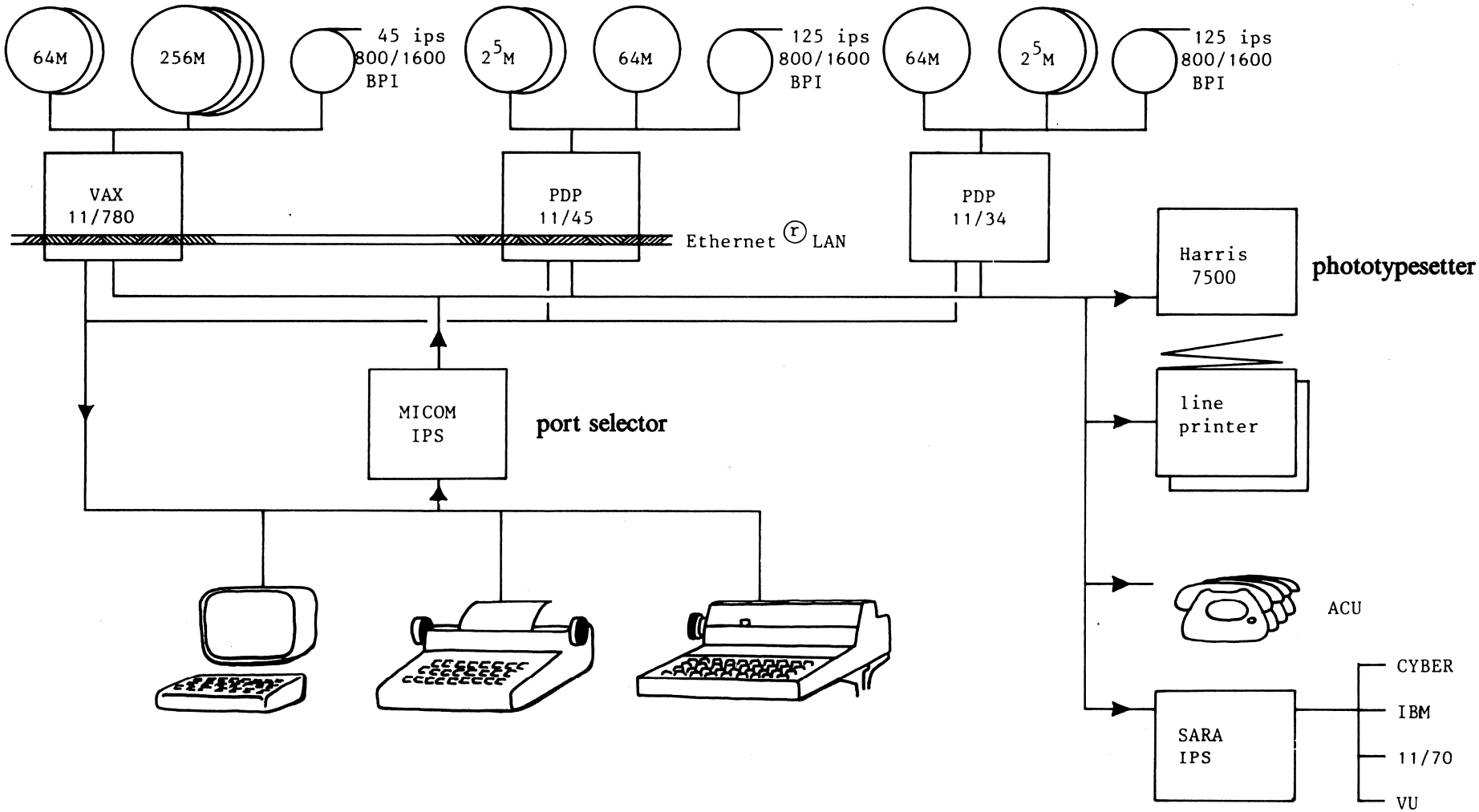


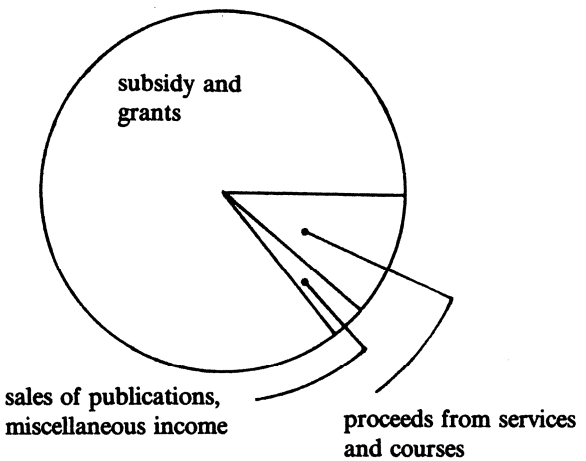
Fig. 3 Computer configuration at CWI (1983)

FINANCES

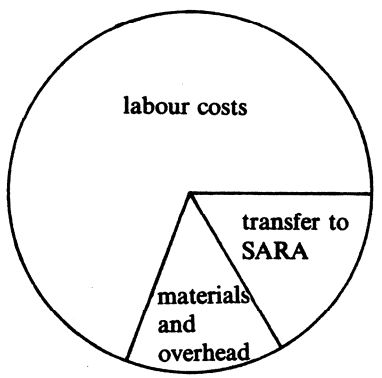
In 1983, SMC spent nearly Dfl. 15 million, of which about Dfl. 1.6 million was allocated to research by the national working communities and over Dfl. 13 million to CWI.
The expenses were covered by a subsidy from ZWO (Dfl. 12.7 million), from SION (Dfl. 0.05 million), from the Free University of Amsterdam (Dfl. 0.1 million) and a grant of nearly Dfl. 0.2 million from the European Community for its ESPRIT-projects. Finally, an amount of about Dfl. 1.8 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	1630	11403	13033
proceeds from services and courses	-	1506	1506
sales of publications	-	159	159
miscellaneous income	-	172	172
	1630	13240	14870
expenses			
labour costs	1627	9207	10834
materials and overhead	3	1843	1846
transfer to SARA	-	2190	2190
	1630	13240	14870
origin of subsidy and grants			
ZWO	1630	11067	12697
SION	-	52	52
VU	-	100	100
ESPRIT	-	184	184
	1630	11403	13033

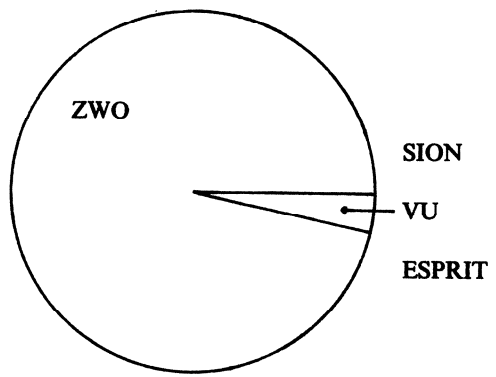
income CWI



expenses CWI



origin of subsidy and grants CWI



FOREIGN VISITORS

Department of Pure Mathematics

J. Auslander (USA)
G. Almkvist (Sweden)
Y. Benoist (France)
D. Chaum (USA)
J.C. Ferrar (USA)
S. Glasner (Israel)
M. Goze (France)
R.L. Griess (USA)
J.I. Hall (USA)
R. Hermann (USA)
A. del Junco (USA)
G. Mason (USA)
H.O. Peitgen (FRG)
S. Ress (UK)
F. Timmesfeld (FRG)

Department of Applied Mathematics

F.V. Bugge Christiansen (Denmark)
M.J. Feigenbaum (USA)
M. Gyllenberg (Finland)
S. Hubbell (USA)
M. Ianelli (Italy)
T. Ikeda (Japan)
R. Mackay (UK)
H. Matano (Japan)
P. de Mottoni (Italy)
K. Nipp (Switzerland)
R.M. Nisbet (UK)
D. Salamon (FRG)

Department of Mathematical Statistics

A. Baddeley (UK)
P.J. Bickel (USA)
D.M. Chibisov (USSR)
L. Devroye (Canada)
F. Götze (FRG)
P. Janssen (Belgium)
M. Maejima (Japan)
D.M. Mason (USA)
P. Rousseeuw (Belgium)
M. Schumacher (FRG)
J.A. Wellner (USA)

Department of Operations Research and System Theory

F. Baccelli (France)
I. Bárány (Hungary)
A. Bensoussan (France)
C.I. Byrnes (USA)
D.J. Evans (UK)
A. Federgruen (USA)
B.L. Fox (Canada)
R.L. Francis (USA)
F. Guerra (Italy)
M. Haimovich (USA)
J. Han (People's Republic of China)
R.G. Jeroslow (USA)
J. Krarup (Denmark)
E.L. Lawler (USA)
L. Lovász (Hungary)
S.K. Mitter (USA)
T.J. Ott (USA)
J.L. Palacios (Venezuela)
G. Picci (Italy)
A.J. Pritchard (UK)
D.B. Shmoys (USA)
R.J.B. Wets (Austria)
Z.-D. Yuan (People's Republic of China)

Department of Numerical Mathematics

H. Brunner (Switzerland)
D. Evans (UK)
M.J. Feigenbaum (USA)
I. Graham (Australia)
G.C. Hsiao (FRG)
D. Laurie (South Africa)
J. Leendertse (USA)
P. Rabinowitz (Israel)
J.M. Sans-Serna (Spain)
J. Scott (UK)
L.S. Shampine (USA)

Department of Computer Science

Arvind (USA)
R.L. Baber (FRG)
E. Best (FRG)
S.D. Brookes (USA)
J. Darlington (UK)

D. Duce (UK)
G. Enderle (FRG)
J. Gurd (FRG)
F.R.A. Hopgood (UK)
C.B. Jones (UK)
F. Kimura (Japan)
S.K. Kung (USA)
P. Marchant (UK)
B. Mélèse (France)
T. Neumann (FRG)
T. Reps (USA)
W.C. Rounds (USA)
G. Schiffner (FRG)
D.S. Scott (USA)
J.T. Schwartz (USA)
J. Tiuryn (Poland)
J.V. Tucker (UK)
R. Yeomans (UK)
J.I. Zucker (USA)

LIST OF PUBLICATIONS

Department of Pure Mathematics

Report series

ZW 182 J. Auslander, D. McMahon, J. van der Woude & T.S. Wu (1983). Weak disjointness and the equicontinuous structure relation.

ZW 184 H. Gzyl (1983). Integration of the linear filtering problem by means of canonical transformations.

ZW 185 B. Hoogenboom (1983). Intertwining functions on compact Lie groups I, summary of results.

ZW 186 P.C. Greiner & T.H. Koornwinder (1983). Variations on the Heisenberg spherical harmonics.

ZW 187 C. Betz & H. Gzyl (1983). Probabilistic approach for comparing first eigenvalues.

ZW 188 B. Hoogenboom (1983). The generalized Cartan decomposition for a compact Lie group.

ZW 189 J. de Vries (1983). Tychonov's theorem for G-spaces (a note on a paper by S.A. Antonyan).

ZW 190 H. Gzyl (1983). Evolution semigroups and Hamiltonian flows.

ZW 191 A.E. Brouwer, A.M. Cohen & H.A. Wilbrink (1983). Near polygons with lines of size three and Fischer spaces.

ZW 192 J. de Vries (1983). The equicontinuous structure relation and extension of functions defined on G-spaces.

ZW 193 J. Vinárek (1983). Hereditary subdirect irreducibility in graphs.

ZW 194 A.E. Brouwer & H.A. Wilbrink (1983). Two infinite sequences of near polygons.

ZW 195 J. Vinárek (1983). Projective monads and extensions of functors.

ZW 196 A.E. Brouwer (1983). The uniqueness of a regular near octagon on 288 vertices.

ZW 197 A.E. Brouwer & A.M. Cohen (1983). Local recognition of Tits geometries of classical type.

ZW 198 A.E. Brouwer & A.M. Cohen (1983). Computation of some parameters of Lie geometries.

ZW 199 T.H. Koornwinder & J.J. Lodder (1983). Generalised functions as linear functionals on generalized functions.

ZW 200 J. de Vries (1983). G-spaces: compactifications and pseudocompactness.

ZW 201 J. van de Lune (1983). Some observations concerning the zero curves of the real and imaginary parts of Riemann's zeta function.

ZW 202 A.M. Cohen & A.G. Helminck (1983). Trilinear alternating forms on a vector space of dimension seven.

ZW 203 G.F. Helminck (1983). Uniqueness of Whittaker models for irreducible objects in *Alg (Mp (k))*.

ZN 104 J. de Vries (1983). Pseudocompactness for G-spaces.

ZN 105 A.E. Brouwer (1983). A note on the uniqueness of the Johnson scheme.

Publications in journals, proceedings, etc.

Z 1 E.P. van den Ban (1983). Asymptotic behaviour of Eisenstein integrals. *Bull. Amer. Math. Soc. 9,* 311-314.

Z 2 A.E. Brouwer (1983). On the uniqueness of a certain thin near octagon (or partial 2-geometry, or parellelism) derived from the binary Golay code. *IEEE Trans. on Inf. Theory IT-29,* 370-371.

Z 3 A.E. Brouwer & H.A. Wilbrink (1983). The structure of near polygons with quads. *Geom. Dedicata 14,* 145-176.

Z 4 A.E. Brouwer & H.A. Wilbrink (1983). A (57, 14, 1) strongly regular graph does not exist. *Indag. Math. 45,* 117-121.

Z 5 A.E. Brouwer, P. Duchet & A. Schrijver (1983). Graphs whose neighbourhoods have no special cycles. *Discrete Math. 47,* 177-182.

Z 6 A.E. Brouwer & A.M. Cohen (1983). (with an appendix by J. Tits). Some remarks on Tits geometries. *Proc. KNAW Series A, 86,* 393-402.

Z 7 A.M. Cohen (1983). Points and lines of metasymplectic spaces. *Ann. Discrete Math. 18,* 193-196.

Z 8 A.M. Cohen (1983). Exceptional presentations of three generalized hexagons of order 2. *J. Combinatorial Theory (A), 35,* 79-89.

Z 9 A.M. Cohen & D.B. Wales (1983). Finite subgroups of $G_2(\mathbb{C})$. *Communications in Algebra 11,* 441-459.

Z 10 M. Hazewinkel (1983). The art of applying mathematics. *Acta Appl. Math. 1,* 1-3.

Z 11 M. Hazewinkel (1983). Operations in the K-theory of endomorphisms. *J. of Algebra 84,* 285-304.

Z 12 M. Hazewinkel & C.F. Martini (1983). Representations of the symmetric groups, the specialization order, Schubert cells and systems. *Enseignement Math. 29,* 53-87.

Z 13 J. van de Lune (met H.J.J. te Riele) (1983). On the zeros of the Riemann zeta function in the critical strip, III. *Math. of Comp. 41,* 759-767.

Z 14 J. de Vries (1982). Glicksberg's theorem for G-spaces. J. Novak (ed.). *General Topology and its Relations to Modern Analysis and Algebra V, Proc. 5th Prague Topol. Sympos. 1981*, Helderman Verlag, Berlin, 663-673.
Z 15 J. de Vries (1983). Linearizatsija deistbii lokal' no kompaktnyck grupp (Linearization of actions of locally compact groups), *Trudy Mat. Inst. Akad. Nauk* SSR *154,* 53-70.

Other publications
Z 16 B. Hoogenboom (1983). *Intertwining functions on compact Lie groups*, dissertation (RU Leiden), CWI, Amsterdam
Z 17 A.E. Brouwer (1983). Some new two weight codes and strongly regular graphs, presented to *Discrete Applied Math.*
Z 18 A.E. Brouwer (1983). Distance regular graphs of diameter 3 and strongly regular graphs, to appear in *Discrete Math.*
Z 19 A.E. Brouwer (1983). Four MOLS of order 10 with a hole of order 2, presented to *J. Statist. Inder. Planning.*
Z 20 A.E. Brouwer & H.A. Wilbrink (1983). A symmetric design with parameters 2-(49, 16, 5), to appear in *J. Comb. Th.*
Z 21 A.M. Cohen (1983). *Tits construction of the Ree groups*, Lecture notes, RU Utrecht.
Z 22 T.H. Koornwinder (with R. Askey & M. Rahman) (1983). An integral of products of ultraspherical function and a q- extension, preprint.

Department of Applied Mathematics

Report series.
TW 233 J.A.J. Metz, F.H.D. van Batenburg (1983). Holling's 'Hungry Mantid' model for the invertebrate functional response considered as a Markov process, part 0: A survey of the main ideas and results.
TW 234 S.N. Chow (1983). Virtual and global continuation of periodic orbits.
TW 235 O. Diekmann, H.A. Lauwerier, T. Aldenberg, J.A.J. Metz (1983). Growth, fission and the stable size distribution.
TW 236 J.V. Lankelma (1983). Computational aspects of two component chromatography.
TW 237 H.A. Lauwerier (1983). The parametrisation of the unstable invariant manifold for a class of horseshoe maps.
TW 238 E.J.M. Veling (1983). Asymptotic analysis of a singular Sturm-Liouville boundary value problem.
TW 239 N.M. Temme (1983). Traces to Tricomi in recent work on special functions and asymptotics of integrals.
TW 240 N.M. Temme (1983). Laplace type integrals: transformation to standard form and uniform asymptotic expansions.
TW 241 O. Diekmann (1983). The dynamics of structured populations: some examples.
TW 242 O. Diekmann, H.J.A.M. Heijmans, H.R. Thieme (1983). On the stability of the cell size distribution.
TW 243 H.A. Lauwerier (1983). Chaos and order.
TW 244 J.J.E. van der Meer (1983). Clines induced by a geographical barrier.
TW 245 H.A. Lauwerier (1983). Bifurcation of a map at resonance 1:4.
TW 246 H.A. Lauwerier (1983). Local bifurcation of a logistic delay map.
TW 247 J.V. Lankelma (1983). Stochastical dynamical systems with cyclic structure.
TN 103 M. Bakker, N.M. Temme (1983). Sum rule for products of Bessel functions: comments on a paper by Newberger.
TN 104 J. Grasman (1983). Karakterisering van spectra bij ijking van tracers.

Publications in journals, proceedings, etc.
T1 J. Grasman, D. Ludwig (1983). The accuracy of the diffusion approximation for some discrete stochastic processes. *J. Appl. Prob. 20,* 305-321.
T2 J. Grasman, B.J. Matkowsky (1983). Singular perturbations of epidemic models involving a threshold. F. Verhulst (ed.) *Asymptotic Analysis II: Surveys and new trends*, Springer, Lecture Notes in Mathematics 985, Berlin etc., 400-412.
T3 J. Grasman (1983). Asymptotic methods in mathematical biology. F. Verhulst (ed.) *Asymptotic Analysis II: Surveys and new trends,* Springer, Lecture Notes in Mathematics 985, Berlin etc., 76-95.
T4 J. Grasman (1983). Subharmonic and chaotic solutions of the forced Van der Pol relaxation oscillator. K. Smitt (ed.) *Proc. of Equadiff IV,* Springer, Lecture Notes in Mathematics Berlin etc., 1017.
T5 J. Grasman, P.I.M. Johannesma (1983). Plasticiteit in neurale en sociale processen, Een systeemtheoretische benadering. *Systemica 3,* 419-436.
T6 N.M. Temme (1983). The numerical computation of the confluent hypergeometric function U (a,b,z). *Numer. Math. 41,* 63-82.
T7 O. Diekmann, H.A. Lauwerier, T. Aldenberg, J.A.J. Metz (1983). Growth, fission and the stable size distribution. *J. Math. Biol. 18,* 135-148.

Other publications
T8 J. Grasman (1983). A historical note on the definition of relaxation oscillations, preprint.

Department of Mathematical Statistics

Report series
SW 93 A.J. van Es, R.D. Gill & C. van Putten (1983). Random number generators for a pocket calculator.
SW 94 K.O. Dzhaparidze (1983). On iterative procedures of asymptotic inference.
SW 95 W.R. van Zwet (1983). A Berry-Esseen bound for symmetric statistics.
SW 96 A.W. Ambergen & W. Schaafsma (1983). Interval estimates for posterior probabilities in a multivariate normal classification model.

SW 97 H.C.P. Berbee (1983). Periodicity and absolute regularity.
SN 11 A.J. van Es & C. van Putten (1983). Probability plots.
SN 12 R.D. Gill (1983). The sieve method as an alternative to dollar-unit sampling: the mathematical background.
SD 115 B.F. Schriever (1983). Attitude-onderzoek openbaar vervoer in Rotterdam en omgeving: statistische analyse enquête naar denkbeeldige verplaatsingen.

Publications in journals, proceedings, etc.
S 1 H.C.P. Berbee (1983). A bound on the size of point clusters of a random walk with stationary increments. *Ann. Probability 11*, 414-418.
S 2 R.J.M.M. Does (1983). An Edgeworth expansion for simple linear rank statistics under the null-hypothesis. *Ann. Statist. 11*, 617-624.
S 3 A.J. van Es, R.D. Gill & C. van Putten (1983). Random number generators for a pocket calculator. *Statistica Neerlandica 37*, 95-102.
S 4 R.D. Gill (1983). Large sample behaviour of the product limit estimator on the whole line. *Ann. Statist. 11*, 49-58.
S 5 P. Groeneboom & R. Pyke (1983). Asymptotic normality of statistics based on the convex minorants of empirical distribution functions. *Ann. Probability 11*, 328-345.
S 6 P. Groeneboom (1983). The concave majorant of Brownian motion. *Ann. Probability 11*, 1016-1027.
S 7 C. van Putten & J.H. van Schuppen (1983). The weak and strong Gaussian probabilistic realization problem. *Journal of Multivariate Analysis 13*, 118-137.
S 8 B.F. Schriever (1983). Scaling of order dependent categorical variables with correspondence analysis. *International Statistical Review 51*, 225-238.
S 9 W.R. van Zwet (1983). An inequality of random replacement sampling plans. P.J. Bickel, K.A. Doksum, J.L. Hodges, Jr (eds.). *A Festschrift for Erich. L. Lehmann; In Honor of his Sixty-Fifth Birthday,* 441-448.
S 10 W.R. van Zwet (1983). Ranks and order statistics. M. Haseeb Rizvi, Jagdish Rustagi, David Siegmund (eds.). *Recent Advances in Statistics, Papers in Honor of Herman Chernoff on his Sixtieth Birthday*, 407-422.

Other publications
S 11 P. Groeneboom (1983). Estimating a monotone density. To appear in *Proceedings of the Neyman-Kiefer Conference*, Berkeley, 20 june-1 july.
S 12 P. Groeneboom & D.R. Truax (1983). A monotonicity property of the power function of multivariate tests, Preprint MSRI 016-'83 of the Mathematical Sciences Research Institute, Berkeley, USA.
S 13 A. van Heeringen (1983). Relaties tussen leeftijd, mobiliteit en produktiviteit van wetenschappelijke onderzoekers. *Serie achtergrond studies RAWB no. 10.*
S 14 R. Helmers & M. Husková (1983). A Berry-Esseen bound for L-statistics with unbounded weight functions. To appear in *Proceedings of The Third Prague Symposium on Asymptotic Statistics*, Kutna Hora, Tsjechoslowakije, 29 july-2 august.
S 15 H.J. Mac Gillavry (1982). Variability of Foraminifera V., The case of Lepidorbitoides-Comparing group index estimates by the normal and lognormal models. *Proceedings of the Koninklijke Nederlandse Akademie van Wetenschappen, Series B, Volume 85 (4).*
S 16 H.C.G. Kemper et al. (1983). *Growth and health of teenagers: a multiple longitudinal study in Amsterdam, the Netherlands.* Coronel Laboratory for Occupational and Environmental Health, Univ. of Amsterdam.
S 17 J. Renkema (1983). Onderzoek naar woorden rijkdom: taalstatistische analyse via een microcomputer. *Tijdschrift voor Taalbeheersing 5*, 275-289.
S 18 P. Splinter et al. (1983). *Growth and health of teenagers.* Jan Swammerdam Instituut, Univ. van Amsterdam.

Department of Operations Research and System Theory

Report series
BW 177 J.B.G. Frenk, A.H.G. Rinnooy Kan & L. Stougie (1983). A hierarchical scheduling problem with a well-solvable second stage.
BW 178 M. Hazewinkel, S.I. Marcus & H.J. Sussmann (1983). Nonexistence of finite dimensional filters for conditional statistics.
BW 179 E.A. van Doorn (1983). A note on the overflow process from a finite Markovian queue.
BW 180 J.K. Lenstra, A.H.G. Rinnooy Kan & L. Stougie (1983). A framework for the probabilistic analysis of hierarchical planning systems.
BW 181 J.C.P. Bus (1983). The infinite horizon optimal control problem on manifolds.
BW 182 E.A. van Doorn (1983). On orthogonal polynomials on a halfline and the associated kernel polynomials.
BW 183 E.A. van Doorn (1983). Some analytical aspects of the peakedness concept.
BW 184 G. Picci, J.H. van Schuppen (1983). On the weak finite stochastic realization problem.
BW 185 M. Hazewinkel, J.H. Lewis & C.F. Martin (1983). Symmetric systems with semi-simple structure algebra: the quaternionic case.
BW 186 E.A. van Doorn (1983). Connectivity of circulant digraphs.
BW 187 P.S. Krishnaprasad, S.I. Marcus & M. Hazewinkel (1983). Current algebras and the identification problem.
BW 188 J.K. Lenstra & A.H.G. Rinnooy Kan (1983). Scheduling theory since 1981: an annotated bibliography.
BW 189 G.A.P. Kindervater & J.K. Lenstra (1983). Parallel algorithms in combinatorial optimization: an annotated bibliography.
BW 190 E.A. van Doorn (1983). A note on Delbrouck's approximate solution to the heterogeneous blocking problem.
BW 191 J.H. van Schuppen (1983). The weak stochastic realization problem for discrete-time counting processes.
BW 192 J.P.C. Blanc (1983). The relaxation time of two queueing systems in series.

BW 193 C. van Putten & J.H. van Schuppen (1983). Invariance properties of the conditional independence relation.

BW 194 A. Bensoussan & J.H. van Schuppen (1983). Optimal control of partially observable stochastic systems with an exponential-of-integral performance index.

BN 34 J.M. Anthonisse & J.K. Lenstra (1983). Operational operations research at the Mathematical Centre.

Publications in journals, proceedings, etc.

B 1 J.M. Anthonisse & J.K. Lenstra (1983). Operationele besliskunde op het Mathematisch Centrum. C.B. Tilanus, O.B. de Gans, J.K. Lenstra (red). *Kwantitatieve Methoden in het Management,* Aula-paperback 69, Het Spectrum, Utrecht, 252-258.

B 2 K.R. Baker, E.L. Lawler, J.K. Lenstra & A.H.G. Rinnooy Kan (1983). Pre emptive scheduling of a single machine to minimize maximum cost subject to release dates and precedence constraints. *Oper. Res. 31,* 381-396.

B 3 J.D. van der Bij & J.H. van Schuppen (1983). Prediction of railway power demand. *Automatica 19,* 487-494.

B 4 J.P.C. Blanc (1983). Time dependent analysis of a queueing model by formulating a boundary value problem. *Proc. Internat. Seminar on Modelling and Performance Evaluation Methodology,* Paris.

B 5 J. Blazewicz, J.K. Lenstra & A.H.G. Rinnooy Kan (1983). Scheduling subject to resource constraints: classification and complexity. *Discrete Appl. Math. 5,* 11-24.

B 6 M.A.H. Dempster, M.L. Fisher, L. Jansen, B.J. Lageweg, J.K. Lenstra & A.H.G. Rinnooy Kan (1983). Analysis of heuristics for stochastic programming: results for hierarchical scheduling problems. *Math. Oper. Res. 8,* 525-537.

B 7 E.A. van Doorn (1983). Some analytical aspects of the peakedness concept. *Proc. 10th Internat. Teletraffic Congress,* Montréal.

B 8 M.L. Fisher, B.J. Lageweg, J.K. Lenstra & A.H.G. Rinnooy Kan (1983). Surrogate duality relaxation for job shop scheduling. *Discrete Appl. Math. 5,* 65-75.

B 9 G. Koch, P.J.C. Spreij (1983). Software reliability as an application of martingale & filtering theory. *IEEE Trans. Reliability R-32.*

B 10 J.K. Lenstra & A.H.G. Rinnooy Kan (1983). An MPS prize for excellence in computational mathematical programming? *COAL Newsletter, 8,* 10.

B 11 C. van Putten & J.H. van Schuppen (1983). The weak and strong Gaussian probabilistic realization problem. *J. Multivariate Anal. 13,* 118-137.

B 12 J.H. van Schuppen (1983). Convergence results for continuous-time adaptive stochastic filtering algorithms. *J. Math. Anal. Appl. 96,* 209-225.

B 13 A. Schrijver (1983). Short proofs on the matching polyhedron. *Journal of Combinatorial Theory (B) 34,* 104-108.

B 14 A. Schrijver (1983). Bounds on the number of eulerian orientations. *Combinatorica 3,* 375-380.

B 15 A. Schrijver (1983). Packing and covering of crossing families of cuts. *Journal of Combinatorial Theory (B) 35,* 104-128.

B 16 A.E. Brouwer, P. Duchet & A. Schrijver (1983). Graphs whose neighborhoods have no special cycles. *Discrete Mathematics 47,* 177-182.

B 17 A. Schrijver (1983). Min-max results in combinatorial optimization. (A. Bachem, M. Grötschel & L. Lovász, eds.). *Mathematical Programming;* Springer-Verlag, Heidelberg, 439-500.

B 18 A. Schrijver (1983). Bounds on permanents, and the number of 1-factors and 1-factorizations in bipartite graphs. (E.K. Lloyd ed). *Combinatorial Surveys,* Cambridge University Press, Cambridge, 107-134.

Other publications

B 19 H. Nijmeijer (1983). *Nonlinear Multivariable Control: a Differential Geometric Approach,* Dissertation (RU Groningen), CWI, Amsterdam.

B 20 P.J.C. Spreij (1983). Parameter estimation for a specific software reliability model. Memorandum 431, TH Twente, Enschede.

B 21 C.B. Tilanus, O.B. de Gans & J.K. Lenstra (red.) (1983). *Kwantitatieve Methoden in het Management,* Aula-paperbrack 69, Het Spectrum, Utrecht.

B 22 A.J. Schrijver (1983). *Supermodular Colorings,* Report AE 4/83, Univ. van Amsterdam.

Department of Numerical Mathematics

Report series

NW 144 P.J. van der Houwen (1983). Algebraically equivalent linear multistep solutions of Volterra integral equations and certain systems of ODEs.

NW 145 B.P. Sommeijer & P.J. van der Houwen (1983). Software with low storage requirements for two-dimensional nonlinear parabolic differential equations.

NW 146 J. van de Lune & H.J.J. te Riele (1983). On the zeros of the Riemann zeta function in the critical strip, III.

NW 147 A.O.H. Axelsson & J.G. Verwer (1983). Boundary value techniques for initial value problems in ordinary differential equations.

NW 148 H.B. de Vries (1983). The multi-grid method in the solution of time-dependent nonlinear partial differential equations.

NW 149 P.J. van der Houwen (1983). Stability results for discrete Volterra equations.

NW 150 J.G. Verwer & H.B. de Vries (1983). Global extrapolation of a first order splitting method.

NW 151 P.J. van der Houwen & H.J.J. te Riele (1983). Linear multistep methods for Volterra integral and integro-differential equations.

NW 152 P.J. van der Houwen & B.P. Sommeijer (1983). Stability in linear multistep methods for pure delay equations.

NW 153 H.J.J. te Riele (1983). New very large amicable pairs.

NW 154 P.W. Hemker, P. Wesseling & P.M. de Zeeuw (1983). A portable vector-code for autonomous multigrid modules.

NW 155 H.J.J. te Riele & Ph. Schroevers (1983). A comparative survey of numerical methods for the linear generalized Abel integral equation.
NW 156 H.B. de Vries (1983). A comparative study of ADI splitting methods for parabolic equations in two space dimensions.
NW 157 P.J. van der Houwen & B.P. Sommeijer (1983). Linear multistep methods with minimized truncation error for periodic initial value problems.
NW 158 P.W. Hemker (1983). Multigrid methods for problems with a small parameter in the highest derivative.
NW 159 E.J. van Asselt (1983). Termination strategies for Newton iteration in full multigrid methods.
NW 160 E.J. van Asselt (1983). On M-functions and nonlinear relaxation methods.
NW 161 J.G. Verwer & K. Dekker (1983). Step-by-step stability in the numerical solution of partial differential equations.
NW 162 P.W. Hemker (1983). Mixed defect correction iteration for the solution of a singular perturbation problem.
NN 29 J. van de Lune & H.J.J. te Riele (1983). Rigorous high speed separation of zeros of Riemann's zeta function, III.
NN 30 H.J.J. te Riele (1983). Iteration of number-theoretic functions.
NN 31 G.T. Symm, B.A. Wichmann, J. Kok & D.T. Winter (1983). Guidelines for the design of large modular scientific libraries in Ada, second interim report.
NN 32 J. Kok (1983). Ada vergeleken met Pascal.

Publications in journals, proceedings, etc.
N 1 S. Amini, C.T.H. Baker, P.J. van der Houwen, P.H.M. Wolkenfelt (1983). Stability analysis of numerical methods for Volterra integral equations with polynomial convolution kernels. *J. of Integral Equations 5*, 73-92.
N 2 K. Dekker & J.G. Verwer (1983). Estimating the global error of Runge-Kutta approximations for ordinary differential equations. *Differential-Difference Equations*, ISNM 62, eds. Collatz et al., Birkhäuser, 55-71.
N 3 P.W. Hemker (1983). The use of defect correction for the solution of a singularly perturbed ODE. *Procs. of the Conference on the Numerical Treatment of Ordinary Differential Equations* (R. März ed.), 91-103, Humbold Universiteit, Berlin, DDR.
N 4 P.W. Hemker (1983). Numerical aspects of singular perturbation problems. *Asymptotic Analysis II* (F. Verhulst ed.), Springer LNM 985, 267-287, Springer Verlag.
N 5 P.W. Hemker & P.M. de Zeeuw (1983). Defect correction for the solution of a singular perturbation problem. *Scientific Computing, IMACS Transactions on Scientific Computation, Vol. 1,* (R.S. Stepleman ed.), North Holland Publ. Comp., pp. 113-118.
N 6 P.W. Hemker, R. Kettler, P. Wesseling & P.M. de Zeeuw (1983). Multigrid Methods: Development of fast solvers. *J. Applied Mathematics and Computation 13*, 311-326.
N 7 P.J. van der Houwen & B.P. Sommeijer (1983). Improved absolute stability of predictor-corrector methods for retarded differential equations. *Differential-Difference Equations,* ISNM 62, eds. Collatz et al, Birkhäuser, 137-148.
N 8 P.J. van der Houwen & B.P. Sommeijer (1983). Analysis of Chebyshev Relaxation in Multigrid Methods for nonlinear parabolic equations. *ZAMM 63*, 193-201.
N 9 P.J. van der Houwen & B.P. Sommeijer (1983). Predictor-corrector methods with improved absolute stability regions. *IMA J. Numer.Anal. 3*, 417-437.
N 10 P.J. van der Houwen & H.B. de Vries (1983). A fourth order ADI method for semidiscrete parabolic equations. *J. Comp. Appl. Math. 9*, 41-63.
N 11 J. van de Lune & H.J.J. te Riele (1983). On the zeros of the Riemann zeta function in the critical strip. III, *Math. Comp. 41*, 759-767.
N 12 H.J.J. te Riele (1983). Iteration of number-theoretic functions. *Nieuw Archief voor Wiskunde, Vierde Serie, 1*, 345-360.
N 13 J.G. Verwer, S. Scholz, J.G. Blom & M. Louter-Nool (1983). A class of Runge-Kutta-Rosenbrock methods for solving stiff differential equations. *ZAMM 63*, 13-20.
N 14 P.H.M. Wolkenfelt (1983). Modified multilag methods for Volterra functional equations. *Math. Comp. 41*, 301-316.
N 15 P.H.M. Wolkenfelt (1983). On the relation between the repetition factor and numerical stability of direct quadrature methods for second kind Volterra integral equations. *SIAM J. Numer. Anal. 20*, 1049-1061.

Department of Computer Science

Report series
IW 218 J.A. Bergstra & J.W. Klop (1983). Process algebra for communication and mutual exclusion.
IW 219 T. Krijnen & L.G.L.T Meertens (1983). Making B-trees for B.
IW 220 F.A.H. van Harmelen (1983). On the implementation of an editor for the B programming language.
IW 221 A.K. Lenstra (1983). Factoring multivariate polynomials over finite fields.
IW 222 J.A. Bergstra & J.W. Klop (1983). A process algebra for the operational semantics of static data flow networks.
IW 223 J.A. Bergstra & J. Tiuryn (1983). PC-compactness, a necessary condition for the existence of sound and complete logics of partial correctness.
IW 224 J.A. Bergstra, A. Cmielienska & J. Tiuryn (1983). Another incompleteness theorem for Hoare's logic.
IW 225 P.M.B. Vitányi (1983). An optimal simulation of counter machines: the ACM case.
IW 226 P.M.B. Vitányi (1983). On the simulation of many storage heads by a single one.
IW 227 J.A. Bergstra & J.W. Klop (1983). A proof rule for restoring logic circuits.
IW 228 P.M.B. Vitányi (1983). On the simulation of many storage heads by one.
IW 229 A.K. Lenstra (1983). Factoring multivariate integral polynomials.
IW 230 A.K. Lenstra (1983). Factoring multivariate integral polynomials, II.
IW 231 J.A. Bergstra & J.W. Klop (1983). An abstraction mechanism for process algebras.

IW 232 J.A. Bergstra & J.W. Klop (1983). An algebraic specification method for processes over a finite action set.
IW 233 A.K. Lenstra (1983). Factoring multivariate polynomials over algebraic number fields.
IW 234 J.A. Bergstra, J.W. Klop & J.V. Tucker (1983). Algebraic tools for system construction.
IW 235 J.A. Bergstra & J.W. Klop (1983). The algebra of recursively defined processes and the algebra of regular processes.
IW 236 J.A. Bergstra & J.V. Tucker (1983). The axiomatic semantics of programs based on Hoare's logic.
IW 237 J.A. Bergstra & J.J.Ch. Meyer (1983). On specifying sets of integers.
IW 238 J.W. de Bakker & J.I. Zucker (1983). Compactness in semantics for merge and fair merge.
IW 239 P.M.B. Vitányi & L.G.L.T. Meertens (1983). Big omega versus the wild functions.
IW 240 P. Klint (1983). A survey of three language-independent programming environments.
IW 241 J.A. Bergstra & J. Tiuryn (1983). Process algebra semantics for queues.
IW 242 A.K. Lenstra (1983). Polynomial factorization by root approximation.
IW 243 P.M.B. Vitányi (1983). Distributed elections in an archimedean ring of processors (preliminary version).
IW 244 P.M.B. Vitányi (1983). The simple roots of real-time computation hierarchies (preliminary version).
IW 245 P.M.B. Vitányi (1983). An $_N 1.618$ lower bound on the time to simulate one queue or two pushdown stores by one tape.
IW 246 P.M.B. Vitányi (1983). On two-tape real-time computation and queues.
IW 247 J.N. Akkerhuis (1983). Typesetting and Troff.
IW 248 A. Nienhuis (1983). On the design of an editor for the B programming language.
IN 22 T. Hagen & J. McKie (1983). The European Unix network.
IN 23 P.M.B. Vitányi (1983). Automatentheorie, complexiteit en algoritmen.
IN 24 H.D.A. Tan (1983). VLSI-algoritmen voor herkenning van context-vrije talen in lineaire tijd.
IN 25 P. Klint (1983). Het software house- een simulatiespel.
IN 26 J.A. Bergstra & J.J. Smeets (1983). Formele ontwikkeling van schermverloopschema's en interaktieve programma's.

Publications in journals, proceedings, etc.

I 1 J.W. de Bakker, J.A. Bergstra, J.W. Klop & J.J.Ch. Meyer (1983). Linear time and branching time semantics for recursion with merge. J. Diaz (ed.). *Proc. 10th ICALP*, Lecture Notes in Comp. Science, 154, Springer, Berlin, 39-51.
I 2 J.W. de Bakker, J.J.Ch. Meyer & J.I. Zucker (1983). On infinite computations in denotational semantics. *Theoretical Computer Science, vol. 26*, 53-82.
I 3 J.W. de Bakker & J.I. Zucker (1983). Processes and a fair semantics for the ADA rendez-vous. J. Diaz (ed.). *Proc. 10th ICALP*, Lecture Notes in Comp. Science, 154, Springer, Berlin, 52-66.
I 4 J.W. de Bakker & J.I. Zucker (1983). Processes and the denotational semantics of concurrency. *Information and Control, vol. 54*, 70-120.
I 5 J.A. Bergstra (1983). Disk allocation for cartesian product files, a counter example, *EATCS Bulletin*, 20 juni.
I 6 J.A. Bergstra & J.W. Klop (1983). Formal proof systems for program equivalence. D. Bjørner (ed.). *Formal Description of Programming Concepts II*, North-Holland, Amsterdam, 289-302.
I 7 J.A. Bergstra & J.W. Klop (1983). Initial algebra specifications for parametrized data types. *EIK 19, 1/2*, 17-21.
I 8 J.A. Bergstra & J.W. Klop (1983). A proof rule for restoring logic circuits. *Integration, the VLSI Journal, I*, 161-178.
I 9 J.A. Bergstra & J. Terlouw (1983). Standard model semantics for DSL, a data type specification language. *Acta Informatica, 19*, 1, 97-113.
I 10 J.A. Bergstra & J.V. Tucker (1983). Expressiveness and the completeness of Hoare's logic. *JCSS 25*, 267-284.
I 11 J.A. Bergstra & J.V. Tucker (1983). Hoare's logic and Peano's arithmetic. *TCS 22*, 265-284.
I 12 J.A. Bergstra & J.V. Tucker (1983). Initial and final algebra semantics for data type specifications, two characterization theorems. *SIAM J. of Computing, 12, 2*, 366-387.
I 13 J.A. Bergstra & J.V. Tucker (1983). The completeness of the algebraic specification methods for data types. *Information and Control, 54, 3*, 186-200.
I 14 P.J.W. ten Hagen (1983). Interactive techniques. *Eurographics 83*, Tutorial Lecture Notes.
I 15 P.J.W. ten Hagen & J. Derksen (1983). Parallel input parsing. *Proc. VIMS Workshop*.
I 16 P.J.W. ten Hagen (1983). The future of 3D-GKS. A. Ishizuka (ed.). *Proc. Nicograph Conference*.
I 17 A.K. Lenstra (1983). Factoring multivariate polynomials over finite fields. *Proc. 15th ACM Symposium on Theory of Computing*, ACM, New York, 189-192.
I 18 A.K. Lenstra (1983). Factoring multivariate integral polynomials. J. Diaz (ed.). *Proc. 10th ICALP*, Lecture Notes in Comp. Science, 154, Springer, Berlin, 458-465.
I 19 A.K. Lenstra (1983). Factoring polynomials over algebraic number fields. J.A. van Hulzen (ed.). *Proc. Computer Algebra*, Lecture Notes in Comp. Science, 162, Springer, Berlin, 245-254.
I 20 L.G.L.T. Meertens (1983). Incremental polymorphic type checking in B. *Conf. Record 10th ACM Symp. Principles of Programming Languages*, ACM, New York, 265-275.

I 21 P.M.B. Vitányi (1983). On the simulation of many storage heads by a single one (extended abstract). J. Diaz (ed.). *Proc. 10th ICALP*, Lecture Notes in Comp. Science, 154, Springer, Berlin, 687-694.

I 22 P.M.B. Vitányi (1983). On efficient simulations of multicounter machines. *Information & Control 55*, 20-39.

Other publications

I 23 J.A. Bergstra, F. Botman & G.P.A.J. Delen (1983). Functionele specificatie van een SMX codegenerator. Report CAP Gemini Ned. BV, Utrecht.

I 24 J. A Bergstra & Th.P. van der Weide (1983). Some general operators for designing information systems structured as transaction flow diagrams. KU Nijmegen, Vakgroep Informatica, internal report no. 45.

I 25 P.J.W. ten Hagen & L.R.A. Kessener (1983). GKS-3D, the 3D extension of GKS. ISO/TC97/S5/ WG2/Doc. no. 238.

I 26 A.H. Veen (1983). Introduction to data-driven computer architectures. *Symposium Data Flow Computing*, Utrecht.

I 27 A.H. Veen (1983). Data-driven computer architectures. *Workshop The New Generation of Programming Languages and Supporting Computer Architectures*, Antwerpen.