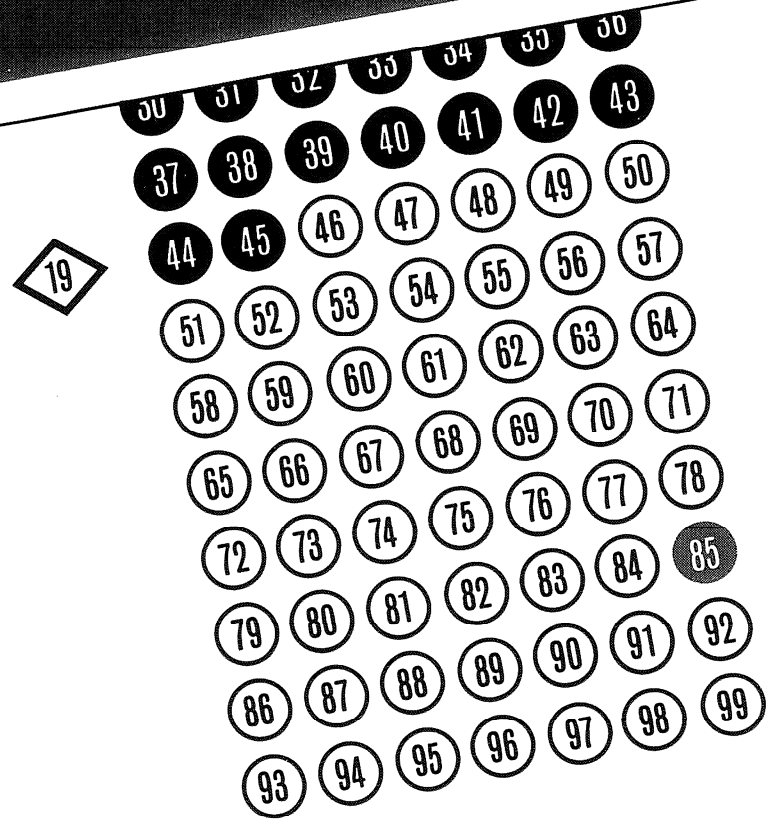
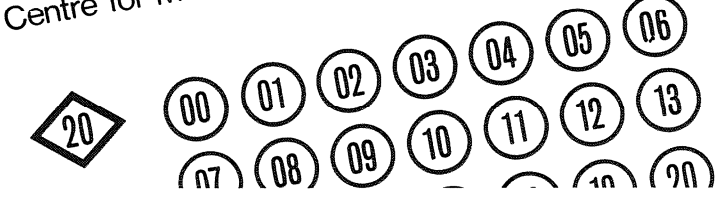
ANNUAL REPORT

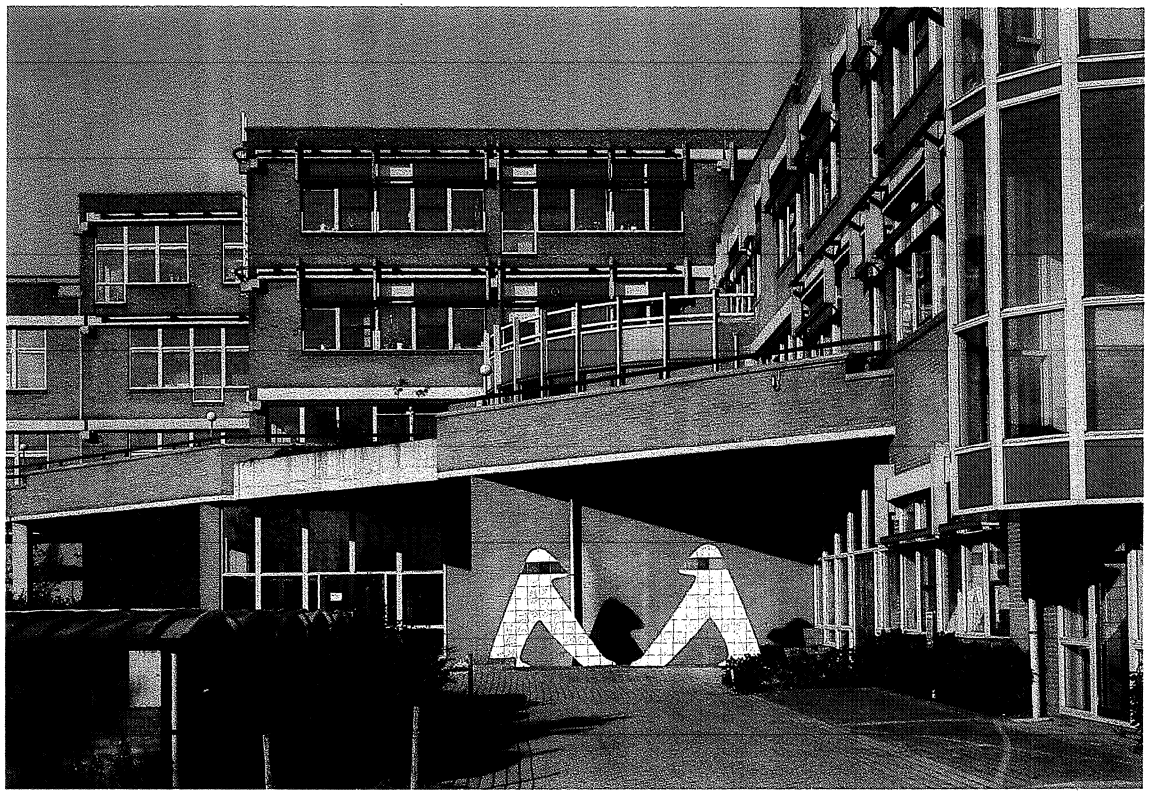


Centrum voor Wiskunde en Informatica
Centre for Mathematics and Computer Science



ANNUAL REPORT '85

Centre for Mathematics and Computer Science
Centrum voor Wiskunde en Informatica



The Stichting Mathematisch Centrum was founded on february 11 1946, as non-profit institution aiming at the promotion of mathematics, computer science, and their applications. It is sponsored by the Dutch Government through the Netherlands Organization for the Advancement of Pure Research (ZWO).

Board of Directors

P.C. Baayen (scientific director)
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Centre for Mathematics and Computer Science (CWI)

Kruislaan 413
1098 SJ Amsterdam
The Netherlands

P.O. Box 4079
1009 AB Amsterdam
The Netherlands

Telephone 020-592 9333
(from abroad) 31 - 20 592 9333

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Introduction

The Centre for Mathematics and Computer Science (CWI) is the research institute of the Stichting Mathematisch Centrum (SMC), which was founded on 11 February 1946.

The aims of the foundation SMC reach farther than running 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 contacts between mathematicians and between computer scientists, but also between these and practitioners of disciplines to which mathematics and computer science can make relevant contributions; on the other hand, by doing scientific research in mathematics and computer science and directing the research of young scientists, 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 Scientific 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 its 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 enjoys eight national working communities, in the fields of Numerical Mathematics, Stochastics, Discrete Mathematics, Operations Research and System Theory, Analysis, Algebra and Geometry, Logic and Foundations of Mathematics, and Mathematical Physics.

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 (as CWI was called before September 1983) 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 encompasses 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 evaluate 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

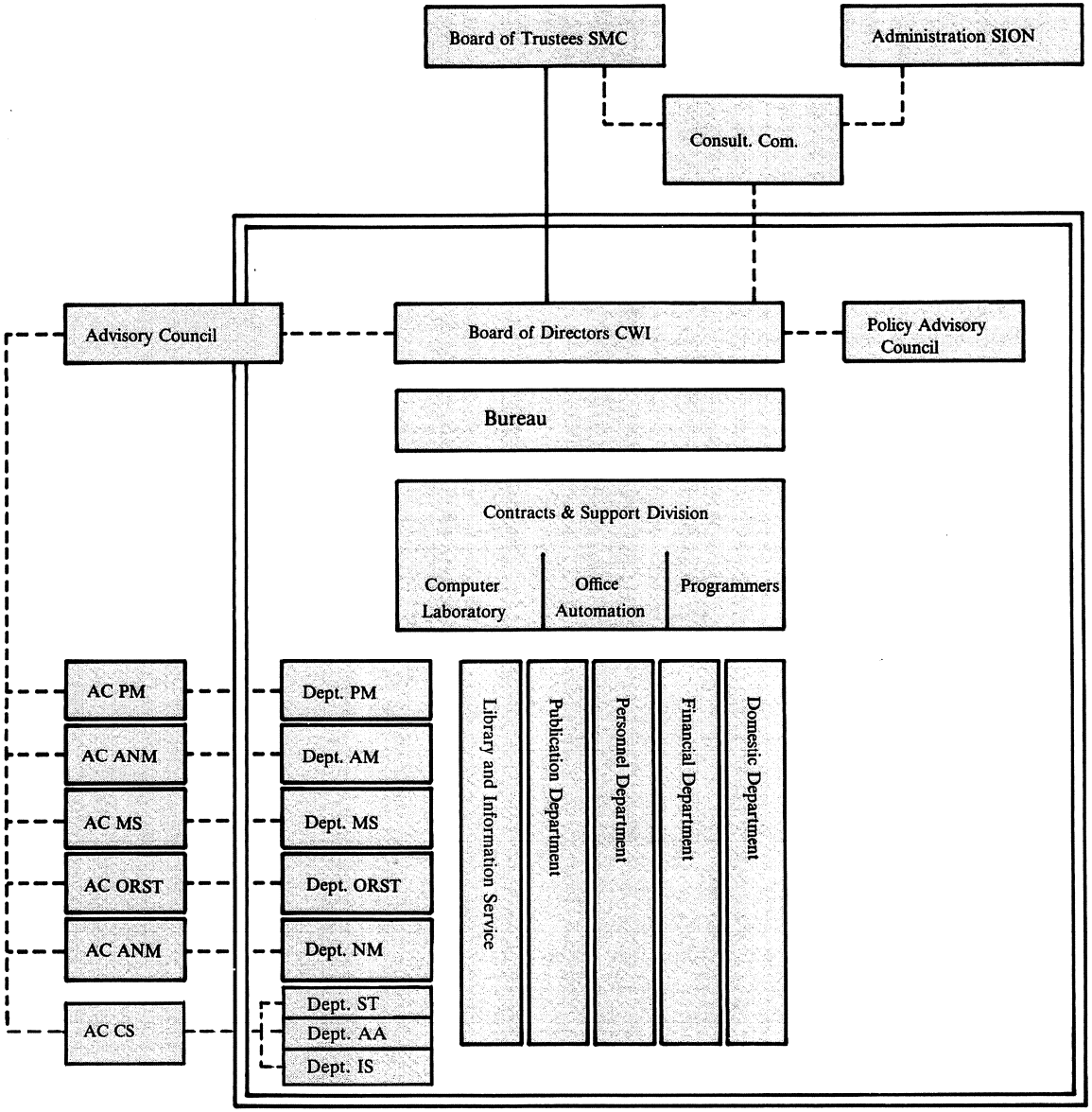


Fig. 1 Organisation of the Centre for Mathematics and Computer Science (CWI)

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 internationally. 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 eight scientific departments:

- Pure Mathematics;
- Applied Mathematics;
- Mathematical Statistics;
- Operations Research and System Theory;
- Numerical Mathematics;
- Software Technology;
- Algorithms & Architecture;
- Interactive Systems.

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

Research Programs

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

At a national level a workshop was organized, in which some 50 representatives of industry, government, large technical institutes and the academic world took part, in order to discuss CWI's function as a 'centre d'excellence'. In this workshop the importance of fundamental research, as traditionally carried out by CWI, was underlined, but it was also explicitly stated that the collaboration with industry and the transfer of knowledge should receive greater emphasis. The *European Symposium on Mathematics in Industry (ESMI),* co-organized by CWI to stimulate the use of mathematical techniques for industrial problems, may be regarded as an expression of this shift in policy.

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. This revision involved not only the regrouping, and in cases extension of existing projects, but also the undertaking of new ones. The consequent growth of the department made a reorganization necessary, so that the originial computer science department is now split into three separate departments, viz.:

- Software Technology;
- Algorithms and Architecture;
- Interactive 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.

In May, approximately 50 representatives of industry, government, large technical institutes and the academic world participated in a national workshop in order to discuss CWI's function as a "centre d'excellence" in computer science.

In October, the use of mathematical techniques for industrial problems was discussed by some 70 participants at the 'European Symposium on Mathematics in Industry' (ESMI), organized by CWI and Nijmegen University.
One of the invited speakers was dr. E. van Spiegel, director-general for science policy of the Ministry of Education and Science.

Every year one of the CWI research topics will be explained in the Annual Report in general terms. This year's contribution is about parallel algorithms in combinatorial optimization.

THE PARALLELIZED TRAVELING SALESMAN

G.A.P. Kindervater, J.K. Lenstra
(Department of Operations Research and System Theory)

Combinatorial computations often take an inordinate amount of time. To what extent can parallel computers be of any help? We investigate this question by looking at an old problem.

A salesman, starting from his home city, is to visit exactly once each city on a given list before returning home. Given the distances between the cities, he wishes to find the shortest tour. This is the *traveling salesman problem* (TSP).

It is not only because of its catchy name that the TSP attracts a lot of attention. The TSP has applications in areas like vehicle routing and machine scheduling. It is also a typical problem of *combinatorial optimization,* since one has to choose the best out of a finite set of configurations. It could even be called prototypical: research on the TSP has led the way to many major developments in combinatorial optimization.

The TSP is simple to state but hard to solve. Why is it so hard? After all, there are only finitely many different tours. Checking all of them and selecting the shortest one is certainly not a complicated solution procedure. True, but it takes a lot of time. For eleven cities, there are twice as many tours as there are letters in a 465-page book on the subject [2]. For bigger problems, the number of tours soon exceeds the number of atoms in the universe, and no one has ever proposed to check those one by one.

The problem, then, is to develop an *efficient* solution procedure. It is now commonly accepted to call an algorithm efficient if, for n cities, the number of computational steps is bounded by a *polynomial* in n (e.g., n^2 or $10n^{74}+n-18$). Exponential algorithms (e.g., with 2^n steps) do not qualify. Complete enumeration is superexponential and highly inefficient.

A polynomial algorithm for the TSP is unlikely to exist. For if there were such a method, it could be used for a host of other problems which are widely held to be intractable. This result from complexity theory forces one to make a choice. If one insists on optimality, then some form of enumeration has to be applied. Much can be done to escape the curse of exponentiality, but *enumerative methods* are ultimately inefficient. If, on the other hand, the solution procedure must be efficient, then one loses the guarantee of optimality. Two such *heuristic methods* are illustrated here. The nearest neighbor rule (Figure 3) tells the salesman always to go to the closest unvisited city; the resulting tour can be arbitrarily bad in relation to the optimum. The doubled tree rule (Figure 4) produces a tour which is easily seen to be no longer than twice the optimum. Both heuristic rules require a computational effort proportional to n^2.

We now make a machine for *parallel computing* available to the salesman. We take the nicest model he could wish, with an infinite number of processors and a constant interprocessor communication time. Can it beat his traditional sequential machine, which performs all computations one by one?

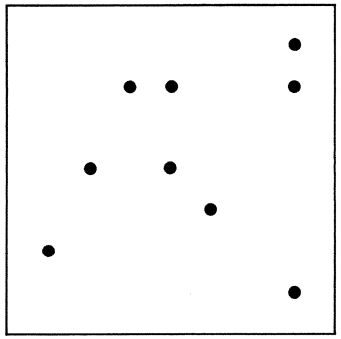
The old computer must at least inspect all city coordinates, which takes time proportional to n. The parallel computer would set a new standard of efficiency if it would run in *polylog* time, i.e., in time bounded by a polynomial in the logarithm of n: for any k, $\log^k n < n$ if n is large enough. In a polylog parallel computation, no single processor is given the time to inspect the entire problem instance.

The doubled tree rule can indeed be implemented to run in polylog time (in fact, in $\log^2 n$ time on $n^2/\log^2 n$ processors [1]). But a polylog algorithm for the nearest neighbor rule is unlikely to exist [1]. This is a complexity result similar to, but on a different level than, the probable intractability of the TSP itself. Loosely speaking, the nearest

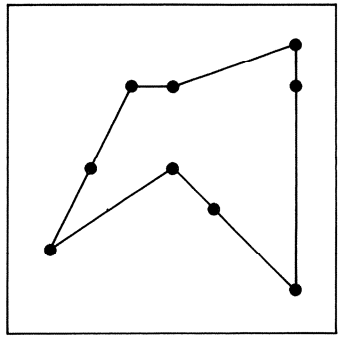
neighbor rule requires at least n^{α} time for some $\alpha>0$, even if unbounded parallelism is allowed. One may view this as a confirmation of the inherently sequential character of the heuristic.

Let us finally take a brief look at the parallelization of enumerative methods. Our parallel machine turns brute force techniques into efficient algorithms for finding an optimal salesman tour and even for playing a perfect game of chess on an $n \times n$ board. It is a very powerful model, but hardly realistic. If a polynomial time bound is considered reasonable, then certainly a polynomial bound on the number of processors should be imposed. However, for this more realistic model we are back where we were before: brute force is inefficient and the TSP is hard. Nevertheless, parallelism has much to offer to extend the range of practicality of enumerative methods. Little work has been done in this direction. We hope to return to it in a future report.

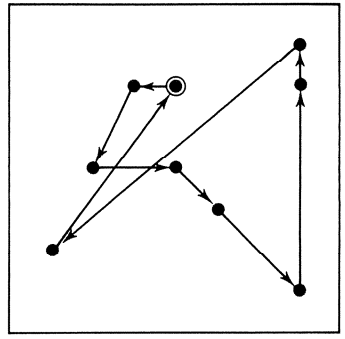
1 *Nine cities in the plane.*



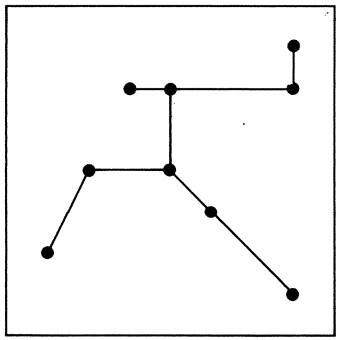
2 *The optimal tour.*



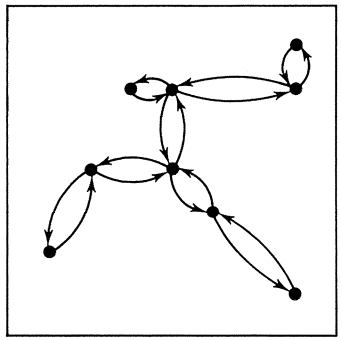
3 *A nearest neighbor tour;* ◉ = *home city.*



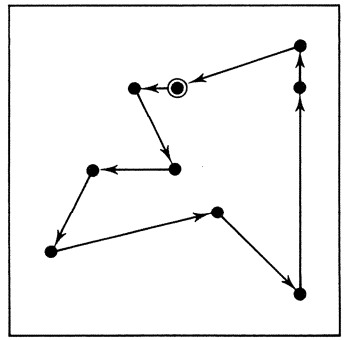
4 *The doubled tree rule.*



(a) The minimum spanning tree.



(b) A traversal of the doubled tree.



(c) A tour: start at ◉ and skip cities visited before.

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1. G.A.P. Kindervater (1985). *The Parallel Complexity of TSP Heuristics,* 12th International Symposium on Mathematical Programming, Cambridge, MA, USA, August 5-9, 1985.
2. E.L. Lawler, J.K. Lenstra, A.H.G. Rinnooy Kan, D.B. Shmoys (eds.) (1985). *The Traveling Salesman Problem: A Guided Tour of Combinatorial Optimization,* Wiley, Chichester, U.K.

Department of Pure Mathematics

M. Hazewinkel (head of department)
E.P. van den Ban
J.T.M. van Bon
A.E. Brouwer
D. Chaum
A.M. Cohen
J.H. Evertse
J.A.M. van de Graaf
A.G. Helminck
G.F. Helminck
T.H. Koornwinder
J. van de Lune
J.C. van der Meer
J.K. Scholma
J. de Vries

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

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

Currently, there are the following research projects:

- Algebra and discrete mathematics;
- Analysis;
- Algebraic mathematical physics;
- Dynamical systems.

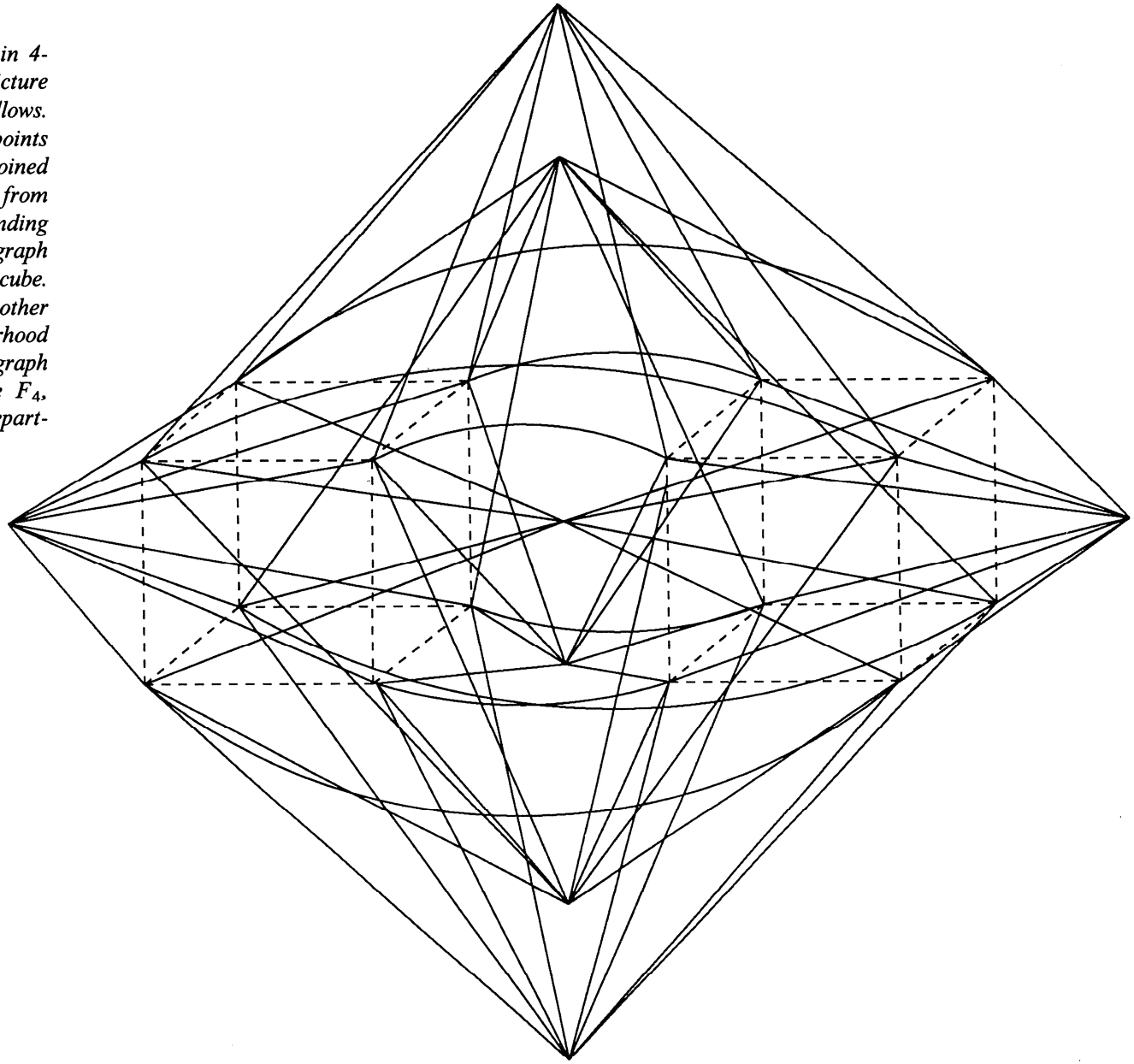
Algebra and discrete mathematics

The research of Brouwer, Cohen, Van Bon, and A.G. Helminck is concerned with combinatorics, finite geometries and finite groups. During the last few years the research has been focused on Lie-type geometries, i.e., geometries concerned with parabolic subgroups of Chevalley groups, and, more generally, with geometries of Buekenhout-Tits type. The Pure Mathematics department has developed a large and quite unique know-how in this field.

The work on the monograph on distance-regular graphs by Brouwer, Cohen, and A. Neumaier (Universität Freiburg) is largely finished. For this publication many research problems have been investigated and partly solved. For example, estimations have been derived for the valence and diameter of a distance-regular graph with a given number of vertices. These estimations turned out to be useful in making a list of possible parameters of distance-regular graphs with 1024 vertices at most. Of a number of parameter combinations it has been proved that, apart from isomorphism, the related distance-regular graphs can be determined uniquely. Furthermore, Brouwer contributed a chapter to the *Handbook of Combinatorics.* Cohen continued his research on finite subgroups of groups of exceptional Lie-type, and determined all finite subgroups that normalize an elementary Abelian subgroup which cannot be imbedded in a torus.

Chaum, Evertse, and Van de Graaf are engaged in research on cryptography. It is to be expected that in the next few years the use of distributed computer systems will be greatly increased, for example, in electronic payment systems and in networks in which confidential information is transmitted. The computers in distributed systems are usually connected by unsafe channels. In order to prevent that information transmitted through these channels is tapped or falsified, it is necessary to employ cryptographic techniques so as to ensure the safety of the system.

The '24-cell' is a regular convex polytope in 4-dimensional Euclidean space. The picture displays a graph which relates to it as follows. The 24-cell has 24 vertices, which are the points of the graph; two points of the graph are joined by a (broken) line or an arc, if the vectors from the centre of the 24-cell to the corresponding vertices create an angle of 60°. The graph induced on the neighbors of any point is a cube. Apart from this graph, there is only one other graph all of whose points have a neighborhood graph which is a cube. Properties of this graph reoccur in certain geometries of Lie type F_4, studied and characterized at the CWI department of Pure Mathematics.



In October, an international course on cryptography was organized at CWI.

To a large degree the research efforts were focused on the Data Encryption Standard (DES). It has been shown that block numbers can be cracked faster if they have certain linear structures. It was shown that DES does not have such structures. Further research concerned cryptographic protocols, in particular their security. In October an international course in cryptography was held at CWI.

Analysis

The research in this project is carried out by Van den Ban, A.G. Helminck, Koornwinder and Van de Lune. Its goal is harmonic analysis on (pseudo-) Riemannian symmetric spaces, the study of special functions and their group theoretic interpretation, the study of (zero patterns of) special analytic functions, and various problems of a number theoretic nature.

Van den Ban's research dealt with the asymptotic behaviour of matrix coefficients of representations related to a semi-simple symmetric space.

Koornwinder is interested in special functions and group theory. He continued his investigations into the relation between Jacobi functions and hypergeometric orthogonal (e.g., Wilson) polynomials and their group-theoretical interpretation. He gave a more conceptual and less computational proof for the last part of de Branges' proof of the Bieberbach conjecture.

The project on the numerical verification of the Riemann hypothesis, carried out by Van de Lune in cooperation with Te Riele and Winter of the Numerical Mathematics department, has been suspended. By using the CYBER 205 supercomputer the work was considerably speeded up. It is now shown that the first 1.5×10^9 non-trivial zeros of the zeta-function are all simple and lie on the vertical with real part 1/2.
In cooperation with E. Wattel (Free University Amsterdam), Van de Lune has been working on various problems, one of which is concerned with convex polygons and analytic inequalities.

Algebraic mathematical physics

In the work of Sato, Miwa and Jimbo on completely integrable evolution equations, a generalization of the θ-function, viz., the τ-function, plays an important part. The research of G.F. Helminck dealt with the question in how far these functions can be interpreted as θ-functions. His research was further concerned with the Kadomtsev-Petviashvili hierarchy of partial differential equations.

Hazewinkel's research was focused on the part played by Yang-Baxter equations (classical r-matrix, quantum R-matrix) in exact solvability (lattice systems) and integrability. Special attention was paid to the relation with θ-functions and representations.

The research of Van der Meer is carried out in cooperation with R. Cushman (Utrecht University). It deals with normal forms of Hamiltonian systems.

Dynamical systems

De Vries continued his work for a monograph on topological dynamics. Further research deals with the interaction between topological dynamics and ergodic theory.

Other research of De Vries is carried out in cooperation with M. Hušek (Prague). They are investigating what conditions a reflexive subcategory must satisfy, if the reflector is to preserve products. Applications of results yielded simplified proofs for known results concerning almost periodic and strongly almost periodic compactifications of products of semitopological semigroups.

Department of Applied Mathematics

H.A. Lauwerier (head of department)
O. Diekmann
B. Dijkhuis
J. Grasman
H.J.A.M. Heijmans
B. de Kerf
J.B.T.M. Roerdink
H.N.M. Roozen
T.J.H. Smit
H.E. de Swart
N.M. Temme

trainees:
H. Heesterbeek
A.M. de Roos

In the first half of this century, linear analysis and related disciplines grew into impressive and useful tools. 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;

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.

The research is carried out by Diekmann, M. Gyllenberg (Helsinki University of Technology, temporarily CWI), Heijmans, and H.R. Thieme (Universität Heidelberg, temporarily CWI), and by S.A. van Gils (Free University Amsterdam, temporarily Michigan State University). The most important new results in this project were in perturbation theory for dual semigroups. A generalization was given of the concept of bounded perturbation of a generator, and a new variant was found of the variation-of-constants formula in the context of dual semigroups on nonreflexive spaces. The incentive for this research came from models for age dependent population growth, but functional differential equations turned out to fit excellently in this scheme. By this new approach a large class of nonlinear problems can now be called semi-linear, so that there are now standard techniques for proving linearized stability, the existence of a centre manifold, and Hopf bifurcation.

J.A.J. Metz (University of Leiden, and adviser of the department) and O. Diekmann finished their editorial work on the book *Dynamics of Physiologically Structured Populations,* to be published in 1986.

Various reports were published on stable distributions, in which the theory of positive operators played an important part, either explicitly or implicitly. Further progress was made in the research of predator-prey-patch dynamics and on predator-prey interaction in which the prey is vulnerable to the predator for a very short period of its life only. This research is done in cooperation with R.M. Nisbet and W.S.C. Gurney (University of Strathclyde).

Stochastic aspects of dynamical systems

In order to trace the origin of stochastic

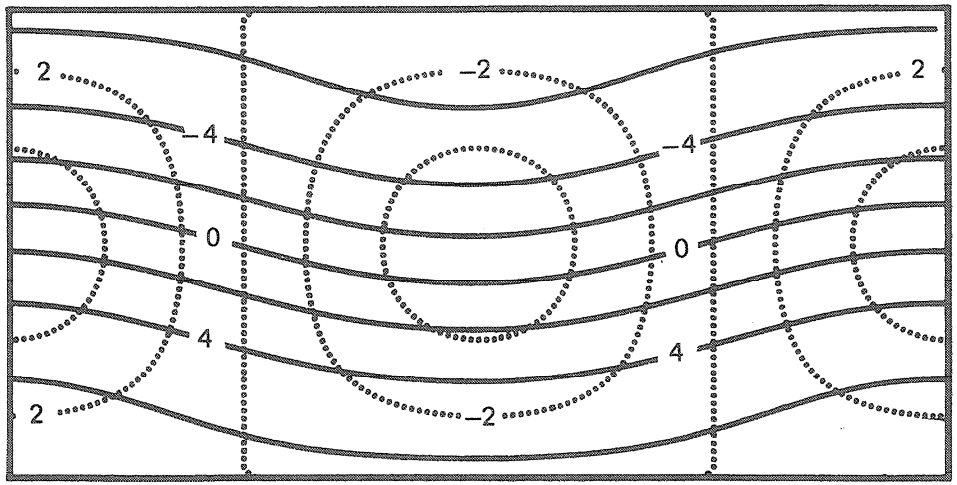
behaviour in biological and physical systems, a mathematical investigation must be made both of the dynamics of deterministic systems with complex behaviour and of systems with stochastic perturbations. Bifurcation theory, analysis of ordinary and partial differential equations, and the theory of stochastic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

This research project is carried out by Grasman, Roerdink, Roozen and De Swart. It deals with the following problems: stochastic birth and death processes, random walks on lattices, dynamical systems with stochastic perturbations and its application to spectral models of the atmosphere. Stochastic perturbations are necessary for models of low order: without them such models end in one of the stable equilibrium states. Models of higher order turn out to have a strange attractor, which alternately goes through the various substates of the state space.

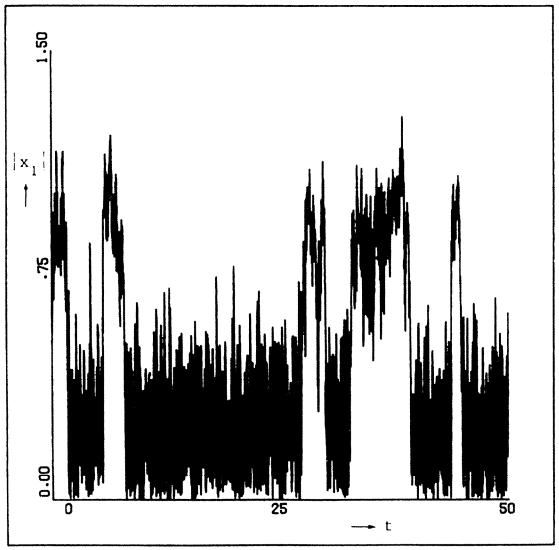
Furthermore, the relation between the lifetime expectancy of a mechanical apparatus and the theory of stochastic dynamical systems was studied. A paper on this topic was read at the Workshop on the road-vehicle system and related mathematics at Lambrecht (FRG).

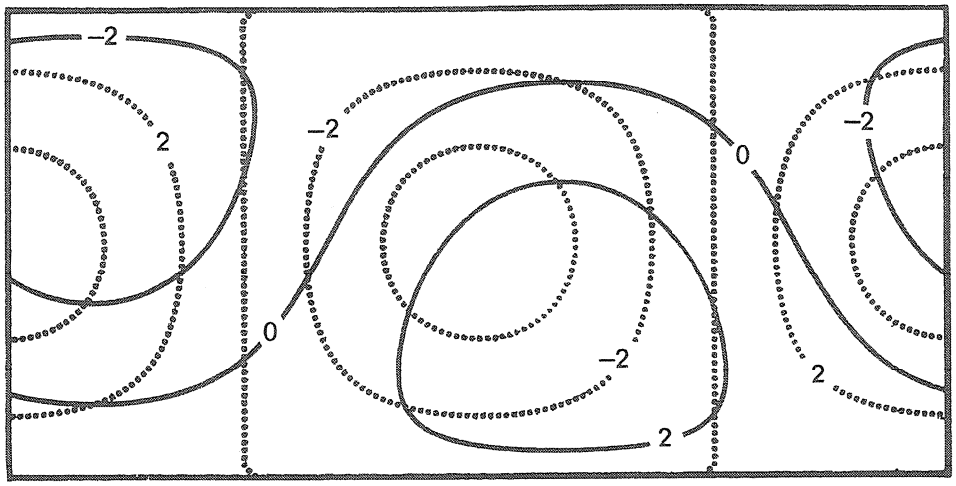
Roerdink investigated stochastic walks on inhomogeneous random lattices, approached from a more general mathematical viewpoint instead of being fixed on specific areas of application.

A large-scale climatological phenomenon such as El Niño causes considerable damage along the coast of Peru, as well as in Australia and Indonesia: heavy rainfall, floods, droughts, fish mortality, etc. The study of mathematical models of large-scale weather patterns can be important in gaining insight in the development of such phenomena.
Photo RBP Press-Service



Changeable weather type: crossing depressions





Fair weather type: high pressure region; depressions are diverted

In weather-forecasting, models of the atmosphere are analyzed by means of a (super)computer. A practical problem is that refinement of the lattice in the model leads to rapidly increasing costs without much gain in information. In an STW-project, CWI has attacked the problem - in collaboration with KNMI (the national meteorological institute) - by taking a spectral model instead of a lattice model. Such a model turns out to be very suited for the description of large-scale (long-term) effects, to which mainly the low frequencies contribute. The high frequencies, which determine the chaotic character of the weather, are represented by noise. The model exhibits arbitrary transitions between two semi-stable types of weather (see diagram above).

The research of Roozen deals with the dynamics of biological populations, which are asymptotically described by means of ray equations. By defining the boundary conditions in both the starting point and the end point of the rays, the confidence contours in state space are numerically constructed and the expected extinction times are determined. This method has been applied to systems consisting of two populations with interaction.

De Swart continued his research on spectral models of atmospheric circulation, in cooperation with J.D. Opsteegh (Royal Netherlands Meteorological Institute). A three-component spectral model of the barotropic potential vorticity equation was investigated. By means of results from the stochasticly forced model, a Markov model was constructed with which a description can be given of the time evolution of the probability distribution in the phase space. The research is now focused on the analysis of spectral models of higher order, both barotropic and baroclinic, which have richer internal dynamics and give rise to chaotic behavior.

In cooperation with J.A. Aten (University of Amsterdam), Grasman and Smit are studying stochastic processes in biology. On the basis of experimental data, it was tested whether models with one and with two stochastic transitions give a good description of the cycle of biological cells. The model with one transition proved to be the most satisfactory. There is a definite chance that descendents of cells which have been exposed to radiation have a rest phase in their cycle. A general transition probability model was formulated which contains all of the possibilities mentioned.

Asymptotics and applied analysis

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

The research of Temme deals with the asymptotics of integrals. He rounded off his work on Laplace integrals with a study of so-called incomplete integrals. A characteristic is that next to the asymptotic parameter there are two uniformity parameters. An important application is the incomplete beta integral. Results in this project already published will be incorporated in a monograph on this subject.
An algorithm was designed to compute the incomplete gamma function for large values of the parameters. Asymptotic and numerical aspects of a double integral in which a modified Bessel function occurs, were investigated.

The cooperation with J.T.F. Zimmerman (Netherlands Institute for Sea Research) was continued with respect to the research on residual currents in tidal areas.

The research of Grasman is focused on the asymptotics of nonlinear oscillations. As part of the investigation of relaxation oscillations, the influence of stochastic perturbations on the period was studied, and models with chaotic oscillations were formulated. A phase-diffusion equation was derived for spatially distributed oscillators. Results will be published in the monograph on *Asymptotic Methods for Relaxation Oscillations,* to appear in 1986.

Dijkhuis continued his research on localizability in quantum mechanics. It was proved that the propagation speed of perturbations which are localized at a certain moment according to the definitions of Newton and Wigner, is unbounded. However, the effect of that part of the perturbation which propagates with superluminal velocity, decreases very fast (at least exponentially) as the distance increases. Because of that superluminal effects are not measurable at macroscopic distances.

Lauwerier continued his research on discrete dynamical systems. He published papers on the Pythagoras tree as a Julia set, and on Hopf bifurcation in host-parasite models from population dynamics.

Department of Mathematical Statistics

R.D. Gill (head of department)
A.W. Ambergen
H.C.P. Berbee
A.L.M. Dekkers
K. Dzhaparidze
A.J. van Es
S. van de Geer
C. Heesterman
R. Helmers
A.J. Koning
A.P. van der Plas
M. Rottschäfer
A. Verbeek
M.M. Voors
trainee:
P.E. ter Burg

In mathematical statistics, as in other fields of mathematics, a new synthesis between theory and applications takes place, 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. The emphasis is on dependent stochastic processes and estimation of 'abstract' parameters such as curves or surfaces. Much attention is paid to the process of hypothesis forming and model building as well as to the activities which take place within an already precisely formulated model. This is reflected in the research and consultation of the department in such areas as bootstrap methods, semiparametric models, and density estimation. New areas of application of statistics have even led to the introduction of new principles of statistical inference, e.g., for dealing with the only partially specified models used in the analysis of clinical cancer trials.

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

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

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

Semiparametric statistics

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

Dzhaparidze continued his research on optimality properties of estimators in a large class of models for the intensity of a multivariate counting process. He reported on his research at the Centenary Session of the International Statistical Institute.

In cooperation with J.A. Wellner (University of Washington), Gill investigated a semiparametric model of Y. Vardi (Bell Laboratories) for combining a number of stratified or weighted samples. Examples of this model are of importance in such diverse areas as econometrics, case-control studies in epidemiology, and the observation of parts of a renewal process (e.g., the duration of telephone calls registered in a telephone-exchange). A complete set of consistency, asymptotic normality and efficiency results was constructed.

In the course of the year Heesterman joined this research project. Her research is concerned with the application of new techniques from semiparametric estimation theory in a

model for dependent survival times, as developed in biostatistics by Clayton and Cuzick.

The research project on stochastic censoring carried out by Gill and Heesterman continued in cooperation with P.K. Andersen and N. Keiding (Statistical Research Unit, Copenhagen) and OØ. Borgan (University of Oslo). Andersen, Borgan, Gill and Keiding are working on a book on statistical models for counting processes, to be completed in 1987.

The cooperation with the Netherlands Interuniversity Demographic Institute was continued concerning the investigation of the usefulness of recent developments in the theory of stochastic censoring, such as counting processes models, the semiparametric Cox regression model, etc.

Helmers continued his research on the precision of bootstrap estimators for the distribution of statistical quantities. It was shown that the one-term Edgeworth expansion estimator and the bootstrap distribution estimator give an asymptotically more precise estimation of the distribution of a studentized U-statistic than the classical normal approach.

In cooperation with Helmers, Ter Burg has begun an investigation of the jackknife, the bootstrap, and the delta-method estimators for the bias and variance of estimators.

Helmers' cooperation with R.J.M.M. Does (University of Limburg) and C.A.J. Klaassen (University of Leiden) was continued. Their research is focused on Edgeworth expansions for functions of uniform spacings.

Van Es and Helmers investigated the asymptotic behaviour of elementary symmetric polynomials.

The cooperation between Helmers and P. Janssen (Limburgs Universitair Centrum, Belgium) and R.J. Serfling (Johns Hopkins University) resulted in a joint publication on asympotic properties of generalized L-statistics.

Stochastic processes

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

The problems involved in Markov representation touch in important ways on system theory and statistical mechanics. Berbee has investigated some special systems for which the Markov representation problem is still open.
Above the critical temperature one-dimensional Ising models with long range may generally be described as chains with infinite connections. A generalization of a weakened form of Ruelle's Perron-Frobenius theorem was deduced, and an inequality was investigated which is useful to the study of phase transitions.

As part of the research project on the statistical analysis of stochastic processes, Dzhaparidze worked on the English edition of his book *Parameter Estimation and Hypothesis Testing in Spectral Analysis of Stationary Time Series,* to be published by Springer Verlag in 1986.

With A. Sieders (ZWO), Dzhaparidze gave a generalization of a theorem of Ibragimov and Khasminski on large deviations of maximum likelihood estimators. For a large class of estimators (not only maximum likelihood estimators) these deviations may now be evaluated. Special attention was paid to applications in nonlinear regression.

Van der Plas started research on a semi-Markov model in which two states are aggregated, and in which the intensity between these states has to be estimated.

Applied statistics

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

Ambergen continued his research in the field of discriminant analysis. Under the supervision of W. Schaafsma (University of Groningen) he is writing a doctoral disserta-

High tide water levels (represented by the polygonal line with dots) observed in Hoek van Holland at the Dutch coast during the winter months (the stormy period) over the years 1901-1980 are plotted against the exceedance probability. Only high waters sufficiently far apart in time are taken into account, in order to ensure that observations are approximately independent. The arrow indicates the highest water level, 3.85 meter above NAP, attained during this 80 years period (NAP≡ mean sea level, Amsterdam). This was caused by the storm surge of the 1st of February, 1953 when in several parts of the Netherlands the sea-dikes broke and part of the country was flooded.

A generalized Pareto distribution with estimated shape (represented by the dotted curve) turned out to fit the observations quite well. The much simpler exponential distribution (represented by the straight line) also gives a fairly reasonable approximation. On the basis of these probability models estimates for a safe level of the sea-dikes can be given. The statistical analysis is still in progress.

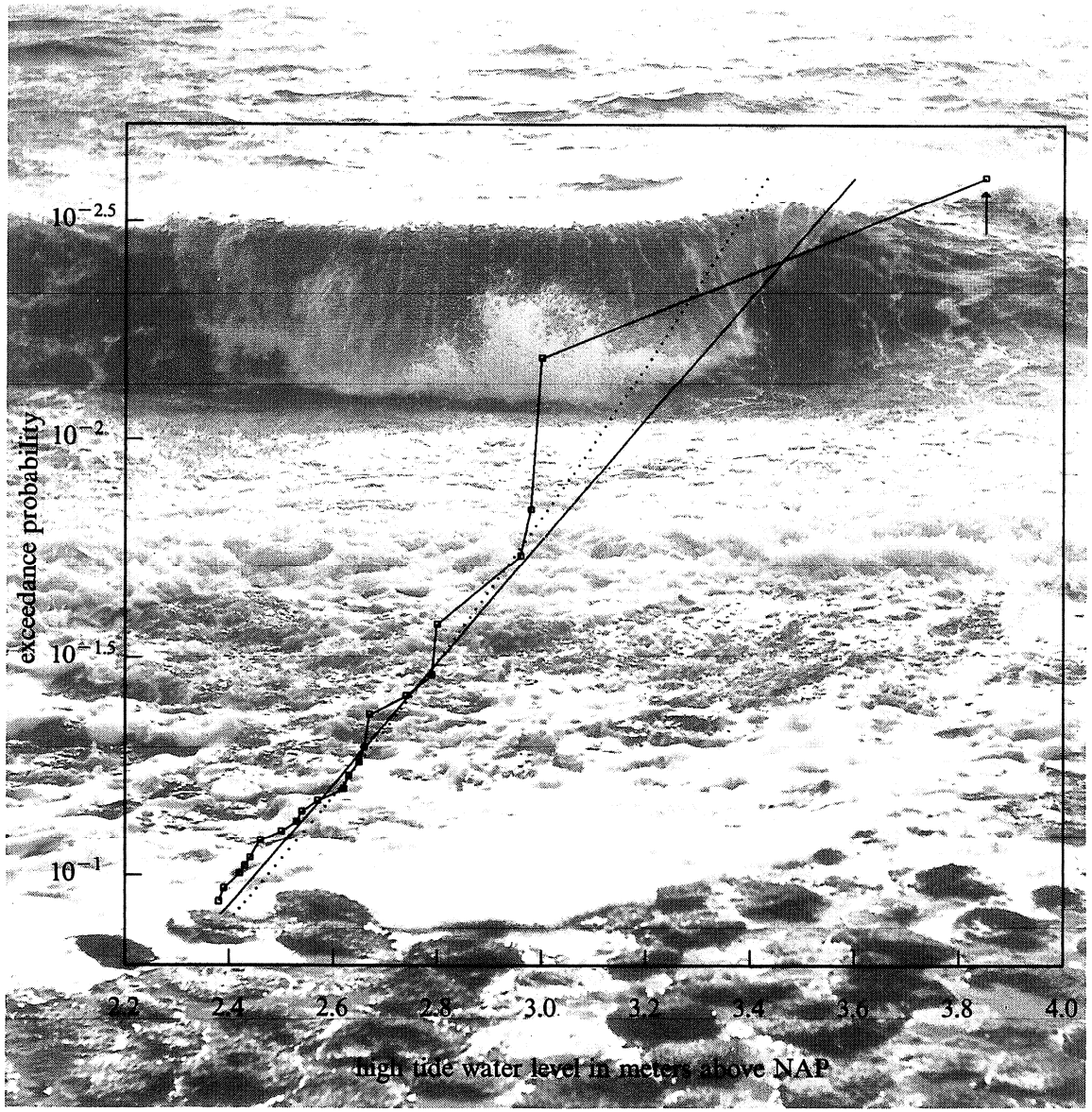


Photo Dienst Getijdewateren Rijkswaterstaat

tion based on results gained during the last few years. For various large classes of classification models the derivations of the asymptotic distribution of estimators for a priori probability have been unified.
The computer program POSCON (posterior confidence interval), written by D.M. van der Sluis (University of Groningen), was made available. This program contains implementations of Ambergen's results.

Van de Geer's research is focused on breakpoint methods for statistical models with abrupt changes in the parameters. In extending the two-phase model to the multidimensional model it turned out that by means of the theory of empirical processes general results may be deduced for any regression model. In this way numerous known special models, such as nonlinear regression, two-phase regression, and isotone regression, are gathered in one theory.

Consultation

The consultation activities of the department were various. Dekkers, Helmers, and Van der Horst (Technical Support Division) continued the cooperation with L. de Haan (Erasmus University Rotterdam, and adviser of the department) for the project on the probability of extreme water levels at the North Sea Coast and the IJsselmeer area. This concerns a project carried out with Rijkswaterstaat (Public Works) and the Royal Netherlands Meteorological Institute. The research is focused on two problems, viz., on an investigation of correspondences and differences between various possible selection methods, and on the statistical analysis of selected high-water levels in the period 1901-1985. A multidimensional approach was decided on, which should make it possible to estimate the probability of a simultaneous exceedance of certain levels at various places along the coast.

As a continuation of the STW supported project on the statistical analysis of traffic flows a number of analyses was made to determine the capacity of a motorway. For this methods from the field of stochastic censoring were used.

For Rijkswaterstaat (Public Works) Dzhaparidze, Van Es, and Voors have made a statistical analysis of water levels in the IJsselmeer to determine the probability that a certain level will be exceeded. An investigation was made of the frequency distribution of the average levels. A central question in determining the desired quantiles was to decide which extrapolation method had to be used.

In cooperation with H. Moed and T. van Raan of the governmental Advisory Council for Science Policy, an investigation is being made of the citations of publications in various fields of knowledge. The aim is to construct a useful stochastic model for being cited in successive years in scientific publications.

The Institute for Perception Research is developing a method for the acoustic analysis of speech signals, so as to segment speech automatically in a number of independent units, and to compare the resulting segmentation to the phonetic transcription. CWI provides mathematical and statistical support.

Department of Operations Research and System Theory

J.K. Lenstra (head of department)

J.M. Anthonisse	M.W.P. Savelsbergh	L. Stougie
O.J. Boxma	A. Schrijver	S.L. van de Velde
E.A. van Doorn	J.M. Schumacher	*trainees:*
G.A.P. Kindervater	J.H. van Schuppen	J.L. van den Berg
B.J.B.M. Lageweg	S.A. Smulders	I.L. Braam
J.W. Polderman	P.J.C. Spreij	W.P. Groenendijk

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 has to choose between enumerative methods, which eventually result in an optimal solution but often only after exponential computing time, or approximative algorithms, which are fast but do not guarantee an optimality of the resulting solution.

The general aim of the research is the design and analysis of combinatorial algorithms. Specific research projects include polyhedral combinatorics, stochastic integer programming, parallel computers and computations, and interactive planning methods.

Several members of the department contributed to the three books, which were published this year: *The Traveling Salesman Problem: a Guided Tour of Combinatorial Optimization,* edited by E.L. Lawler, J.K. Lenstra, A.H.G. Rinnooy Kan and D.B. Shmoys (Wiley, 1985), *Combinatorial Optimization: Annotated Bibliographies,* edited by M. O'hEigeartaigh, J.K. Lenstra and A.H.G. Rinnooy Kan (Wiley, 1985), and *Parallel Computers and Computations,* edited by J. van Leeuwen and J.K. Lenstra (CWI Syllabus 9, 1985).

Lageweg, Lenstra and Stougie, in cooperation with J.B. Orlin (MIT, temporarily CWI), gained new results concerning approximation and optimization algorithms for the test cover problem. Together with A.M. Frieze (Queen Mary College, London), Stougie worked on the probabilistic analysis of an approximation method for a special case of this problem.

In cooperation with M. Meanti and C. Vercellis (Università di Milano) and A.H.G. Rinnooy Kan (Erasmus University Rotterdam), Lenstra and Stougie investigated the worst

case behaviour of a class of weighted greedy algorithms for multidimensional knapsack problems.
Stougie and A. Marchetti-Spaccamela (Università di Roma) carried out a probabilistic analysis of the optimal value of a machine scheduling problem in which the weighted sum of the job completion times is minimized. Stougie rounded off his research in the field of stochastic integer programming with a doctoral thesis.

Schrijver and A.H.M. Gerards (Tilburg University) continued their research on matrices with the Edmonds-Johnson property. They found one new forbidden submatrix, which produced various structure results.
In cooperation with Gerards and L. Lovász (Eötvös Lórand University, Budapest), Schrijver made an investigation of signed graphs, i.e., graphs whose sides are divided into two classes, odd and even.
In cooperation with Gerards, C.A.J. Hurkens, and C. Wildhagen (Tilburg University) research of multicommodity flows was started, with a view to applications in the design of integrated circuits. Problems of A. Frank and K. Mehlhorn were studied.
Schrijver finished work on his book *Theory of Integer and Linear Programming,* to be published by Wiley in 1986. He continued the cooperation with M. Grötschel (Universität Augsburg) and Lovász on the book *The Ellipsoid Method and Combinatorial Optimization,* to be published by Springer in 1986.

Kindervater and Lenstra published an annotated bibliography on parallel algorithms and wrote a survey article on the same subject. The research on the parallelization of enumerative algorithms for combinatorial optimization problems was continued. In cooperation with H.W.J.M. Trienekens (Erasmus University Rotterdam) a report was written on practical experience gained on the CYBER-205 in Amsterdam, on the ICL-DAP in London, and on the Manchester Dataflow Machine. Kindervater also obtained results on the parallel computational complexity of traveling salesman heuristics.

In the field of interactive planning methods, there are three research projects.
The project on the development and implementation of vehicle routing algorithms is sponsored by STW. It is carried out by Savelsbergh, Anthonisse and Lenstra, with the road transportation firm Van Gend & Loos as the first user of the CAR system for computer aided routing. The underlying algorithms were further developed. Special attention was paid to the time windows of customers in the clustering phase, the research for which was carried out in cooperation with S. Martello and P. Toth (Università di Bologna), and to the combination of collections and deliveries in a single car during the routing phase. Two computer configurations with advanced facilities for interaction and colour graphics have been ordered to support the research and to serve as a prototype of systems on which the software will be actually implemented. A first version of a logical functional description of CAR was finished.
A part of the INSP, Anthonisse, Lenstra and Van de Velde started a new project in cooperation with TNO-Fibre Institute and the Working Group on Applications of Microcomputers of the Research Corporation of the Netherlands Clothing and Hosiery Industry. The project is concerned with interactive production planning in the clothing industry.
In cooperation with Eindhoven University of Technology, Erasmus University Rotterdam, and Delft University of Technology a project, supported by NFI, was started on design methods for decision support systems.

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 are found 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.

Contacts between Boxma and J.S. Kaufman (Bell Laboratories, Holmdel) led to research on the interaction of two kinds of traffic in a computer system, viz., batch and terminal traffic. With B. Meister (IBM Zurich) queueing time approximations were derived for systems in which a server has to deal with several queues (in cyclic order). These types of systems are of importance for local area networks.
Groenendijk analysed a new service discipline in this type of single server system with several queues. Van den Berg investigated the throughput and end-to-end delay in queueing models for window flow control.

Boxma and Van Doorn were involved in the preparations for the International Seminar on Teletraffic Analysis and Computer Performance Evaluation, to be held at CWI in June 1986.

An extensive investigation of software queueing packages has led to the acquisition of the 'general purpose' package QNAP2; some 'special purpose' packages will also soon be available at CWI.

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

On motorways drivers are sometimes advised to maintain a certain speed, in order to achieve an optimal traffic flow. This speed, or other indications, is displayed on so-called matrix boards. In an STW sponsored project CWI has developed a fluid-like model for the traffic flow. Its predictions are used to derive optimal estimates for the traffic density and speed. The model is highly adaptive.
Photo Dienst Verkeerskunde Rijkswaterstaat

emphasis it puts on the concept of a dynamic system, and on the interaction of a dynamic system with its environment. Besides, the synthesis of control and filtering algorithms is emphasized. Sources of practical problems which motivate research in this area include controller synthesis for airplanes and robots, modelling issues in econometrics, and the design of communication equipment.

Schumacher's research deals with structural properties of linear and nonlinear systems. An affiliation with the research centre of the European Space Agency in Noordwijk, ESTEC, was ended in February with the completion of a report on mathematical methods for the vibration analysis of large spacecraft. As an outgrowth of the work at ESTEC, results on residue formulas for meromorphic matrices were obtained. Schumacher also worked on a new realization algorithm for coupled systems of higher-order differential equations. The activities involve supervising the STW sponsored project on Large Flexible Space Structures, carried out by J. Bontsema at Groningen University under the supervision of R.F. Curtain.

Van Schuppen continued his research on stochastic system theory. Some new stochastic control problems were formulated as a result of the criticism of R.E. Kalman on the use of stochastic linear models in econometrics. As a result of this, attention is now paid to the factor analysis model. A preliminary investigation was made of the strong stochastic realization problem for the representation of a Gaussian vector as factor model. For the representation of stochastic processes a class of stochastic dynamic systems with the factor property was investigated.

The research on the control of overload of communication systems was continued in cooperation with R.K. Boel (University Ghent, Belgium). Also routing problems in telephone networks were investigated.
The cooperation with G. Picci (Università di Padua) concerning the finite stochastic realization problem was continued. The research was focused on the classification of prime matrices, within the set of positive matrices. With a view to a project which is yet to be started, a pilot investigation was made by Van Schuppen into some topics of computer science, viz., the control of distributed data bases and inference techniques for expert systems.

Spreij continued his research on recursive parameter estimation problems for point process systems. The research of Polderman deals with structural properties of adaptive regulators, based on the self-tuning regulator approach.

The STW sponsored project on prediction and control problems for motorways is carried out by Smulders. A new model for the flow of freeway traffic was developed. A simulation of this model was made. This resulted in adjustments of the parameters of the model and of the model itself, and led to a better insight in the workings of the model.

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

Software was developed by Anthonisse and Lageweg to make timetables for postdocs at the Medical Faculty of the Free University Amsterdam. A simulation was made for the transition from the old curriculum to the new, so as to analyse any capacity problems which might arise.

Boxma worked with a Ph.D. student of the Medical Faculty of Utrecht University on the stochastic analysis of oncogenic mutations in cell division.

With a government organization and the Delft Hydraulics Laboratory, Van Schuppen discussed theoretical problems that arise from the application of system and control theory, to practical problems in hydrology and hydraulics.

Department of Numerical Mathematics

P.J. van der Houwen (head of department)
P.W. Hemker
W.H. Hundsdorfer
J. Kok
B. Koren
H.J.J. te Riele
J. Schlichting (CDC)
S.P. Spekreijse
J.H.M. ten Thije Boonkkamp
J.G. Verwer
F.W. Wubs

programmers:
J.G. Blom
W.M. Lioen
M. Louter-Nool
B.P. Sommeijer

D.T. Winter
P.M. de Zeeuw

trainees:
M. Bergman
E. de Goede
J.J. Rusch
T. de Vries

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

The main fields of interest of the department have always been differential and integral equations, numerical software, and computational 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;
- Software for vector computers.

Discretization of initial value problems

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

The research is focused on partial differential equations, in particular on the incompressible Navier-Stokes equation and on difference schemes for differential equations, which are of great importance in numerical fluid dynamics.

Verwer's research deals with convergence and order reduction of diagonally implicit Runge-Kutta schemes in the method of lines. The method of lines approach makes it possible to exploit ideas and results from the B-convergence theory for Runge-Kutta schemes applied to stiff problems. In this way convergence can be proved for interesting classes of nonlinear problems.

The research of Hundsdorfer is concerned with the stability and convergence properties of linearly implicit Runge-Kutta methods applied to stiff semi-linear systems of differential equations.

In cooperation with K. Burrage (University of

Auckland), Hundsdorfer and Verwer have studied B-convergence of Runge-Kutta methods applied to stiff semi-linear systems of differential equations. A criterion was developed which determines whether the order of optimal B-convergence is at least equal to the stage order or one order higher. And in cooperation with J.M. Sanz-Serna (Universidad de Valladolid, Spain) Hundsdorfer and Verwer investigated the convergence of fully discrete Runge-Kutta approximations.
Sommeijer suggested a modification of explicit Runge-Kutta methods. In order to gain a certain degree of precision, schemes were constructed which require fewer evaluations of the right-hand side function than classical Runge-Kutta methods.

As part of the project on Navier-Stokes equations, Ten Thije Boonkkamp and Verwer have investigated the odd-even hopscotch scheme for the numerical integration of time-dependent partial differential equations. As a follow-up of this research Ten Thije Boonkkamp applied the odd-even hopscotch scheme, in combination with a pressure correction technique, to incompressible Navier-Stokes equations.

For the research project on shallow water equations, Van der Houwen and Sommeijer have investigated hyperbolic differential equations. With a view to efficient methods for the integration of large systems of differential equations with oscillating solutions, predictor-corrector methods of a generalized type were studied. Together with De Vries they investigated the Cauchy problem for hyperbolic equations for which the frequencies of the main Fourier components in the solution are located in a given frequency interval. For the special case of hyperbolic equations which describe one-dimensional waves, a fourth-order accuracy difference scheme was constructed and applied to shallow water equations.

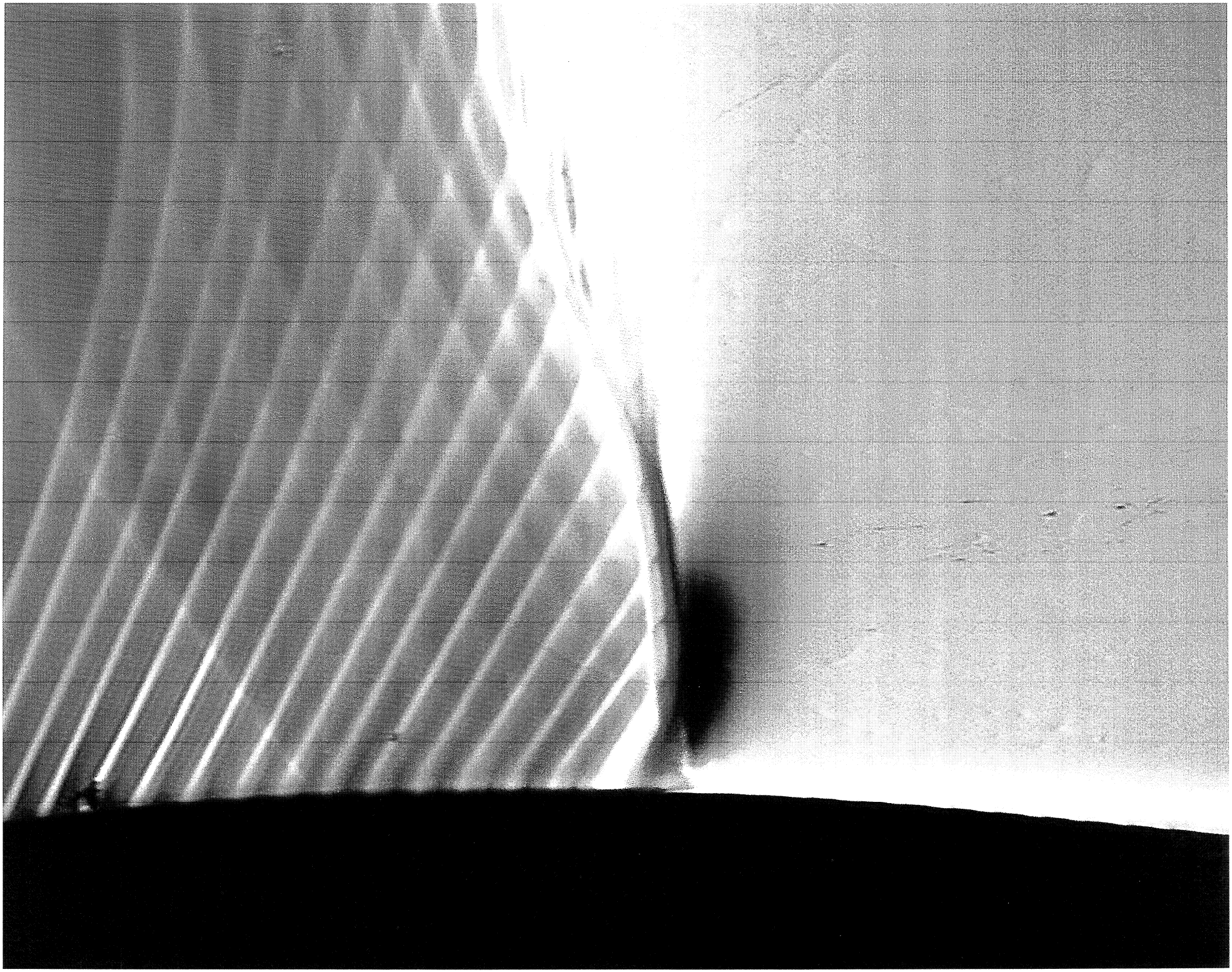
The STW sponsored research project on shallow water equations was continued. An explicit Runge-Kutta scheme, specially chosen so as to make an optimal use of the facilities of the CYBER 205, was compared by Wubs to the ADI method as used by Rijkswaterstaat (Public Works) for shallow water equations. The explicit methods turned out to be attractive on the CYBER 205.

Wubs, Van der Houwen, Sommeijer and De Goede continued the research on the stabilization of explicit methods, with a greater emphasis on theory this year. Special attention is paid to the user-friendliness of the program developed by Wubs for the CYBER 205.
The research on Volterra equations is continued by Blom, in cooperation with H. Brunner (Université de Fribourg). Blom developed a collocation method for general nonlinear Volterra equations of the second kind. By means of this method the right integration step is chosen automatically.

Multigrid techniques for boundary value problems
Research in numerical analysis of boundary value problems is mainly 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 also substantially improved by this new technique. Especially interesting are the results of using multigrid methods on vector computers.

Hemker's research deals with defect correction and its theoretical background, in particular with the fundamental analysis of the multigrid algorithms and their relation to other defect correction techniques. Special attention was paid to recent convergence proofs for multigrid algorithms and to the convergence analysis of nested iteration techniques.
Hemker and De Zeeuw continued their



Furthermore, numerical software is developed for vector computers and made available in the NUMVEC library (see below). The work on this project is carried out by Te Riele, Lioen, Louter-Nool, Schlichting, and Winter, in cooperation with H.A. van der Vorst (Delft University of Technology, and adviser of the department).

Partly for the short course on Supercomputers in Science and Engineering, held in Southampton, Te Riele wrote a survey paper of problem areas in (numerical) mathematics, in which vector and parallel processors play a crucial role.

Louter-Nool investigated the efficiency of a collection of linear algebra subprograms for elementary vector operations, the so-called BLAS (Basic Linear Algebra Subprograms), as made available on the CYBER 205 by the manufacturer, compared to a CWI version of these subprograms.

Te Riele, Lioen, Sommeijer, Winter, and De Zeeuw are maintaining a library for numerical software for vector and parallel processors in FORTRAN, the so-called NUMVEC library. The documentation is written as much as possible in accordance with that of the NAG library.

Schlichting investigated a number of algorithms for the solution of large bidiagonal systems on the CYBER 205. The aim was to develop as fast an algorithm as possible, using the specific facilities of the CYBER 205.

◄ *Schlieren picture of a transonic air flow in a wind tunnel channel. The striated region to the left of the shock wave (the dark vertical line) is the supersonic area where the flow velocity exceeds the speed of sound.*

Photo Delft University of Technology, Department of Aerospace Engineering

Department of Software Technology

J.W. de Bakker (head of department)

J.C.M. Baeten	J.W. Klop	*trainees:*
J.A. Bergstra	J.N. Kok	S. van Egmond
F.S. de Boer	P.J.F. Lucas	A. Eliens
N.W.P. van Diepen	P.M. Rodenburg	F.C. Heeman
L.C. van der Gaag	J.J.M.M. Rutten	G.J. Hofman
R.J. van Glabbeek	F.W. Vaandrager	H.B.P. Knops
J. Heering	A. Verhoog (BSO)	F. Uytenboogaard
P.R.H. Hendriks	J.C. van Vliet	S.J. van Veen
P. Klint	J.B. Warmer	

In its Computer Science Stimulation Program (INSP) the Dutch government has stressed the importance of research in computer science. CWI has received additional finds from this Program, in order to grow into a *centre d'excellence* in the field of computer science. The selected research fields in the three computer science departments of CWI are to a large extent connected with the facts that hardware rapidly becomes cheaper and that processing power increases. As a consequence, distributed processing is now an important issue, and the strongly increased demand for high-quality software has stimulated research in software engineering, programming languages and environments, and the design of information systems. In the department of Software Technology a considerable part of the research is carried out in the framework of ESPRIT.

The department has the following research projects:

- concurrency;
- specification languages;
- extensible programming environments;
- interactive text processing;
- expert systems and other aspects of artificial intelligence.

Concurrency

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

In a close cooperation between De Bakker and J.J.Ch. Meijer (Free University Amsterdam), E.-R. Olderog (Universität Kiel), and J.I. Zucker (SUNY, Buffalo), a number of semantic models was investigated for (languages with) concurrency concepts, such as parallel execution, synchronization and communication. Results were obtained concerning the relation between (or the equivalence of) operational and various denotational semantics.

As part of the ESPRIT project 415, *Parallel Architectures and Languages for AIP: a VLSI directed approach,* De Bakker, Kok, and Rutten are involved in the Working Group on Semantics, of which De Bakker is chairman. They did the editorial work for a deliverable made by the Working Group to the European Community. Another aspect of the research concerned the language POOL (Parallel Object Orientated Language). In cooperation with P. America and F.J. van der Linden (Philips Research), an operational semantics was developed. The work is now concerned with the design of a denotational semantics for POOL. For the proof methodology of POOL, De Boer has made an investigation of the proof theory of a CSP-like language extended with process creation.

Kok continued work on the SION supported project on the semantics of dataflow and functional programming. He developed a model for non-deterministic dataflow.
Van Veen and De Vink evaluated various models (operational, denotational) for the semantics of logic programming, with or without parallel versions and with or without infinite computations.

Eliens has started to investigate the semantics

of OCCAM, with a view to applying a number of semantics techniques developed recently as part of the project on the definition of OCCAM. An evaluation will be made of the definitions thus developed.

The department continued the research carried out as part of the National Project on Concurrency, supported by SION and directed by De Bakker in cooperation with W.P. de Roever (Catholic University Nijmegen) and G. Rozenberg (University of Leiden). CWI has taken the initiative to the organization of the PARLE Conference (Parallel Architectures and Languages Europe), to be held in 1987.

Specification languages

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

The project is carried out by Baeten, Van Glabbeek, Vaandrager, Klop, Rodenburg, and J.A. Bergstra (University of Amsterdam, and adviser of the department). The main emphasis is on process algebra, with a view to verification, specification, and design of distributed software. It is done as part of ESPRIT project 432: Meteor (A formal approach to industrial software development). In developing a theory for distributed software, several features have to be considered, e.g., synchronous and asynchronous communication, synchronous and asynchronous cooperation, dataflow, interrupt mechanisms, fairness and unfairness. So far there is no model which gives a satisfactory description of all of these features. The research efforts are concentrated on the design of a family of axiom systems, in which each axiom system embodies a certain combination of features. Another aspect of the research is dedicated to proving the consistency of all of the axiom systems by the construction of a model. Furthermore, the research on process algebra is concerned with the analysis of a number of simple case studies.

Scientific director P.C. Baayen addressed a delegation of science journalists from EC countries visiting CWI. In particular they were informed about CWI's participation in ESPRIT-projects.

Extensible programming environments

This year the research on this project was carried out, as part of the ESPRIT project GIPE (Generation of Interactive Programming Environments), by Van Diepen, Heering, Hendriks, Klint, and A. Verhoog (on assignment from the Bureau for Systems Development). The work on the algebraic specification of a simple programming language was completed. In this experimental specification a first version was used of an algebraic specification formalism, which is now further developed.

Further research concerned partial evaluation and ω-completeness of algebraic specifications, with special attention to automatic (partial) ω-enrichment, a new concept which is likely to be of importance in generating optimizing compilers from algebraic specifications.

A first version of a global design of a programming environment based on language definition was published. In order to gain experience with algebraic specification, the work is now aimed at the definition of a language with goto-statements and at the definition of polymorph type-from-context inference.

Interactive text processing

The goal of this research project is to design and implement a system which during the input of the text makes the final output visible on the screen. The research is carried out by Van Egmond, Heeman, Van Vliet and Warmer. In order to gain experience with the interactive processing of complex structured texts, special attention was paid to the design and implementation of subsystems for the interactive processing of tables and of mathematical formulas. For both systems a test implementation is being developed, which links up with existing software available under UNIX. In cooperation with L.G. Bouma and J. Bruijning (University of Amsterdam), the facilities of some existing systems for document processing were evaluated. Warmer and Van Vliet compiled an extensive annotated bibliography on this subject.

Expert systems and other aspects of artificial intelligence

This is a new research project, which was started in the second half of this year. It is carried out by Van der Gaag, Lucas, and R.G. van Soest (University of Amsterdam, temporarily CWI). As the field is very wide and the research group relatively small, it was decided to limit the efforts to research on expert systems. These information systems are rapidly gaining in importance, and many organizations are now investigating the role of expert systems for decision support.

The experience gained at Delft University of Technology in the development of the expert system shell DELFI-2 was taken as a starting point. In close cooperation with H. de Swaan Arons (Delft University of Technology), work was begun on an extension of the DELFI-2 system, so as to create a tool with sufficient flexibility to be of use in a great diversity of problem areas. DELFI-2 is implemented in Pascal. The possibilities of using PROLOG for the implementation of an expert system shell have been investigated.
Further research is concerned with the foundations of expert systems. Techiques from theorem proving and logic programming are compared with methods from expert systems.

Department of Algorithmics and Architecture

L.G.L.T. Meertens (head of department)
T.A. Budd
J.C. Ebergen
L.J.M. Geurts
A. Janssen
M.L. Kersten
S.J. Mullender
S. Pemberton
G. van Rossum
F.H. Schippers
A.P.J.M. Siebes
P.M.B. Vitányi

programmers:
F. van Dijk

A.J. Jansen
J.G. Steiner
T.J.G. Krijnen

trainees:
E. Verweij
J. Zwaan

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

- Complexity and algorithms;
- Architectural transparency;
- ABC;
- DAISY;
- Constructive algorithmics.

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 more and more important. As larger problems are undertaken and systems of greater complexity used, there is a growing need for efficient algorithms.

Vitányi is doing research on sequential algorithms. He started writing a monograph on counting, which will deal with all algorithmic aspects of counting, from arithmetic through number representations to recursive algorithms.

He continued his research on relations between data structures. Recently W. Maass (University of California in Berkeley), M. Li (Cornell University) and Vitányi proved independently that for the simulation of a two-tape machine by a one-tape machine the known n^2 time lower bound is optimal. All three made use of a remarkable notion introduced by Kolmogorov, Chaitin and others in the 1960s and 1970s, so-called algorithmic complexity. Li and Vitányi joined forces to determine lower bounds for other simulations.

Further research of Vitányi is concerned with distributed algorithms. Technological progress has stimulated research in networks, both in wide-area networks and very small scale networks that fit into one cabinet. The algorithmic problems connected with networks are of crucial importance. In computer networks synchronization problems connected with the operation of such complexes are bound to become acute. Vitányi designed time-driven and yet logically time-independent algorithms for the synchronization of the local clocks of the processors. Without efficient congestion control large-scale systems will be swamped by communication messages. Special attention was therefore paid to the design of message-thrifty algorithms.

Mullender and Vitányi investigated the problem of setting up communication-when-needed between processes in a multiprocessor network, where processes have names but no permanent addresses. This problem arose out of the design objectives of the Amoeba project, which aims at the design of a distributed operating system (see below).

Vitányi also did research in VLSI complexity. He showed that sublinear propagation delay in VLSI circuits carries a far greater penalty

than was commonly realized. He reported on this research at the 26th *IEEE Symposium on the Foundations of Computer Science.*

Architectural transparency

In the early days of computers, the computer was an expensive machine shared by many people. Nowadays there is a growing tendency to use a personal computer, and in the future it is likely that per person a large number of microcomputers will be available. This proliferation of computers makes it necessary to connect them in a network, so that data may be exchanged. At present such a network is unpleasantly obtrusive: each machine is autonomous, and special actions are required if one wants to make use of the communication facilities between machines. The research project on architectural transparency aims at the development of software architectures which make the hardware architecture transparent, so that the user of the system is not even aware that he is in fact using several machines. The research is carried out under Mullender, in close cooperation with the Computer Science department of the Free University of Amsterdam under A.S. Tanenbaum. So far the project has resulted in the design and implementation of the Amoeba Distributed Operating System.

This year, a number of Whitechapel MG-1 workstations was installed to realize the Amoeba system. The Amoeba Kernel, the basic software for each machine in the Amoeba system, is running on these workstations, and interprocess communication software is now being developed. Work is also concerned with the creation of an interface between UNIX and Amoeba, so that Amoeba software can be developed and partially tested on the UNIX machines. For the Amoeba machines a software library has been constructed which allows UNIX applications to be run on top of Amoeba.

The work was both concerned with software development, and research. This provides cross-fertilization between theory and practice, so that implementations may be equipped with optimal algorithms and theoretical work may be done based on real-world problems. The locate problem has been investigated, i.e., the problem to localize objects in a computer network, such as files, processes, or services, which may move from machine to machine.
In cooperation with Vitányi fundamental results have been obtained in connection with a theoretical lower bound for the number of messages necessary to find an object, and algorithms were designed which achieve this lower bound. This result will have consequences for the COST-11 research project, carried out in cooperation with ten research institutes in eight European countries, which deals with problems in the field of operating system services in wide-area networks. In the COST-11 project the Amoeba system has been chosen as the implementation vehicle, so that research can be done on problems concerning scale, viz. the design of systems and algorithms which continue to perform satisfactorily as the system grows.

Further research dealt with the Amoeba File Server, which combines a number of concepts from the operating systems world, the distributed systems world, and the database world in a novel way. By means of caches with concurrency control the file service provides mechanisms which allow both sophisticated and simple applications to use its services efficiently.

Attention was also paid to process management, mechanisms for starting, stopping, migrating, and debugging processes in a distributed system. An elegant and simple mechanism has been designed with which all this can be neatly realized.

ABC

As hardware becomes cheaper, the possibility of personal computing comes within reach of an increasingly large public, both for private and for professional use. The available software, however, is often an obstacle to making an effective use of the possibilities that are actually presented. The aim of the ABC project is to design, implement, and distribute a simple, structured, interactive progamming language, embedded in a corresponding environment, which meets modern views and possibilities in the field of personal computer use. To this end the language B has been designed, which is suit-

able for structured programming, and which is both easy to learn and to use for inexperienced users. After four years, enough experience has been gained to revise this language. From the start the name B had been intended as a working title only; the revised version will bear the definitive name ABC.

As a start to the revision process, all known wishes and points of criticism have been collected and classified.
The release of the Mark 1 implementation for the IBM-PC and compatibles marked a milestone. Not only is this the first release of a B system for microcomputers, it also incorporates several new optimizations and offers a facility through which users can define their own binding of keys to editor commands. Together with the release *The B Programmers' Handbook* was published, authored by Geurts, Meertens and Pemberton, and containing all user-oriented documentation on B and the Mark 1 system.
Work continued on a next version, specifically aimed for use in Dutch schools, under a grant of the Ministry of Education and Science. In this version, the (natural) language dependent parts are contained in separate modules. This made it possible to demonstrate a "French" version of B (with, e.g., 'METTRE i+1 DANS i' instead of 'PUT i+1 IN i') at the Paris Educatec '85 exhibition as part of the presentation of the Dutch Ministry of Education and Science.
The ABC philosophy makes no distinction between files and variables. All global variables are 'permanent' and survive between execution of programs, until a user explicitly deletes them. The current Mark 1 system automatically saves the contents of each B variable to a file at the end of a session and automatically reads them back in the next session. This approach has several drawbacks. Budd designed a method, comparable to virtual memory management, in which at any time only a small part of a large value has to be present in RAM and changes to variables are written through to the disk with only a bounded delay and in such a way that the memory image on disk is guarenteed to be consistent.
Van Rossum wrote an entirely new version of the B editor for text handling, aiming at improved performance. This new editor was an instant success: it soon became the preferred editor of many people throughout the institute.
For several future extensions a preliminary design was prepared: one for computer graphics, one to allow the programming of interaction if the user can point with a mouse, and a collection of functions for vectors and matrices.

DAISY

In September a new project was started on distributed adaptive information systems (DAISY). The aim of this project is the design of (theoretical) models and the implementation of tools which will enable the realization of an adaptive and efficient information system. The architecture envisioned is the so-called AMOS-architecture which covers the following levels: applications, man-machine interface, operations, and storage of objects. So far the research has concentrated on two subprojects, Godel and Mstar.

The Godel project, carried out by Kersten and Schippers, aims at the design and realization of a programming language for the construction of adaptive information systems and knowledge-based applications. Essential aspects of the language are: data-driven information processing, logic programming, cooperative process structures, and an object-centered approach. Central to this language is the guardian concept, a high-level (declarative) description of a process which reacts (algorithmically) to changes (and states) in the knowledge bank. A first language description will be published in 1986. A functional prototype is now being developed in C-PROLOG.
Kersten and Siebes are working on the Mstar project, a Multiprocessor Main Memory Data Base Machine. The aim of this project is to gain knowledge and experience in the field of database machines. The market for database machines is estimated at US $ 1.5 to 2 billion a year. However, at present there are only a few database machines commercially available. The reasons for this are the fundamental problems encountered in the development of these systems, such as hardware development, the design and realization of large programs, and in the developments in the field of database modelling. Research currently focuses on

the theoretical issues raised by the machine architecture contemplated.

The DATABASE MACHINE project will be carried out in cooperation with Philips Research. The aim of this cooperation is to use a specific language and machine concept as the basis of the design and implementation for a database machine of the nineties.

Constructive algorithmics

This research project aims at the development of formalisms and methods to derive algorithms from a specification, with unification of the specification formalism and the algorithmic formalism proper, and the development of (pre)algorithmic concepts and notations on a high level of abstraction. The notion of 'algorithm' as used above comprises not only traditional computer programs, but any process-defining system description built in accordance with a recursive syntax from discrete basic elements.

Ebergen continued his research on VLSI design, the aim of which is to reduce the design of a chip to the design of a program. The research was particularly concerned on the one hand with the specification and design of programs for components, and on the other with the translation of these programs into an integrated circuit. The research is carried out in cooperation with Eindhoven University of Technology, under the supervision of M. Rem, and with Washington University in St. Louis, Missouri.

Various kinds of specifications have been investigated and techniques have been developed to derive programs on the basis of these specifications. In 1985, however, the research was mainly concerned with realizations of a program in the form of an integrated circuit by means of a composition of a number of basic components. Various techniques have been developed to translate programs into delay-insensitive composition of basic components.

In cooperation with R.S. Bird (University of Oxford, UK) and D.S. Wile (University of Southern California) Meertens made an inventory of the concepts and notations of a number of 'transformation-friendly' algorithmic notational systems and distilled a 'common basis'.

Together with Verweij, the possibility was examined to develop a single unified notational framework permitting specification in the procedural (or imperative), applicative (or functional) and deductive (or logic) styles.
The aim is in particular that a change of style is not necessarily a global transformation (really, a translation to another language), but can be effected by piecemeal local transformations. This should make it possible to describe many global complex and specialized transformations that involve a change of style, like recursion removal, in terms of simple transformations of general applicability. A promising approach to integrating procedural and applicative specifications appears to be to view a procedural specification not so much as a state transformer, but, rather, as an expression transformer (having Dijkstra's predicate-transformer semantics as a special case).

Department of Interactive Systems

P.J.W. ten Hagen (head of department)
C.L. Blom
W. Eshuis
A.A.M. Kuijk
M.M. de Ruiter
H.J. Schouten
T. Tomiyama
C.G. Trienekens
P.J. Veerkamp
W.E. van Waning

programmers:
R. van Liere
J. Kaandorp

trainee:
M. van Dijk

The exchange of information between man and machine or between two machines, when it occurs at program execution times, is termed interaction. Cheap computing facilities allow for dedicated interaction processors to exchange complex information structures in real time. One aspect of the recent developments in hardware is the technological improvement of graphic screens, such as raster screens in advanced workstations. The interactive manipulation of data by means of a representation on the screen is a new development of great importance.

The research of the department is divided in the following research projects:

- computer graphics;
- interactive workstations;
- dialogue programming;
- intelligent CAD systems;
- computer integrated manufacturing.

Computer graphics
The aim of this project is to design a functionally complete graphics systems, with special support for interactive use. The C implementation of the Graphical Kernel System (GKS) was handed over to industry. This involved the production of a definitive release, for which a number of improvements were made and tested exhaustively. An extra facility was added, allowing to link it to new hardware, whether advanced or not, in such a way that the local intelligence of each graphic workstation can be used optimally. The whole system was thoroughly documented, which completed this research project. The work was carried out by De Ruiter, together with Bakker, Rauwhorst, and Burger from the Contracts & Support Division.

Ten Hagen, De Ruiter, Van Dijk, Veerkamp, and Bakker continued the research on GKS-3D. In cooperation with L.R.A. Kessener (Eindhoven University of Technology), Ten Hagen revised the GKS-3D proposal, which revision is now submitted to ISO as a Draft International Standard (DIS). Van Dijk, Veerkamp, and De Ruiter are working on a GKS-3D implementation in C under UNIX. The aim is not only to illustrate the reliability of the GKS-3D design, but also to give a wholly professional implementation, which can be marketed by industry.

The STW sponsored project on facilities for raster graphics in programming languages is carried out by Ten Hagen, De Ruiter, and Trienekens, in cooperation with J. van de Bos and W. Theunissen (University of Leiden) and L.R.A. Kessener and M. van Lierop (Eindhoven University of Technology). The research at CWI is focused on the pattern expressions which are the primitives for raster images. A representation was designed for the pattern primitives, which actually allows the possibility of making a raster workstation interactive.

A number of text and demonstration programs for GKS and GKS-3D were developed by Kaandorp. As a fairly large number consisted of programs to define fractals interactively, and then to draw them, the focus of this part of the research has shifted to compiling a systematic library for fractal generation.

Interactive workstations
The aim of this project is to develop advanced interactive workstations. This work is done in collaboration with industry, which provides the hardware and gives important information about application characteristics, especially from the world of CAD. The task of CWI is to design the architecture of such workstations and to see to their programmability. The idea is eventually to develop a

fifth generation (intelligent) workstation with a built-in mechanism to support the interactive dialogue.

Blom, Kuijk, Schouten, and Troiani (Contracts & Support Division) completed the first prototype of the high-level interactive workstation as a GKS machine. The research efforts are now centred on the realization of a control structure in which the feedback processes are located in the workstation.

Window manager facilities available in current terminals require that these facilities are integrated in GKS. Ten Hagen and De Ruiter designed an extension of GKS, so-called segment grouping, which allows GKS integratable window management facilities to be addressed in a uniform way, regardless of the type of window manager. This grouping was implemented for the prototype workstation by Blom and Kuijk, and turned out to be an enormous improvement in efficiency, which is independent of the hardware.

The design for a virtual terminal with the necessary operators' interface was largely finished. The implementation will be made for such an environment that several GKS applications can be executed simultaneously on one terminal.

Dialogue programming

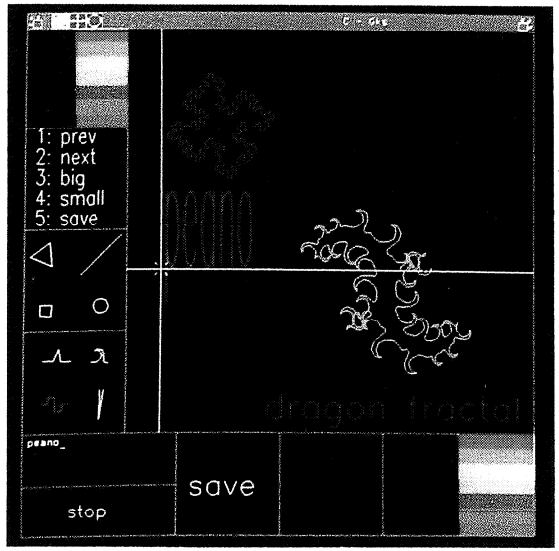
One of the most important aspects of the interactive process is the dialogue, i.e., the form in which the interaction takes place. By dialogue programming is meant the specification of all possible questions and answers, as well as the state of the (visible) interface at each stage of the dialogue. A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

Ten Hage and Van Liere continued the research on dialogue cells. The input and prompt parts of the specification language for interaction were improved, and various implementation parts were integrated.

In its first, experimental version the run-time system for dialogue processing has three components: a dialogue control structure based on the input syntax; a graphical interface; and an application interface. Van Liere and Ten Hagen designed a run-time system which can be distributed over a multi-processor, but which can also be run on a single processor. Ten Hagen and Schouten designed a parallel interface with the graphical system GKS. In order to achieve this, an extension of GKS had to be made, so as to realize the functionality needed for parallel processing of GKS. A dialogue environment was defined with graphical interaction primitives, so-called radicals.

Intelligent CAD systems

The research of Tomiyama is focused on design theory, i.e., a theory for the representation and manipulation of design information.



At the department of Interactive Systems a system of "dialogue cells" is under development. This provides the programmer with an environment by which he can easily create user interfaces. Both text and drawing can be manipulated in parallel through several input devices which can have different meanings in different windows on the screen.

His work was mainly concerned with an elaboration of the relation and significance of intentional versus extensional descriptors. This is a method to introduce abstract mechanisms in the frameworks for design information.

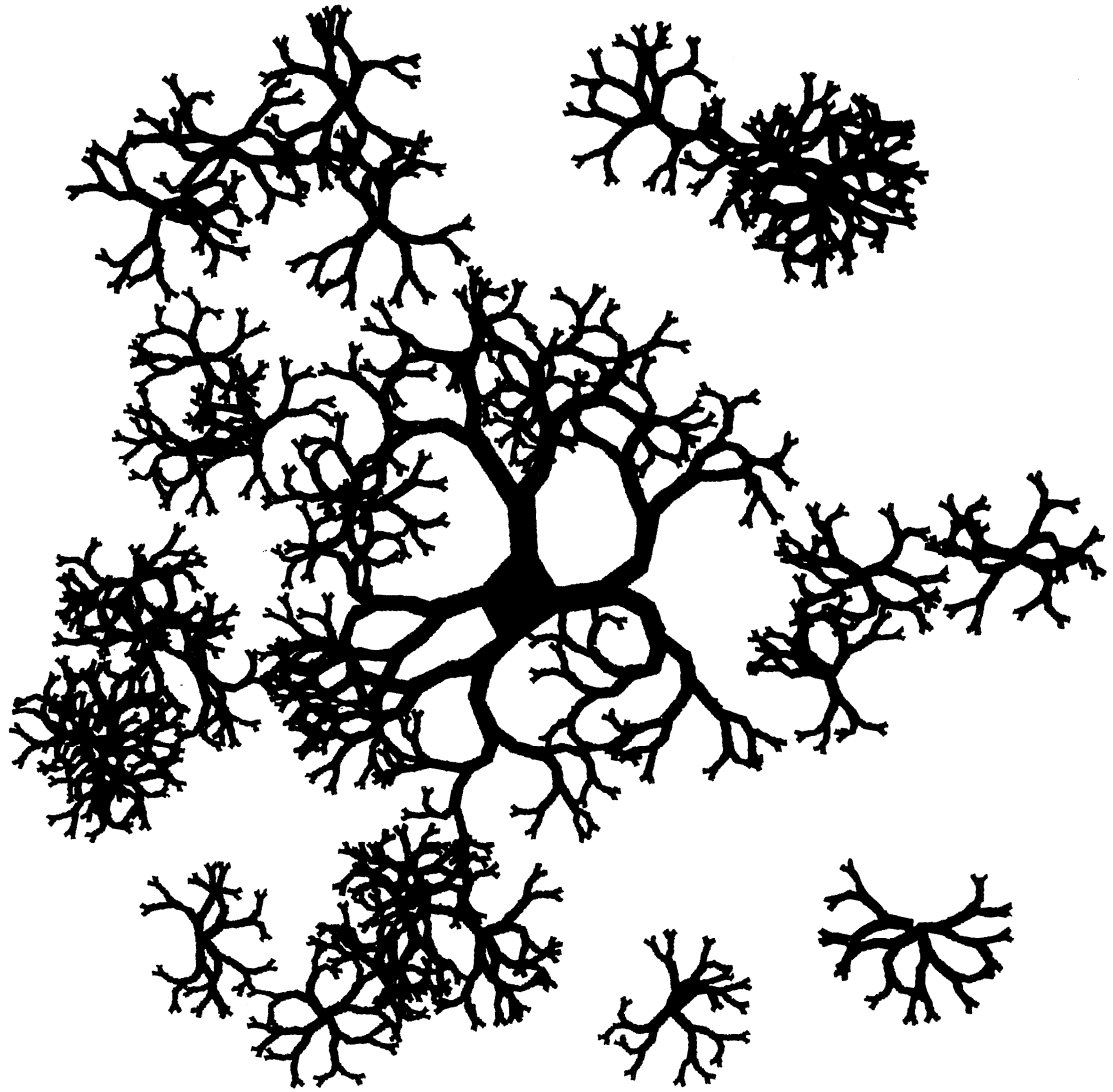
Ten Hagen and Tomiyama began work on the design of an experimental CAD system,

III CAD (Intelligent, Integrated, Interactive CAD), to investigate the introduction of techniques from artificial intelligence in CAD. This requires CAD information to be formalized to a much greater degree than usual. Furthermore, for the application of automatic reasoning about CAD problems the information must be organized in such a way that knowledge relevant to one specific reasoning can be extracted and symbolically represented.

Eliens and Ten Hagen are doing research on interactive methods bases. These are information systems in which, besides data, interactive procedures are stored to either process these data or generate new ones. What is special about the stored interactive data is that, if considered necessary by the system, they can be combined to form new procedures. In linking interactive methods, the system must moreover be capable of constructing another satisfactory user interface from it all.
The research is concerned with the definition and use of such methods, as well as with programming tools for the development of methods bases.

Computer integrated manufacturing

This project is a continuation of the ESPRIT pilot project on Design Rules for CIM systems, carried out by Blom, Ten Hagen, Kuijk, and Janssen. The final report was revised and published as a book by North-Holland Publishing Company in its special ESPRIT series.



Irregular ramiform seeding fractal

Supporting Services

Contracts and Support Division

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

The commissions mainly came from scientific institutes, government institutions, banks, consulting agencies, organization bureaux and industry. An interesting commission in 1985 was the development of software for handling data about dialects in the Netherlands collected by the Meertens Institute of the Royal Dutch Academy of Science.
The supporting function of this division is not restricted to the scientific departments. For example, the office automation within the CWI is amongst its responsibilities. It is also involved in projects such as the translation of the Russian Mathematical Encyclopedia.

The Computer Laboratory of the Contracts and Support division looks after CWI's computing facilities, in particular a Local Area Network based on Ethernet. An important part of the task of the Computer Lab is the management of EUNET, the European Wide Area Network of UNIX^{TM}. CWI acts as the main 'gateway' between Europe and North America for EUNET/USENET. In 1985 the hardware was considerably extended with many work stations and personal computers. The use of UNIX hardware strongly increased, in particular for text processing. Because of these extensions work was started to construct an integrated file system for all computers within the CWI.

As from January 1986 the name and tasks of the Contracts and Support Division have changed as a consequence of an internal reorganization.

Library and Information Service

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

Publication Department

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

Computer Equipment

At the end of 1985 the CWI hardware configuration consisted of four VAX-750, one VAX-780 and two PDP-11 computers, three SUN and three Whitechapel MG-1 work stations, and a 3B2 microcomputer. These are interconnected through a local ETHERNET network. Peripherals consist of various printers, a Harris phototypesetter, a Versatec and disk storage of about 6 gigabytes. Furthermore there are 5 Olivetti M-24 and 7 Apple MacIntosh microcomputers, mainly used stand alone, sometimes as terminals.

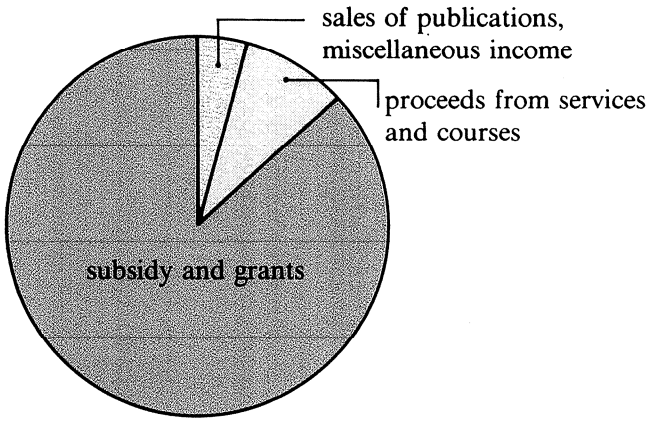
Finances

In 1984, SMC spent nearly Dfl. 17 million, of which about Dfl. 1.5 million was allocated to research by the national working communities and over Dfl. 15 million to CWI.
The expenses were covered by a subsidy from ZWO (Dfl. 13 million), from SION (Dfl. 0.06 million), from INSP (Dfl. 1.1. million), from the Free University of Amsterdam (Dfl. 0.1 million), from STW (Dfl. 0.05 million) and from a grant of more than Dfl. 0.8 million from the European Community for its ESPRIT-projects. Finally, an amount of about Dfl. 2 million was obtained as revenues out of third-party-services, courses and other sources.

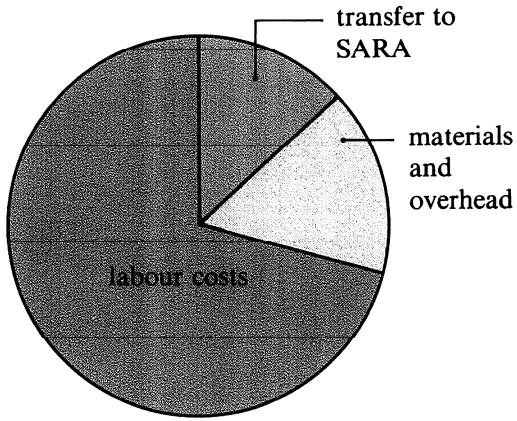
During 1985 CWI also employed 7 researchers in positions financed by STW and industry. These are not included in the adjacent financial summary.

	national working communities	*CWI*	*SMC*
	× *Dfl.* 1000		
income			
subsidy and grants	1527	13264	14791
proceeds from services and courses	-	1423	1423
sales of publications	-	112	112
miscellaneous income	-	529	529
	1527	15328	16855
expenses			
labour costs	1504	10646	12150
materials and overhead	13	2409	2422
transfer to SARA	-	1750	1750
	1517	14805	16322
origin of subsidy and grants			
ZWO	1527	11085	12612
SION	-	59	59
INSP	-	1100	1100
VU	-	127	127
STW	-	52	52
ESPRIT	-	840	840
	1527	13263	14790

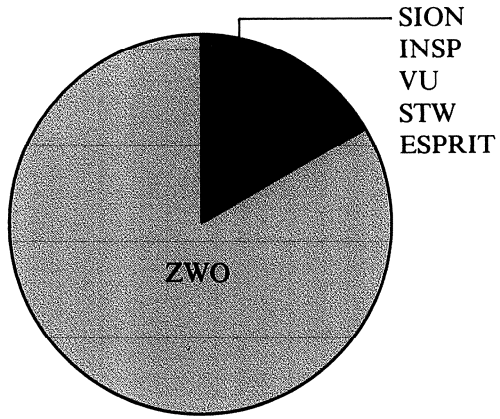
income CWI



expenses CWI



origin of subsidy and grants CWI



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S 11 D.M. VAN DER SLUIS, W. SCHAAFSMA, A.W. AMBERGEN. POSCON user manual, *A decision support system in diagnosis and prognosis,* Rekencentrum Rijksuniversiteit Groningen, augustus 1985.

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