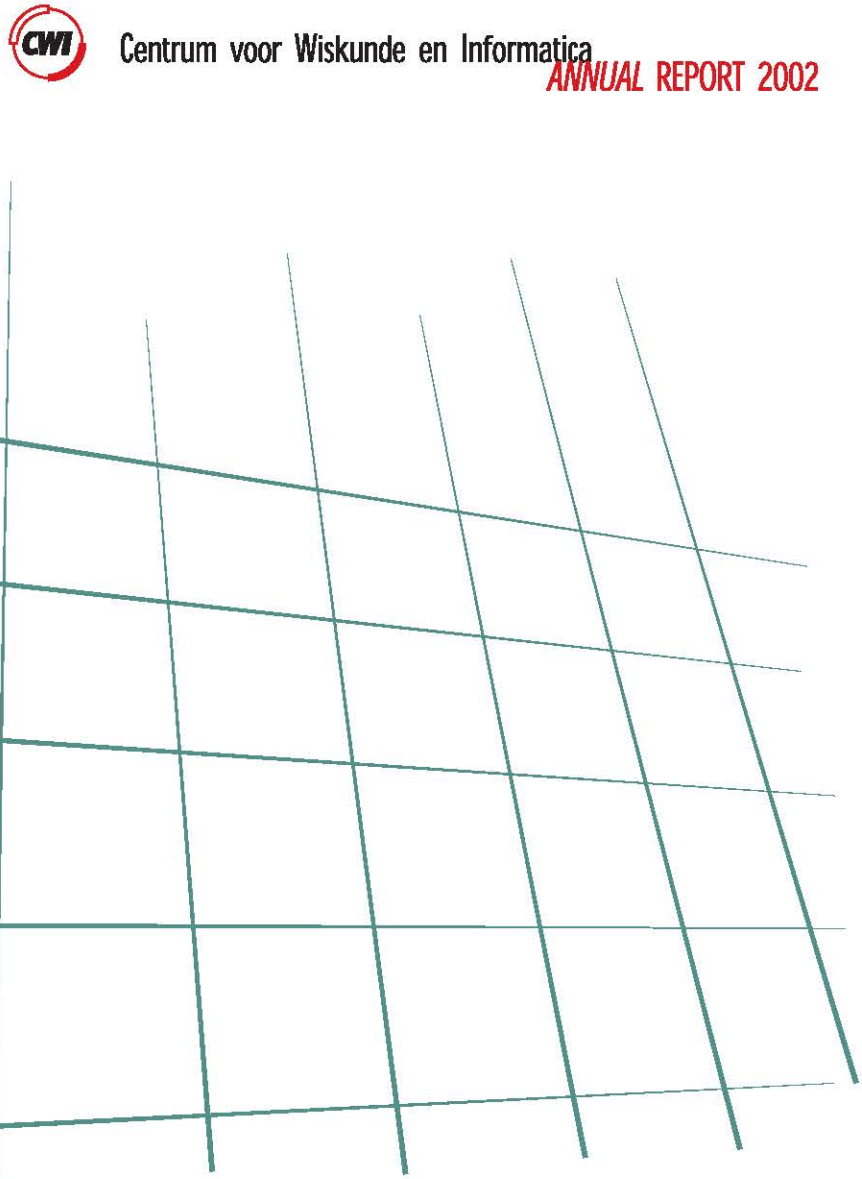

Centrum voor Wiskunde en Informatica

ANNUAL REPORT 2002

CWI is the National Research Institute for Mathematics and Computer Science. It is sponsored by the Netherlands Organization for Scientific Research (NWO).

General Director
G. van Oortmerssen
(till May 1, 2003)

CWI is a founding member of ERCIM, the European Research Consortium for Informatics and Mathematics. CWI participates in the Telematics Institute and the Amsterdam Science & Technology Centre (WTCW). CWI is a Member of the World Wide Web Consortium (W3C) and runs the W3C Office in the Benelux.

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Contents

This Annual Report is complementary to the Jaarverslag CWI (in Dutch), which concentrates on the Institute's management including financial and social aspects. A complete overview of CWI's research activities is also available.
This Annual Report and the other reports can be ordered at:
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INTRODUCTION

In many respects 2002 was a year of preparation for the future. The institute has been involved in drafting many proposals for large national and international projects, which, if awarded, will require additional research capacity. We are expecting a growth of the institute in the coming years.

In 2000, the European heads of government set an ambitious goal for Europe: to become the leading knowledge economy by the end of the first decade of the century. The Dutch government has consequently set an even more ambitious goal for the Netherlands: To be among the frontrunners within Europe.
It is quite clear, that Information and Communication Technology (ICT) is an important driving force in this development. It is also evident, that a lot of research is needed for developing our country into a leading innovative, knowledge-based society.
In particular, the fields of research which are covered by CWI, mathematics and computer science, will play a role of increasing importance. Many innovations are derived directly from new research results in these disciplines. But also progress in many other fields of science is powered by mathematics and informatics. A clear example is biotechnology, where advanced computer modelling and simulation techniques, data mining and visualization, are helping scientists to make new discoveries. At the same time, the life sciences inspire new developments in informatics, such as genetic algorithms and new developments in neural networks.

The importance of mathematics and informatics is widely recognized. Several advisory committees have recently underlined the need to double the research capacity in information technology. CWI is ready to play its role in a national effort to accelerate developments to realize the envisaged innovative, knowledge-based society.
Although research budgets are in general under pressure due to the downturn of the economy, the Dutch government has launched a large, four-year programme, the so-called Bsik programme, to boost research in a number of spearhead areas, among which ICT. CWI is involved in several initiatives for the Bsik programme. One of these proposals is BRICKS: Basic Research in Informatics for Creating the Knowledge Society. This proposal is a nation-wide effort of CWI, NWO and universities to strengthen fundamental research in ICT. It focuses on the priorities which are set in the research agenda for computer science, NOAG-i.

In addition, CWI was also involved in many expressions of interest for the forthcoming Sixth Framework Programme of the European Union. These expressions of interest will be the basis for proposals for Integrated Projects and Networks of Excellence, to be submitted in 2003. In anticipation of the growth of the research capacity which will be needed to execute the Bsik and European projects, CWI has expanded its research staff last year with 10 FTE. This growth was financed from CWI's financial reserve.

It will be clear that the preparation of the Bsik proposals has taken a lot of time and energy of senior staff at CWI. Notwithstanding this, 2002 was quite a productive year in terms of scientific output. In this Annual Report, several examples are given of exciting results of CWI's research programme. Two new pilot research themes were started, on Advanced Communication Networks, and Nonlinear Dynamics and Complex Systems, which is proof of CWI's ability to take new initiatives in research.

CWI is a vibrant research centre, attractive to young talent from all over the world, with extensive interactions with its environment. Our broad network of partners in the Netherlands as well as abroad, provides opportunities for playing a leading role in building the consortia required to perform the large research projects necessary for developing our new information society. CWI with its enthusiastic and qualified staff is ready for the future!

Gerard van Oortmerssen

OVERVIEW

Scientifically, 2002 was a productive year for CWI, with the acknowledgement of the quality of its researchers. There were seventeen PhD degrees, which is exceptionally high, and two researchers were appointed part-time professors. Lex Schrijver and Jan Willem Klop were awarded an honorary doctorate, and Jaco de Bakker received an important Dutch royal honour on the occasion of his retirement. The pilot research groups performed well. The pilot Visualization and 3D Interfaces was positively evaluated and continued as a full theme. Three NWO innovation impulse subsidies were granted to CWI researchers. Finally, a very impressive book by Lex Schrijver was completed.

Although the scientific output was very strong, last year's growing perspectives were postponed. Anticipating ICES-KIS III funds, plans for considerable growth tentatively started in 2002. The institute grew with about 10 FTE in temporary staff. ICES-KIS III was delayed, though, and new financing from the European Sixth Framework Programme can only be expected in about a year. During the year many initiatives were started for the ICES-KIS III (Bsik) financing, like BRICKS, PRESTO, I-CARE and MultimediaN. In addition, 35 project proposals were prepared for the Sixth Framework Programme of the EU, three of them coordinated by CWI.

Research

Seventeen researchers completed their PhD thesis, more than average. Topics were in the areas of software systems (2), numerical methods for flows (3), process algebra and specification tools (4), multimedia database systems (3), stochastics, factorization, quantum computing, and on-line scheduling.

Two new pilot research groups started: Advanced Communication Networks (PNA2) and Nonlinear Dynamics and Complex Systems (MAS3). The first group is concerned with performance analysis of various communication networks, mainly using methods from queueing theory. It develops models for network traffic, algorithms for dimensioning and control of wireless networks and mechanisms for economical assignment of bandwidth and other network resources. For more information, see the text in the next chapter.
The second pilot group performs analytic and numerical research on fundamental aspects of non-linear dynamics and pattern recognition, in particular, electrical discharge. Applications include very powerful high-tension semiconductor-switches and LCD screens. Researchers of this second group discovered how electrical discharges, like lightning, branch off. They have shown that this phenomenon is a direct consequence of the simplest mathematical model of a discharge. So far this was considered impossible. The theory is also applicable to 'upstream lightning': Discharges of a thundercloud to a much higher ionosphere, that take place on a much larger scale than ordinary lightning towards the ground, and appear to branch off considerably more. On May 6 results were published in the internationally renowned journal *Physical Review Letters*, and appeared in the magazine of the American Physical Society and as Nature Science Update.

International cooperation

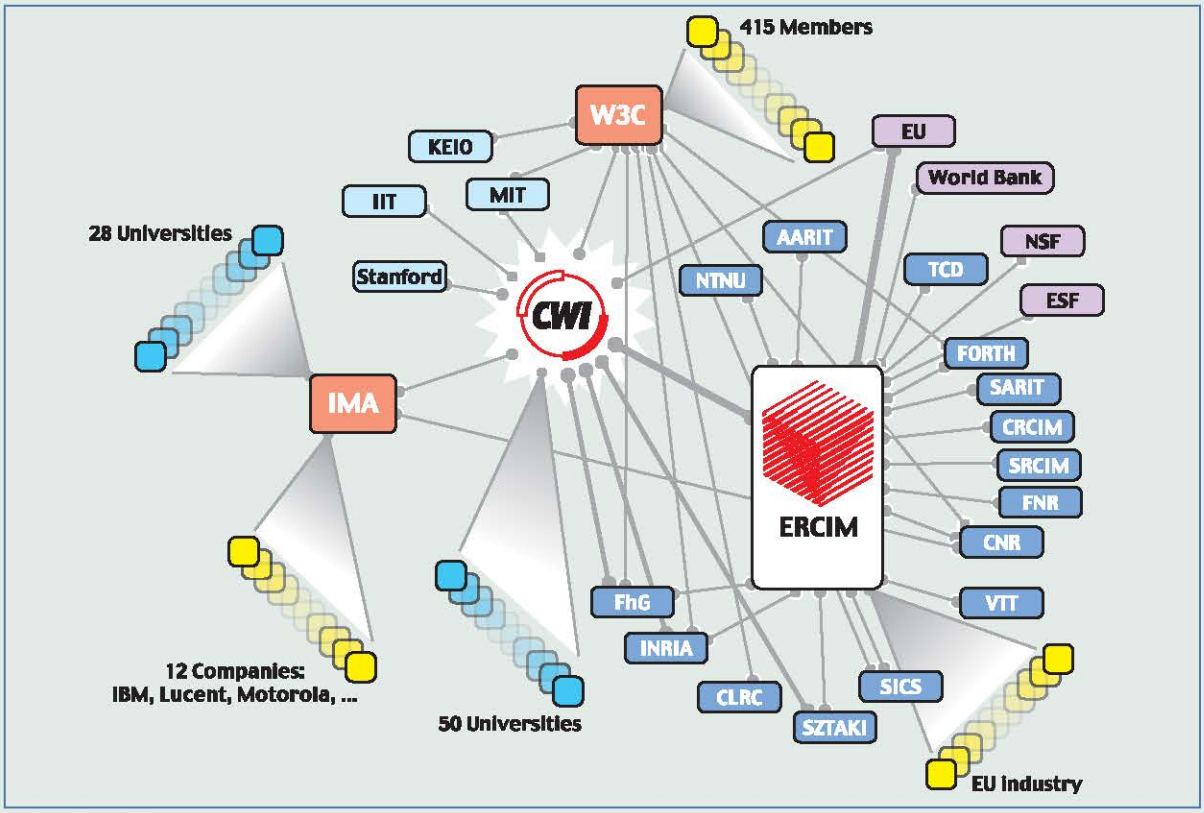
The importance of international cooperation in scientific research is growing. Some time ago the European Committee launched a plan to adopt a unified European Research Area where research institutes in various countries collaborate closely and attune their programmes. ERCIM, the European Research Consortium for Informatics and Mathematics, plays an important role in this development. ERCIM can be regarded as an example of the Networks of Excellence the European Committee wants to accomplish. ERCIM not only strengthened its internal research network, but also the liaisons with ESF, NSF and W3C (see below).

To strengthen the international research network CWI cooperates with IMA, the Institute for Mathematics and its Applications in Minneapolis. Last year eight Dutch researchers visited IMA, and IMA professor Doug Arnold gave a lecture at CWI. In the area of computer research a participation in Dagstuhl was prepared, the International Conference and Research Centre for Computer Science in Wadern, Germany. Bilateral contacts were made with the Fraunhofer-Gesellschaft in Germany. Also seven trainees from India worked at CWI.

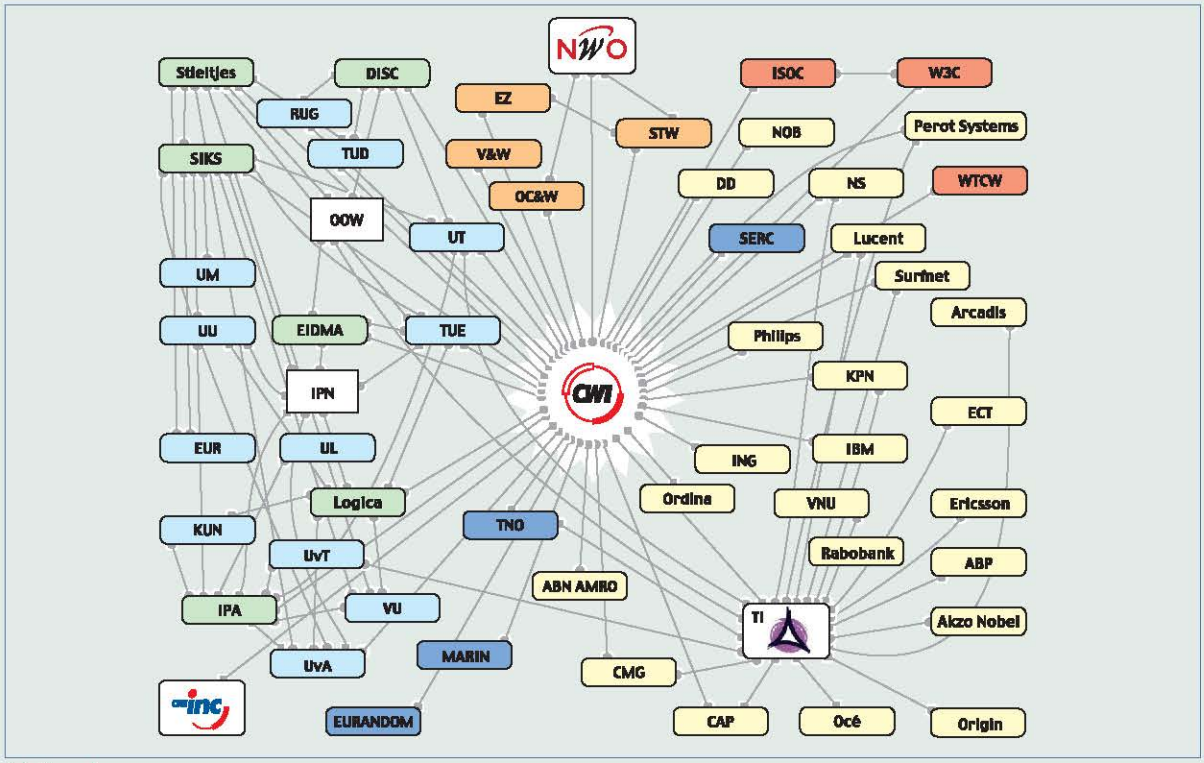
ERCIM

In 2002 ERCIM – the European Research Consortium for Informatics and Mathematics made preparations for the new Sixth Framework Programme of the EU. A new Task Force was established for this purpose, in which CWI plays an active role. ERCIM submitted five expressions of interest for Networks of Excellence. Apart from the European Union, ERCIM also strengthened other international ties. It welcomed

CWI's relation networks



International



National

two new members: NTNU (Norwegian University of Science and Technology) and FNR (Fonds National de la Récherche, Luxembourg). Additionally, ERCIM signed an agreement with the European Science Foundation (ESF) and organized strategic workshops with the EU and the US National Science Foundation. In February one of these workshops was held at CWI, and in May a strategic meeting took place between PESC (Standing Committee for Physical and Engineering Sciences of ESF) and ERCIM. Preparations were also made for ERCIM to become the new European Host of the World Wide Web Consortium in 2003 (see below).

ERCIM president Gerard van Oortmerssen at the PESC-ERCIM strategic workshop at CWI, May 2002.

Within ERCIM there is a Task Force for Human Resource Management, which will develop plans to stimulate mutual exchange of researchers within ERCIM, and to jointly attract young talented staff from outside Europe. An important item, because young talent in exact sciences becomes increasingly scarce in Europe. To promote mobility ERCIM introduced a Fellowship Programme, see www.ercim.org .

At present, ERCIM has member organizations in sixteen European countries. ERCIM was founded in 1989 by GMD (Germany), INRIA (France), and CWI (The Netherlands). Nowadays ERCIM comprises more than 10,000 European researchers in computer science and applied mathematics. Gerard van Oortmerssen, director of CWI, is currently president. Activities are: International working groups, joint research projects, a web-based overview of research areas of ERCIM-institutes, a Fellowship Programme, the Cor Baayen Award, an Event Sponsorship Programme and several publications. One of the publications is ERCIM News, steadily growing in circulation and increasingly read by policy makers. Researchers outside ERCIM institutes can also contribute. CWI coordinated the special jubilee issue about ERCIMathematics (no. 50), in cooperation with Prof. Tom Koornwinder (UvA).

World Wide Web Consortium

On May 6, the W3C Benelux Office opened. The new office is an extension of the Dutch W3C Office, managed by CWI since 1998, to the entire Benelux. The extension emanates from the World Wide Web Consortium policy to open offices in more countries and to regionalize existing offices as much as possible, resulting in an easier accessible communication between national organizations and companies and W3C. This must be done because, world-wide, the consortium consists of more than four hundred knowledge institutes and companies, engaged in Web standards, like XHTML, XML, and SVG.

Because of increasing regionalization a series of events was organized under the name 'W3C Intertop Tour'. The closing session was on June 3 in Brussels, organized by the W3C Benelux Office. Topic of the meeting was 'WWW Interoperability': Attuning specifications for the Web, so programs and services can connect better. The activities of the W3C Benelux Office include publishing a monthly newsletter, and organizing tutorials. In 2002 two meetings were organized together with ISOC.nl (Internet Society Nederland) intended for researchers, policy makers and industry, and one international W3C meeting on Web Ontology.

Lively discussions at the international W3C Web Ontology Meeting at CWI, April 2002.

W3C reached an agreement with ERCIM, who will be the new 'W3C European Host' as of January 1, 2003. Thus making ERCIM the physical head office of W3C in Europe. The change aims at enforcing research relations within Europe and improving Web technology development. See www.w3.org .

Knowledge transfer and spin-off

Economically 2002 was not a very successful year and, in particular, the ICT sector suffered. This also influenced our spin-offs, companies based on CWI's research. Regretfully, it proved there was no future for

Oratrix, which designed authoring and player systems for Web-based multimedia. Three colleagues returned and ultimately, Oratrix was declared bankrupt. Eidetica was taken over by another company, Filter Control Technologies. This means continuity for personnel and technology, which can be considered a success. SIG and Epictoid developed quite satisfactorily and a new spin-off started, Adaptive Planet, emanating from the research group SEN3 (see text box). Adaptive Planet was showcased together with CWI at the ICT Knowledge Conference in The Hague.

Telematics Institute

The TI-projects Systems Validation Centre (SVC) and Digital Media Warehouses (DMW) were rounded off. More results of SVC can be found in the next chapter. Within the DMW project CWI collaborated with Twente University, KPN Research, Perot Systems and of course the Telematics Institute (TI). A demonstrator was developed and over fifty publications were written. See http://monetdb.cwi.nl/acoi/DMW/. New TI-projects are ArchiMate and Topic-based Interaction with Archives (Topia). The aim of the ArchiMate project is to bring integration within the different modelling domains that enterprises use. Such domains are, for example, software modelling (UML), business process modelling (TestBed) and organization structure modelling (Organization Diagram). The other new TI-project, Topia, develops a system that generates presentation structure around media objects returned from semantic-based queries.

NWO

One of NWO's goals is to stimulate high quality and innovation in scientific research, effectuated by granting innovation impulse subsidies. In 2002 NWO granted three of these subsidies to CWI researchers: Monique Laurent, Jason Frank, and Bert Zwart (seconded from TU/e). Laurent received the innovation impulse for her VIDI-proposal 'Semidefinite Programming and Combinatorial Optimization' about more efficient optimization, Frank for his VENI-proposal 'Geometric Numerical Methods for Continuum Mechanics' and Zwart for the VENI-proposal 'Asymptotic Analysis of Queueing Systems'. NWO grants subsidies to young excellent researchers to stimulate innovation in scientific research and to offer talented researchers a more attractive prospect of a scientific career.

Research schools

In 2002 CWI collaborated in a national note 'New dimensions, extended reach – a national strategy for mathematical research and related master courses', of the Platform for the Dutch Mathematics Research Schools (OOW) and NWO's Advisory Committee Mathematics. On April 18, it was presented to Secretary General Mr H.J.E. Bruins Slot of the Ministry of Education, Cultural Affairs and Science in The Hague.

Mathematical research at Dutch universities is subject to great pressure. The substantially declining number of students over the last decade caused the loss of many jobs in mathematical research. To meet the increasing need for mathematical experts seven measures are proposed. One of them is to concentrate and extend mathematical research. An initiative in line with this target is the kick-off of 'PDE@CWI'. Since September four mathematical top researchers of various universities are seconded at CWI for one day each week: Arjen Doelman (UvA), Hans van Duijn (TU/e), Joost Hulshof (VU) and Bert Peletier (UL). This way CWI stimulated cooperation in the area of non-linear differential equations and applied mathematics, an area where CWI has already been active for many years.

WTCW / Sciencepark Amsterdam

The Amsterdam Science & Technology Centre (WTCW) is a consortium of companies, local government and knowledge institutes in and around Watergraafsmeer in Amsterdam, of which CWI is one. The projects of WTCW within the framework of ICES-KIS II ended this year. These projects dealt with Multimedia Information & Analysis, Biotechnology and Bioinformatics, Biodiversity and environment and Virtual Lab. New projects for the next ICES-KIS round were prepared. WTCW organized the large-scale conference iGrid2002: Focusing on e-science, Grid and Virtual Laboratory, attended by hundreds of visitors.

The consortium in Watergraafsmeer plans to expand its activities under a new name: Sciencepark Amsterdam. The aim is to attract more high tech companies, and more facilities for researchers, like a large conference centre. The Sciencepark Amsterdam made strong ties,

Prime Minister Balkenende visits the Sciencepark Amsterdam, December 2002.

both nationally and internationally, with government and research centres. Visitors were: Prime Minister Balkenende, Minister De Geus for Social Services and Employment, members of the Ministry for Economic Affairs and the City of Amsterdam (EZ), misters Vest

(MIT), Sobel (US Ambassador) and Kvamme (Chairman of PCAST, a council advising President Bush). Two members of Parliament paid a visit to CWI.

Conferences and events

CWI organized several conferences, meetings and seminars, among which the second SAFE-NL workshop and the second ToKeN2000 workshop, and the annual holiday course for teachers of mathematics. Furthermore, the RESQ kick-off meeting on quantum computing, was prepared.

Imagination

In October CWI organized CWI in Bedrijf, the annual day for trade & industry with the theme: 'Imagination'. "Logic will take you from A to B, but imagination takes you anywhere", Albert Einstein once said. Imagination plays an important part in every creative process, also in practicing science. Also literally more and more images are used in practicing science (visualization, virtual reality) and communication processes (multimedia). During the afternoon lecture, Hendrik Lenstra gave an appealing example of imagination in science. For about 120 people he talked about mathematically filling up a 'hole' in Escher's famous litho 'Prentententoonstelling'. Following CWI in Bedrijf was the annual Day for the Public, where 1500 people visited Sciencepark Amsterdam. The national theme was 'safety'.

Distribution of euro coins

Researchers from CWI and the University of Amsterdam organized the national Study Group Mathematics with Industry in 2002. During one week in February sixty mathematicians from various organizations tackled practical problems from trade and industry. The science magazine *Natuur & Techniek* came up with the question of the distribution of euro coins: How many French or German euro coins could people have in their purse a year after their introduction? The Study Group made a model, and to verify this experimentally, the group and *Natuur & Techniek* had students measure the distribution of euro coins – a one-time experiment in which thousands of people participated. It turned out that the large coins spread significantly faster than the smaller coins. Other topics were the optimization of rose growth in greenhouses and the cooling of aquarium water in Artis Zoo.

CWI researcher Mark Peletier being interviewed on national television in the Jeugdjournaal (Childrens' News), to explain how mathematics might help cooling aquarium water in Artis Zoo.

Other public activities were a scientific day in museum NEMO with CWI's competition 'Build the Best Parcel' in June, lending CWI's ENIGMA decoder from WW II to first-year students in Computer Science (TU/e) and a visit to CWI from students of mathematics from the UvA. CWI's Personal Space Station (virtual reality in PC-format) was exhibited in the Holland Pavilion of SC2002 in Baltimore in November.

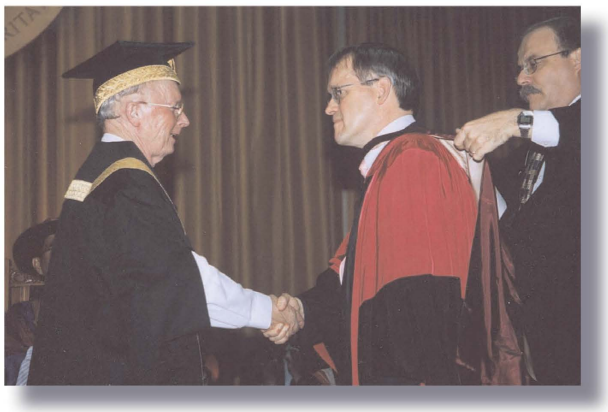
The yearly 'Build the Best Parcel' Contest for the public: How to build a paper construction which carries the heaviest weight.

Personalia

For his outstanding research Paul Vitányi was appointed CWI Fellow as of January 1, 2003. He withdrew as theme leader of INS4, Quantum Computing and Advanced Systems Research. Harry Buhrman succeeded him. Mark Peletier became theme leader for MAS1, Nonlinear PDEs: Analysis and Scientific Computing.

Honorary doctorates for Schrijver and Klop

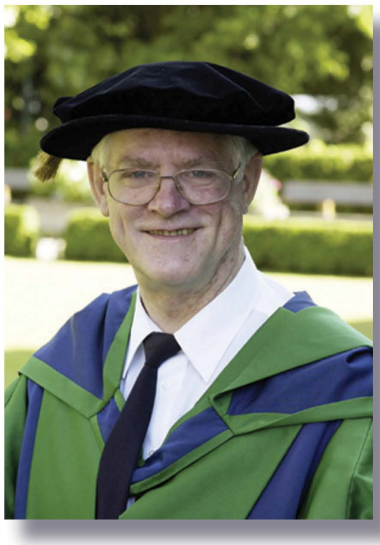
Two CWI researchers received a doctor honoris causa degree for their research: Lex Schrijver and Jan Willem Klop. On June 15 **Lex Schrijver** received the degree at the University of Waterloo in Canada.



Lex Schrijver gets his doctor honoris causa degree at the University of Waterloo in Canada. Picture: UW.

The announcement says: "Schrijver's reputation was largely achieved with his book, Theory of Linear and Integer Programming, described as 'the most outstanding piece of scholarly work in the field of mathematical programming'". Previously Lex Schrijver received several prestigious awards and since 1995 he is a member of the Royal Netherlands Academy of Arts and Sciences. His impressive new survey, the three-volume book 'Combinatorial Optimization, Polyhedra and Efficiency' will be published by Springer-Verlag in 2003, and is intended for mathematicians, computer scientists, operations researchers and economists.

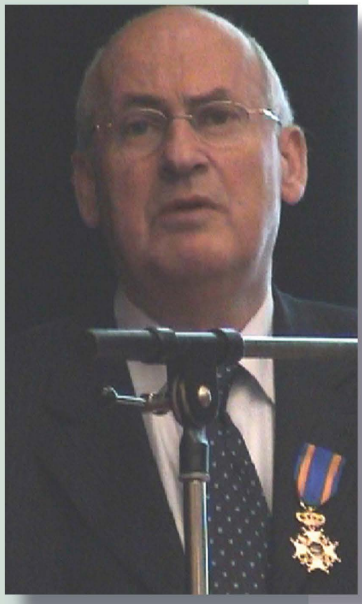
On July 11, **Jan Willem Klop** received the degree at the English University of East Anglia. Jan Willem Klop is researcher at CWI and the Catholic University Nijmegen, and professor of Applied Logic at the Vrije Universiteit in Amsterdam. He cooperated with Jan Bergstra and Jos Baeten on the development of process algebra (ACP). Currently he works in the area of term rewriting systems, amongst others as co-author of the impressive book 'Term Rewriting Systems'.



Jan Willem Klop on the occasion of his doctor honoris causa degree at the University of East Anglia (UK). Picture: UEA.

Appointment of Ebert and Koren to full professors
As of March 1 Ute Ebert is appointed full professor (parttime) at the Faculty of Technical Physics at Eindhoven University of Technology. This makes Ebert the first female professor of Physics at this university. Ute Ebert works for CWI since 1998. She previously worked in Heidelberg, Jeruzalem, Essen and Leiden. Since January she leads the new pilot research group Nonlinear Dynamics and Complex Systems. Barry Koren, leader of MAS2, was appointed full professor (parttime) in Numerical Fluid Dynamics at the Faculty of Aerospace Engineering at Delft University of Technology. His current research focuses on computational methods for two-fluid flows (water-air flows around sea vessels, jets propelled from rocket engines into ambient air) and on genetic algorithms for aerodynamic design.

Royal honour for Jaco de Bakker
August 30, Prof.dr. Jaco de Bakker was appointed 'Ridder in de Orde van de Nederlandse Leeuw'. On the occasion of his farewell symposium at CWI De Bakker received the honour from M. van der Horst, Amsterdam alderman ICT. Jaco de Bakker is one of the pioneers of Dutch computer science, especially in the areas of mathematical semantics of programming languages and reasoning on program correctness. He worked at CWI for 38 years and saw to it that the term 'computer science' was added to the name of the former Mathematical Centre. In 1973 he was appointed professor at the Vrije Universiteit in Amsterdam and in 1989 he became a member of the Royal Netherlands Academy of Arts and Sciences (KNAW). He wrote over a hundred and fifty scientific articles and books. De Bakker takes great pride in the fact that an exceptionally large number of researchers from his research group were appointed professor: 32 in all. De Bakker also played an important role in CWI Management.



Jaco de Bakker speeches after having received his royal decoration.

In memoriam Edsger Dijkstra
On August 6, world famous computer scientist Edsger Dijkstra passed away at the age of 72. Edsger Dijkstra gathered fame with his contributions to computer science, especially with his ideas on structured programming.

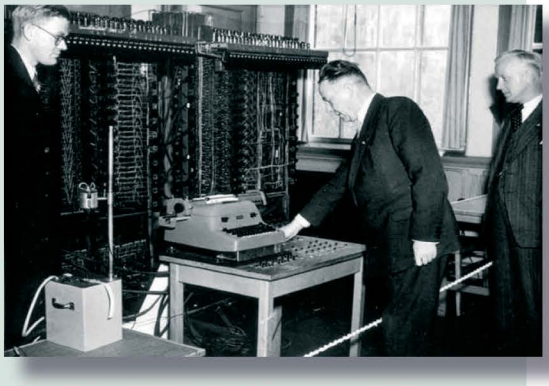
E.W. Dijkstra (left) in 1954, in front of the former building of the MC (CWI), together with Bram Loopstra and Dijkstra's future wife, Ria Debets. Picture: G.A. Blaauw, CWI Archive.

Nowadays his ideas are deployed in practically all computer languages. E.W. Dijkstra worked at the Mathematical Centre, now CWI, from 1952 to 1962. From 1962 to 1984 he was professor at Eindhoven University of Technology. Since 1973 he was also associated with the Burroughs Corporation. From 1984 till his retirement in 1999 he worked at the University of Austin, Texas. He received many awards, among which the ACM Turing Award (1972), the equivalent of the 'Nobel prize for computer science'. Dijkstra was married and had three children.

Farewell Mike Keane
In March Mike Keane said goodbye to CWI, because his Dutch retirement date was nearing. Keane came to CWI in 1994 as group leader of the present PNA4 and as researcher in stochastics. He also did consultancy work for Philips, EURANDOM and Hewlett Packard. In 1991 he was chosen as member of the KNAW. Keane loves to cross borders: He used to work in Texas, Germany, France and in the Netherlands also at Delft University of Technology and the University of Amsterdam. He had twenty PhD students and a large number of guests. Mike Keane will teach at the Keio University in Japan for a year and from there he will go to Connecticut.

Cooperation CWI – Adaptive Planet
September 2001, at the ICT-Kennis Conference in The Hague, researchers of CWI happened to meet Adaptive Planet (AP). For years, both worked on concepts for the development and control of software components technology. They appeared to be so complementary that cooperation to integrate both concepts was almost inevitable. Promising results instigated the start of Adaptive Planet B.V., a spin-off of this cooperation. Through CWI Incubator B.V., CWI participates in Adaptive Planet B.V. In September 2002 part of the technology was used in the first project. The technical maintenance service of Kone Elevators & Escalators B.V. was equipped with a mobile computing program. Annually this saved Kone over a hundred thousand euros. A second trial project will start in May 2003 with Océ Technologies B.V. An existing application of Océ will be translated into the technological concepts of AP and CWI.

Fifty years of computers in the Netherlands
Fifty years ago, on June 21, 1952, the Netherlands entered the computer era. That day the first Dutch programmable computer was brought to use, it was called the ARRA, Automatische Relais Rekenmachine Amsterdam. It was built at



Opening of the ARRA in 1952, by minister Rutten (Economic Affairs). Left Bram Loopstra (MC), right mayor d'Ailly of Amsterdam. Picture: CWI Archive.

the Mathematical Centre (now CWI). The ARRA was inaugurated by D'Ailly, Lord Mayor, and Rutten, Minister of Economic Affairs. As a token of its mathematical ability a program was run for generating a random figure: A mathematical tour de force. After the festive beginning the machine did not do much more. A second ARRA, operational one and a half years later, performed with great success. Successors of the ARRA made so-called 'flutter calculations' for Fokker, calculations for designing aeroplane wings.

RESEARCH HIGHLIGHTS

Geometric Numerical Methods for Continuum Dynamics

Qualitative properties of numerical simulations of continuum dynamics are studied at CWI (geometric integration). In particular atmospheric fluids were studied with particle-based numerical flow models, in cooperation with Imperial College of London. The ongoing research includes the simulation of ferromagnetic materials.

The project started in 2002, and is funded by the Netherlands Organization for Scientific Research NWO (Innovative Research Grant VENI). The work extends developments in the previous decade in the field of geometric integration, primarily focused on ordinary differential equations, to continuum systems (fluids, solids) described by partial differential equations.

In many areas of scientific interest, numerical simulations are pushed beyond the limits of classical considerations in numerical analysis such as global error and stability. In molecular dynamics and celestial mechanics, for example, systems that are known to be sensitive to initial conditions are integrated numerically over very long time intervals, despite the fact that the global error has long reached 100 percent. In this case, the user is interested in exploring the qualitative features of the solution rather than in exactly reproducing the trajectory starting from a given initial value.

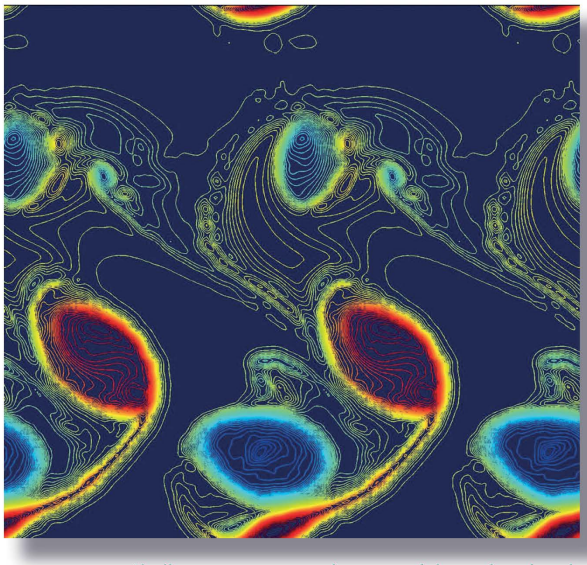


Figure 1: Shallow water atmospheric model simulated with the Hamiltonian Particle-Mesh method, which conserves circulation, energy and geostrophic balance. The contours are lines of constant potential vorticity.

In the late 1980s and throughout the 1990s, the field of geometric integration arose to develop and analyze numerical methods for ordinary differential equations (ODEs) with the above purpose. Figure 3 illustrates the difference between a geometric integrator and an ordinary method for an ODE of interest in atmospheric dynamics. The most important discovery in geometric integration is that, roughly speaking, a numerical method which retains some property, such as energy conservation or reversibility, actually produces the solution of a perturbed problem with that property. By analyzing the perturbed problem, one can make statements about the quality of the solution far beyond the range of global error analysis. (Hairer, Lubich & Wanner, Geometric Integration, Springer-Verlag, 2002.)

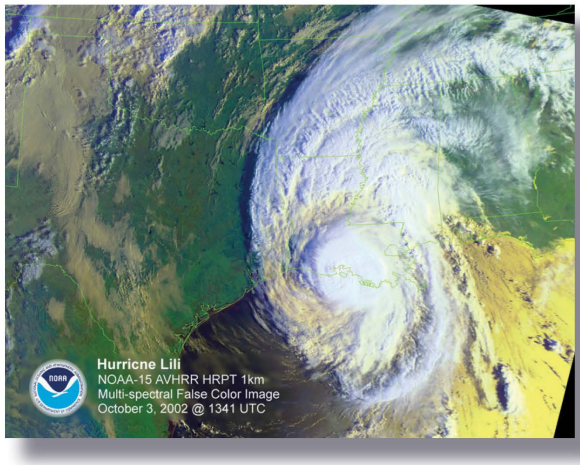


Figure 2. Vortical structures occur on all scales in the atmosphere, like hurricanes. Geometric numerical methods conserving properties such as circulation are particularly suited to describe these phenomena (courtesy NOAA/National Climate Data Center, USA).

Scientists studying continuum processes may also be more interested in the qualitative behaviour of a solution than in the exact solution starting from a particular initial state. One example is climate simulations, which may be carried out over intervals of 100 years or more. Currently, interest in geometric integration is shifting to partial differential equations (PDEs). In some sense, methods for PDEs have had 'geometric' qualities for a long time; the use of monotone methods and Riemann solvers for solving hyperbolic problems is a good example. However, there are new developments as well. CWI, in cooperation with Imperial College of London, has made

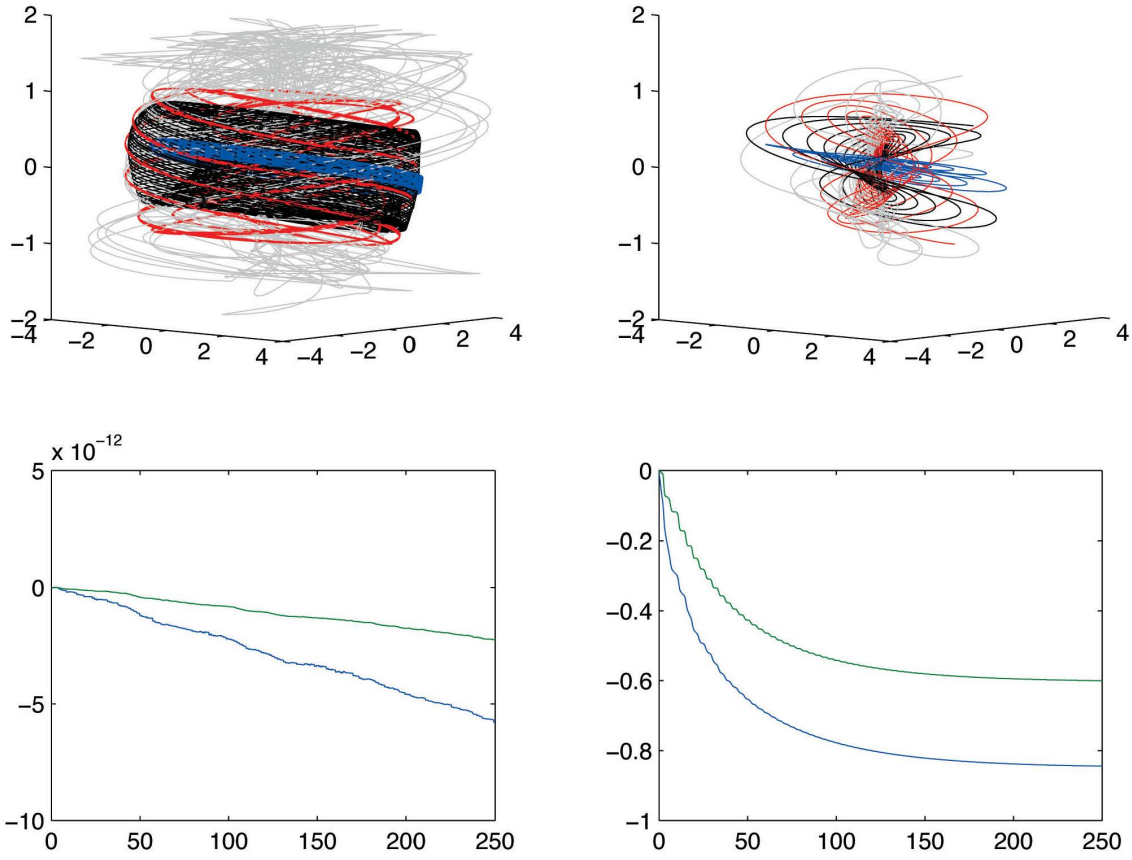


Figure 3. Solutions of the 5-component Lorenz model for 4 different initial states, distinguished by colour (top two plots), including one chaotic trajectory (in grey). This model studies geostrophic balance in atmospheric/oceanic fluids. The bottom two plots indicate change in total energy (blue) and enstrophy (green), both of which should be conserved in time. The left two plots are for a geometric integrator, which conserves energy and enstrophy to within 0.01 billionth. The right two plots are for an ordinary method, which damps out more than 80 percent of the energy, and introduces an artificial steady state.

considerable progress in the last two years in the development of geometric methods for atmospheric fluids using particle-based numerical fluid models. The Hamiltonian Particle-Mesh method combines finite mass fluid particles for advection with a grid for fast evaluation of derivatives, such that the resulting method conserves energy and circulation (vorticity) in addition to mass.

Other research at CWI on geometric integration concerns the simulation of ferromagnetic materials. In particular, the equations governing the flow of magnetic orientation in such materials implicitly define a set of conservation laws for energy and momentum. A numerical method applied to the equations of motion would normally not retain any discrete analogue of such conservation laws. We are currently investigating a method with precisely this property.

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Software Quality Assurance by Detecting Code Smells

Software inspection is a known technique to improve software quality. Traditionally, software inspection is a formal process involving labour-intensive manual analysis techniques. At CWI, a tool is developed that supports automatic code inspection, by means of automatic detection and visualization of 'code smells', which are high-risk parts of software. This allows early detection of signs of project deterioration. The new jCOSMO code smell browser can be used by software developers in companies, and eventually in open source development projects.

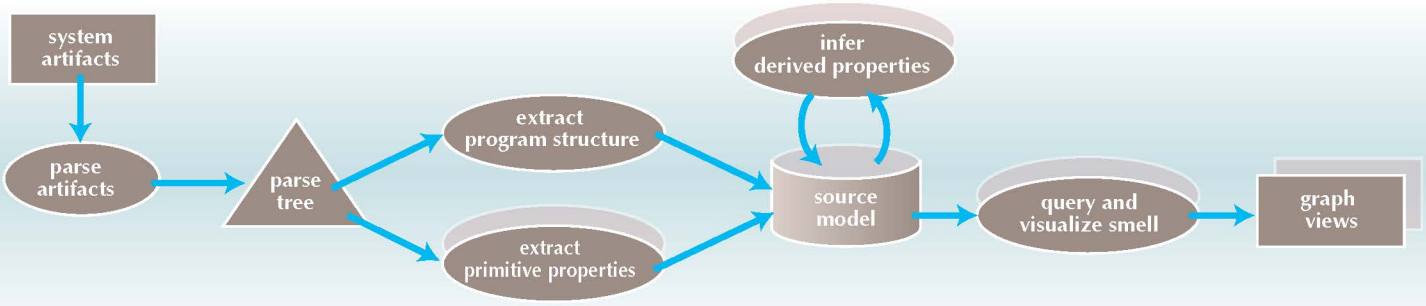

Figure 1: Architecture of the jCOSMO code smell browser.

Software inspection involves careful examination of the code, design and documentation of software, checking them for aspects that are known to be problematic from past experience. Since it is done in the beginning of the software development cycle, potential problems are identified when it is still cheap to fix them. Existing tools that support automatic code inspection (for example, the well-known C analyzer LINT) tend to focus on improving code quality from a technical perspective: Fewer bugs (defects) mean higher quality of the code. From this perspective, code inspection boils down to low-level bug-chasing. The tools typically look for problems with pointer arithmetic, memory (de)allocation, null references and array bounds errors.

CWI focuses on a different aspect of code quality, by reviewing code for problems that are generally associated with bad program design and bad programming practices. We look for these problems using code smells, high-risk parts of software. The metaphor was introduced to describe patterns in code that indicate that it could benefit from refactoring. Refactoring is the process of changing a software system in such a way that it does not alter the external behaviour of the code yet improves its internal structure. It improves quality by tidying up the code and reducing its complexity. Examples of code smells include duplicated code, methods that are too long, classes that perform too much tasks, classes that violate data hiding or encapsulation rules and classes that delegate the majority of their functionality to other classes.
Code smells can be used as beacons to assess and explore the quality of a software system: When a system possesses a lot of smells, its quality is questionable and the smells guide the way to the places that need to be improved. To experiment with this idea, the jCOSMO code smell browser was created, a prototype tool for automatic detection and visualization of code smells in JAVA. An overview of the architecture of the tool is shown in figure 1. The browsing consists of two main phases: code smell detection and visualization. During detection, the source code is parsed and a source model is created that describes program structure and occurrences of code smells. During visualization, this source model is queried to generate different views on the source code and its smells.

Closer examination shows that code smells can be characterized by a number of smell aspects that are observable in source code. We distinguish two types of smell aspects: Primitive smell aspects that can be observed directly in the code, and derived smell aspects that are inferred from other aspects. An example of a primitive aspect is *method m contains a switch statement*, an example of a derived aspect is *class C does not use methods offered by its parent*.

This distinction is used in the design of the smell detection process. First, a parser reads the source code and produces a parse tree containing all structural information contained in the code. Second, an analyzer reads these parse trees and traverses them according to the program structure. During this traversal, all information about entities and primitive smell aspects that are found is stored in a repository. Finally, these facts are combined and manipulated using relational algebra to infer derived smell aspects. This step is needed, for example, to compute the 'refused bequest' smell which indicates that a child class does not use any of the methods that were offered by its parents.

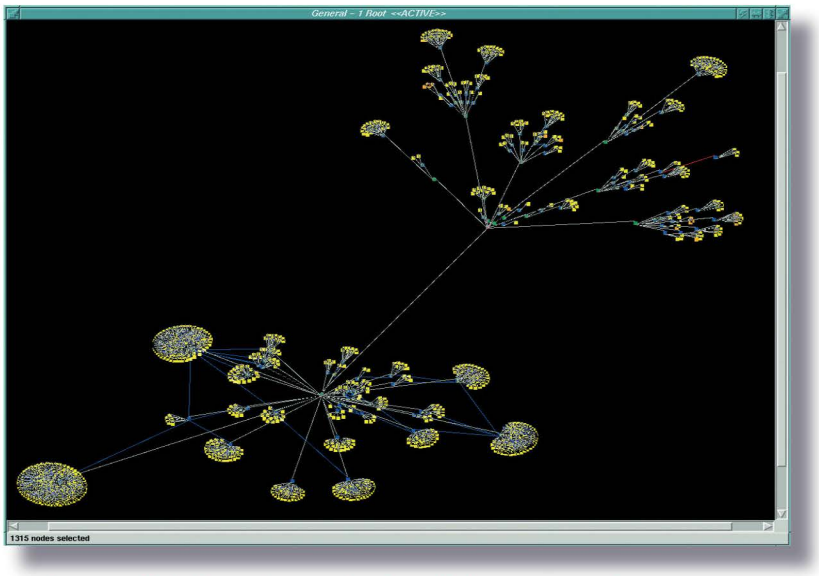

Figure 2: jCOSMO visualization of code smells that occur in a subject system.

The next phase is presentation of detected smells to the user. To allow quick assessment of the quality of potentially large software systems, the tool should provide overviews of the complete system, showing if the system contains bad smells, what parts are affected and where the concentration of smells is the highest. To satisfy these requirements, we visualize the extracted source model using structured graphs. The nodes in these graphs are the program entities of the system (e.g., packages, classes, methods) and the edges are the relations between these entities (e.g., composition, inheritance, calls). The primitive properties of various types of nodes and edges are represented using different colours and can be selectively hidden in views on the graph. Graph layout algorithms are used to improve comprehensibility of the views. We implemented two approaches for visualizing code smells in these graphs. In the first, code smells are shown using additional nodes which are connected to the entities that possess the given smell. Figure 2 shows an example of such a view. In the second, code smells are used during the computation of the graph layout, by ordering the nodes in such a way that nodes with the most smells come first, in the upper left corner of the picture. Another possible approach would be to vary node attributes such as colour or size of nodes that possess certain smells.

The prototype has been evaluated with several users and their feedback was generally positive: They felt that the graphical overviews were useful for quality assurance and refactoring support. Future work includes extension of the set of detected code smells and experimentation with different visualization techniques.

jCOSMO is available as free software, the distribution can be downloaded from:
www.cwi.nl/projects/renovate/javaQA

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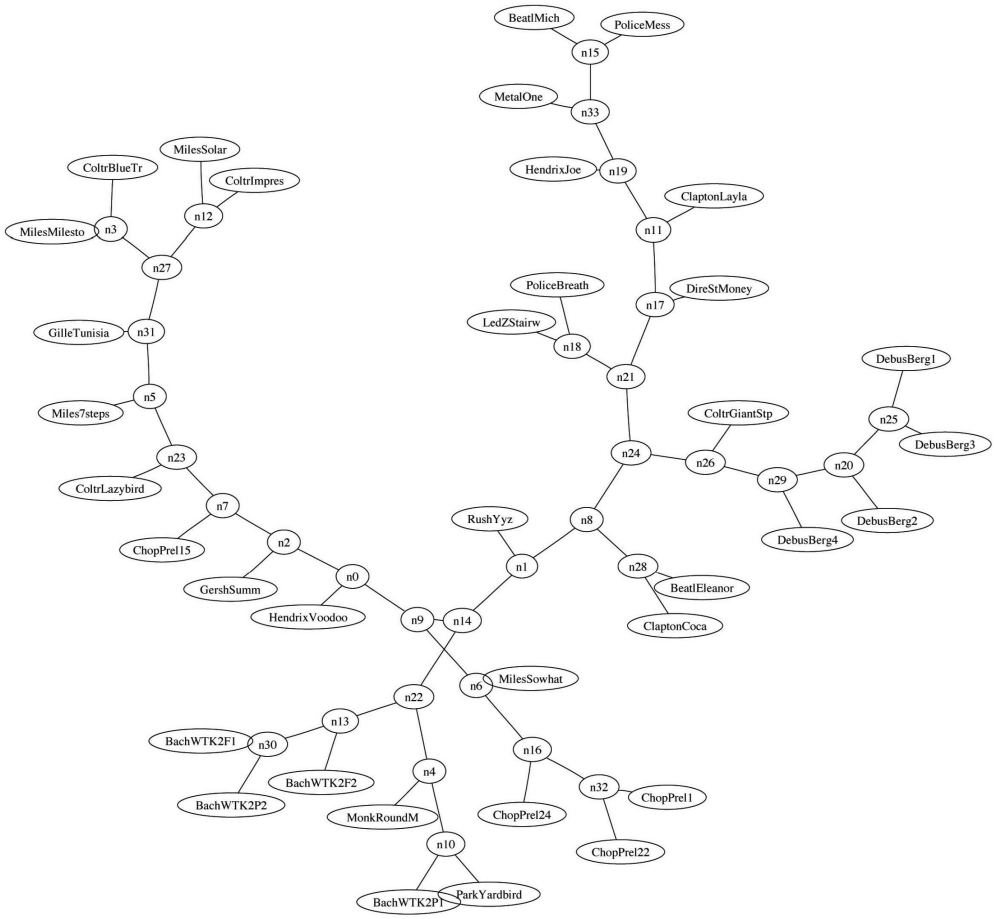
Compression-based Learning

Scientists sometimes dream of it: How can we qualify the best model from two or more possibilities? At CWI, research is done to make this choice in an optimal way, by means of the Minimum Description Length Principle (MDL). Researchers concentrate on applications of MDL in model selection and in finding similarities. Nowadays, the similarity measurement tool developed at CWI can discern different styles of music; in future it might even determine whether a specific text is really written by Shakespeare.

To be able to forecast future events, science wants to infer general laws and principles from particular instances. This process of inductive inference is the central theme in statistics, pattern recognition and the branch of artificial intelligence called 'machine learning'. A relatively recent method for inductive inference is the Minimum Description Length Principle. It is based on the theory of Kolmogorov complexity which tells us that the more regularities or patterns we can discern in a given set of data, the fewer bits we need to describe that data, and the more we have learned from that data.



CWI's similarity measurement tool compared twelve pieces of rock music, twelve pieces of jazz and twelve pieces of classical music. The pieces were represented as MIDI files. This gave rise to a 36x36 'distance' matrix. A standard method was used to cluster the 36 objects, so that objects that are similar according to the chosen metric are placed close together. This method is based on deriving a phylogeny tree based on the distances. The tree will group objects in subtrees: clusters of similar objects. The results are promising.

According to MDL, we should look for a hypothesis such that the number of bits needed to describe the hypothesis plus those to describe the data on the basis of the hypothesis is minimized. This leads to an automatic trade-off between complexity of the hypothesis and goodness-of-fit. As such, it can be viewed as a mathematical formalization of the celebrated Occam's Razor: Given two theories both fitting the data equally well, we should select the shortest (simplest) one.

Originally, this idea was used to determine the optimal number of parameters in model selection problems. With a given, finite set of points, we can always find a polynomial that fits the data perfectly. However, adopting this polynomial as a hypothesis for the data does not seem a very good idea, because it reflects the random fluctuations in the data rather than the general underlying pattern. It can be mathematically shown that it is better to adopt a relatively simple polynomial with small but nonzero error. MDL will automatically provide such a polynomial.

At CWI we study a more ambitious version of this problem. Suppose two research groups propose two quite different models for the same phenomenon, a very common situation in biology and econometrics. Both models fit the available data about equally well and have the same number of parameters. Do we have any reasons to prefer one of the two models over the other? Recent research showed that the answer is 'yes': Due to differences in 'functional form', one of the two models can still be a lot more complex than the other. Practically this means that the simpler model will lead to better predictions of future data generated by the same process. CWI has played a key role in refining MDL so it can now account for such phenomena.

As an example, consider two classical models describing the relationship between physical dimensions (e.g., light intensity) and their psychological counterparts (e.g., brightness): Stevens' model (a power law: $y = a^x + b$), and Fechner's model (a logarithmic relationship: $y = a \log x + b$). Both models have two free parameters. Nevertheless, according to current versions of MDL, Stevens' model is in a sense more complex than Fechner's. This explains an empirical observation made in experimental psychology: In several experiments, Stevens' model fit the measured experimental data somewhat better than Fechner's model. However, when they were then tested on a new, independently obtained set of experimental data, Fechner's model could predict the new data more accurately.

Another application of inductive inference is determining similarities between different documents. We could determine the minimum number of bits needed to transform document A into document B or vice versa. The lesser the bits, the more similar the documents. Making this idea precise leads to a universal similarity metric. It cannot be computed in practice, but it is possible to approximate it. This has intriguing potential applications. There is considerable doubt whether all plays ascribed to Shakespeare actually have been written by him. With the similarity metric, it is possible to make a pairwise comparison between all of Shakespeare's plays. This results in a similarity matrix, supplying real numbers indicating e.g. how closely *Othello* is related to *A Midsummer Night's Dream*. This number will depend on the similarity between the vocabularies and the grammatical constructions used in the two plays. It then becomes possible to identify clusters within Shakespeare's works. One would expect the comedies to form one cluster, and the classic tragedies another. There may also be 'outliers', plays that do not resemble any of Shakespeare's other plays. It seems likely that these have not been written by Shakespeare after all.

At CWI we have been working on an analogous problem. Instead of literary works, we compared the similarity of music files encoded in the MIDI-format (Musical Instrument Digital Interface), representing various classical and popular pieces of music. Apart from two strange misplacements of pieces by Bach and Chopin, the method separates jazz, rock and classical music reasonably well. It does so without any prior knowledge of the structure of music files – exactly the same method could be used for other types of files such as English language texts or biological data, like DNA sequences.

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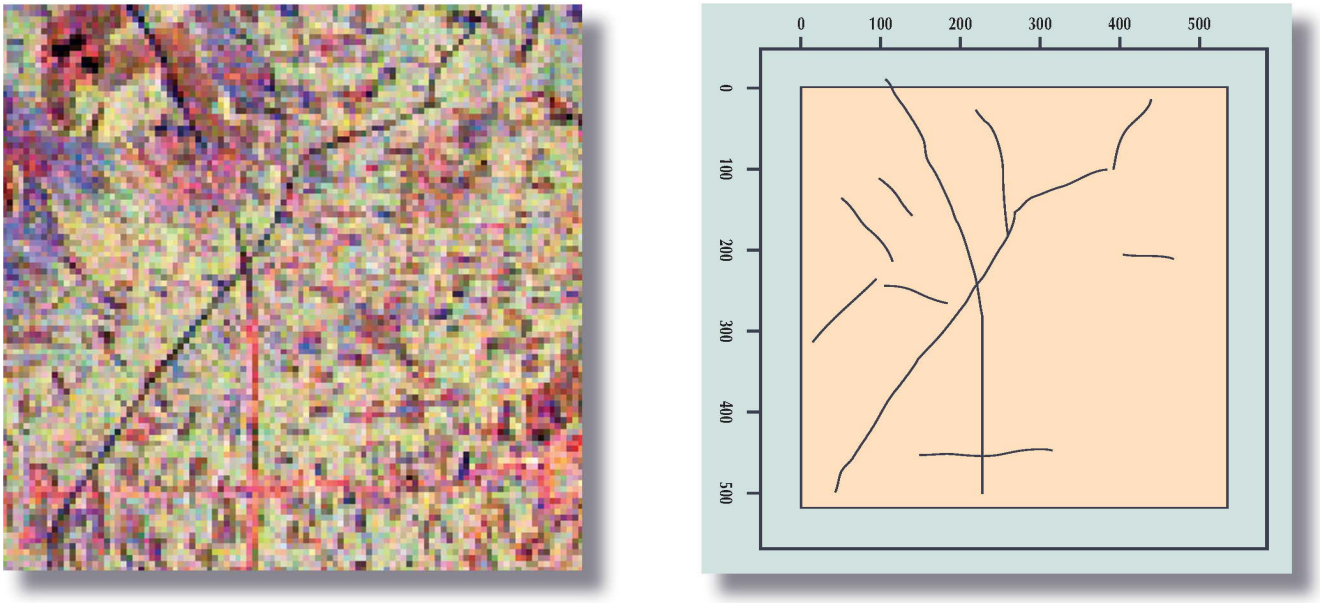
Inference for Random Sets

Image analysis and spatial statistics are widely used in medical diagnostics (body scans), satellite technology (cartography) and analysis of spatial correlation, for instance in forestry and epidemiology. At CWI, scientists of the group Signals and Images studied the problem of extracting linear features such as road networks from remotely sensed images. A new set of models was constructed, based on Monte Carlo Markov Chain simulation. The corresponding new simulation procedures are faster and more precise than former methods.

Many images found in microscopy, material science and biology can be described as a set of independent, randomly placed particles. Think for example of the distribution of pine trees in a forest, or, more aggressively, the distribution of fallen bombs. A formal description of such a random set is called a Boolean model. Notwithstanding the strong independence assumptions, inference is not trivial because of the occlusion effect: Only the image of all particles is observable rather than individual ones.

However, not all images can be described as completely random spatial patterns, due to interaction. Examples are the distribution of cells in cat retina (eyes), metal particles in an alloy and road networks. Cats' eye cells arrange themselves in two lattices, hard particles cannot penetrate each other and roads tend to be long, straight and have perpendicular crossings. Therefore, a class of more realistic models was studied, permitting correlation between the particles: Gibbs random set models defined by a parametric density, quantifying the interaction structure. The goals of CWI's research were to investigate the maximum likelihood estimation of these models, to devise efficient and exact techniques for them, and to develop useful models for image analysis practice.

For the last mentioned goal, CWI researched the practical problem of extracting linear features – such as road networks – from remotely sensed images, in collaboration with researchers of the Ariana project of INRIA Sophia Antipolis (France). They previously introduced the so-called Candy model, a Gibbs model for random sets consisting of line segments. In contrast to the Boolean model, there is interaction between the segments in the sense that configurations in which the segments tend to be aligned or cross at angles of about 90 degrees are favoured over patterns with many short, isolated segments or with an abundance of sharp crossings.



Countryside region in Malaysia and extracted road map. Picture left: NASA.

Analysis of the interaction structure was used to define an efficient simulation algorithm. With this method the maximum likelihood estimation of the model parameters was carried out, and its uniqueness, consistency and asymptotic normality was established. The ideas were tested on publicly released satellite images obtained from the NASA/JPL website. An example is presented in the figures which show a rural region in Malaysia (left) and the extracted road network (right).

CWI's group also generalized various perfect simulation algorithms to the random sets context and investigated their relative efficiency for a range of random set models including the Candy. Most perfect algorithms are based on well-known Monte Carlo samplers. For example, coupling from the past (CFTP) exhibits the dynamics of a spatial birth-and-death process, like the famous 'Life' simulator. It is particularly effective when the sampled distribution possesses some partial order structure. However, it generates a lot of objects that have no effect on the final outcome. In contrast, the clan of ancestors (ANCS) method aims to avoid births of objects that eventually do not matter, but does not take any model structure into account other than the range of interaction. It turned out that both methods take longer if the interaction strength increases, and that the ANCS method is more sensitive to the interaction range than CFTP.

Finally, a new method was proposed that for the first time allows the use of change moves that alter a single feature of the random set, a crucial step in using exact simulation in image analysis practice. A C++ library is under construction.

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db.cwi.nl/projecten/project.php4?prjnr=125

Advanced Communication Networks

The current trend in telecommunications is geared towards the availability of any application, at any time, at any place. This will eventually lead to universal accessibility to a common network infrastructure that supports all imaginable communication services. CWI's researchers aim at the application of queueing theory in communication networking, with a wide range of applications, e.g., in wireless services and network economics research.

Technological innovations in networking are taking place at a rapid pace. Only a decade ago, the narrowband telephone modem was essentially the only Internet access technology available. Since then, a broad range of broadband techniques have been developed: DSL, cable, but also wireless technologies that will ultimately provide high-quality access via mobile phones. This is only the beginning: It is envisaged that in the near future virtually all electronic devices will be assigned an Internet address, and it cannot be predicted what other innovations will bring.

The support of a broad variety of communication services over a single infrastructure inevitably leads to challenging performance issues. A voice user asks for essentially real-time service, in particular low delay, whereas these delay requirements are far less stringent when sending an e-mail. In fact all traditional (telephony, web-browsing) and less traditional (real-time gaming, remote surgery, video-on-demand) services have their specific quality of service (QoS) requirements. Of course the network can be designed to meet the most stringent of these requirements, but this will clearly lead to a low utilization, and consequently a waste of resources. This explains the research effort invested in traffic management mechanisms that are capable of differentiating between applications, thus enabling a broad spectrum of QoS levels.

Queueing theory is all about congestion effects at scarce resources. More precisely: It describes what happens when customers are competing for the same limited service. This explains why queueing theory has become an essential tool in designing and dimensioning communication networks. It helps to understand how congestion arises, but also how congestion can be avoided – in particular, it facilitates the development of QoS differentiation mechanisms. Queueing has been a popular topic with mathematicians since the early 1900s. One of its crucial features is its probabilistic character: Customer behaviour is inherently random, like the requests for voice calls arriving at a telephone exchange or the distribution of the size of documents sent over the Internet.

CWI's Advanced Communication Networks theme (PNA2) aims at the application of queueing theory in communication networking. Previous research usually focused on models with a single type of users, justified by the dedicated networks that were common in those times. The development of new models started with the advent of technologies enabling the integration of services into a single network. These models had to be sufficiently flexible to incorporate a high level of heterogeneity: i.e., capturing a wide range of applications, each of them having their own performance requirements, covering both wired and wireless transmission. CWI's research has focused on novel scheduling mechanisms, such as Generalized Processor Sharing (GPS), that are capable of offering multiple QoS levels. A key research issue in this area concerns the protection of user classes against 'misbehaving' traffic streams – in this way GPS mitigates the impact of heavy tails. This strand of research requires sophisticated probabilistic techniques, such as large deviations methods, and also thorough knowledge of Gaussian processes.

The recent developments in networking have led to new challenging research directions. One important field concerns performance support for wireless services. Current wireless systems like GSM are highly customized for carrying voice traffic, and offer only limited low-bandwidth data applications, such as short messaging services (SMS). The next generation of wireless networks like UMTS are specifically designed to support a wide range of high-speed data applications, such as Web-browsing sessions, document transfers, and imaging services, in addition to conventional voice calls. The integration of these heterogeneous applications raises similar challenges as described above for wireline systems. In wireless environments, these issues are further exacerbated by the relatively low bandwidth and scarcity of spectrum (see the UMTS licence auctions), and the propagation characteristics of wireless signals.
In particular, the transmission rate in wireless communications fluctuates considerably over time due to multi-path propagation effects. These rate fluctuations provide an opportunity to achieve

Due to both the ongoing increase of traffic volume and the introduction of new network services, major infrastructural upgrades need to be made, like here in the Sciencepark Amsterdam. The networking group at CWI explores the trade-off between efficient use of network resources and the quality of service offered. Photo: CWI.

throughput gains by scheduling data transmissions. Recent research in PNA2 has explored the QoS of such 'channel-aware' or 'opportunistic' scheduling algorithms, as perceived by users. The research showed that user-level performance may be evaluated by means of a Processor-Sharing model with a variable service rate. The variable service rate captures the throughput gains achieved by the channel-aware scheduling algorithms.

A second major effort is invested into network economics research. As argued above, a prerequisite for the support of heterogeneous applications involves the capability to offer multiple performance levels. A next step is to decide how these performance levels should be priced. Evidently, without any pricing, or with just a flat-fee, all users would opt for the premium class, disabling performance differentiation. This can be seen in today's Internet: The flat-fee does not encourage 'economical use' of resources. The consequence is that the Internet tends to be used by users who are relatively insensitive to congestion, thus pushing away services that require stringent performance guarantees (such as voice users). This phenomenon is usually called the 'tragedy of the commons'. A way to prevent this 'tragedy' from happening is by charging. Performance-sensitive users are usually willing to pay more for the service than congestion-indifferent users. Hence by choosing the prices of the different performance levels appropriately, incentives can be given such that only the performance-sensitive users join the premium class. Recent research in PNA2 focused on this type of problems. The approach followed incorporates microeconomic and game-theoretic elements into the queueing framework.

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Discrete Tomography

Discrete Tomography (DT) is concerned with the reconstruction of images from their projections in a small number of directions. In a joint research project between CWI and the University of Leiden both theoretical foundations and practical algorithms are being developed. Possible applications are the improvement of electron-microscopy techniques, quality control of silicon wafers and the reconstruction of the shape of heart chambers from orthogonal biplane cardiac angiograms.

Tomography concerns recovering images from a number of projections: How can an image of an object be constructed, of which only the density distribution in a number of directions is known. An example of such a reconstruction problem can be found in medical CAT-scanners: Groups of parallel X-rays are sent through the body in a number of directions, providing information about the density distribution inside the body. From these partial data, an image must be reconstructed which approximates the true cross-section as good as possible. Most of today's tomographic techniques are based on continuous tomography: The unknown image is considered to be a continuous, real-valued function. Therefore real analysis can be used to tackle the reconstruction problems.

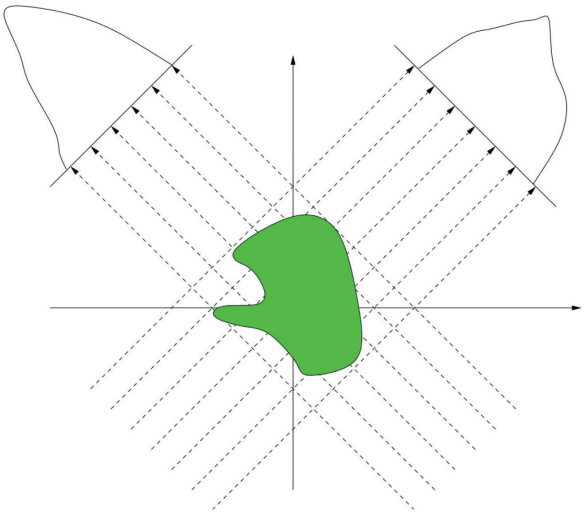

Figure 1: Scans from a number of directions provide information about the density distribution inside the object.

Recent developments in the field of electron-microscopy gave rise to a new set of tomographic problems. It has now become possible to count the number of atoms lying on each line in a crystal lattice, measuring along the lattice's principal directions. When attempting to reconstruct the crystal structure from these partial data, continuous tomographic techniques cannot be used, because the unknown image is binary instead of real-valued: A lattice cell either contains one or no atom, but it certainly will not contain half an atom. Introducing this extra constraint transforms the problem from an analytic problem into a combinatorial problem. Because of the additional constraints on the unknown image, one may hope that it is possible to reduce the number of measurement directions that is necessary for reconstruction. In the particular application of electron-microscopy this is even a necessity, since measuring the crystal lattice destroys some of its structure. The new theory helps to improve existing electron-microscopy techniques.

0	0	0	0	0	1	1	1	3
0	0	1	0	0	0	1	1	3
0	0	0	1	0	0	1	0	2
0	0	1	1	1	0	1	0	4
0	1	1	1	1	1	1	0	6
0	1	0	1	0	1	0	0	3
0	1	1	0	0	1	1	0	4
1	1	0	0	0	0	1	0	3
1	4	4	4	2	4	7	2	

Figure 2: A binary tomography problem. The binary image is unknown, except for its projections in the horizontal and vertical direction.

Figure 2 shows an example of a binary tomographic reconstruction problem, where the projections in two directions are available. From these projections the unknown image (which is also shown) must be reconstructed. Besides binary reconstruction problems, one can also consider problems where the number of

possible pixel values is greater than two, so where the range of values is not restricted to 0 and 1, but e.g., to 0, 1, 2, ..., 15. The field of Discrete Tomography covers all such problems, as long as the pixel values form a discrete set.

Discrete Tomography is a relatively new research direction. Many problems of DT have been introduced as combinatorial problems around 1960. It was only in 1994 however, that the name discrete tomography was introduced by Larry Shepp. The revival of interest in DT problems in the past decade was motivated by new developments in electron-microscopy. Being able to scan objects at the atomic scale is not just important for research purposes. The semi-conductor industry is interested in DT as a tool for controlling the quality of silicon wafers carrying etched patterns of electrical circuits. DT has many applications in fields such as medical imaging, data security and image compression as well.

Recently, Tijdeman (University of Leiden, The Netherlands) and Hajdu (University of Debrecen, Hungary) have made a new mathematical analysis of DT, in a numbertheoretic context. After obtaining several theoretical results, they used these results to construct a new algorithm for solving DT problems. The first implementation of this algorithm, written in MATLAB, showed the feasibility of the approach for reconstructing certain types of images. In the first half of 2002 CWI researcher Joost Batenburg developed several improvements for this algorithm, resulting in an implementation which often runs more than 50 times faster than the initial implementation. Figure 3 shows a binary image which can be reconstructed with the algorithm.

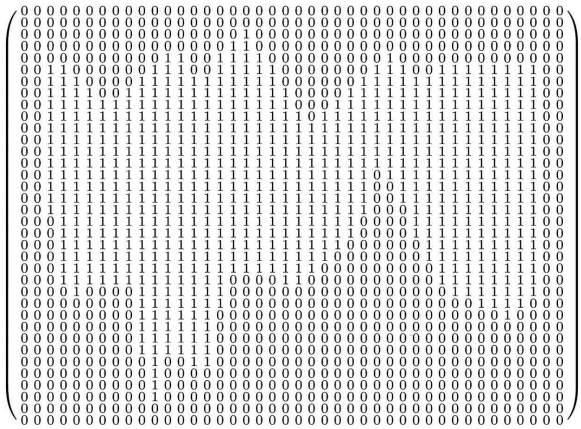

Figure 3: A binary image which can be reconstructed from projections in four directions by the algorithm of Hajdu and Tijdeman. The original algorithm runs in 2901 seconds, the improved version requires only 45 seconds.

In the current project researchers at the University of Leiden and CWI will further develop the mathematical theory and develop practical algorithms based on the theoretical results. The algorithm of Hajdu and Tijdeman will be improved further and extended. Other algorithmic approaches will be investigated as well. The experience at CWI with large-scale computer calculations will be put in here, for developing methods to reconstruct the large problem-instances that arise in practice.

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Firm Foundations for Telecom Standards

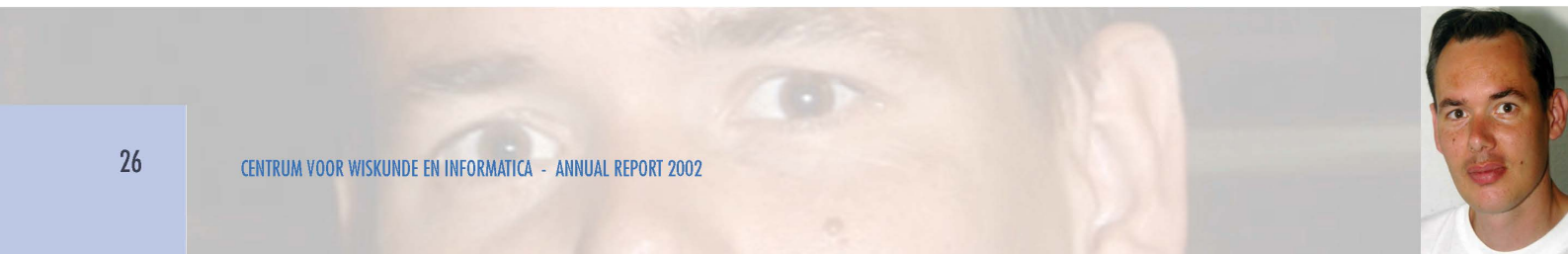
The increasing complexity of embedded systems and their omnipresence in modern society is a driving force behind recent research on formal methods, which work even when the human mind cannot capture the full complexity of the total system behaviour. In order to target this research to telecom standards, in 1999 the Systems Validation Centre (SVC) was founded as a cooperative effort of CWI, the University of Twente and Telematics Institute, with industrial support from companies like CMG, IBM, KPN and Lucent. Over the past four years, SVC has verified embedded systems and network protocols within telecom standards, using state-of-the-art techniques. This has led to substantial improvements in their design.

The SVC project was built on a strong foundation of theoretical research. µCRL, developed at CWI, is a language for specifying and analyzing embedded systems in an algebraic fashion. It is based on the classic theories of process algebra and abstract data types. A specialized toolset supports the analysis and manipulation of specifications written in µCRL. These specifications are automatically converted into a symbolic format, where a range of tools is available for optimization, theorem proving, state space generation and model checking.

The use of these tools and techniques in the development of complex embedded systems and state-of-the-art telematics standards was assessed in a number of real-world case studies. The results were reflected back into foundational research and tool development, by posing new theoretical questions and further challenging the developers of automated tools.

One successful case is the verification of the IEEE P1394.1 Draft Standard for High-Performance Serial Bus Bridges, which aims at the standardization of

SVC puzzles over the IEEE P1394.1 draft standard for high-performance serial bus bridges.
Illustration: I.A. van Langevelde, CWI.



connections between FireWire serial buses (bus bridges). The part of this standard which is to guarantee 'hot-pluggability' and 'plug-and-play', has grown towards a protocol which is too complex to be understood by mere human wit. This research project, in cooperation with researchers from Eindhoven University of Technology, led to the detection of and solutions to many flaws in this standard, including a fatal error in the loop detection algorithm, which had the potential of bringing the protocol to a grinding halt.

Another case is the verification of an Erlang optimization of the Transaction Capabilities Procedures of the Signalling System No. 7, a protocol for intelligent network services, in close cooperation with Ericsson. Both the original and the optimized version of the protocol were specified in μCRL, in order to verify that the latter is a correct optimization of the former. This effort revealed a number of bugs in the optimization, the most noticeable of which resulted in a memory leak which would have been hard to localize by more conventional means.

The experience gained within SVC demonstrated how formal methods have grown mature. The theoretical foundation has been proven a solid base for the construction of toolsets, the applicability of which is wide enough to span the gap between the theory of formal specification and model checking and the practice of modern embedded systems and telematics standards. SVC continued until January 2003, and has stimulated various dedicated successor projects at participating sites, including projects on improving the quality of embedded systems at CWI, and projects on formal testing, performance analysis and dependability analysis at the University of Twente.

Wan Fokkink shows an application of FireWire Networks.

Research project: Systems Validation Centre (SVC)
Project leader: Wan Fokkink
E-mail: Wan.Fokkink@cwi.nl
URLs: www.cwi.nl/sen2, svc.telin.nl

ORGANIZATION

Research

Cluster - Theme	Cluster leader Theme leader
Probability, Networks and Algorithms	**A. Schrijver**
- Networks and Logic – Optimization & Programming	A.M.H. Gerards
- Advanced Communication Networks (pilot)	M.R.H. Mandjes
- Stochastics	J. van den Berg
- Signals and Images	H.J.A.M. Heijmans
Software Engineering	**P. Klint**
- Biography of Aad van Wijngaarden	P. Klint
- Interactive Software Development and Renovation	P. Klint
- Specification and Analysis of Embedded Systems	W.J. Fokkink
- Coordination Languages	J.J.M.M. Rutten
- Evolutionary Systems and Applied Algorithmics	J.A. La Poutré
Modelling, Analysis and Simulation	**J.G. Verwer**
- Nonlinear PDEs: Analysis and Scientific Computing	M.A. Peletier
- Computing and Control	B. Koren
- Nonlinear Dynamics and Complex Systems (pilot)	U.M. Ebert
Information Systems	**M.L. Kersten**
- Standardization and Knowledge Transfer	M.L. Kersten
- Data Mining and Knowledge Discovery	M.L. Kersten
- Multimedia and Human-Computer Interaction	H.L. Hardman
- Visualization and 3D Interfaces	R. van Liere
- Quantum Computing and Advanced Systems Research	H.M. Buhrman

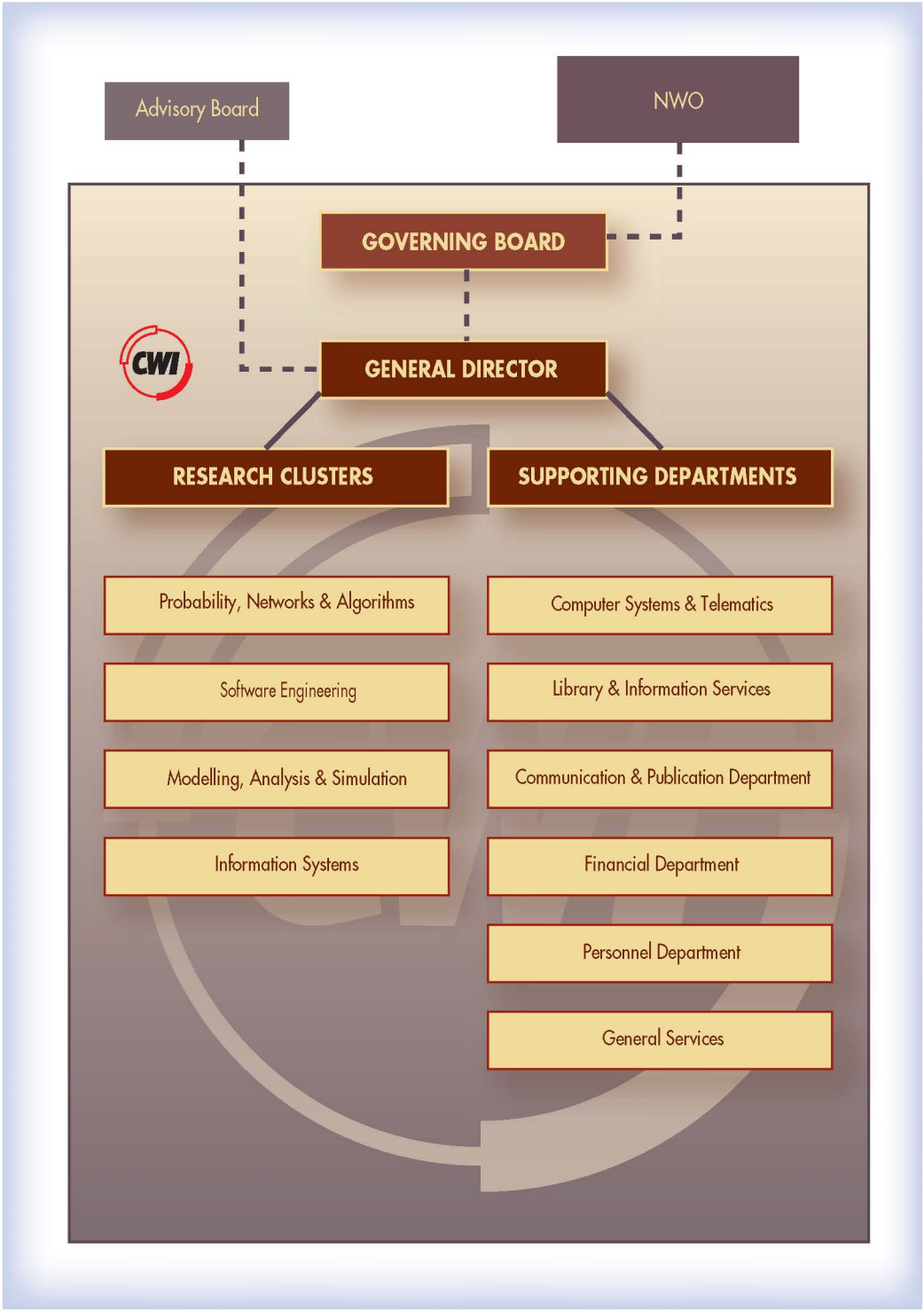
Management

Management Team
G. van Oortmerssen (director)
M.L. Kersten, P. Klint, A. Schrijver, J.G. Verwer (cluster leaders)
D.G.C. Broekhuis (controller)

Governing Board
L.A.A.M. Coolen, chairman
P.W. Adriaans (University of Amsterdam, Perot Systems)
F.A. van der Duyn Schouten (University of Tilburg)
M.H. Overmars (University of Utrecht)
H.A. van der Vorst (University of Utrecht)

Advisory Board
J. van Leeuwen (University of Utrecht), chairman
H.A. Harwig (Philips Research Laboratory, managing director)
B. Larrouturou (INRIA in France, president)
L.A. Peletier (University of Leiden)
G. Wiederhold (Stanford University, USA)
M. Westermann (Twinning Network, director)

On December 31, 2002

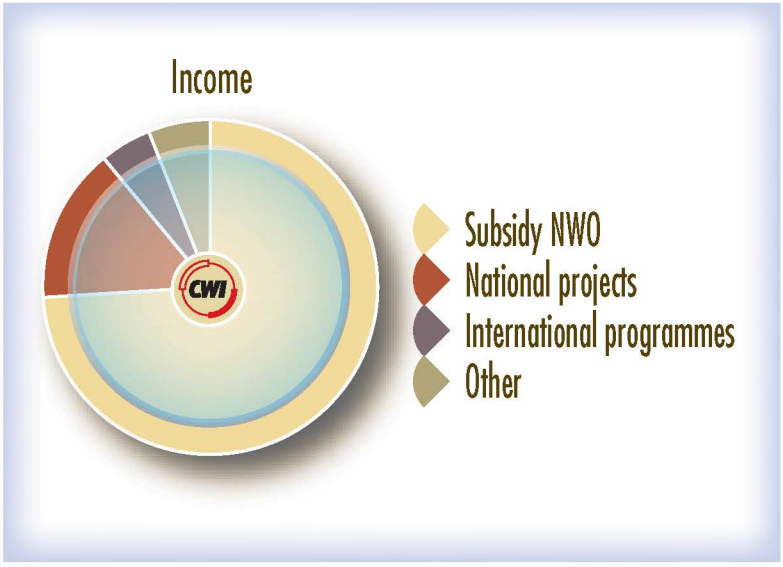

Advisory Board
NWO
GOVERNING BOARD
CWI
GENERAL DIRECTOR
RESEARCH CLUSTERS
SUPPORTING DEPARTMENTS
Probability, Networks & Algorithms
Software Engineering
Modelling, Analysis & Simulation
Information Systems
Computer Systems & Telematics
Library & Information Services
Communication & Publication Department
Financial Department
Personnel Department
General Services

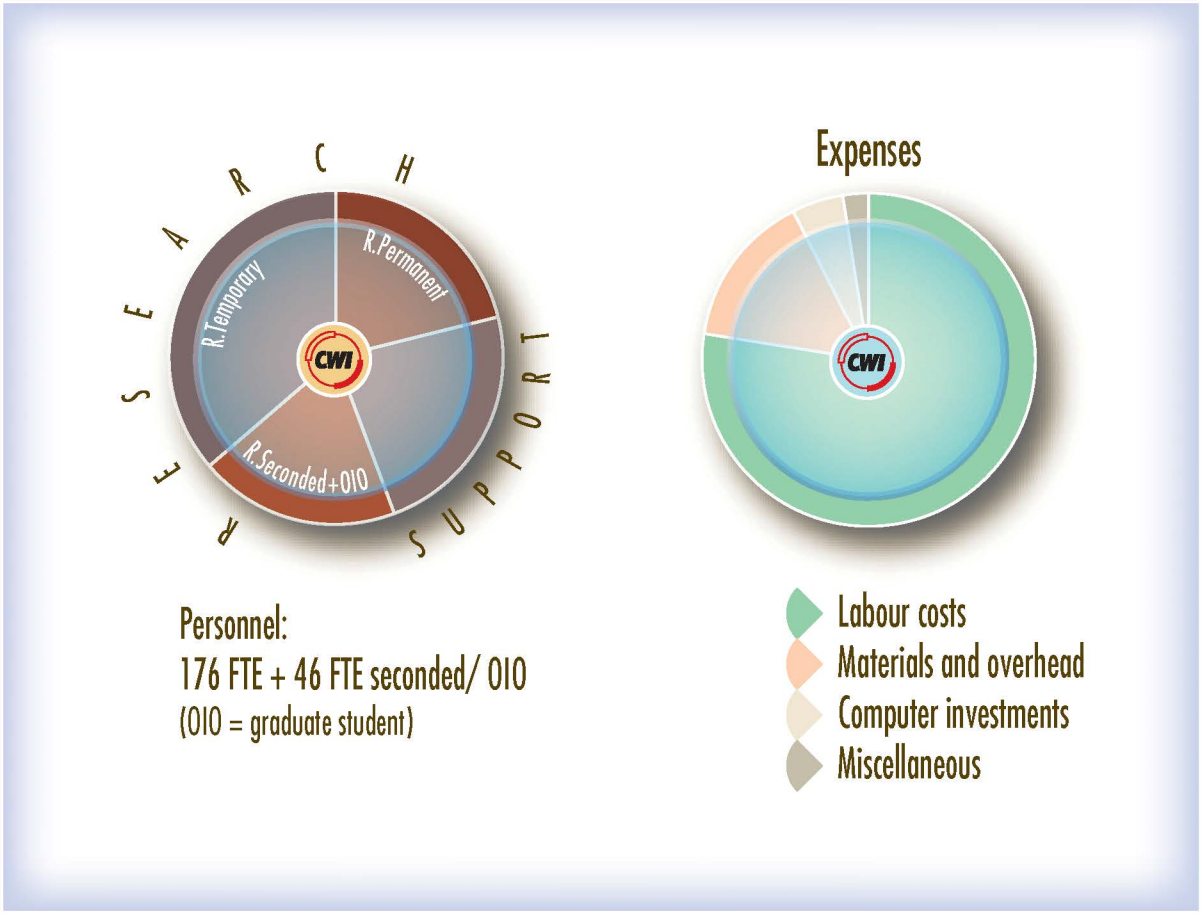
FINANCES, PERSONNEL

Finances 2002

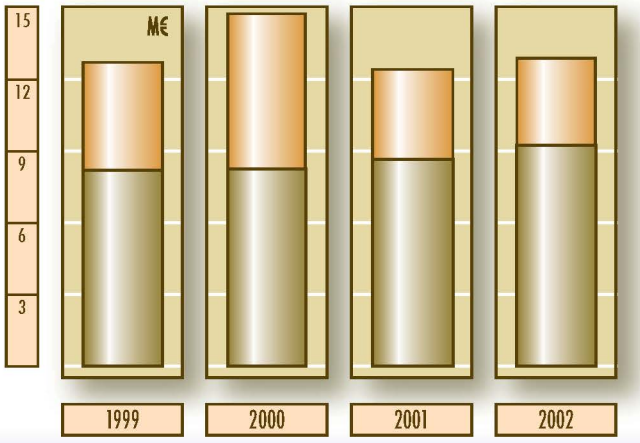
In 2002, CWI spent M€ 12.88. The expenses were covered by a basic subsidy from NWO (M€ 9.47), by income from national projects and programmes (NWO, Telematics Institute, WTCW/ICES-KIS, total M€ 1.98) and international programmes (M€ 0.63), and finally by M€ 0.81 as revenues out of third-party-services and other sources.

Due to a change in NWO's accounting standards regarding the institute's depreciations, these figures are lower than last year.
Following the new system for the numbers of last year, the expenses in 2001 were M€ 12.41 (Annual Report 2001: M€ 14.21).



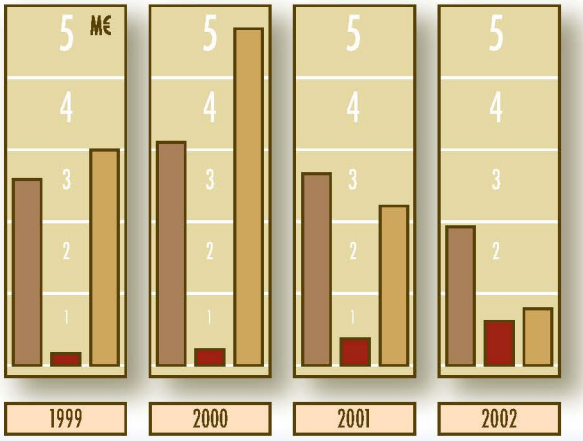


CWI Income

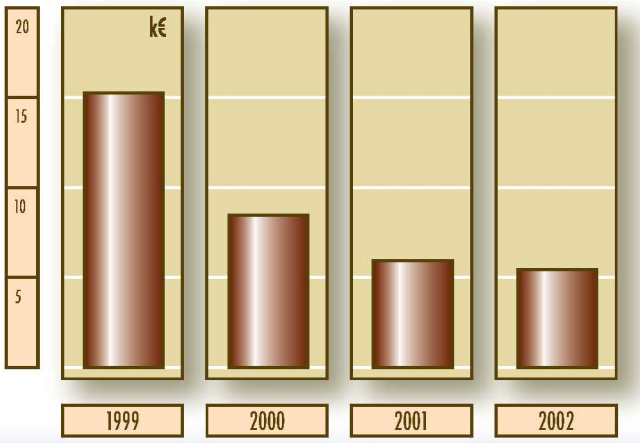


For numbers concerning the year 2002, see the remarks in the text (p.30).

Breakdown of non-NWO Income



CWI Budget Computer Equipment



CWI PhD THESES

Author
Title
Thesis advisor(s) (for external advisors the university's name is added)

P.A. Boncz
Monet: A Next-Generation DBMS Kernel For Query-Intensive Applications
M.L. Kersten

E.H. van Brummelen
Numerical Methods for Steady Viscous Free-Surface Flows
P.W. Hemker

S.H. Cavallar
On the Number Field Sieve Integer Factorisation Algorithm
R. Tijdeman (University of Leiden)

W.K. van Dam
On Quantum Computation Theory
P.M.B. Vitányi

R. Gennari
Mapping Inferences
K.R. Apt

J.I. den Hartog
Probabilistic Extensions of Semantical Models
J.W. de Bakker

T. Kuipers
Techniques for Understanding Legacy Software Systems
P. Klint

D. Lanser
Numerical Methods for Atmospheric Flow and Circulation Problems
J.G. Verwer

B. Lastdrager
Sparse Grids and Numerical Time Integration
J.G. Verwer

S.P. Luttik
Choice Quantification in Process Algebra
J.A. Bergstra (University of Amsterdam) and J.F. Groote (Eindhoven University of Technology)

S. Manegold
Understanding, Modeling, and Improving Main-Memory Database Performance
M.L. Kersten

L.M.F. Moonen
Exploring Software Systems
P. Klint

S.W.W. Rolles
Random Walks in Stochastic Surroundings
M.S. Keane

A.R. Schmidt
Processing XML in Database Systems
M.L. Kersten

R. van Stee
On-line Scheduling and Bin Packing
J.A. La Poutré and J.N. Kok (University of Leiden)

Y.S. Usenko
Linearization in μCRL
J.F. Groote (Eindhoven University of Technology) and W.J. Fokkink

M.B. van der Zwaag
Models and Logics for Process Algebra
J.A. Bergstra (University of Amsterdam)

CWI RESEARCH PROGRAMMES

Probability, Networks and Algorithms
Cluster leader: A. Schrijver

Networks and Logic – Optimization and Programming
Theme leader: A.M.H. Gerards

Networks and optimization

Design, analysis and implementation of optimization and approximation algorithms for combinatorial problems with the help of methods from graph theory, topology, discrete mathematics, geometry, and integer and linear programming, with special attention to network problems (flows, routing and VLSI-design), and scheduling and timetabling.

Constraint and integer programming

Study of the foundations and applications of constraint programming, in particular the design and implementation of an adequate programming environment for constraint programming, and the use of constraint programming for various optimization problems drawing on integer programming techniques.

Algorithmic and combinatorial methods for molecular biology

Mathematical analysis of molecular structures in biology and the design, analysis and implementation of algorithms for computational molecular biology. The methods come from combinatorics (graph theory and combinatorial optimization), computer science (constraint programming and computational complexity) and mathematical programming (linear, integer, and semi-definite programming).

Advanced Communications Networks
Pilot leader: M.R.H. Mandjes

Wireline networks, TCP/IP

The development of queueing theoretic models, methods, and algorithms for studying congestion phenomena in communication networks. The focus is on service integration and quality differentiation, as well as feedback-based flow-control protocols, e.g., TCP. Continued research on log-tailed phenomena, and the impact on network performance.

Wireless networks, UMTS

The development of queueing theoretic models and algorithms for dimensioning, engineering, and operating integrated-services wireless networks, underlying next-generation mobile communication systems. Current projects concern processor-sharing models for best-effort wireless services and effective bandwidth calculations for integrated-services wireless.

Network economics

Economic allocation of available resources (bandwidth, buffer space) to users, in particular: Charging network users on the basis of their contribution to congestion by packet marking, allocating bandwidth through auctions, and allocating cost among network users in conjunction with network measurements.

Stochastics
Theme leader: J. van den Berg

Probability

Fundamental and applied research, in particular mathematical models of biological and physical processes with self-organized critical behaviour, dynamic percolation phenomena near criticality, reinforced random walks on finite graphs, and random spatial processes.

Statistics

Fundamental and applied research, in particular saddlepoint approximations, Poisson intensity functions, resampling, bootstrap calibration and the Stringer bound, statistical methods for compound sums, with applications in finance, and ongoing research on estimating the intensity of oil pollution in the North Sea.

Stochastic analysis

Fundamental and applied research, in particular statistical methods for dynamical stochastic models, and statistical inference for stochastic processes related to financial data.

Ergodic theory

Fundamental and applied research, in particular classification of Bernoulli schemes, fractal analysis, and superexponential convergence.

Signals and Images
Theme leader: H.J.A.M. Heijmans

Image understanding, retrieval, and indexing

Feature extraction, and content-based image retrieval and indexing, in particular spatial grouping, image understanding, feedback-operated user interfaces for design and image retrieval, and creating a photo database of whales with visual identification.

Image representation and analysis

Research on (multiresolution) representations for images and their applications in image analysis, coding and watermarking, with special attention to the design of new morphological and adaptive wavelets.

Stochastic geometry

Parameter estimation for random sets, and spatial statistics.

Software Engineering
Cluster leader: P. Klint

Biography of Aad van Wijngaarden
Theme leader: P. Klint

Composition of a scientific biography of Aad van Wijngaarden (1916–1987), founding father of computer science In the Netherlands and former director of CWI. Historical research.

Interactive Software Development and Renovation
Theme leader: P. Klint

Software renovation

Development of new technology for the renovation and maintenance of legacy systems,

including documentation generation and domain-specific languages.

Domain-specific languages

The aim is to develop methods for selecting suitable DSL domains, and for capturing domain knowledge into a DSL and its compiler, and to study the practical use of domain-specific languages and styles in various settings such as financial engineering and PDE solving.

Generic language technology

Redesign, reimplementation, and improvement of the ASF+SDF Meta-Environment, in particular the development of a flexible and extensible generic environment to be used in domain-specific language prototyping and software renovation. Specific aims are: compilation of ASF+SDF to C, unparsing, parser generation, global architecture, and application of developed components in other generic environments.

Specification and Analysis of Embedded Systems
Theme leader: W.J. Fokkink

Distributed systems

The study of specification, analysis and testing techniques for computer-controlled systems, by developing and implementing algorithms for the analysis and verification of distributed systems with the μCRL toolset. Techniques and algorithms are assessed via case studies (communication protocols, embedded systems, hybrid systems, etc.).

Process theory and verification

Fundamental study of verification techniques and the development of methods for proof checking as a means to improve the quality of mathematical proofs, thus establishing the correctness of programmed systems 'beyond reasonable doubt'. Central issues are process theory, binary decision diagrams, automated deduction, and term rewriting.

Coordination Languages
Theme leader: J.J.M.M. Rutten

Formal methods for coordination languages

Development, on the basis of transparant semantic models, of formal methods for coordination languages, with special attention to UML and JAVA. Aims are to provide formal underpinnings, methods and tools for rigorous development and compositional verification of embedded real-time systems within UML, a critical assessment of UML, to extend JAVA with a notion of component, and to develop an accompanying programming environment.

Coordination and component-based software architectures

Development of formal models for components and component-based software that (1) capture the relevant semantics of a component, as well as its syntax, in its interface; (2) allow compositional derivation of the properties of a system from those of its constituent components; and (3) support notions of distribution and mobility.
Other work concerns coordination patterns and protocols in various real-life applications, an experimental testbed for control-oriented coordination programming on heterogeneous platforms, a new channel-based exogeneous coordination model $P\varepsilon\omega$, and coordination programming for constraint satisfaction.

Exploratory research: coalgebraic models of computation

Development of coalgebra as a unifying mathematical framework for (transition dynamical, probabilistic) systems. Continued study of weighted automata and behavioural differential equations, of generalized coinduction schemata, and of coalgebraic logic, which generalizes modal logic.

Evolutionary Systems and Applied Algorithmics
Theme leader: J.A. La Poutré

Evolutionary systems

Study of evolutionary systems in economics, e-commerce and management, including: economic and commercial strategies, complex adaptive systems, adaptive agents, e-commerce, negotiation and trade, bounded rationality, interaction games, automatic programming, information filtering, optimization, dynamization, autonomous systems of trade agents in e-commerce, and evolutionary exploration systems for electronic markets.

Neural networks and discrete algorithms

Classification of data by several types of neural networks, concerning, e.g., benchmark classification problems, scaling, remote sensing, filtering, event prediction and decision support. Study of financial systems, including neural networks for prediction, event prediction, and decision support, computational methods, and mathematical modelling. Design of algorithms applicable in on-line design and management environments, in particular the use of quality of service in managing and optimizing on-line scheduling for multimedia processes.

Modelling, Analysis and Simulation
Cluster leader: J.G. Verwer

Nonlinear PDEs: Analysis and Scientific Computing
Theme leader: M.A. Peletier

PDEs in the life sciences

Mathematical modelling and numerical simulation for life sciences, in particular biology and medicine. Current projects concern: Mathematical modelling of biochemical processes in living cells and study of signal transduction, mathematical modelling and simulation of regulatory networks and the dynamic architecture of living cells (Silicon Cell), numerical methods for mixed parabolic-gradient systems modelling the development of neuronal connections in the nervous system (axon growth), numerical study of partial integro-differential equations modelling the growth of phytoplankton, dynamic modelling of the exchange of solutes and particles between biofilms and water, and the application of ROD theory to DNA.

PDEs at CWI

Generating research in analysis of PDEs by creating a 'hot spot' of PDE-analysis at CWI. Current projects concern: Writing a textbook on the role of symmetry in partial differential equations, researching patterns in gravity-driven groundwater flow by derivation and mathematical analysis of amplitude equations, linearization in free boundary problems, Spike hierarchy in the Gray-Scott model and geometric methods in numerical analysis.

Numerical analysis of PDEs

Numerical solution of partial differential equations. Current projects concern: Geometric numerical methods for continuum mechanics and numerical solution of the time-dependent advection-diffusion-reaction equations.

Asymptotics and special functions

Studies of partial differential equations in connection with applied analysis, asymptotics, special functions and analysis. Constructing numerical upper bounds for remainders of uniform asymptotic expansions and construction of convergent expansions with asymptotic properties, based on multi-point Taylor expansions of analytic functions. Numerical evaluation of Airy and Scorer functions, including zeros of Scorer functions. Contributions to the revision of the Handbook of Mathematical Functions of Abramowitz and Stegun.

Computing and Control
Theme leader: B. Koren

Computational fluid dynamics

Computation of fluid flows in liquids, gases, plasmas, or combinations of these (multi-fluid flows). The present emphasis lies on the development of numerical methods for the computation of free-surface flows, discontinuous Galerkin method for convection-diffusion problems, and discretizations of the equations of relativistic magnetohydrodynamics. Current research includes sparse-grid methods for transport problems, Navier-Stokes solver for water flows around moving ships, rapid changes in complex flows, hp-adaptive methods for 3D convection dominated flows, and numerical singular perturbation problems.

Computational number theory and data security

Development of new mathematical and computational techniques for the solution of number-theoretic problems, with applications in cryptography, crystallography, and medicine. Triggered by the emergence of public-key cryptography, the project studies algorithms for factorization and primality testing, for computing discrete logarithms, and for the solution of large, sparse systems of linear equations over finite fields. In addition, classical conjectures like the Riemann hypothesis and the Goldbach conjecture are studied, as well as problems involving Euler's ϕ-function and the sum-of-divisors functions. Another project concerns mathematical aspects of discrete tomography.

Control and system theory

Development of theory and algorithms for control of discrete-event and hybrid systems, in connection with motorway, railway and air traffic, and other networks. Motivated by control and signal processing, research in realization theory and system identification theory concerns Gaussian systems, finite stochastic systems, positive linear systems, and hybrid systems. Application to positive systems in the biosciences.

Nonlinear Dynamics and Complex Systems
Pilot leader: U.M. Ebert

Analytical and numerical study of nonlinear dynamics in spatially extended systems, described by deterministic as well as stochastic PDEs, with application to spontaneously formed spatio-temporal patterns in electric discharges. Other research concerns phytoplankton growth, polymer diffusion, and basic questions in PDE analysis and numerics. Concrete projects include pattern formation in barrier discharges, streamer discharges in gases, numerical methods for leading edge dominated dynamics, streamer-like phenomena in semiconductor devices, numerical solution of time-dependent advection-diffusion-reaction equations, reptation models for polymer diffusion, analytical models for phytoplankton dynamics, and pulled fronts.

Information Systems
Cluster leader: M.L. Kersten

Standardization and Knowledge Transfer
Theme leader: M.L. Kersten

Research into applied logic, including dynamic logic, tableau reasoning, construction of electronic textbooks for logic, and interactive information engineering; digital library projects; research on Hopf algebras of noncommutative symmetric functions, and on identification clouds for the automatic indexing of texts; multimedia delivery infrastructures; knowledge transfer on evolving standards, primarily within the context of W3C, and participation in standardization activities and organizational support for W3C.

Data Mining and Knowledge Discovery
Theme leader: M.L. Kersten

Data mining

Knowledge discovery from hidden relationships (correlations) in vast amounts of data which either prohibits human evaluation or makes it too tedious, with special attention to relational databases and sequential data, e.g., time series, mining in biology (DNA), medicine (physiological time series) and economic data.

Multimedia databases

The objective is to achieve efficient storage and retrieval of multimedia data, such as pictures, video and audio, in particular by using feature detectors to simplify and speed-up multimedia data query. This is complemented by an effective query articulation technique for image and video retrieval.

Database architecture

Research into the architecture of next generation database systems and dissemination of Monet database technology.

Multimedia and Human-Computer Interaction
Theme leader: H.L. Hardman

Distributed adaptive hypermedia

Building on expertise in structured document languages and languages for semantic descriptions of multimedia, research continues in two complementary threads – development of the required Web technology (Web Infrastructure Innovation), and of methodologies and tools for integrating and processing semantics with multimedia (Multimedia Semantics). Parallel construction of software demonstrators.

Social user interfaces

Research into humanoid interfaces, such as discourse planning and management, multi-channel communication, and level of quality services of avatars, by applying AI-based methods. The focus is on high-level control of facial animation, expression sculpting with constraints, cognitive facial expression repertoire, hand gestures in multi-modal communication, emotional and expressive talking heads, model-based recognition of facial and hand gestures, non-photorealistic avatars in ambient intelligent systems, and expressive avatars in VR.

Visualization and 3D Interfaces
Theme leader: R. van Liere

Data visualization

Study and development of methods for interactive scientific visualization of large data sets, and putting them into practice. The primary application domain is bioinformatics, particularly the development of a VR desktop system (Personal Space System) for biological microscopic imaging.

3D interfaces

Novel techniques for 3D user interfaces are designed and studied. The present focus is on distributed collaborative virtual environments for multi-actor scenarios, augmented with tactile feedback and audio/video, on the VR desktop system mentioned above, and on distributed VR for cell biology.

Quantum Computing and Advanced Systems Research
Theme leader: H.M. Buhrman

Quantum computing

Investigation of quantum information and communication technology, quantum computer architectures, quantum algorithms, quantum communication complexity, quantum complexity classes, quantum information retrieval, quantum simulation of quantum mechanical physical systems at the elementary level (computational quantum matter) and quantum information theory.

MDL Learning and algorithmic statistics

Design, implementation, and comparative analysis of a series of practical applications of machine learning techniques. Applications include automatic grammar generation from large text corpora, pattern recognition (learning optimal model granularity) and comparative evaluation of predictive accuracy of MDL and new forms of stochastic complexity. Basic research in 'algorithmic' sufficient statistics, with applications in cognitive psychology. Study of the relation between data compression and generalization properties and prediction in the sense of the 'minimum description length' paradigm.

Algorithms, complexity, and genomics

Design and analysis of algorithms for distributed and parallel systems. Limitations and possibilities of future systems are identified by exploiting fundamental mathematical techniques of (Kolmogorov) complexity theory. A major item is descriptional complexity leading to the 'incompressibility method' and 'learning by compression'. Furthermore, the design, development and assessment of computational tools for the exploration of genomic data (bioinformatics algorithms).

INTERNATIONAL AND NATIONAL PROGRAMMES

This appendix summarizes the major national and international projects in which CWI participates. The following data are given for each project:
- title,
- period,
- co-operation with other institutes,
- CWI project leader(s).

European Programmes

NeuroCOLT II (27150): Neural and computational learning
1998–2002
11 universities across Europe
P.M.B. Vitányi

DEDUGIS (28115): Deductive Constraint Databases for Intelligent Geographical Information Systems
1998–2002
CNR/CNUCE, Univ. Pisa, GMD FIRST Berlin, Univ. Würzburg, Sistemi Territorialli Pisa, DEBIS Berlin, INTECS Pisa, SISTEMA Grosseto
K.R. Apt

IST – Information Society Technologies

Natural biofilms as high-tech conditioners for drinking water
2000–2003
Univ. Barcelona, Wasserforschung Mainz GmbH, Czech Acad. Sc., Univ. Amsterdam
J.G. Verwer

TRIAL Solution
2000–2003
Univ. Koblenz-Landau, Heidelberger Akad. Wissenschaften, Trinity College Dublin, Univ. Nice-Sophia Antipolis, FIZ Karlsruhe, Ges. f. Wiss.-Techn. Information, Open Univ. (UK), TU Chemnitz, Univ. Köln, Springer-Verlag, Harri Deutsch, Shang IT
M. Hazewinkel

QAIP – Quantum Algorithms and Information Processing
2000–2002
Univ. Oxford, Univ. Bristol, Univ. Aarhus, Univ. Paris Sud, Hebrew Univ. Jerusalem, Weizmann Inst., Technion Israel, Univ. Waterloo, IMCS, MGU Moscow, Univ. Calgary
H.M. Buhrman

QUIPROCONE – Quantum Information Processing & Communications (29064)
2000–2003
70 partners across Europe
P.M.B. Vitányi

EULER-Takeup (29445)
2001–2002
Georg-August Univ. Göttingen, FIZ Karlsruhe, Università Degli Studi di Firenze
A.L. Ong

QUESTION-HOW – Quality Engineering Solutions via Tools, Information and Outreach for the New Highly-enriched Offerings from W3C: Evolving the Web in Europe (28767)
2001–2003
INRIA, SICS, Fraunhofer Gesellschaft, CNR (Pisa), CLRC, Hebrew Univ. Jerusalem
I. Herman

ONTOWEB – Ontology-based information exchange for knowledge management and electronic commerce (29243)
2001–2004
100 partners across Europe
H.L. Hardman

EUROPHLUKES – Photographic database of cetaceans (whales) (EVRI-CT-2001-20007)
2001–2004
MARIS B.V., Sea Watch Foundation, Alnitak, CiRCé, ESPARTE, CEMNA, Museu de Baleia, IMAR, Tethys, Univ. College Cork, Wild Idea, Ecologic, Greenland Inst. of Natural Resources, Oceanopolis, GREC, Projecto Delfirn, Whale Watch Azores
H.J.A.M. Heijmans

FOUNDIT – Feedback-Operated User Interface for Design and Image Retrieval (28427)
2001–2003
Univ. Gent, Sophis Systems, N.V. Pianezza Paolo SNC, Clama Mattress Ticking NV, Chantemur
E.J. Pauwels

MASCOT – Metadata for Advanced Scalable Video Coding Tools (26467)
2001–2003
Ecole Nationale Supérieure des Mines de Paris (ENSMP-CMM), Association pour la Recherche et le Développement des Méthodes et Processus Industriels (Armines-CMM), Heinrich-Hertz Institut (HHI), Philips France S.A.S. (LEP), Groupe des Ecoles des Télécommunications (GET-ENST), Univ. Politècnica de Catalunya (UPC), Vrije Univ. Brussel (VUB), Poznan Univ. of Technology (PUT)
H.J.A.M. Heijmans

OMEGA – Correct development of real-time embedded systems in UML (33522)
2001–2004
Institut National Polytechnique de Grenoble (INPG/Verimag), EADS Launch Vehicles SA (EADS LV), Israel Aircraft Industries Limited (IAI), Univ. Nijmegen, Stichting Nationaal Lucht- en Ruimtevaartlaboratorium, Kuratorium OFFIS E.V. (OFFIS), Christian-Albrechts Univ. Kiel, Weizmann Institute of Science (WIS), France Telecom SA (FT), Centre National de la Recherche Scientifique (CNRS/Verimag), Univ. Joseph Fourier Grenoble 1 (UYF, Verimag)
F.S. de Boer

Biovision – Roadmap to successful deployments from the user and system ingrator perspective (IST-2001-38236)
2002–2003
British Telecommunications Plc (BT), Teletrust Deutschland (TTT), NPL Management Ltd (NPL), Consiglio Nazionale delle Ricerche (CNR), Daon Ltd, Government Communications Headquarters (GCHQ), Nationwide Building Society (NW), Fachhochschule Giessen-Friedberg, Univ. of Applied sciences (UGF)
B.A.M. Schouten

MKM.net: Mathematical Knowledge Management Network (IST-2001-37057)
2002–2003
Univ. Bath, The Numerical Algorithms Group (NAG), Univ. College London, Heriot-Watt Univ., Univ. Birmingham, Univ. Pierre et Marie Curie (France), German Research Centre for Artificial Intelligence (DFKI), Saarland Univ., Research Institute for Symbolic Computation (RISC), The Software Competence Center Hagenberg (SCCH), Univ. Bologna, Univ. Koblenz-Landau, Univ. Bialystok (Poland)
M. Hazewinkel

NAME: Network for Agile Methodologies Experience (IST-2001-37482)
2002–2003
Libera Università di Bolzano (LUB), Datasiel Sistemi e Technologie di Informatica S.P.A., Universidad Politécnica de Valencia (UPVLC), Technische Universität München (TUM), Università degli Studi di Cagliari (UCA), Univ. of Sheffield
L.M.F. Moonen

Control and Computation (33520)
2002–2004
Institut National Polytechnique de Grenoble (INPG), Swiss Federal Institute of Technology Zürich (ETZH), Lunds Univ., PARADES (Italy), ABB Corporate Research Ltd, Electricité de France Service, Centre National de Recherche Scientifique (CNRS), Univ. Joseph Fourier Grenoble I (UJF), Università degli Studi di Siena (UNISI)
J.H. van Schuppen

TMR

DONET: Discrete Optimization: Theory and Applications
1998–2003

Univ. Leuven, London School of Economics and Political Sciences, Univ. Pierre et Marie Curie (Paris), Rheinische Univ. Bonn, CNR, Univ. Lisbon, Société Coopérative ALMA, DASH Associates Ltd, Ecole Polytechnique Fédérale de Lausanne
A. Schrijver, A.M.H. Gerards

ERNSI: Systems Identification
1998–2003
KTH Stockholm, TU Wien, CNR-LADSEB, Univ. Leuven, INRIA, Univ. Rennes, Univ. Cambridge, Univ. Linköping, Univ. Eindhoven, Univ. Delft
J.H. van Schuppen

INCO

SEEDIS: Software Engineering Environments for Distributed Information Systems
1998–2002
Universities of East Anglia, Manchester, and Cyprus, Space Application Services
F. Arbab

RTN

AMORE – Algorithmic Methods for Optimizing the Railways in Europe
2000–2004
Univ. Konstanz, ETH Zürich, IT-DTU Lyngby, CTI Patras, DIS-DIE Rome, L'Aquila Italy
A.M.H. Gerards

DYNSTOCH – Statistical methods for dynamical stochastic models
2000–2004
Universities of Copenhagen, Amsterdam, Berlin, Cartagena, Freiburg, Helsinki, London, Padua, Paris
K.O. Dzhaparidze, P.J.C. Spreij

Cooperation with GMD

TM3 – Advanced numerical simulation for photochemical dispersion models
1998–2002
Univ. Utrecht/IMAU, INRIA/CERMICS, Imperial College London, KNMI, Univ. Twente
J.G. Verwer

Application of techniques from propositional logic for the verification of processes
1998–2002
Univ. Delft
W.J. Fokkink

Distributed Collaborative Virtual Environments
1999–2002
R. van Liere

Mining for groups with distinct behaviour
2000–2004
M.L. Kersten

National Programmes

NWO Council for the Sciences

LT – Performance analysis of communication networks; focus on long-tailed traffic characteristics and fluid queues
1996–2003
Columbia Univ., EURANDOM, Lucent Technologies, Univ. Eindhoven, Univ. Wroclaw, Univ. Twente
M.R.H. Mandjes

Foundations of declarative programming
1997–2007
Univ. Amsterdam, Vrije Univ. Amsterdam
K.R. Apt

PERS – Parameter Estimation for Random Sets
1997–2002
EURANDOM, Univ. Utrecht, Univ. Berkeley
M.N.M. van Lieshout

CIP – Constraint and Integer Programming techniques
1997–2007
Partners in ERCIM WG on Constraints, Univ. of Victoria (Canada), Univ. of Singapore, Brooklyn College (USA)
K.R. Apt

PROMACS: Probabilistic Methods for the Analysis of Continuous Systems
1998–2003
Univ. Eindhoven, Vrije Univ. Amsterdam, Univ. Amsterdam, Univ. Nijmegen, Univ. Dresden, Indiana Univ.
J.J.M.M. Rutten

Rigid sets
1998–2002
Vrije Univ. Amsterdam
J. van den Berg

Statistics for random processes with applications to mathematical finance
1998–2002
Vrije Univ. Amsterdam
K.O. Dzhaparidze

Protocols, reference models and interaction schemes for multimedia environments
1998–2002
Univ. Amsterdam
W.J. Fokkink

Quality of service for multimedia systems
1999–2003
Philips Research
J.A. La Poutré

SICA – System Identification with Computer Algebra
1999–2003
Vrije Univ. Amsterdam, Univ. Eindhoven, INRIA Sophia Antipolis, UCAM
J.H. van Schuppen

WA – Wavelets and their Applications
1999–2003
Univ. Groningen, Univ. Eindhoven, Univ. Twente
H.J.A.M. Heijmans

Evolutionary exploration systems for electronic markets
1999–2003
Univ. Amsterdam
J.A. La Poutré

MRA – Multi-Resolution Approaches
1999–2004
Univ. Delft
H.J.A.M. Heijmans

Dynamo – Semi-automatic hypermedia presentation generation
2000–2002
Univ. Eindhoven, Philips
H.L. Hardman

Numerical singular perturbation problems (network)
2000–2003
Univ. Nijmegen, MGU Moscow, Russian Acad. Sciences, POMI St. Petersburg
P.W. Hemker

Algorithmic methods for special functions by computer algebra
2000–2003
Univ. Amsterdam, J. Segura (Madrid), Editors Abramowitz & Stegun
N.M. Temme

Coordination-based constraint solvers
2000–2003
Univ. Nantes
J.J.M.M. Rutten

Spatial grouping
2000–2004
Univ. Leuven/ESAT
E.J. Pauwels

Average-case analysis
2000–2003
P.M.B. Vitányi

Coordination-based parallel constraint solving
2000–2004
Univ. Nantes
F. Arbab, K.R. Apt

Rapid changes in complex flows
2001–2003
FOM Rijnhuizen, Univ. Utrecht, IMAU
P.W. Hemker

COCON – Coalgebra and Control
2001–2003
Univ. Toronto, Univ. Waterloo
J.H. van Schuppen

ALMA-0 and new foundations for declarative programming
Univ. Amsterdam, Free Univ. Amsterdam
2001–2003
K.R. Apt

FAST – Large-deviations asymptotics and fast simulation
2001–2005
Lucent Technologies, Univ. Twente, Vrije Univ. Amsterdam
M.R.H. Mandjes

Mathematical models of biological and physical processes with self-organized critical behaviour
2001–2005
J. van den Berg

NUMLED – Numerical Methods for Leading Edge Dominated Dynamics
2001–2005
FOM, Univ. Leiden, Ioffe-Institute St. Petersburg, Univ. Amsterdam
U.M. Ebert, W.H. Hundsdorfer

Hierarchical hp-adaptive numerical methods for three-dimensional convection dominated flows (PH 2001)
2001–2005
Univ. Amsterdam, Univ. Delft, MARIN
P.W. Hemker

Extending feasible computation: quantum computing
2000–2003
Univ. Amsterdam, Univ. Twente, Univ. Waterloo, Univ. California, Univ. Chicago, Univ. Politècnica de Catalunya (UPC)
H.M. Buhrman

Dutch-Hungarian cooperation: combinatorial and algebraic structures and algorithms
2001–2003
Univ. Eindhoven
A.M.H. Gerards

Inference for random sets
2001–2005
Univ. Utrecht, Univ. Berkeley, EURANDOM
M.N.M. van Lieshout

CoMoLo – Coalgebra Model Logic: Theory and Applications
2002–2005
Univ. Amsterdam, Univ. Nijmegen
J.J.M.M. Rutten

Universal learning
2002–2005
11 partners across Europe
P.M.B. Vitányi

Numerical modelling of the formation of neuronal connections in the nervous system
2001–2005
Netherlands Institute of Brain Research (NIH)
J.G. Verwer

MOBI-J – Assertional methods for asynchronous channels in JAVA
2001–2004
Univ. Utrecht, Christian-Albrechts-Univ. Kiel
F.S. de Boer

SPP – Discontinuous Galerkin methods and singularly perturbed methods
2002–2004
LLNL Livermore, Univ. Nijmegen, Univ. Amsterdam, Univ. Dresden, Univ. Delft
B. Koren

Dynamic Percolation Phenomena near Criticality (DPP)
2002–2004
Univ. Amsterdam, Univ. Utrecht, Vrije Univ. Amsterdam
J. van den Berg

Complex information retrieval queries in a DBMS
2002–2006
Univ. Twente
A.P. de Vries

Tools and techniques for integrating performance; analysis and system verification
2002–2006
Univ. Eindhoven
W.J. Fokkink

Three-dimensional simulation of phytoplankton dynamics
2002–2006
B.P. Sommeijer

Mathematical aspects of discrete tomography
2002–2006
Univ. Leiden, Univ. Debrecen (Hungary)
H.J.J. te Riele

Networked Adaptive Structured Hypermedia (NASH)
2002–2006
Univ. Eindhoven, SIKS
H.L. Hardman

Special NWO projects

SPINOZA – Logic in action
1997–2002
OZSL, Univ. Utrecht
D.J.N. van Eijck

Enabling quality of service in IP-based communication networks
2001–2005
Univ. Twente
M.R.H. Mandjes

Semidefinite Programming and Combinatorial Optimization (SPCO)
2002–2005
M. Laurent

Geometric numerical methods for continuum mechanics
2002–2005
J.E. Frank

ToKeN2000

Interaction between humans and information systems
1999–2003
Universities of Eindhoven, Maastricht, Delft, Leiden, Nijmegen, and Rijksmuseum Amsterdam
H.L. Hardman

Intelligent Information Retrieval and Presentation in Public Historical Multimedia Databases (I^2RP)
2002–2005
Univ. Groningen, Univ. Leiden, Univ. Maastricht
H.L. Hardman

Medical Information Agent (MIA)
2002–2006
Univ. Maastricht
J.A. La Poutré

Intensive-Care Access to Terminology and Course of Health Exploration and Retrieval (I-Catcher)
2002–2006
Academisch Medisch Centrum, Amsterdam
Z.R. Struzik

Cultural Heritage in an Interactive Multimedia Environment (CHIME)
2002–2006
Univ. Eindhoven, Univ. Amsterdam, Rijksmuseum Amsterdam, National Library of the Netherlands (KB)
H.L. Hardman

STW (Foundation for the Technical Sciences)

Multiresolution image analysis and synthesis
1998–2003
Johns Hopkins Univ., TNO, AKZO-Organon, Thales
H.J.A.M. Heijmans

MOBILECOM: mobile communication networks
1999–2003
Univ. Amsterdam, Vrije Univ. Amsterdam, Univ. Eindhoven, Univ. Delft, KPN, Libertel
R.J. Boucherie

Development of a state-of-the-art Navier-Stokes solver for water flows around moving ships
1999–2003
MARIN
B. Koren

Formal design, tooling and prototype implementation of a real-time distributed shared dataspace
2000–2003
Thales
J.C. van de Pol

Improving the quality of embedded systems by formal design and systematic testing
2000–2003
Weidmüller
W.J. Fokkink

FOM

STREAMERS – Streamer discharges in gases: analysis, simulations and experiments
1998–2005
Univ. Juan Carlos Madrid, Univ. Eindhoven
U.M. Ebert

BARRIER - Pattern formation in barrier discharges
2000–2004
Univ. Münster
U.M. Ebert

SENTER

WATERLAND – Workflow with semi automatic metadata extraction at complete media production in the Netherlands
2001–2005
NOS, TNO-TPD, Univ. Twente, NOB
A.P. de Vries

End-to-End Quality of Service in Next-Generation Networks (EQUANET)
2002–2004
Lucent Technologies, KPN Valley, Univ. Eindhoven, Univ. Twente
M.R.H. Mandjes

Distributed Engine for Advanced Logistics (DEAL)
2002–2006
Almende BV, ERBS BV, Vrije Univ. Amsterdam, Groeneveld Groep BV, Post-Kogeko Transport Groep BV, Vos
J.A. La Poutré

Space-mapping and related techniques for inverse problems in magnetic shape design, with application to an electromagnetic actuator
2002–2007
Univ. Eindhoven
B. Koren

NCF

Parallel implementation of a sparse grid method for time-dependent advection-diffusion-reaction problems
2001–2002
Univ. Delft
B. Koren

EURANDOM

Reinforced random walks on finite graphs
1998–2002
J. van den Berg

Image segmentation with applications to agriculture
1998–2002
Univ. Wageningen
M.N.M. van Lieshout

ICES-KIS Programme

Molecular crowding – mathematical modelling of biochemical processes in living cells
1999–2003
Univ. Amsterdam
M.A. Peletier, J.G. Blom

MIA – Multimedia Information and Analysis
1999–2003
Univ. Amsterdam
M.L. Kersten

Telematics Institute

DMW: Digital Media Warehouse Systems
1998–2002
CTIT, TICO, KPN, Syllogic
M.L. Kersten

SVC: Systems Validation Centre
1998–2002
CTIT, KPN, CMG, Lucent Technologies, TI
W.J. Fokkink

DSL: Domain Specific Languages
1999–2002
ING Bank, Cap Gemini, Lucent Technologies
A. van Deursen

Autonomous Systems of Trade Agents in E-commerce (ASTA)
1999–2003
TNO, ING, KPN, IBM, Bolesian
J.A. La Poutré

Archimate: Architecture Animation
2002–2003
Telematics Institute, Ordina, Univ. Leiden, Univ. Nijmegen
F. Arbab

TOPIA: Topic-based Interaction with Archives
2002
Telematics Institute
H.L. Hardman

KNAW
Statistical methods for compound sums
2000–2004
Gadjah Mada Univ. (Indonesia)
R. Helmers