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

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 Netherlands.

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Colophon
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CWI-AR 2001

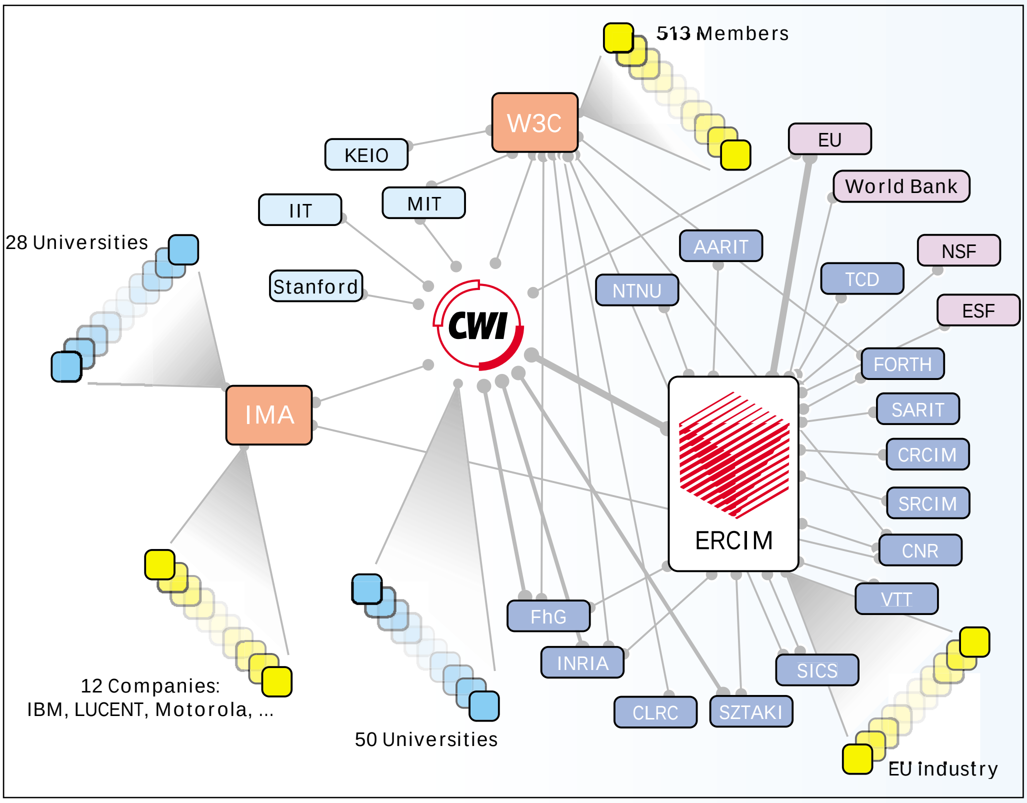
OVERVIEW

The Netherlands is well on its way to becoming an information society, and has the ambition to be at the forefront of these developments. This has certain consequences for research. During 2001 three national reports on ICT-research appeared with cooperation of CWI[1]. They all plead for more government funding for research and for attracting and retaining top talent. This strongly supports the doubling of research capacity suggested by CWI in 2000. The reports also plead for a closer cooperation of knowledge institutions and a stronger interaction between research and trade & industry. This increases the importance of knowledge networks, a development CWI already actively responds to for years. Nationally CWI is a research partner in the Telematics Institute, the Amsterdam Science & Technology Centre (WTCW) and in most research schools in mathematics and computer science. Internationally CWI plays a key role in the prestigious ERCIM (European Research Consortium for Informatics and Mathematics) that includes 10,000 researchers from 15 countries. CWI also maintains excellent relations with numerous international organizations and has a longstanding history as an internet pioneer. This can be retraced in the role the institute is playing in W3C, a consortium in which approximately 500 companies and knowledge institutes all over the world create standards for the Web.
In 2001 CWI again obtained some appealing research results. Record of these can be found in this Annual Report. Here we would like to mention: branching phenomena in gas discharges, signal processing of the fetal heartbeat using wavelets, and large-scale CFD calculations on relativistic magneto-hydrodynamic equations. In addition, twelve researchers completed their PhD thesis and approximately 500 CWI publications were produced. Six new European projects were started with participation of CWI, in the fields of Semantic Web and other web standards (2), image processing (3) and embedded systems. Breakthroughs in research are more and more accomplished on the interface between disciplines and this creates ample opportunities for mathematics and computer science to present themselves in multidisciplinary research. CWI's basic disciplines, for instance, have common ground with life sciences, physics and telecommunication.

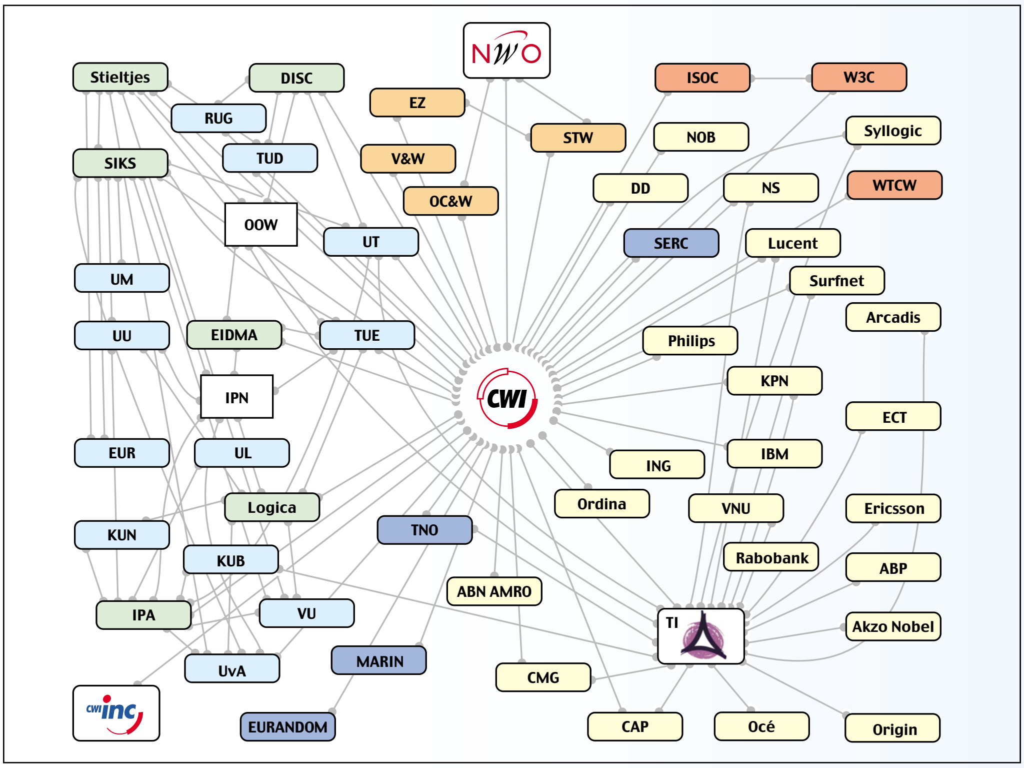
1

1. 'Verlangen naar de eindeloze zee', report by the AWT Verkenningscommissie 'Kennis voor de Netwerkeconomie' (January 2001),
2. 'Samen, strategischer en sterker' by the Task force ICT-en-kennis (July 2001),
3. NOAG-i, the Nationale Onderzoeksagenda Informatica (August 2001).

CWI's relation networks



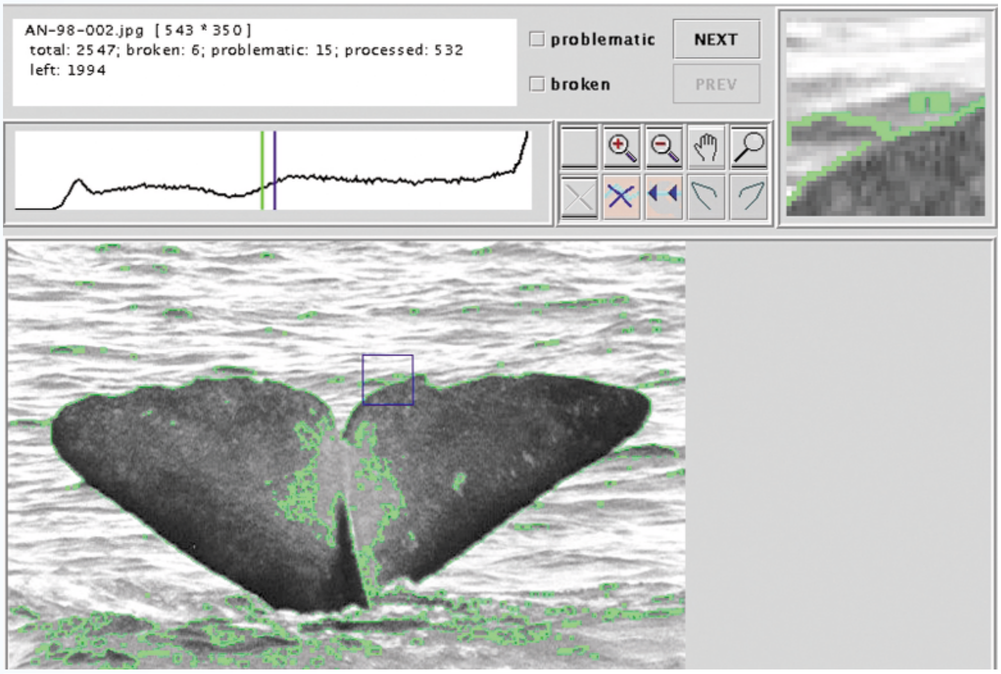
International



National

Interdisciplinary research

An excellent example of CWI interdisciplinary research is the field of life sciences. Among others this contains the 'Silicon Cell' project, aspiring to, eventually, model all processes in a living cell. In this project mathematicians from CWI closely cooperate with biologists from the Universiteit van Amsterdam and the Vrije Universiteit. Additionally, applied mathematical research is done on biological systems like axons, the growth of phytoplankton in oceans and on the exchange of particles in biofilms (a layer of bacteria) that can be damaging to drinking water and therefore have to be avoided.



Recognition and extraction of a contour from a sperm whale fluke.
Illustration programme: CWI. Photo of the fluke: J.N. Ciano, Bleik Canyon, Norway.

Interacting with biology virtual reality techniques were applied in cell biology. A new pilot research theme was started in the field of visualization and virtual reality. Interactive data visualization enables researchers to immediately see what happens when they change their model, for instance while researching large molecules like proteins. Worth mentioning are the 3D user interfaces this group is developing. The great advantage of this CWI approach is the use of standard PC equipment, no expensive equipment is needed. Many universities have already shown a keen interest.
Another two interdisciplinary research groups were prepared: 'Advanced Communication Networks', acting upon the rapid developments in broadband Internet and mobile communication and 'Nonlinear Dynamics and Complex Systems', on the interface between mathematics and physics, initiating research on pattern formation in low temperature plasmas. Possible applications for this research are ultrafast power semi-conductor switches and flat computer screens.

Cooperation: CWI as junction in a knowledge network

Interdisciplinary research, both nationally and internationally, considered of the utmost importance, entails cooperation with other organizations. Therefore, the

Computational Magnetohydrodynamics in Special Relativity

A gamma-ray burst hit the Italian-Dutch Beppo-SAX satellite for about 80 seconds on February 28, 1997 (Figure 1). Its monitor accurately measured the position of the burst, and within eight hours the spacecraft's x-ray telescope found a rapidly fading source of x-rays on the spot. Never before a burst had been pinpointed so accurately and so quickly. Subsequent observation with the powerful Hubble Space Telescope in the optical domain revealed a bright spot surrounded by a somewhat elongated background object (Figure 2). The latter is believed to be a galaxy. If so, it must be near the edge of the observable universe, and the gamma-ray burst represented the most powerful explosion observed thus far. Such bursts emit within the span of minutes or even seconds more energy than the Sun will in its entire life. Since their (accidental) discovery in the late 1960s, their origin and incredible energy remain a mystery. One scenario is a collapsing binary neutron star system, where gravitational energy is converted into kinetic energy of an expanding cloud of protons moving at relativistic speeds. Gamma rays are then generated by electrons accelerated by the intense electromagnetic fields occurring in shock waves. These waves result from collisions inside the proton cloud as well as with the surrounding gas. This scenario with shock waves implies that gamma-ray bursts are followed by long afterglows of x-rays and visible light. The burst of February 1997 provides strong evidence for such a tail.

Since experiments are impossible, insight into the nature of gamma-ray bursts can only be attained by solving the full relativistic equations of magnetohydrodynamics (MHD). At CWI the Computational Fluid Dynamics group addresses this problem, with partners at the University of Utrecht (Astro-Plasmaphysics) and the Institute for Plasma Physics in Rijnhuizen (Numerical Plasma Dynamics). As a first step, a computational method is developed for the relativistic equations of gas dynamics, which form a system of hyperbolic partial differential equations. A tailor-made discretization will take into account the different propagation velocities of rarefaction waves, shock waves, and contact discontinuities. An approximate Riemann-solver will be derived, as well as a staggered-grid approach. These two methods will be tested against a highly relativistic spherical explosion, for which an exact solution exists, thus serving as a severe numerical benchmark. After having passed this test, and a few others, electromagnetic effects will be incorporated and the second step of solving the relativistic MHD equations will be made. This system of equations is still hyperbolic, but its wave patterns are more complex. For its numerical solution approximate Riemann solvers and a staggered-grid approach will be developed as well. CWI's research contribution is crucial for the further development of large-scale computer codes in astrophysics.

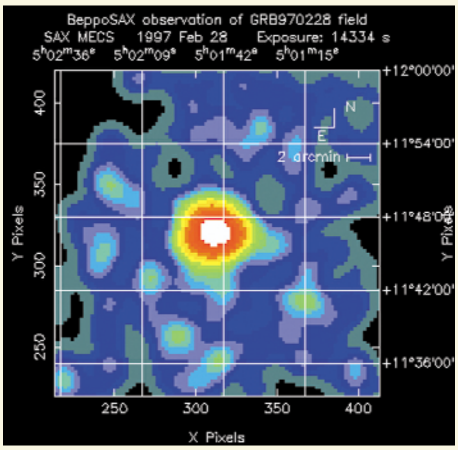


Figure 1. Gamma-ray burst GRB970228.
Beppo-SAX team, Agenzia Spaziale Italiana, ESA.

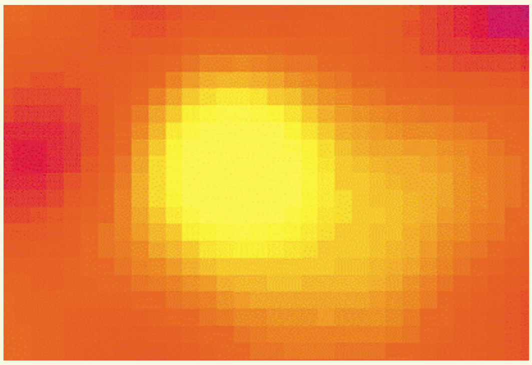


Figure 2. GRB970228 housed in a galaxy?
Team of J. van Paradijs, Hubble Space Telescope, NASA.

European Union and the Dutch government both stimulate the formation of knowledge networks. An excellent example of such a knowledge network is ERCIM, the European Research Consortium for Informatics and Mathematics, in which CWI plays an active role and, at present, fills the presidency. In 2001 ERCIM initiated co-operation with the European Science Foundation and the National Science Foundation in the United States. CWI actively participates in various ERCIM research working groups, including new working groups in the fields of e-learning and e-commerce.
Human capital gains interest, especially the scouting for young talent. For quite some time now ERCIM has a highly successful exchange programme for young researchers. In 2001 six young researchers worked at CWI as ERCIM Fellows. ERCIM can play a significant role in the education of young talent from outside Europe. As part of this programme ERCIM started an HRM Taskforce, assigned to increase international mobility and to stimulate talent from outside Europe.

ERCIM president Gerard van Oortmerssen presents the Cor Baayen Award 2001 to Phong Q. Nguyen (ENS Paris). The award is given annually to a postdoctoral researcher in one of the 'ERCIM countries'.

Within the European Union ERCIM attracts growing attention. The European Commission has launched a plan to create a European Research Area (ERA) in which networks of excellence play a key role. ERCIM serves as a model for these networks of excellence. ERCIM is very positive about the plan to form an ERA and is willing to play an active part in its formation. Within ERCIM plans are made for participation in the 6th Framework Programme.
ERCIM aims at being an open network where national members act as a junction for their country. Through this junction researchers other than from ERCIM-institutes can participate in ERCIM working groups. This entails that Dutch researchers can contact CWI about participation in ERCIM-activities.

CWI also plays an active role in W3C, the international World Wide Web Consortium that designs standards for the Web. Not a surprise, considering the pioneer role CWI played in the early days of the Internet. Technically CWI contributes considerably to SMIL and XHTML. SMIL is the latest multimedia standard for the Web. XHTML forms the bridge between HTML – the lay-out standard for webpages – and

Phytoplankton dynamics -- the struggle for light

It seemed an attractive idea. Collect our scrap iron, and feed it to the tiny organisms in the oceans called phytoplankton. They love it and their population will grow on it. They love carbon dioxide too, extracting it from the atmosphere (the present intake is several gigatons per year). This carbon is transported downward by sinking phytoplankton species, and will eventually end up 'in the deep bosom of the ocean buried' – a mechanism called 'Biological Pump' (Figure 1) . Thus two birds would be killed with one stone: disposal of industrial waste and reduction of the greenhouse effect. Alas, the idea lasted as long as it remained qualitative. At CWI a mathematical model was developed, jointly with the University of Amsterdam (research group on Aquatic Microbiology), that describes the dynamics of phytoplankton. The model is fairly realistic because it incorporates the most essential mechanisms. One of the studies with this model explains the recent field observation that iron fertilization fails to enhance carbon export to the deep ocean.

Phytoplankton is a generic name for a great variety of micro-organisms (algae) that live in lakes and oceans. Modelling its dynamics is of great interest, since phytoplankton provides the basis of the food chain.

Phytoplankton requires light for photosynthesis. In a water column, light intensity decreases with depth, due to absorption. As a result, the phytoplankton production rate, which is determined by the local light intensity, decreases with depth. Furthermore, mortality rates and transport by turbulent diffusion in a water column (mixing) play a role. Also, phytoplankton species often have a specific weight different from that of water, giving rise to vertical transport in the form of sinking or buoyancy. All these processes are incorporated in an integro-partial differential equation of advection-diffusion-reaction type describing the population dynamics of phytoplankton. On the basis of this model we developed both analytical and numerical tools for several studies. One result is that the long-term survival of a particular phytoplankton species ('bloom development') crucially depends on the mixing rate, the water column depth and the vertical velocity. Another result is that the maximal sinking velocity of phytoplankton that can be sustained is inversely proportional to the water turbidity. Hence the downward flux of phytoplankton biomass is very different for clear and for turbid water, explaining why iron fertilization does not enhance downward carbon transport (Figure 1). Since there are thousands of different phytoplankton species, slowly drifting in lakes and oceans (Figure 2), a natural extension of the model is to systems in which various species are competing. Buoyant species seem to have an advantage over sinking species since they can easily reside in the well-lit upper zone close to the water surface, and hence capture a lot of light. Moreover, they have the additional advantage to shade other species at deeper levels. Nevertheless, as it turns out, the balance between survival and death for the various species is very delicate and depends on values of other parameters as well, such as background turbidity, incident light intensity, and specific light attenuation coefficients of the different species.

(http://www.cwi.nl/projects/plankton)

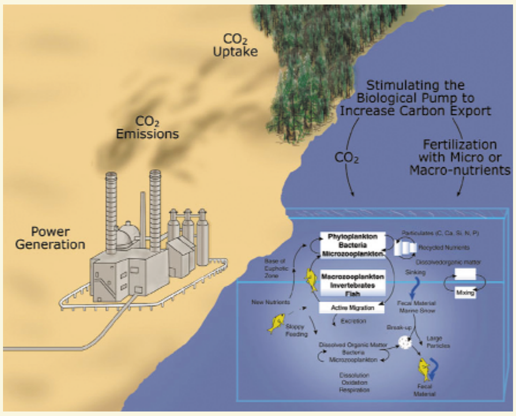


Figure 1. The Biological Pump.

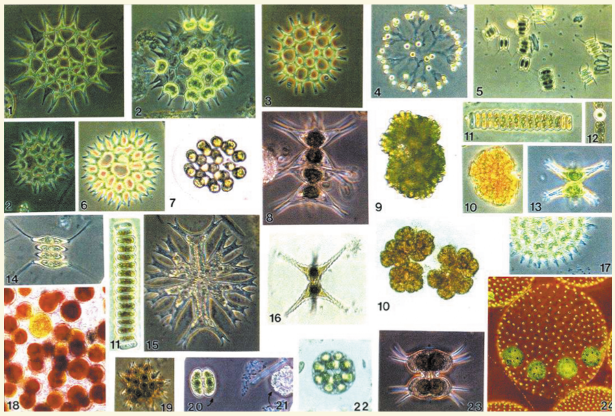


Figure 2. Phytoplankton. ©Gertrud Cronberg

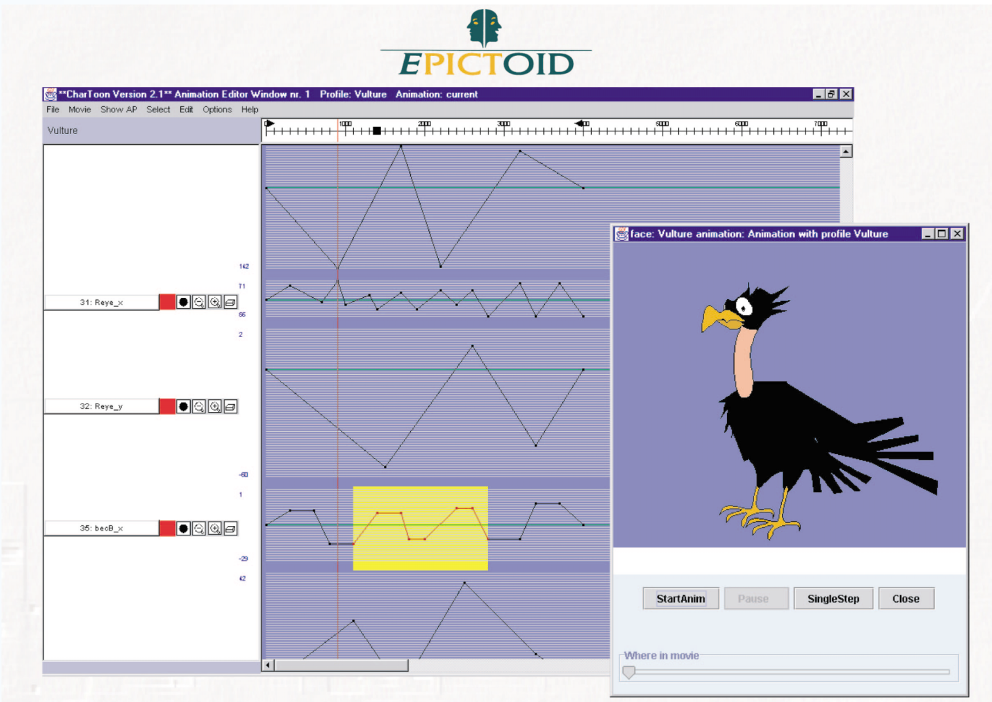
XML, used to structure data. Steven Pemberton, CWI employee, is chairman of the international XHTML and Xforms working groups. Knowledge transfer to future users is realized through W3C offices in various countries. These offices, twelve at this moment, are coordinated by Ivan Herman, researcher at CWI. The W3C Office in the Netherlands is managed by CWI. In 2001 the Dutch office started cooperation with ISOC.nl, the Internet Society Nederland. An interesting combination since both organizations have complementary working fields. Jointly they organized three successful masterclasses, on XML, the Semantic Web, and SMIL.

From 2000 CWI participates in IMA, the Institute for Mathematics and its Applications in Minneapolis. Through CWI other Dutch researchers can also participate in IMA. Additionally, a closer cooperation was effected between CWI and the Indian Institutes of Technology in Delhi and Bombay, resulting in seven Summer Internships. Both researchers and interns were very satisfied with this arrangement.

CWI participates in the Dutch Telematics Institute in the fields of software engineering, multimedia databases, verification of software, and trade agents. CWI is also a research partner in the WTCW (Amsterdam Science & Technology Centre), a cooperation of scientific institutes on the campus of the Science Park also including companies.

Knowledge transfer

February 2001 saw the creation of a new spin-off company: Epictoid. This company is going to market results of recent CWI research on facial animation. Epictoid develops tools for computer animation based on a new principle. This enables the animator to create an animation from moving objects. Epictoid mainly focuses on the technology to create virtual actors and to let them act. Spring 2002 their first product, CharToon, will appear on the market. Earlier research on this was done at CWI within the framework of an STW project.

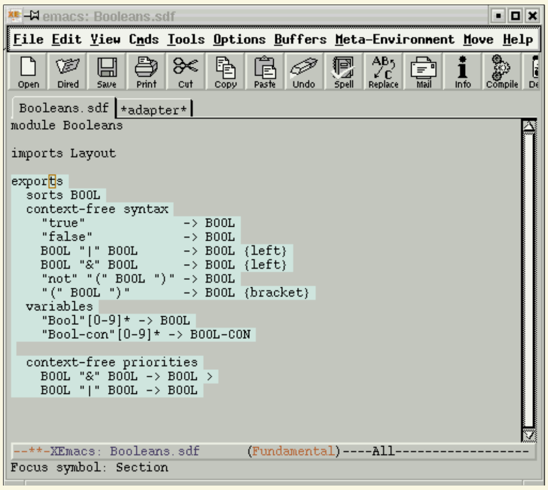


Epictoid's animation editing tool CharToon.

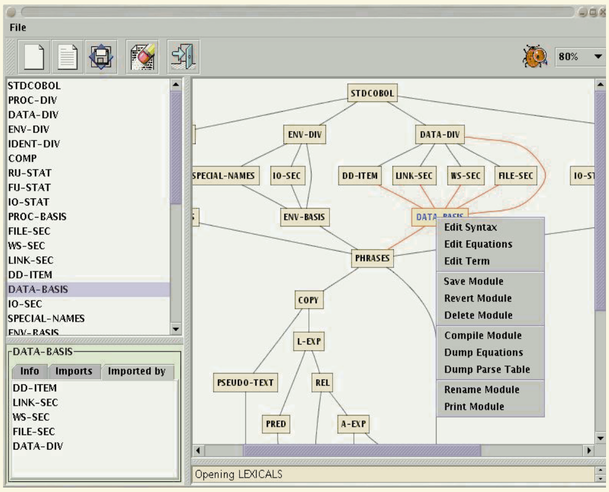
Generic Language Technology

In the Generic Language Technology (GLT) project, a methodology is developed to manipulate (program) texts in a language independent manner. It consists of a collection of tools/components such as parsers, analysers, transformers, translators, and unparsers, which are independent of a specific (programming) language. The language for which a tool should work is a parameter: based on a description of the syntax and semantics of a language, a tool is either generated or instantiated. These tools/components can be used independently as well as in an integrated environment. The GLT project aims to provide a collection of sophisticated components enabling maximal flexibility and reuse. It started in 1984 with the ESPRIT project GIPE (Generation of Interactive Programming Environments). Its main results were the language definition formalism ASF+SDF, and an integrated programming environment, the ASF+SDF Meta-Environment. In ASF+SDF, a Syntax Definition Formalism (SDF) is used to define the lexical, concrete, and abstract syntax of a (programming) language, and an Algebraic Specification Formalism (ASF) to define the semantics of a language by means of algebraic equations. These equations can be executed by interpreting them as rewrite rules. The ASF+SDF Meta-Environment contains structure editors, interpreter, debugger, compiler, and a pretty printer. Applications include the prototyping of languages (e.g., domain specific languages), and of software components in general (e.g., a pretty printer generator and a compiler for ASF+SDF to C code), as well as software renovation. SDF was able to describe old languages like COBOL, but in software renovation various limitations of the implementation of the ASF+SDF Meta-Environment were revealed. Redesign, completely based on software component technology, resulted in an open, extensible architecture, enabling easy generation of stand-alone environments. Its ingredients are:
- The ToolBus, a programmable software coordination architecture.
- The ATerm library, for efficient manipulation of (annotated) terms. Characteristic features are maximal subterm sharing and automatic garbage collection.
- The Scanner-less Generalised LR parser, which can handle arbitrary context-free grammars and does not use a scanner to tokenize the input string, and a parse table generator, which can deal with modular context-free grammar definitions.
- Efficient rewriting technology.

Each ingredient can also be used outside the new ASF+SDF Meta-Environment. ATerm library and parsing technology are quite reusable, and are applied worldwide. The Meta-Environment itself is used both in industry and in academia. The editor is a standard Xemacs editor that communicates with a structure editor via the ToolBus. Next to ongoing development of generic tools/components, including debuggers, the goal is to make the ASF+SDF Meta-Environment itself generic. Ultimately, ASF+SDF will become a parameter of this environment and we will obtain a truly generic Meta-Environment that can be used to construct Meta-Environments for a wide range of specification formalisms.
(http://www.cwi.nl/projects/MetaEnv/)



Syntax directed editing of a grammar specification.



User interface of the new Meta-Environment with a Cobol grammar.

On August 9, 2001 the Supervisory Board of CWI Incubator B.V. was appointed. Members are B. Elkerbout (chairman), Ir. E. Boeve (SATAMA), and Dr. A. ten Wolde (VNO-NCW). CWI Inc. was founded in July 2000 in order to create a visible structure for a systematic stimulation of knowledge transfer to society by way of spin-off companies, based on research done at CWI. One of the appointed tasks for the members of the Supervisory Board is to advise founders of new spin-off companies.

In the Summer of 2001 the CWI research group Evolutionary Systems and Applied Algorithmics proposed a patent with KPN research to effectively assign consumer attention space (banners) on e-commerce websites. Intelligent adaptive software agents bid for consumer attention in consecutive auctions and are able to quickly adapt their bidding strategy in order to concentrate on customers interested in their offers.

Appointments

This year four CWI-researchers were appointed professor: Wan Fokkink, Han La Poutré, Lynda Hardman, and Jan Rutten, all theme leaders. The about twenty professors employed at CWI ensure a good working relation between CWI and the universities. CWI plays an important role in turning young successful researchers into professors of mathematics and computer science.
At the end of the year Jaco de Bakker and Piet Hemker were appointed CWI Fellow (the first CWI Fellow was Piet van der Houwen). Paul Klint succeeded Jaco de Bakker as head of the cluster Software Engineering. The theme led by Piet Hemker, Computational Fluid Dynamics, was slightly adjusted and now goes under the new name of Computing and Control, headed by Barry Koren.

New name for Stichting Mathematisch Centrum

On August 1, 2001 the Stichting Mathematisch Centrum (SMC) changed its name into Stichting Centrum voor Wiskunde en Informatica. In 1946 six professors founded the Mathematisch Centrum (Mathematical Centre, MC) in order to help rebuild the Netherlands after WW II. From 1983 the field of computer science was included in the name, thus becoming Centrum voor Wiskunde en Informatica (Centre for Mathematics and Computer Science, CWI). Formally, however, the name was still SMC. It was now considered time to choose an unequivocal name.
CWI is still conscious of its roots in the Mathematical Centre and the pioneering work done by its employees. In its lifetime the Mathematical Centre built a great name for itself in the Netherlands and in the world. This was based on its fundamental and applied research in mathematics and computer science, the creation of one of the first Dutch computers, its contributions to programming languages like ALGOL60 and ALGOL68, and the implementation of the first civil European internet site.

The year from month to month

Fundamental and applied research is the core activity of CWI. In addition, knowledge transfer is important. This is accomplished in several ways, including the organization of various scientific events. During the year CWI organized five scientific conferences (as main organizer), the annual Summer school for teachers of mathematics (in Eindhoven and Amsterdam), three master classes in web techniques for ICT-people, two days of workshops for specialists from trade & industry, a meeting on broadband developments, a trade & industry day (CWI in Bedrijf), and a day for the public (both annual events), and it contributed to a large number of scientific conferences and exhibitions. A number of them are specified in the survey below.

January

Group picture of the QIP congress January 9–12

QIP 2001: 'Fourth Workshop on Quantum Information Processing'
Quantum information processing is an interface between quantum mechanics and computer science. Its goal is to improve traditional computers by using principles from quantum physics. As a traditional computer works with bits, the quantum computer works with quantum bits. A quantum bit can be in states 1 and 0 at the same time. In theory, quantum computers can solve computational problems much faster than the traditional ones. A quantum computer can, very efficiently, factor large numbers into primes. This might have enormous consequences for the security of internet traffic. In Amsterdam CWI organized a workshop where many heavyweights in this promising field were present. Among the speakers were Charles Bennett and David DiVicenzo (IBM), Gilles Brassard (Montréal) and Nobel Prize winner Gerard 't Hooft (Utrecht). The conference was sponsored by the QAIP project of the European Union.

In January 2001 CWI expanded into a new annex, housing 55 researchers.

March

From March 4 to 9 the First Global Grid Forum was organized by WTCW (Amsterdam Science & Technology Centre) in which CWI also participates. Grids are the computer networks of the future. Computer capacity from grids should eventually become as common as, for instance, the electricity grid. That explains the name, derived from 'power grid'. CWI already used grids in 1999 for breaking the RSA-512 code for securing internet traffic. The Grid conference was an enormous success: over 450 researchers from all over the world came to discuss this important new development. It was a first for American initiatives to be combined with those from Europe and Asia.

On March 17 the Dutch government launched the project 'Drempels weg!' (No more thresholds!) to make the World Wide Web accessible to handicapped people. The accessibility guidelines of W3C were used as a basis. The W3C Office in the Netherlands at CWI contributed to the onset and the contents of this large-scale campaign. Judy Brewer, director of the W3C Web Accessibility Initiative, was one of the keynote speakers. Through the W3C office she was able to contact Minister Van Boxtel and Secretary of State Vliegenthart personally to stress the importance of web standards for an accessible WWW.

Minister Van Boxtel and Secretary of State Vliegenthart speaking with Judy Brewer (W3C) during the manifestation.

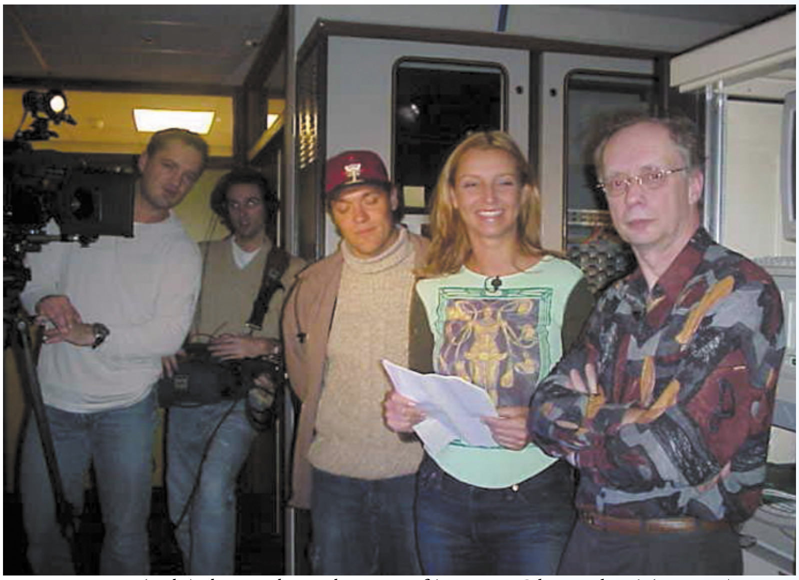
On March 23 CWI employee Ben Schouten, mathematician and artist, obtained his doctorate on the thesis 'Giving eyes to ICT! Or: How does a computer recognize a cow?' Schouten developed a visual system where the computer thinks along with a customer in order to get the desired results quickly. This system offers great opportunities, for instance, for shopping on the Internet, where visual images are indispensable. Secretary of State for Culture, Rick van der Ploeg, was a member of the doctoral committee.

From Ben Schouten's PhD thesis on image recognition: the search action 'pinkish with five digits' produces one remarkable result.

At the end of March Harald van Brummelen, PhD student at CWI, received the Bill Morton Prize at the University of Oxford for his article 'Adjoint shape optimization for steady free-surface flows'.

April

On April 19 and 20 the Dutch Mathematical Congress (NMC) took place, organized by CWI and the Vrije Universiteit in Amsterdam and sponsored by the Dutch Mathematical Society. Over 200 visitors attended the four main lectures and eleven mini symposia. The NMC is a perfect place for young mathematicians to present themselves to the Dutch mathematics community.



Piet Beertema (right) during the tv shootings of 'De Digit@le Revolutie' (Yorin tv).

On April 25, 2001 it was fifteen years ago that .NL was registered as the first country domain in the world. This was done by CWI, in the person of Piet Beertema, who filled a key role in Eunet, the predecessor of the European Internet. The first domain he registered under .NL was CWI.NL, consequently this domain celebrated its fifteenth anniversary. For ten years Piet Beertema remained in control of .NL, until the Foundation Internet Domain registration Nederland (SIDN, Stichting Internet Domeinregistratie Nederland) came into existence in 1996. Beertema is now a board member of this Foundation.

May

Spring 2001 CWI and the University of Amsterdam started preparations for the fourth Dutch Study group Mathematics with Industry 2002. In the timeframe of one week, about sixty mathematicians from all over the Netherlands will try and solve problems from trade & industry. One surprising problem was proposed by the popular scientific magazine Natuur & Techniek: How many French and German euro coins will you have in your wallet by the end of 2002? In order to supply data for the mathematical models it was decided to organize a series of experiments, whereby high-school pupils and volunteers measure the distribution of euro coins. Other problems that were collected dealt with data compression, optimal rose cultivation, cooling of the Amsterdam Zoo aquaria and placing components on filled computerchips. By showing what mathematics can offer, the mathematicians hope to intensify contact with trade & industry.

In memoriam Prof. Dr. J.J. Seidel (1919–2001)

Former governor Prof. Dr. J.J. Seidel passed away on May 8, 2001. Professor Seidel entered the board of governors of the Stichting Mathematisch Centrum (SMC) in 1978. In 1980 he succeeded Ir. E.F. Boon as chairman; in 1984 he retired. Some important events that took place under his governorship were the management chan ge in 1980, when A. van Wijngaarden was succeeded by P.C. Baay-en as scientific director and J. Nuis as managing director, and the change of the name Mathematisch Centrum (Mathematical Centre) into Centrum voor Wiskunde en Informatica (Centre for Mathematics and Computer Science) in 1983. His significance to SMC is clearly depicted in the following fragment from the Jaarverslag (annual report) 1984 of the SMC: “A special word of appreciation for Prof. Dr. J.J. Seidel cannot be omitted. In unsettled times, in which the responsibilities of the Foundation were expanded consi derably by adding national duties, and in which the basis was laid for a good working relationship with the Dutch Stichting Informatica Onderzoek (Foundation Computer Science Research) in the making, he did not only chair the board of governors meetings with wisdom and patience, but he also assisted the newly appointed directors in finding and keeping the right direction.”

June

From June 18 – 23 three international working groups of the World Wide Web Consortium (W3C) gathered at CWI to develop future formats for the Web. The working groups focussed on XHTML, Xforms and Web-accessibility (WAI). XHTML is becoming the new standard text language for the Web, Xforms is a format of importance to e-commerce, and Web-accessibility for handicapped people is of growing interest in the present information society.

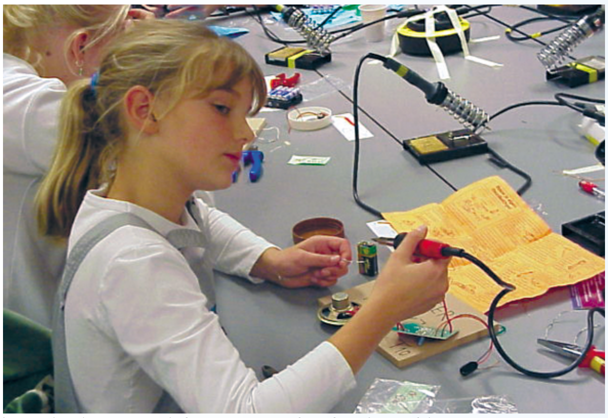
August

SMIL 2.0 became an official W3C Recommendation on August 7, 2001. SMIL is the language that choreographs audio, video, text and images in multimedia presentations. An example of a SMIL Player is the now frequently used RealPlayer. CWI-researchers have contributed considerably to SMIL 2.0 and its predecessors.
Together with ISOC.nl, the W3C Office in the Netherlands organized a SMIL master-class in the Hague on September 5. The topic of the masterclass was also GR*i*NS, a technology playing and editing SMIL.

October

Friday, October 5th, CWI organized the annual event ‘CWI in Bedrijf’ to share the latest developments in CWI-research. This year’s theme was Knowledge Networks. In a knowledge economy an intensive cooperation between knowledge institutions and companies is of great importance. Research results should hit the market quickly, and researchers should be inspired by real-life connections. Maintaining several flexible networks between companies and knowledge institutions gains importance. Over a hundred visitors could inform themselves about recent research developments, like multimedia, the Semantic Web, embedded systems, software transformation, telecom networks, intelligent agents and research on the interface between mathematics and life sciences.

CWI actively tries to attract the attention of a wide audience to mathematics and computer science. It is very important to kindle enthusiasm in young people, especially at a time when the number of students in exact sciences drops dramatically. For this reason CWI sponsors ‘Vierkant for Wiskunde’ and participates in the ‘WTCW day for the public’, held on the national science day (October 7). With reference to the theme ‘nutrition’ CWI demonstrated bending beer tins: if a tin is loaded carefully, a peculiar kind of wave pattern originates that can be described mathematically. There also was a game called ‘Build the best parcel’. The WTCW day for the public was visited by about 2000 people.



The ‘Build the Best Parcel’ contest and the girls’ electronics lab on CWI’s day for the public.

November

On November 30 Mart de Graaf received the Civi-Prize for industrial research with his thesis ‘The Quantum Yao Principle’. His research was performed at CWI. The prize amounted to 25,000 Dutch guilders. Although the topic of his thesis, quantum computing, is very fundamental in nature it surprisingly did qualify for the industry prize! Mart de Graaf graduated at the Universiteit van Amsterdam under Prof. Dr. Harry Buhrman, meanwhile he came to work in his group at CWI as a PhD student.

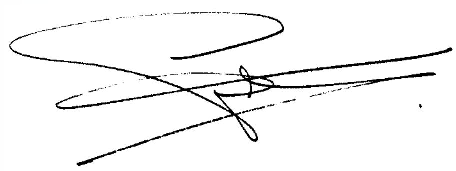
In conclusion

During the second half of the year many large projects were prepared. CWI actively joined the new ICES-KIS rounds of the Dutch government by submitting a number of expressions of interest. In 2002 definite project proposals have to be specified that hopefully can start in 2003. Additionally, dozens of research proposals were prepared for submission in 2002. Earlier plans were prepared within WTCW to develop the area to metropolitan level.

Also in 2001 CWI succeeded in producing appealing results. CWI manages to create a climate where creativity and innovation are stimulated, and it has a strong knowledge network at it's disposal. This strength, combined with a healthy dose of fundamental and applied research, enables CWI to keep on playing an important role in research and society.

Gerard van Oortmerssen

General Director CWI



Compositional Connectors for Coordination of Components

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Introduction

In building a software system out of a number of components, proper communication of a component with its environment is of paramount importance. Several communication models have been proposed. A promising approach is to base the model on the notion of 'channel', a primitive construct providing the basic temporal and spatial decouplings of communicating parties required for the coordination of computing processes. At CWI considerable effort has been put into the development and utilization of a channel-based coordination model (IWIM and its incarnation, the Manifold language) over the past ten years. A new model Ρεω *(Greek for 'I flow', pronounced 'Reo') developed in 2001 uses a generalized notion of channel, enabling dynamic changes in the topology of the connections among components as well as mobility of components and channels preserving that topology. The model is used for the coordination of concurrent, distributed computing processes, and has attracted industrial interest. Applications include dynamic, mobile computing as envisaged in the next generation telecommunication networks.*

Glue code

Modular design and construction of software involves modules that rather intimately know and rely on each others' interfaces; they fit together like pieces in a jigsaw puzzle. In contrast to modules, however, software components are expected to be rather independent of each other and their environment. Because modules are allowed to depend to a certain extent on their environment, the provisions for their interfacing can be designed inside a module. However, if the functionality of a module is to be supported by a component instead, the bulk of this interfacing must be left out of these components, because provisions for interfacing of a component depend on the context wherein it is deployed and the other components that it may interact with.
Thus system components typically do not exactly fit together: significant interfacing gaps must somehow be filled with additional code. Such specific 'glue code' is often written in simplified *scripting languages*. This code is inherently not different from other software, and generates the same problems if systems become more complex: the bulk of specialized glue code also grows in size and rigidity, rendering the system hard to evolve and maintain, in spite of the fact that this inflexible code wraps and connects reusable, maintainable, and replaceable components.

Channels

An alternative is to construct the glue code compositionally on the basis of *channels*. A channel is a point-to-point medium of communication with its own identity and two distinct ends. Channels can be used as the only primitive constructs in communication models for concurrent systems. Like the primitive constructs in other communication models, channels provide the basic temporal and spatial decouplings of the parties in a communication, which are essential for explicit coordination. Channel-based communication models are 'complete' in the sense that they can easily model the primitives of other communication models (e.g., message passing, shared spaces, or remote procedure calls). Furthermore, channel-based models are architecturally expressive and have some inherent advantages over other communication models, especially for concurrent systems that are distributed, mobile, and/or whose architectures and communication topologies dynamically change while they run.

These characteristics make channel-based models attractive from the point of view of coordination. Dataflow models, Kahn networks, and Petri-nets can be viewed as specialized channel-based models that incorporate certain basic constructs for primitive coordination. IWIM is an example of a more elaborate coordination model based on channels, and Manifold is an incarnation of IWIM as a real coordination programming language that supports, e.g., dynamic reconfiguration of Kahn network topologies (which are static). Common to these models is a notion called 'exogenous coordination' in IWIM: actions of entities are coordinated from outside. In dataflow models, for example, the internal activity of a node is synchronized with the rest of the network by its input/output operations. IWIM and Manifold allow much more sophisticated exogenous coordination of active entities in a system.

Future mobile telecommunication is characterized by a complex interplay between concurrent distributed computing processes. Its proper handling requires a highly flexible description of such processes. CWI is developing and utilizing coordination languages and tools for this purpose. (Photo: Dutch Telecom's newest interactive mobile device 'Imode™'. Courtesy KPN.)

Pεω

Pεω is a new channel-based exogenous coordination model developed at CWI. It is based on a calculus of channels, which provides the framework for coordinating complex computing processes in a distributed, dynamic setting, for example mobile telecommunication. In *Pεω* complex coordinators, called *connectors* are compositionally built out of simpler ones. The simplest connectors in *Pεω* are an arbitrary set of channels with well-defined behaviour. *Pεω* is based on the notion of mobile channels, and only deals with connectors and their composition, not with the entities that connect to, communicate, and cooperate through these connectors. Each connector in *Pεω* imposes a specific coordination pattern on the entities (e.g., components) that perform I/O operations through that connector, without the knowledge of those entities.

Channel composition in *Pεω* is a very powerful mechanism for construction of connectors. For instance, we have shown that exogenous coordination patterns that can be expressed as regular expressions over I/O operations can be composed in *Pεω* out of a small set of only five primitive channel types. Work by Jan Rutten (CWI) on a formal semantics for *Pεω* based on coalgebra is aimed to define the channel calculus underlying *Pεω*, and enables the development of the verification and optimization tools to support a practical connector construction framework using *Pεω*. Channels in *Pεω* have exactly two directed ends, each with its own identity: a *source* end that accepts data, and a *sink* end that dispenses data. Only channel end identities (rather than channel identities) are used to refer to and manipulate channels and the data they carry. Every channel receives at its creation time a filter which restricts the set of values that can flow through that channel.

The most important notion in *Pεω* is channel composition through the operation of join, and its inverse split. The join operation combines multiple channel ends into a *node*. Specific semantics define the reading from and writing to these nodes. Nodes synchronize, merge, and fork flows of data, with the side-effect of coordinating the entities that perform those read and write operations. The cornerstone of exogenous coordination in *Pεω* is the subtle timing constraints imposed by the semantics of its composition operator on the channel ends that coincide on a node. A novelty in Rutten's coalgebraic semantics is the simple way in which it captures these constraints through the notion of time streams as twins of their respective data streams.

Examples

The coordination mechanism in *Pεω* is the synchronization inherent in the semantics of nodes. Intuitively, a mixed node non-deterministically selects an eligible data item available through its coincident sink channel ends, removes it, and replicates it into all of its eligible coincident source channel ends, whenever they are all ready to be written to. For example, the following piece of code creates three synchronous channels and joins the source ends of two of them with the sink end of the third, yielding the simple connector shown in Figure 1(a) on the next page.

```
<a, b>  = create(Sync)
<c, d>  = create(Sync)
<e, f>  = create(Sync)
join(b, c)
join(b, e)
```

This connector shows a basic form of exogenous coordination: the number of data items flowing from ab to cd equals the number of take (i.e., destructive read) operations that succeed on f. Thus the data flow is regulated by an entity that need not know anything about the entities that write to a and/or take from d, nor need the latter two entities to know that they are communicating with each other, or that timing and volume of their communication are regulated. *Pεω* allows a rich set of channel types, some of which may at first appear rather unconventional. For instance, FIFO*n* represents an asynchronous FIFO channel that has a source and a sink end with the bounded capacity of *n* data items. SyncDrain is a lossy synchronous channel that has two source ends only, ensures that the two write operations on its two source ends succeed simultaneously, and loses all data items written to it.

As another example, consider the connector in Figure 1(b). The enclosing box represents the fact that the details of this connector are abstracted away and it provides only

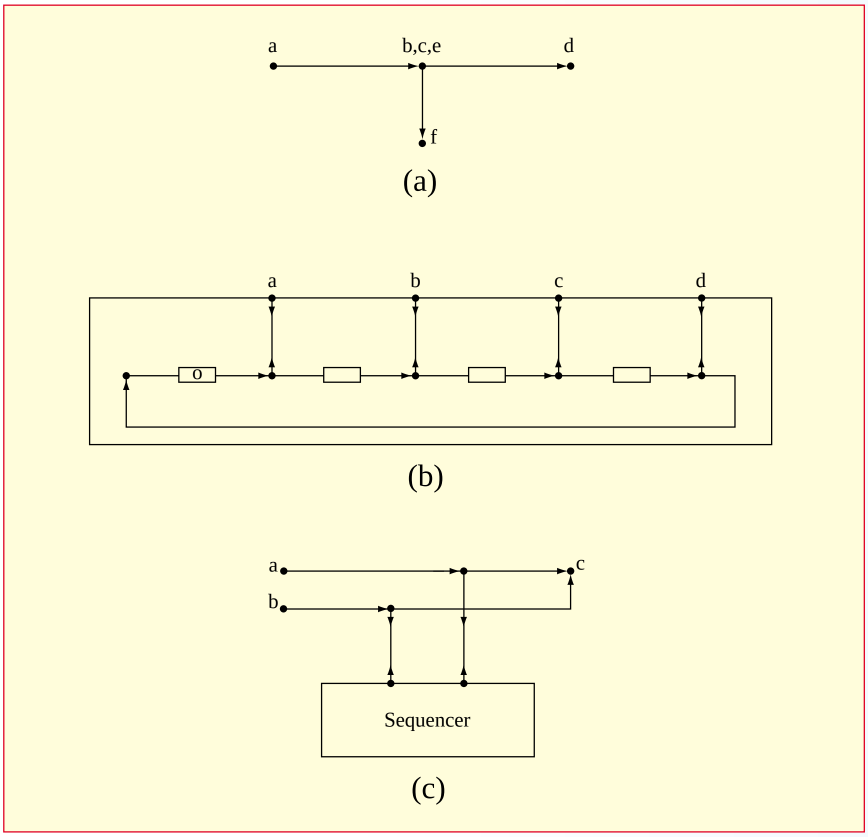

Figure 1.

the four nodes a, b, c, and d for other entities (connectors and/or component instances) to (in this case) take from. Inside this connector, we have four Sync and four FIFO1 channels connected together. The first (leftmost) FIFO1 channel is initialized to have a data item in its buffer, as indicated by the presence of the symbol 'o' in the box representing its buffer. The actual value of this data item is irrelevant. The take operations on the nodes a, b, c, and d can succeed only in the strict left to right order. This connector implements a generic sequencing protocol: we can parameterize this connector to have as many nodes as we want, simply by inserting more (or fewer) Sync and FIFO1 channel pairs, as required. What we have here is a generic *sequencer* connector.

Figure 1(c) shows a simple example of the utility of our sequencer. The connector in this figure consists of a two-node sequencer, plus a pair of Sync channels and a SyncDrain channel connecting each of the nodes of the sequencer to the nodes a and c, and b and c, respectively. It imposes an order on the flow of the data items written to a and b, through c: the items obtained by successive take operations on c consist of, successively, the first item written to a, the first item written to b, the second item written to a, the second item written to b, etc. We can summarize the behaviour of our connector as $c = (ab)^*$: the sequence of values that appear through c consist of repetitions of the pairs of values written to a and b, in that order. The *a* and the *b* in the expression $(ab)^*$ do not represent specific values; rather, they refer to the write operations performed on their respective nodes, irrespective of the actual data items that they write. In other words, the expression $(ab)^*$ is not a regular expression over values, but rather a meta-level regular expression over the I/O operations that produce streams of values on their respective nodes.

Dynamics and mobility

These examples show the key role of timing in the semantics of nodes in *Pεω*. They also demonstrate the intuitive ease with which in *Pεω* connectors can be constructed, represented, and understood graphically, suggesting that a visual programming paradigm is the most natural support environment for *Pεω*. Two other important aspects of *Pεω* are not evident in these simple examples: dynamics and mobility. In *Pεω* the topology of the connectors and the component instances they connect can be dynamically changed. For example, several component instances can in turn be connected to any of the nodes a, b, and c in Figure 1(c), acting as the producers and consumers of the data streams for this connector. Furthermore, the channel ends that are joined to form a node, can be split dynamically. Both components and channels are *mobile* in *Pεω*. A component instance may move from one location to another during its lifetime. The channel ends connected to this component instance then remain connected as it moves to the new location, preserving the topology of channel connections. Furthermore, a channel end may be reconnected to another component instance at the same or a different location. This second form of mobility dynamically changes the topology of channel connections in the system.

Generalized channels

In contrast to other channel based models, *Pεω* uses a generalized concept of channel. In addition to the common channel types of synchronous and asynchronous with bounded or unbounded buffers and FIFO and other ordering schemes, *Pεω* allows an open ended set of other channels, each with its own exotic behaviour. For instance, a channel in *Pεω* need not have a source and a sink end: it can have two source or two sink ends instead. *Pεω* defines a set of operations for dynamic composition of channel ends into nodes of connectors, giving the semantics of the data flow through connectors in terms of the semantics of the I/O operations on their nodes. The semantics of *Pεω* operations is independent of the specific behaviour of the channels they operate on. While *Pεω* is designed to deal with the flow of data, it fundamentally differs from classical dataflow models in three important respects: 1) the topology of connections in *Pεω* is inherently dynamic and accommodates mobility; 2) *Pεω* supports a much more general notion of channels and different channel types; and 3) *Pεω* defines an intuitive and expressive semantics for the connection of channels to channels. Indeed, the last two characteristics are the source of the expressive power of *Pεω*, compared to dataflow models or even IWIM.

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Pattern Forming Systems: Universal and Specific

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Spontaneous patterns

Many processes in Nature exhibit spontaneous formation of patterns in space and time. This happens under widely different conditions; one can think of the surface structure of boiling oil in a pan (convection), sand ripples at the beach, or the growth of corals and snow flakes. However, while the underlying microscopic processes vary widely, the resulting patterns can be surprisingly similar on a larger scale. The physical systems in question are far from equilibrium and the mathematical models describing them are nonlinear. Under scaling-up, these models can converge, as it were, to a common global 'universal' structure. The mathematical reason for this observed universality is given by 'center manifold theorems'. However, even in such a universal limit, some properties will depend on the specific system while others will not. Both aspects, universal and specific, are studied at CWI in relation to patterns formed in electric discharges. They occur in various natural phenomena, as well as in many technical processes.

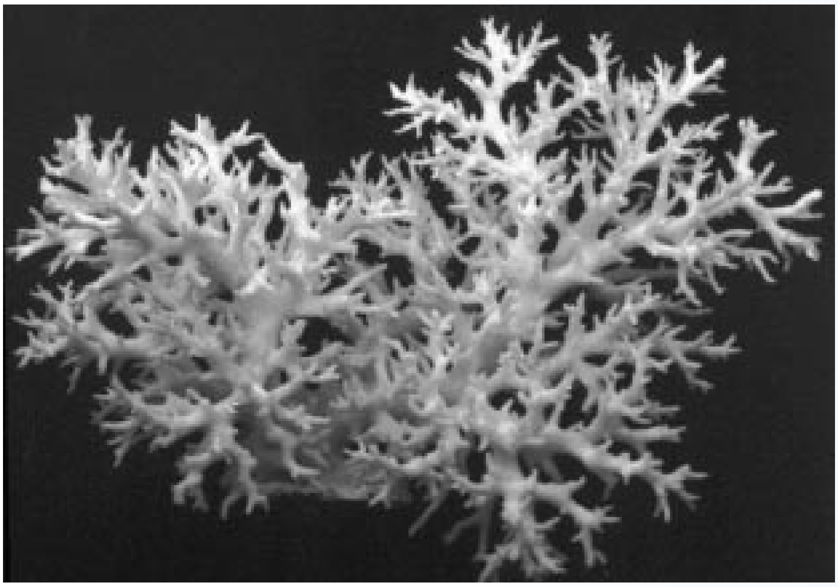
Electric discharges

If matter close to thermodynamic equilibrium is exposed to a weak electric field, a current will flow only if there are initially sufficiently many mobile charges like electrons or ions. This is the case with conducting matter like metals and high temperature plasmas. If, however, a strong electric field is applied to matter of low conductivity, then only a few mobile charges can generate an avalanche of more charges by 'impact ionization'. A low temperature plasma is being created, resulting in an electric discharge. Examples range from natural phenomena like the familiar lightning and St. Elmo's fire, to lamps (neon tubes, high brightness flat computer and TV screens) and industrial plasma reactors for combustion gas cleaning, ozone generation, etc. Technologies based on discharges in semiconductors and gases are applied both in fast high voltage switches and laser pumping. High voltage transformers can be ruined by discharges through the packing oil.

Matter in a discharge is far from global thermal equilibrium and evolves rapidly. The mathematical equations describing the phenomenon are 'nonlinear'. One characteristic of a nonlinear system is that little causes can have great effects, another is the spontaneous formation of patterns in space and time. At CWI two generic cases of patterns are studied in application to discharges. Similar patterns occur in other fields including biological systems. Using analytic and simulation methods, we study both specific systems including all microscopic details and generic, system independent

Pattern formation in Nature

Lightning and its spectrum. (Source: Leon E. Salanave, University of Arizona Press, 1980.)



Pocillopora damicornis, *a coral used to study form and growth with Laplacian and advection-diffusion models (Kaandorp & Kübler, 2001).*

Wind-induced sand ripples on a sand dune near Nida (Lithuania), © Piet Jonas 1998

The minimal model of electric discharges

This model describes the generation and motion of free electrons and ions in a gas under the influence of an external electric field in its simplest form. Since the degree of ionization stays low (less than 10^{-5}), we can neglect gas convection and thermal effects. The rate of change in the electron (ion) density then equals the divergence of the local electron (ion) current density, plus a source term representing the generation rate of electron-ion pairs due to the impact of field-accelerated electrons onto neutral gas molecules. This generation rate is proportional to the electron density, but also depends on the local field strength in a nonlinear way. It becomes substantial if both the electron density is non-vanishing and the local electric field is sufficiently strong. Since the motion of the free electrons and ions is damped by collisions with the gas atoms, the current is composed of a drift term proportional to the field and a diffusive term. The minimal discharge model is given below in formulas. Without space charges the model reduces to a set of linear equations for the evolution of electron (ion) densities in the given external field. As soon as space charges become non-negligible, these charges change the local electric field, which in turn changes the generation and drift rates. This nonlinearity drives the pattern formation described in this article.

$$\partial_t \sigma = -\nabla . \mathbf{j}_\sigma + g, \quad \partial_t \rho = -\nabla . \mathbf{j}_\rho + g$$
$$\rho - \sigma = \nabla . \mathbf{E}, \quad \mathbf{E} = -\nabla \Phi$$
$$\mathbf{j}_\sigma = -\sigma \mathbf{E} - D_\sigma \nabla \sigma, \quad j_\rho = \mu \rho \mathbf{E} - D_\rho \nabla \rho$$
$$g = \sigma |\mathbf{E}| \, e^{-1/|\mathbf{E}|} \text{ (Townsend approximation)}$$

features. For example, for the fast semiconductor switches built at the Ioffe Institute in St. Petersburg, we have modelled a specific device with its material parameters quite in detail, and have proposed a new, far more efficient operation mode. In contrast, we studied gas discharges with a model containing only the minimal set of mechanisms required for describing a discharge with a low degree of ionization. This 'minimal discharge model' is detailed in the above Box.

Universal laws

In studying simplified models, we aim to understand the instabilities which are independent of the specific underlying physical system, and to identify analogies with other pattern forming systems or even 'universal' features. The latter term refers in theoretical physics to the phenomenon that models of widely different physical systems reduce to one, much simpler 'universal' model, when taking a certain limit (long times, large distances, etc.). Mathematically, such a model is a 'center manifold' with only a few parameters. For example, for describing density fluctuations in water close to a critical point (phase transition), one only needs to know that the order parameter of the system under consideration is a real positive number, namely the density, and that the embedding space is 3-dimensional, namely our ordinary non-relativistic physical space. However, computing the position of this critical point requires full knowledge of all interactions between the water molecules and is specific to this particular liquid. Examples of such universal models, related to systems far from equilibrium, include the Ginzburg-Landau equation (1951, originally invented to give a qualitative explanation of superconductivity) and the Korteweg-de Vries equation (1895, the first equation describing a solitary wave or 'soliton'). In a second Box we explain the universal structure of 'pulled fronts' associated with a new center manifold theorem recently identified at Leiden University and CWI. Below we discuss two other universal structures in application to gas discharges and biological systems.

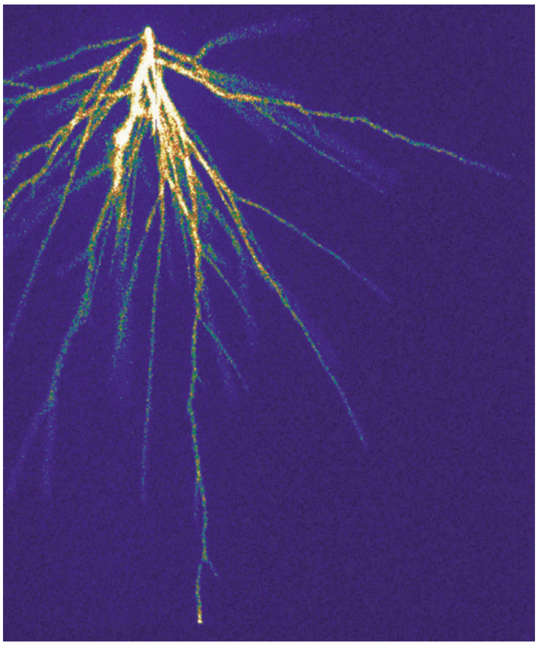


Figure 1. Two views of a streamer. To the left a time-integrated picture (exposure time 10^{-6} seconds); to the right a snapshot of the same event (exposure time 10^{-9} seconds), showing the propagating heads of the streamer channels. (Courtesy E. van Veldhuizen, Eindhoven University of Technology.)

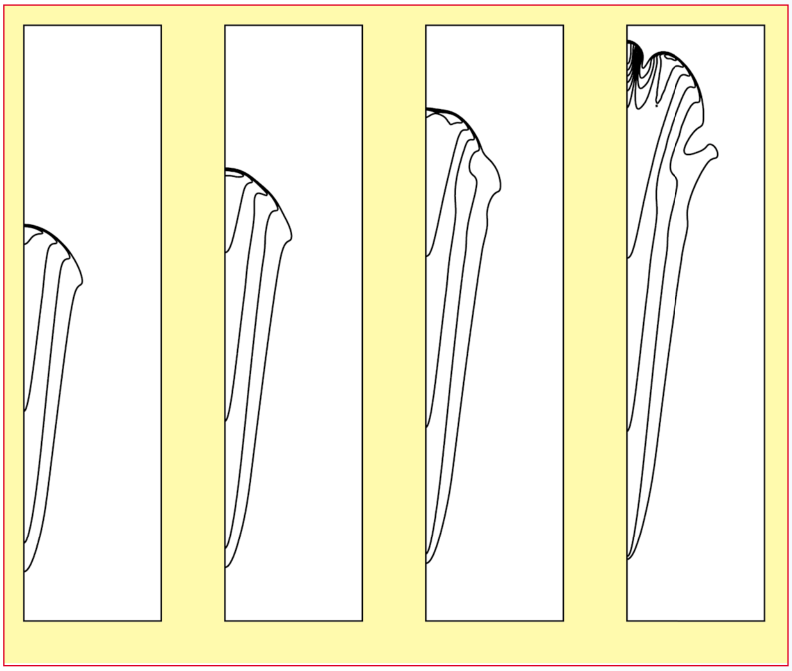
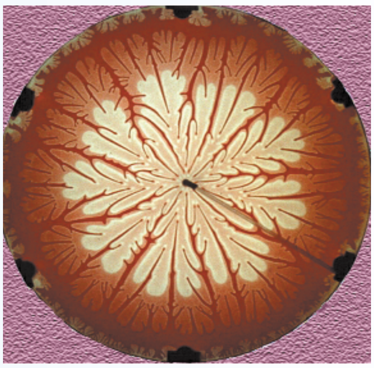


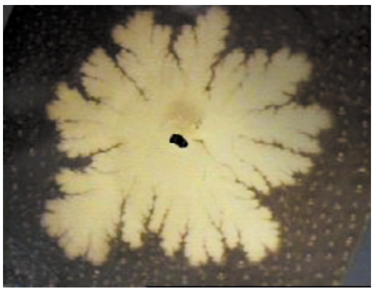
Figure 2. Four snapshots of the evolution of a streamer, resulting from a numerical simulation on the basis of the minimal model of electric discharges. The streamer tip is seen to become unstable and branch. (A. Rocco, U. Ebert, W. Hundsdorfer, CWI)

Streamer discharges and Laplacian growth

A streamer is a rapidly growing channel of high local ionization (see Figure 1). It arises when, for instance, a strong electric field is applied to a gas. It can branch spontaneously. A small ionization seed in the gas will initially undergo a rapid, but still linear increase. After some time accumulating space charges make the dynamics non-linear, creating a streamer. Streamers are observed in early spark formation, and are used, for example, in plasma reactors for ozone generation or combustion gas cleaning, where their branching may increase efficiency. Current theory focuses on stationary modes of propagation, and is unable to describe branching phenomena. Studies at CWI of the minimal model described in the first Box, both simulation and analytic, have shown that this model does indeed predict branching (see Figure 2). The analytic studies related streamer branching to the universal model of Laplacian growth, which describes such widely different phenomena as viscous fingering, dendritic solidification, and branched growth of bacterial colonies, corals or embryonal tissue. Laplacian growth refers to the motion of the boundary separating a region where the 'potential' (a scalar function Φ) is constant from a region where this potential satisfies Laplace's equation $\Delta\Phi=0$. The displacement of the boundary is determined by $\nabla\Phi$. This model applies to the stage of tip splitting in the streamer simulations. A very steep front separates a non-ionized 'outer' region from the fully ionized region inside the streamer, where the electric potential is constant. In the non-ionized region (no space charges) the potential satisfies Laplace's equation. The minimal discharge model predicts that the velocity of the boundary is a monotonically increasing, nonlinear function of the local field strength (in the much investigated case of viscous fingering this function is linear). The same model applies to, for example, coral growth, where the potential Φ can be identified with the food concentration, which is zero inside the coral, and the local growth velocity is determined by the local food availability, which is proportional to the potential's gradient. The Laplacian growth model can explain the onset of instabilities as in Figure 2. This is a conceptual breakthrough, because until now stochastic mechanisms were thought to underly the branching phenomenon in streamers. The details of the emerging patterns after branching are determined by microscopic, system-dependent stabilization mechanisms, in which the width of the space charge layer between the ionized and non-ionized regions plays a central role, as we discovered.



(a) Viscous fingering.



(b) Bacterial colony.

(c) Dendritic solidification, demonstrated by a snowflake.

Examples of Laplacian growth. (a) Air is injected into a layer of glycerol; (b) Bacteria grown on a plate of agar; (c) Snow crystal, size 3.7 mm. Photo by Patricia Rasmussen, Caltech USA, 2002.
Courtesy (a) and (b): Center for Polymer Studies, Boston University.
Courtesy (c): Kenneth G. Libbrecht, Caltech. http://www.snowcrystals.net Copyright© 2002 Rasmussen & Libbrecht.

Algebraic convergence of pulled fronts -- a new center manifold theorem

A system far from equilibrium can stay for some time in an unstable state into which another state penetrates in the form of a front. Examples are the penetration of turbulent flow into a laminar region with strong shear flow, of bacterial colonies into a food-rich region, or of an ionization front into a non-ionized region with a strong electric field. The mother of all equations describing such phenomena is a nonlinear reaction-diffusion partial differential equation called the Fisher-Kolmogorov equation:

$$\partial_t u = \partial_x^2 u + u - u^2$$

The initial state $u(x,0) = 0$ can be shown to be unstable, i.e., a small disturbance can very quickly grow out to substantial size. The state characterized by $u(x, t) = 1$ turns out to be stable. If the system was initially in the state $u = 0$, a wave front between these two states propagates with a certain, time-dependent velocity v, whose asymptotic expansion for large times is given by:

$$v(t) = a + b/t + c/t^{3/2} + O(1/t^2)$$

where a, b and c are numerical constants (equal to 2, -3/2, and $3\sqrt{\pi}/2$, respectively). Note that the leading correction terms for large, but finite times are algebraic, not exponential (as it would be for fronts propagating into a metastable rather than an unstable state). The universal term $\sim 1/t$ was derived by Bramson (1983) in a lengthy paper. Using asymptotic expansions and resummations, U. Ebert and W. van Saarloos recently determined the next order universal term $\sim 1/t^{3/2}$ (the time-dependent shape of the wave front), and showed that the higher order terms are not universal, but depend on details of the initial conditions. They found that their method also applied to many other equations, including those with more complicated differential operators (e.g., the Swift-Hohenberg equation), certain integro-differential equations, coupled sets of reaction-diffusion equations, and the minimal discharge equations. In all these cases the velocity $v(t)$ of the 'pulled' wave front is given by the above expression, only with different equation-specific numerical constants, whereas the higher order part $O(1/t^2)$ is non-universal. This is the result of a new 'center manifold theorem': in the limit of large times, not the full equation is relevant, but only a restricted mathematical substructure. Wave fronts with such an algebraically slow relaxation pose various problems to analytical perturbation theory and to numerical schemes with local refinement. Both are presently under investigation at CWI.

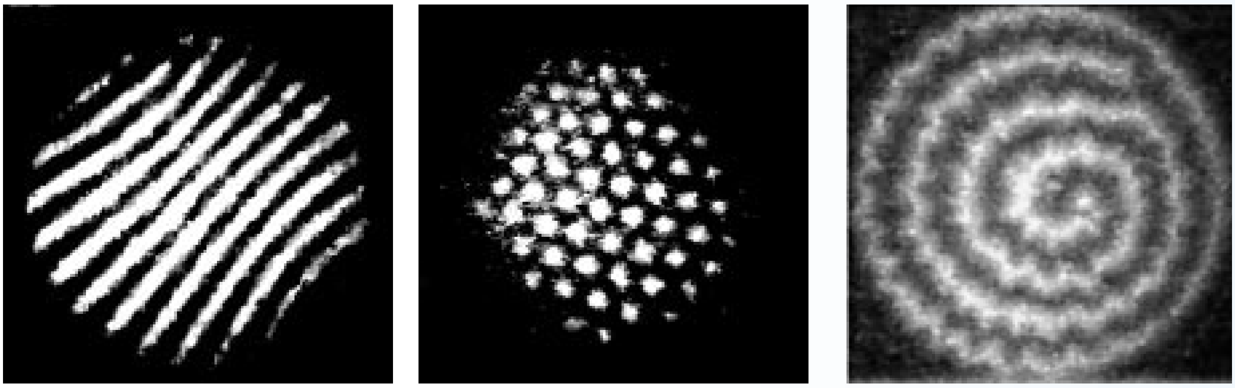


Figure 3: Patterns observed in the gas discharge layer of a barrier discharge device: stripes (left), hexagons (centre), and zigzag - modulated rotating spirals (right).

Barrier discharges and Ginzburg–Landau expansions

A barrier discharge device resembles a sandwich: first a planar electrode, then a 'barrier' layer of low conductivity, a gas discharge layer, and again a planar electrode. The device is driven by dc or ac voltage. The barrier has a simple linear response to an applied voltage. The gas discharge layer is described by the minimal discharge model, together with surface ionization terms at its boundaries, and its response to an applied electric field is highly nonlinear. When driven by a homogeneous and stationary (dc) voltage, patterns in space and time can be formed in the gas discharge layer, some simple ones (stationary stripes and hexagons, and rotating spirals) being shown in Figure 3. Similar patterns are observed in spore forming dictyostelium, where starving cells form a primitive multi-cell organism, in convective phenomena, etc. They are generic for a Turing or a Turing-Hopf instability close to a supercritical bifurcation. A Turing or a Turing-Hopf instability leads to patterns with a rather well-defined finite wave length that are stationary or propagating, respectively. A bifurcation point is a critical value of the control parameter of a dynamical system, at which a qualitative change in the system's behaviour takes place. A supercritical bifurcation means that the state of the system varies continuously when the control parameter varies continuously. It can be shown that for Turing or Turing-Hopf instabilities close to supercritical bifurcation, the underlying center manifold is the Ginzburg-Landau equation that describes the modulation and the interactions of the wave patterns. The analysis can be extended to weakly subcritical bifurcations. At a (weakly) subcritical bifurcation, the system jumps to a (somewhat) different state when the control parameter is varied continuously. However, the transition at which a dc voltage barrier discharge operates in experiments (from Townsend to glow discharge) is generally believed to be deeply 'subcritical', in which case the above knowledge does not apply. However, our investigations have revealed that in systems with quite a narrow discharge gap, like in the experiments shown in Figure 3, the transition can also be supercritical, or exhibit unexpected 'mixed' transitions. This theoretical finding explains the observed patterns qualitatively and creates the basis for our ongoing quantitative studies of pattern formation in these systems.

References

See URL: http://www.cwi.nl/~ebert/

Virtual Reality in Biological Microscopic Imaging

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Introduction

On the cellular level, many components display a highly dynamic behaviour. New fluorescent labeling techniques have become available in the past decade, allowing visualization of the dynamics of proteins and other molecules in living cells. Using confocal light microscopes, time-dependent 3D (= 4D) data sets of biological objects, such as cells and tissues, have been obtained. This enables the study of processes that we recognize as 'life' at the molecular and cellular level. Unfortunately, when studying 4D visualizations, biologists still struggle with the extraction of usable information from the images. Virtual reality gives a user the experience of being immersed in a computer-generated virtual world. In cooperation with the Swammerdam Institute of Life Sciences at the University of Amsterdam, CWI has addressed the role of virtual reality in understanding structural information from 4D biological data. We postulate that for understanding biological processes, qualitative visualization studies should precede quantitative image processing.

Structure in Cell Biology

'Structure' is an extremely important concept in biology. Examples include the 3D folding of the polypeptide chain in proteins, the spatial organization of the cell, and the arrangement of cells in a tissue. At all levels of organization, i.e. from macromolecule up to organism, structure determines function to a large extent. To study structure, a broad range of microscopy techniques is available. For example, modern confocal microscopes in combination with labeling techniques can capture multichanneled (i.e., observed at several frequencies) 4D data sets of cellular components, cells and tissues. These complex data sets are difficult to analyze with traditional visualization techniques. A particular problem that has been studied is the decondensation of chromatin. Time series of 3D images were made of the process of chromatin decondensation after cell division (mitosis). During mitosis, chromatin is densely packed in the chromosomes. After mitosis, part of the chromatin decondensates to form a new nucleus. The difficulty is that the spatial distribution of chromatin is highly complex, as is its dynamic behaviour. The goal of the visualization was to perceive and find patterns in the movement of chromatin during this formation.

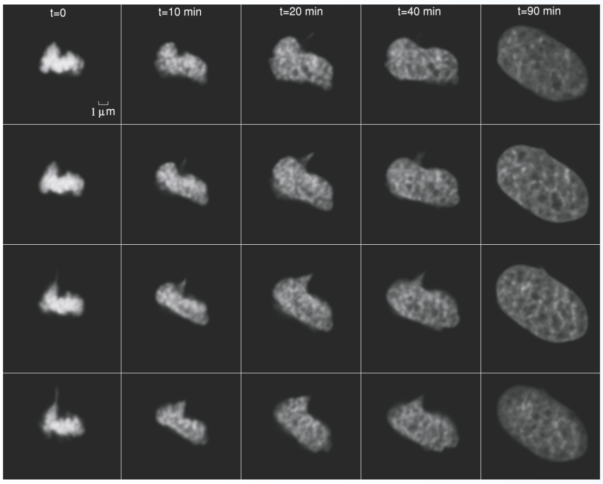

Figure 1. Decondensation of chromatin during and after mitosis. Columns of data represent different time steps, rows are cross-sections within the 3D data set.

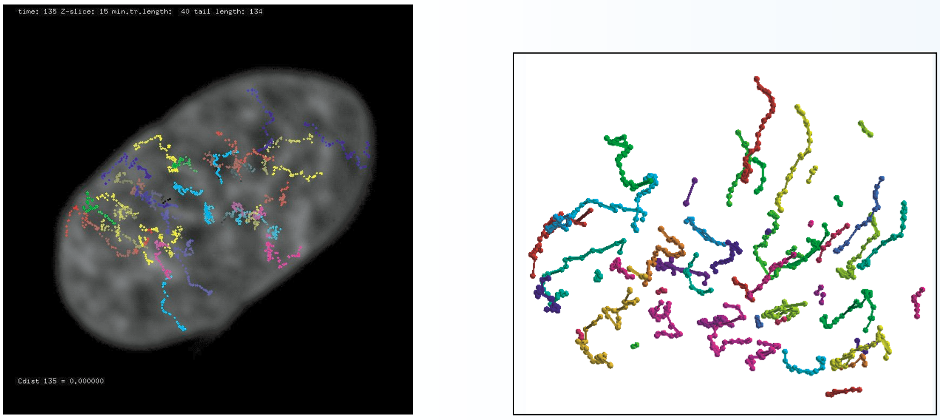

Figure 2. To the left: a 2D cross-section of the data at one time step (in gray scale). Superimposed on this are the computed tracks of the features, representing dense chromatin regions. To the right: 3D view of a subset of the tracks. Colours are used to label the tracks in both views.

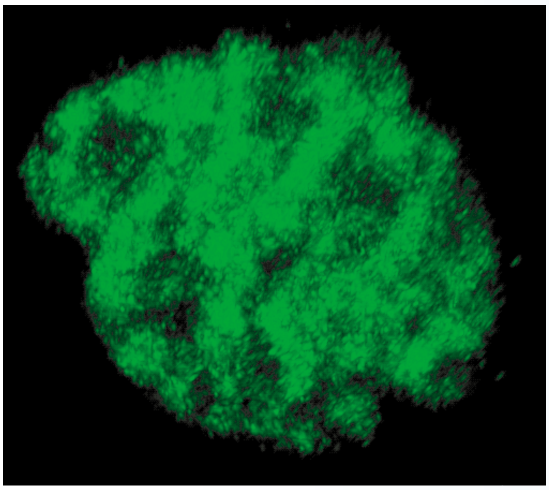

Figure 3. Chromatin data for one step in the decondensation process. High intensity levels in the data, seen as bright green spots in the semi-transparent green image, indicate compact chromatin regions. These are used to analyze the movement of the entire chromatin.

After using a palette of virtual reality techniques, the apparent chromatin decondensation was in fact the formation of chromatin-poor regions in the nascent nucleus. Perceiving these formations on a desktop workstation is difficult, primarily because of the dynamics of the spatial relationships. The definition of compact chromatin domains as concentration variations varies over time and the spatial correlations between convoluted chromatin domains are difficult to follow. Based on the general understanding of the process we gained using virtual reality, we were able to ask specific questions which were then translated into 4D image analysis algorithms. Thus a feature tracking technique was developed to study the movement of recognizable condensed chromatin domains. Features were used to represent these dense regions. A feature is defined by local maximal intensities in the data by a 5-dimensional attribute vector $< x, y, z, i, t >$, in which x, y, and z are the feature's position, i denotes its intensity value and t is the time step. Figure 1 shows a portion of the data. Figure 2 shows two views of these data, and Figure 3 a snapshot of the chromatin density.

Perceiving Biological Structures

Scientific visualization techniques, such as 3D (volume) rendering, iso-surfacing, object annotation, path tracing and editing, and object tracking have been used to render time-dependent confocal data sets. Visualization is challenging here for various reasons. First, in many cases the autonomy of cell components is not well understood and cannot be determined. This makes (semi-automatic) classification, extraction and segmentation of the data more difficult. Second, confocal data are very noisy. This can lead to difficulties in the segmentation and tracking of objects. Third, object sizes often approach the resolution of the microscope. This leads to ambiguities and visual artifacts when objects are extracted from the data. Finally, during scanning the cell can translate, rotate and expand. These additional external movements must be corrected through global non-affine transformations.

Obtaining accurate and robust depth information from visualizations of biological data is an important aspect in perceiving their structure. Computer graphics practitioners have used various depth cues to make objects appear 3D on a 2D display. 'Primary' cues such as binocular disparity, convergence and accommodation are based on the psychology of perception and the cognitive processing of visual information, whereas 'secondary' cues like perspective, texture, shading and shadows, reference frames and motion, come from the visual arts and have been standard in 3D computer graphics. It is not well understood which cue is essential for the correct interpretation of spatial information in an image, nor what the importance of a particular cue is when used in combination with other cues.

Biologists still struggle with perceiving the complexities of structure. Biological objects are generally highly convoluted and evolve over time. Furthermore, they tend to be densely packed, and their spatial relationships are difficult to perceive. Several virtual reality technologies can help in better perceiving these dynamic structures:

- head tracking

Motion parallax (the apparent angular velocity of objects which is inversely proportional to real distance) based on head tracking is a very powerful cue to generate depth and shape information. Although we lack formal evidence, we believe that motion parallax aids the spatial resolution of object distributions and object correlations in 4D biological data. There is formal evidence that stereo and motion cues do increase task performance in understanding the structural complexities of information nets in three dimensions. Many aspects of these formal studies also apply to cellular structures, even though these studies were conducted with time-independent data. We surmise that motion parallax provides crucial depth information when the cellular structures change over time.

- stereo vision
Binocular disparity allows depth information to be obtained from two slightly different projections of an object. It can only be used for objects at distances closer than a few metres. The human visual system also uses accommodation, convergence and their interrelation as cues for depth perception. However, there are no displays available which can maintain the accommodation cue in stereo vision. Depth of field rendering techniques have been developed that may reduce this problem.

- large display
With a large display, the cellular structure can be scaled so that the foreground objects near to the biologist are perceived to be very far from those in the background. This induces a feeling of spaciousness when the biologist gazes at foreground objects. Furthermore, large displays enhance the sensation of 'presence' which aids spatial judgments.

- spatial input
Interaction can support perception by making the biologist more efficient in extracting meaningful information from data. Interaction comprises, for example, on-the-fly data cutting and slicing, line, surface and volume measurements, placement of annotation markers, and the interactive tracing of line structures. Although spatial (3D) input techniques still suffer from technical drawbacks, we believe that they are a natural and transparent way of directly manipulating a biological object, and thereby contribute to the perception of the object. The use of 2D input devices for 3D interaction is more indirect and less transparent.

Proteus

The Proteus system is a virtual environment for the exploration of multi-channel (observations at several wavelengths), time-dependent, 3D images obtained by confocal microscopy. A biologist is presented with a data set representing 3D cellular structure which is scaled, probed and manipulated as if it were a real cell (see Figure 4). Available visualization techniques for the display of 4D biological data include the interactive control over volume and iso-surface rendering parameters (e.g., transfer functions and iso-values), data selection tools to cut and paste data regions, free hand drawing tools for path tracing, distance measuring tools, and tools for tracking features in the data.

The Proteus user interface is based on the metaphor of a virtual hand which performs all interaction, and can grab and directly manipulate the data (see Figure 4). However, Proteus still suffers from poor ergonomics: the system must be used in a dark room, the wand causes considerable arm strain when used for an extensive period, wired tracking systems are tedious, prolonged use may cause eye strain, and the rendering lag caused by volume rendering is too high. Virtual environments will be really useful for research in biological microscopic imaging only when integrated into the normal daily work environment. Therefore CWI is currently developing the Personal Space Station, a virtual environment that addresses these issues.

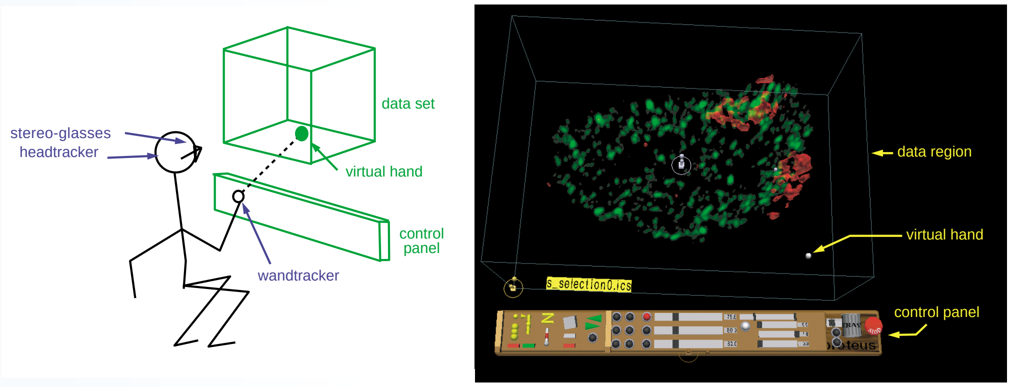

Figure 4. The Proteus system. To the left: a biologist is seated in front of a 3D cellular structure. To the right: example of the user interface, showing transcription sites (green) and X-chromosomes (red) in a cell nucleus.

The Personal Space Station: affordable 3D interaction

Until now, interaction in virtual environments has mostly been realized with generic wire-based input devices, such as a wand or stylus equipped with a magnetic tracker. Interaction techniques that use these devices are often indirect, are difficult to use, and lack precision, which can result in loss of task performance, discomfort, and user fatigue. Interactive tasks should be done in a more direct and natural way. However, in back-projected display systems, such as a CAVE, interaction is problematic: hands and other body parts block the display resulting in occlusion of the image, and the physical projection surface prohibits direct interaction with the virtual world behind the surface. In 2001, we started to build a virtual environment which will allow the user to interact directly with a virtual world. This Personal Space Station (PSS) provides an environment for 3D applications based on wireless and direct interaction that can be

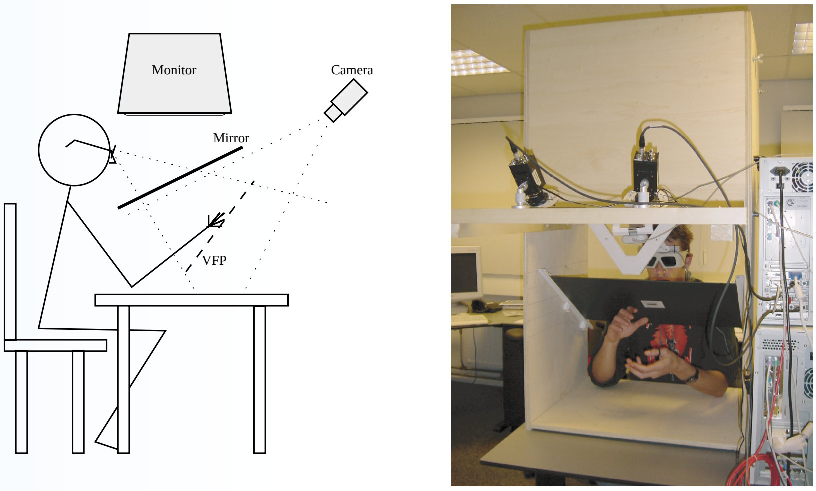

Figure 5. Schematic (left) and real (right) views of the Personal Space Station. The head tracked user, his hand reaching into the configurable Virtual Focus Plane (VFP), is comfortably seated, and interaction is direct.

used in normal office working conditions; it will fit on a user's desk and can be used under normal lighting conditions while the user is comfortably seated. A PSS can be built at low costs, using only off-the-shelf commodity components. The PSS uses a mirror in which a stereoscopic image of the virtual world is reflected from a display surface (see Figure 5). The user reaches under the mirror to interact with the virtual objects directly with the hands or with task specific input devices. The virtual space is superimposed over the physical space without obscuring the image. Thus advantage is taken of the user's unique hand-eye coordination to stimulate various sensory-motor cues. The user is 'attracted' to the objects seen; as soon as an object comes within arm's reach, his natural reaction is often to reach out and try to manipulate the object. In demonstrations with several example applications to many users, both experienced and novel to VR, we found that interaction indeed 'comes natural'. The combination of simple, wireless interaction devices, hand-eye coordination, and visual feedback relieves the user of having to reason about the desired interaction to be performed.

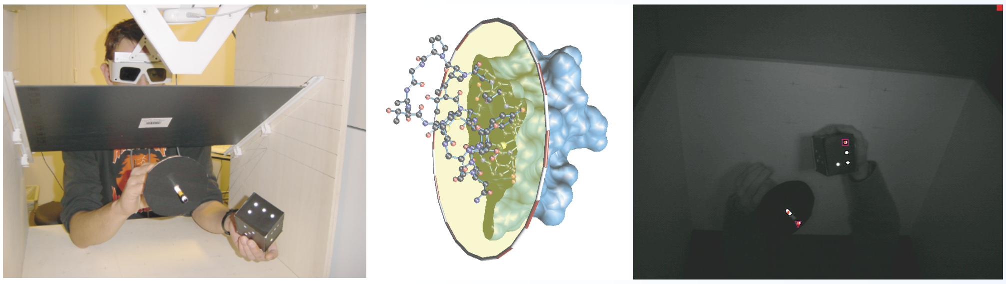

Figure 6. Interacting with a molecule. Left: a cube is used to position and orient a molecule, and the cutting plane device to cut the surface. Centre: the virtual world. Right: snapshot of the patterns captured from one of the cameras.

Cameras are used to track interaction. A camera's field of view is determined by its position and orientation, as well as its internal geometry and optical characteristics. The tracking space is the intersection volume of both cameras' field of view. It is illuminated by rings of IR leds mounted closely around the camera lenses. IR-pass filters in front of the lenses are used to cut off the light below a chosen wavelength. IR light from the leds is reflected by markers into the lens such that, after thresholding, blobs of white pixels occur in the acquired image. A simple interactive molecule viewer has been implemented to demonstrate the capabilities of the PSS. By using a cube device in the non-dominant hand simultaneously with a cutting plane device in the dominant hand (see Figure 6), all kinds of cross-sections can be obtained. Cameras track patterns of 4 reflective markers which are then used to compute the position and orientation of the cube.

Control and System Theory of Biochemical Cell Reaction Networks

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Introduction

The classification of genes in humans, animals, and plants has increased the urgency of research on mathematical models for the biochemical processes in cells. One way of studying these models is to apply concepts and results of control and system theory. This research also bears on the design of drugs. In cooperation with biologists of the Vrije Universiteit (Free University) in Amsterdam, CWI is carrying out research on modelling, model reduction, and control problems for biochemical cell reaction networks.

Biochemical reaction networks

The understanding of the basic processes of life and the design of drugs are based on biological, biochemical, and mathematical models of the network of chemical reactions in a cell. For example, the selection of chemicals for drugs and their effectiveness depends on knowledge of the numerical values of parameter estimates for mathematical models of biochemical reaction networks. Our current knowledge about these networks is quite limited: the complete reactions of a cell are known for only a few cells. Realistic models of biochemical reaction networks can easily contain a 1000 up to 15.000 ordinary differential equations. Biologists are establishing contacts with mathematicians, including control theorists, to analyse the dynamic properties of cell reaction networks. A particular aim is to reduce models of high dimension to models of low dimension, and to understand the role of feedback loops in such networks.
In biology the main concept for life is the cell. In a cell the basic biological functions take place such as energy conversion, the conduction of electric signals, movement (contraction, expansion), etc. The model for the processes in a cell is based on biochemistry and physics. Chemical substances engage in chemical reactions with other substances and there is a chain of such reactions. The reactions are facilitated or catalyzed by other chemical substances called enzymes, or proteins, which in turn are produced by messenger-DNA and by the genes of the cell. For several cells the complete reaction network is known but for most cells there is only partial knowledge of the network.
A mathematical model of a biochemical reaction network takes the form of an ordinary differential equation. For each chemical reaction there is one differential equation. The dependence of the differential equation on the other substances is based on physics, and is well modelled. However, the speed of a reaction is often determined on the basis of empirical data, and is only approximately modelled. The differential equations are often in terms of polynomial or of rational functions.

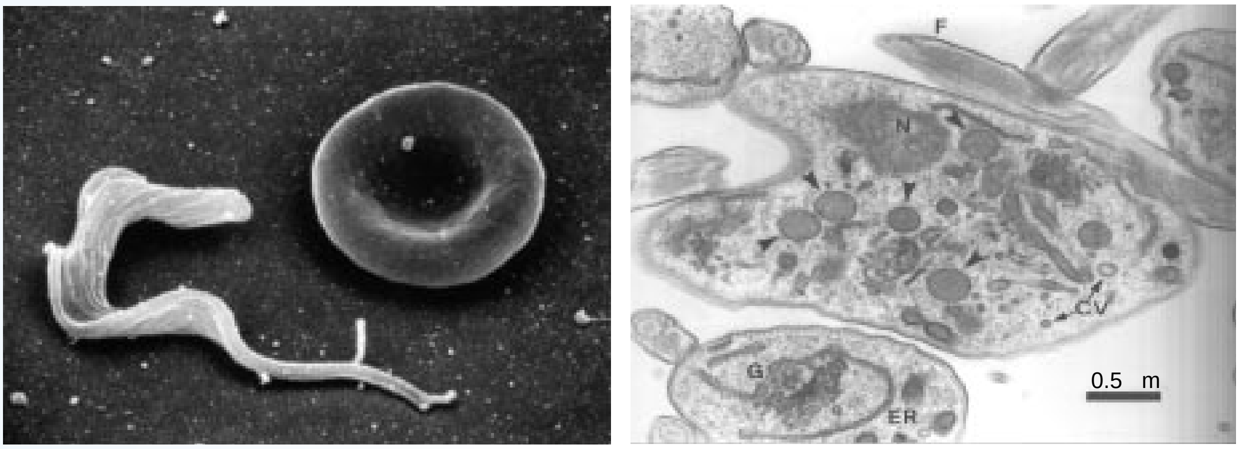
Experiments, data collection, and techniques from the field of system identification are used to estimate the parameters in the mathematical model. The parameters refer primarily to the reaction constants. A major problem is that reliable data are very hard to obtain. An experiment on a cell can almost never be repeated because the cell is destroyed in the measurement process. Data from different cells or from different plants or animals may not be compatible. Hence, the parameter values have large errors. One goal is therefore to find properties of networks that can be accurately measured. The problems facing biologists currently include how to handle very large mathematical models of biochemical reaction networks. In a typical cell the number of reactions is potentially about half the number of genes, in a human cell of the order of 15.000. A mathematical model in the form of an ordinary differential equation of dimension 15.000 can numerically be treated only poorly. The parameter values of the model may only be known with a large uncertainty, or are even not known at all. It is therefore necessary to explore other ways to analyse the behaviour of the biochemical processes in a cell by simplifying those models and to understand the limitations of such a simplification process.

An example of a simple model is that of part of the cell reaction network of the parasite *Trypanosoma brucei*. Dr. Barbara Bakker has formulated a model for part of the chemical reactions of the cell. The mathematical model consists of about 20 ordinary differential equations. The model has been used to determine with metabolic control analysis the reactions that cause the greatest change in the steady-state glycolytic flux if their activity is slightly (differentially) perturbed. Bakker's results can be used to target drug design for these parasitic cells on those reactions with the highest sensitivity coefficients. Inhibition of those reactions will have the highest effect on the metabolism of glucose. Of particular interest is the possibility to control the biochemical reaction network by influencing the operation of enzymes. An enzyme catalyses a reaction by providing space to the reactants for the reaction. If the end product of a related reaction in the chain occupies the space on the enzyme for the reaction, then the reaction is said to be inhibited. Inhibition may also take place by substances which are externally supplied, say by intake of a drug or by injection. Inhibition is therefore an important control mechanism for the network.

Our research, carried out jointly with biologists Hans Westerhoff and Barbara Bakker (Vrije Universiteit in Amsterdam), focuses on model reduction based on reaction speeds, analysis of graphs of a biochemical reaction network, and feedback loops in biochemical reaction networks.

Problems for control and system theory

For the modelling, identification, and control of biochemical reaction networks as formulated above, CWI brings in its research expertise in positive linear systems and in system identification of compartmental systems. These networks are mainly modelled by rational positive dynamic systems: ordinary differential equations of which the right-hand side is a polynomial or a rational function with positive coefficients. This subclass of dynamic systems is closed with respect to linear and rational feedback laws if networks are concatenated or if the enzymes can be influenced by inhibition. Model reduction problems have been formulated based on the difference in reaction speeds. Fast reactions can be approximated by memoryless relations, whereas slow reactions are retained in the model. A second issue requiring investigation is the dependency of the concentrations of the intermediate chemical substances on the model coefficients.



The metabolism of Trypanosoma brucei*, a parasite causing African sleeping sickness, is analysed in a mathematical model of its cell reaction network. To the left: A scanning electron micrograph of a bloodstream trypanosome (left) next to a red blood cell (picture Andreas Seyfang). To the right: In a trypanosome, metabolic breakdown of glucose takes place by glycolysis, a process occurring in glycosomes (indicated with arrows in the central cell). Metabolic control analysis can help, for example, to find candidate enzymes that can be effectively targeted by drugs to inhibit glycolytic flux, and thus stop the parasite's growth. (Courtesy Barbara Bakker, Free University, Amsterdam.)*

As viewed from system theory, the biological 'metabolic control coefficient' is actually a sensitivity coefficient. A third aspect of the investigation is the graph that may be associated with each cell reaction network. The feedback loops in the graph clarify the natural regulation mechanism of the cell. Decomposition of large cell reaction networks into elementary cycles is of interest. Stability of cell reaction networks due to the varying stimulation by enzymes is of interest to drug design and understanding of the cell's functions. Effectiveness of inhibition and drug treatment is aided by understanding the stability properties. The use of control synthesis is at this point not clear but may be useful later.

Part of the research was been carried out in cooperation with Mr. Siddhartha Jha (IIT Kanpur, India) during his internship at CWI from May till July 2001.

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Wavelets and the Unborn Child

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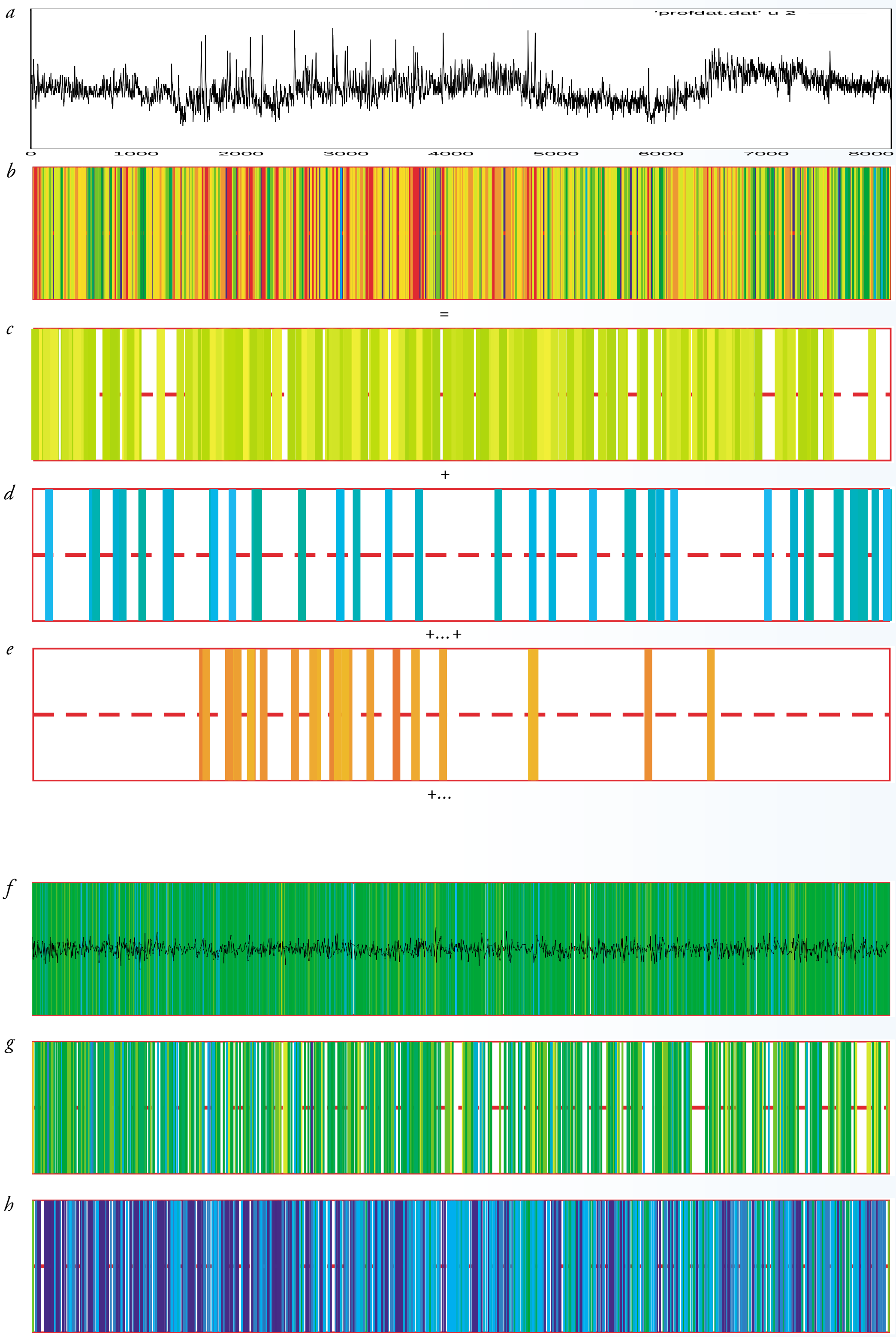
Introduction

During labour, the attending medical staff use fetal heart rate recordings for evaluation of fetal well being and may base immediate intervention, such as a Caesarean section or taking a fetal scalp blood sample, on this. Using characteristics derived in real-time from the heart rate, obstetricians can predict a good outcome very well. However, in cases of fetal heart rate patterns considered 'bad' by the obstetrician, at least half of these turn out to have been false alarms and the (operative) intervention unnecessary. Decision making can be improved by providing relevant information contained in the heart rate on a more solid, objective basis, making it independent of the personal experience of the specialist. This is enabled by recent progress in the modelling and analysis of heartbeat inter-beat dynamics, using the most advanced methods of signal processing (wavelet transform). CWI is tackling the mathematical side of this problem in cooperation with the Academic Medical Centre in Amsterdam (W.J. van Wijngaarden) and the Institute of Information and Computing Sciences of Utrecht University (R. Castelo). After mimicing the obstetrician's expert knowledge, the ultimate goal is to provide better than human performance by automated learning of predictive models.

Heart rate monitoring

Fetal heart rate monitoring started in the 1970s, and is now performed worldwide. Its aim is to warn in time for hypoxia (decreased oxygen content in tissue) during the hours preceding delivery, in which case intervention is necessary. The interpretation of observed cardiotocograms (CTGs) is a skill which is acquired through years of experience. Nevertheless, these visual interpretations by experts still differ widely. Whereas normal CTGs generally lead to a normal delivery, an abnormal CTG turns out to have indicated a real problem in only half of the cases at best. Not knowing this in advance, the clinicians do not take chances and intervene. Thus the number of interventions has dramatically increased since the introduction of CTG monitoring; many of these having been unnecessary. Computerized CTG analysis can lead to uniform and objective interpretation by providing a reproducible determination of fetal heart rate characteristics. The resulting automated system will be based on better external information, such as a complete pregnancy history. It will draw more useful information from the fetal heart rate recordings by using new analysis approaches which have shown their potential in heartbeat studies of adults. Finally, data mining algorithms are used to extract from this integrated information a generic model for effective heart rate monitoring leading to better fetal outcome prediction.



The Hölder exponents of a signal (a), indicating its local 'roughness', can be represented as a coloured 'barcode' (b). (Blue = smooth, red = rough.) Time points with the same colour have the same roughness. The complete barcode consists of interwoven monochromatic sets (c-e), often with a fractal structure. Simple processes like Brownian noise (f) are monochromatic, or 'monofractal'. Whereas the beats of a healthy heart (a) form a complex, multifractal pattern, diseases like congestive heart failure are characterized by more regular (g) or smoother (h) beat patterns, their barcodes being almost monochromatic or bluish, respectively.

Three obstacles

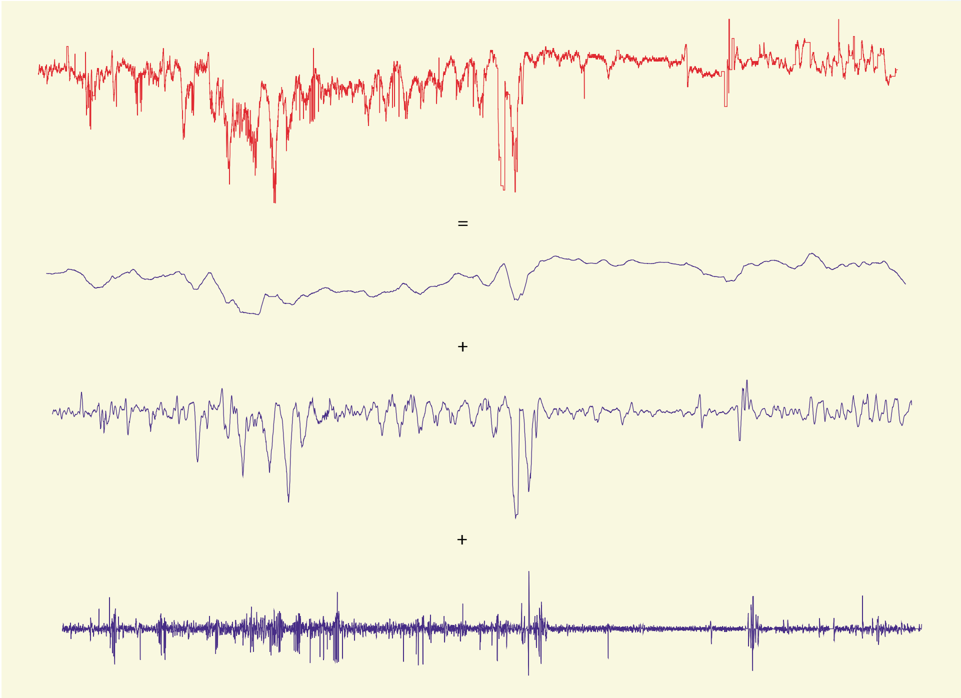
Fluctuations of human heartbeat intervals have been studied recently with modern (statistical) methods such as wavelet-based multifractal analysis and detrended fluctuation analysis. The captured scaling and correlation characteristics provide new insights into the non-linear dynamics of the heart, pointing for example to malfunctioning.
Three obstacles prevent direct application of these methods to fetal heartbeat. First, the statistical techniques require large data sets (about 2^{15} ~ 30,000) to provide reliable estimates. Because the typical heart rate of a fetus is 130 beats per minute, the generation of such a data set takes more than four hours. However, decisions about an intervention have to be taken at considerably shorter notice (10 – 60 minutes). Another serious problem is the presence of sudden drops in the heart rate of the fetus (deceleration). These 20 – 200 beats long drops, which do not necessarily imply hypoxia, spoil standard analysis methods because their inter-beat intervals can be an order of magnitude larger than the other heartbeat fluctuations. The third, and perhaps most serious obstacle is that fetal heartbeat during labour is very complex and dynamic, and its characteristics non-stationary.

Multifractals and wavelets

In time series, such as heart rate recordings, the signal is a non-differentiable ('singular') function at almost all in points time. The strength of a singularity, indicating the local 'roughness' of the signal, is measured by the so-called Hölder exponent. A signal may contain singularities of different strengths. The set of all singularities with the same Hölder exponent can be fractal, i.e., the pattern of their time points exhibits self-similar features on various scales. If a signal contains fractal sets with different Hölder exponents, it is called multifractal. A relatively simple process like fractional Brownian noise is monofractal: all singularities in the signal have the same strength. In several complex phenomena, such as fully developed turbulence, this is not the case. The signals produced by these processes are characterized by many interwoven fractal sets of singularities forming an intricate, unique 'barcode' of the process. Such signals are quite normal: heart rate fluctuations of healthy individuals are multifractal. Several methods have been developed over the years to analyze a signal by decomposing it into a number of elementary building blocks. In the classical Fourier method these building blocks are sine and cosine functions, which keep undulating to infinity. A relatively new method uses highly localized, wave-like functions, called wavelets. The wavelet method is well-suited to detecting singularities in a signal, and determining their strength (local roughness), characterized by the Hölder exponent.

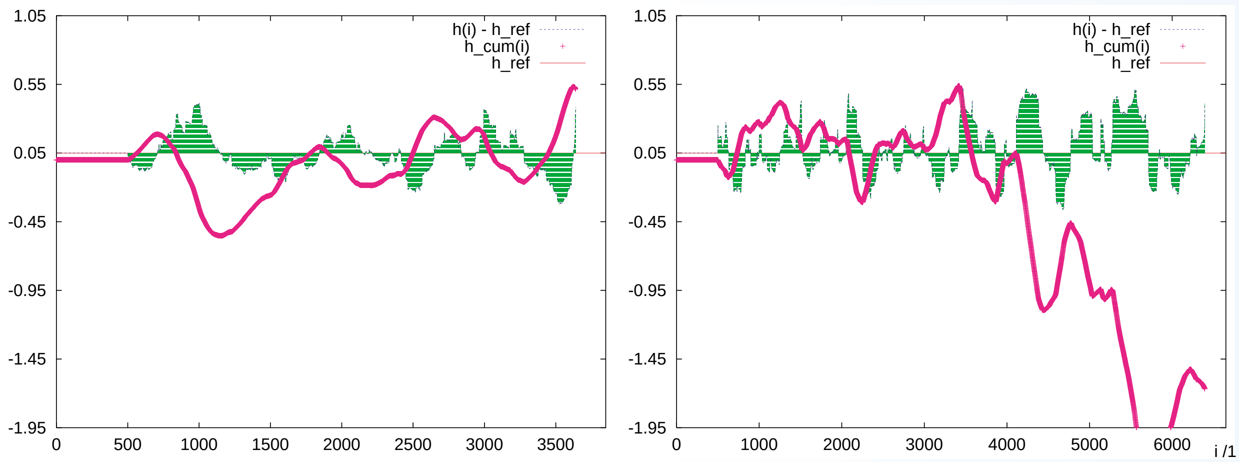
Three remedies

By applying wavelet techniques to multifractal signals, CWI has been able to provide reliable roughness estimates based on local information, thus avoiding the need of large data sets. This has been shown to be helpful in obtaining short-time characteristics of fetal heartbeat variability. Ultimately these characteristics are expected to be obtained in an automated scheme fit for real-time implementation.
Furthermore a signal decomposition scheme has been designed, different from the standard wavelet decomposition method, in order to capture the unique features of the fetal heartbeat analyzed by obstetricians in standard clinical practice. This decomposition separates the high frequency variability component from the deceleration component, thus minimizing the influence of decelerations on the estimation of the signal's roughness spectrum.

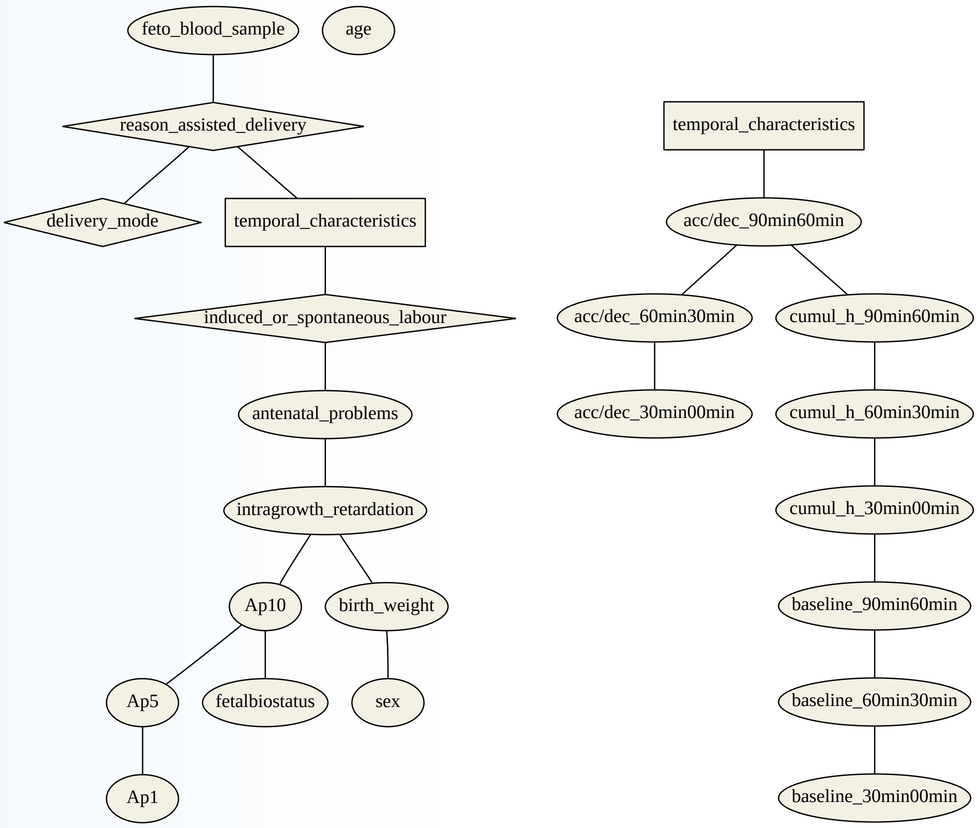


Mimicing the obstetrician – decomposition of fetal heartbeat (a) into meaningful components: (b) baseline, (c) accelerations/decelerations, and (d) 'normal' variability.

Most standard characteristics derived from the fetal heartbeat signal are non-stationary, reflecting dynamic changes in the condition of the fetus and the degree of stress to which it is subjected. The departure of the spectral model from stationarity has been used as an advantage. A cumulative indicator, measuring the departure from a prefixed stationary reference, has proved a novel promising characteristic with diagnostic potential. If the indicator oscillates near zero or steadily increases, the outcome is good. In the case of hypoxia the indicator plunges down to negative values, even after an initially stable condition, reminding us that during labour problems may occur any moment.



The cumulative Hölder exponent (red line), i.e., the linear time integral of local exponents, appears to be a characteristic with diagnostic potential. A non-decreasing line (a) is a good sign, whereas a drop of this line (b), corresponding to decreasing roughness of the signal, indicates a bad outcome.



Simplified version of the best dependence network obtained with data mining techniques.

Discovering the unknown model

Devising methods to extract new information from the fetal heartbeat signal, for example possibly useful new characteristics, is only part of our research. By integrating this information with external data concerning the status of the fetus, we aim to discover a computerized model which not only mimics the obstetrician's working praxis, but goes beyond it by revealing new knowledge. To this end we carried out a study with a thousand fetal heartbeat records, each covering three half-hour intervals just before birth. From these records we derived the following time series characteristics:
(1) the 'baseline', i.e., the short-time average heart rate level
(2) the short-time average integral of accelerations and decelerations
(3) the 'cumulative' Hölder exponent, i.e., the integral of local exponents relative to an estimated average exponent.
Together with data such as fetal blood composition, these characteristics form a bulk of data to which we have applied data mining techniques to find an underlying 'delivery model'. In particular, by taking a Bayesian approach we derived graphical Markov models from the data and employed them to capture and represent the conditional independencies among the random variables that we identified in our data.
By applying the Markov Chain Monte Carlo method, we obtained a posterior distribution over the set of models. This distribution weighs the different competing models and provides a measure of the uncertainty of each of them, as well as a notion of the support that they receive from the data. This measure of uncertainty, combined with the opinion of the expert, provided a sound way of selecting the most economical models. We have found to our satisfaction primary agreement of the best models with

the expert's knowledge. For example, in the computer model fetal heartbeat characteristics are connected to fetal outcome variables, like Apgar scores and biochemical composition of the blood, only via the decisions of the obstetrician. (An Apgar score is a kind of report mark for the baby, reflecting its status in minutes after birth, giving an indication of the need of resuscitation.) Indeed, in practice there is no evidence that these characteristics are directly related to the fetal outcome. Also the cumulative Hölder exponent appears to play a substantial role in the network of dependencies, on a par with established monitoring quantities like baseline heart rate and acceleration/deceleration integral. Whether we can find a better characteristic than the present cumulative Hölder exponent (a simple linear integral) deserves further study.

The computer will probably never completely replace the specialist, but it can be turned into a useful tool in guiding the obstetrician at work and provide for consistency of fetal heart rate interpretation and labour management. The satisfactory results so far give hope that by continuing our research along these lines we may obtain predictive models for fetal surveillance, and discover unknown relationships that are relevant to the domain expert.

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- Signals and Images	H.J.A.M. Heijmans
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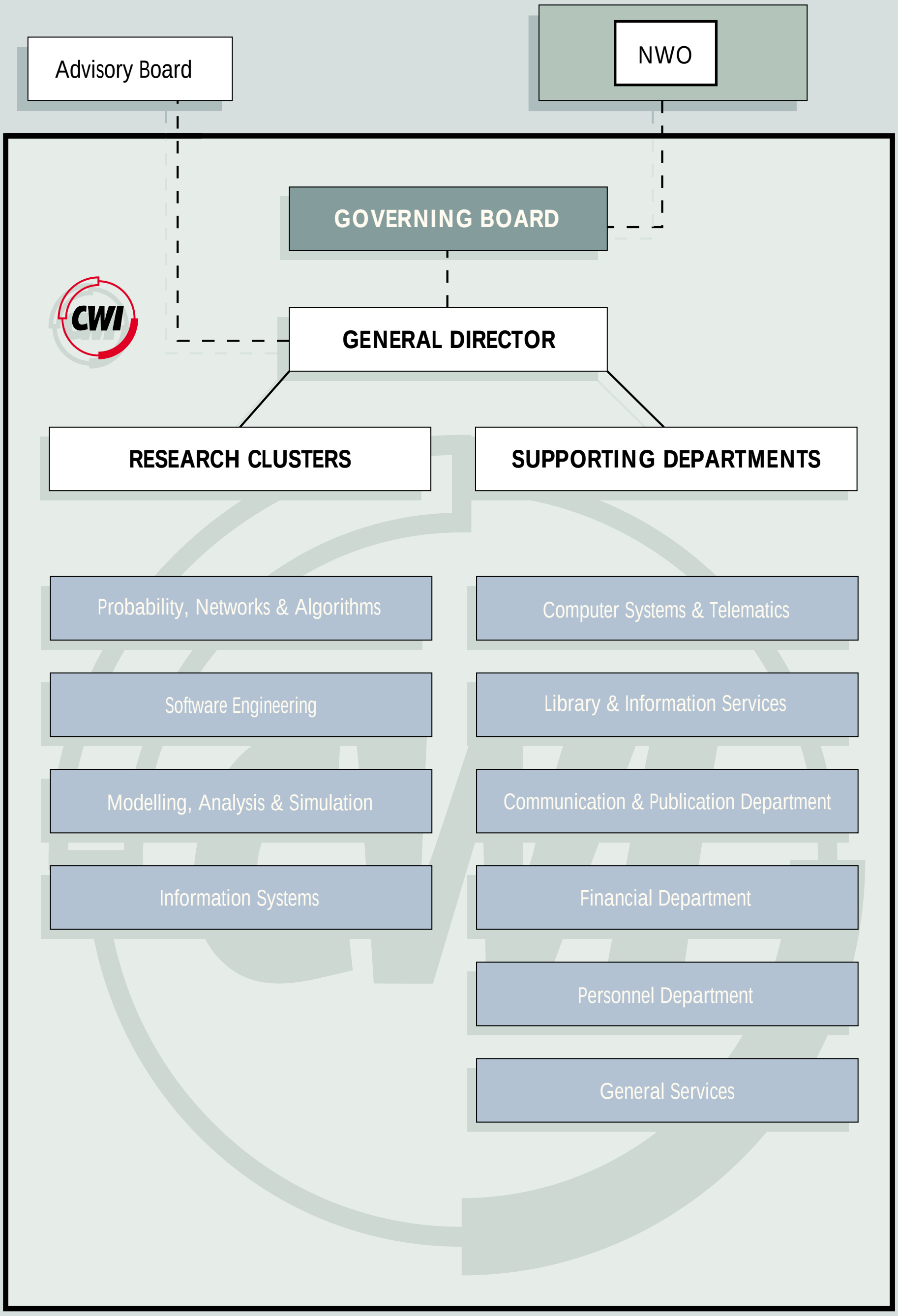
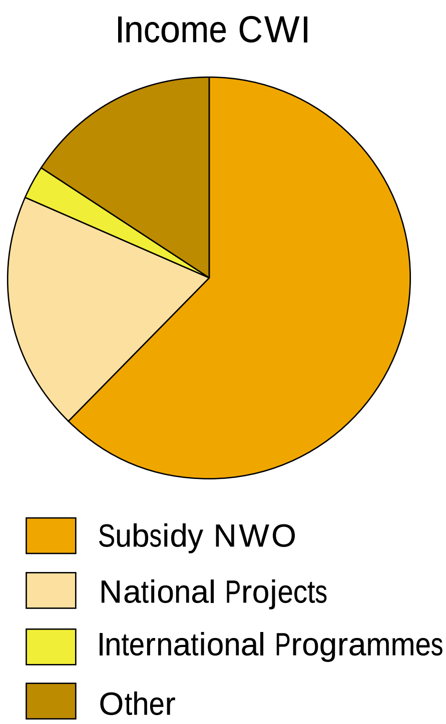
M. Westermann
G. Wiederhold (Stanford University, USA)

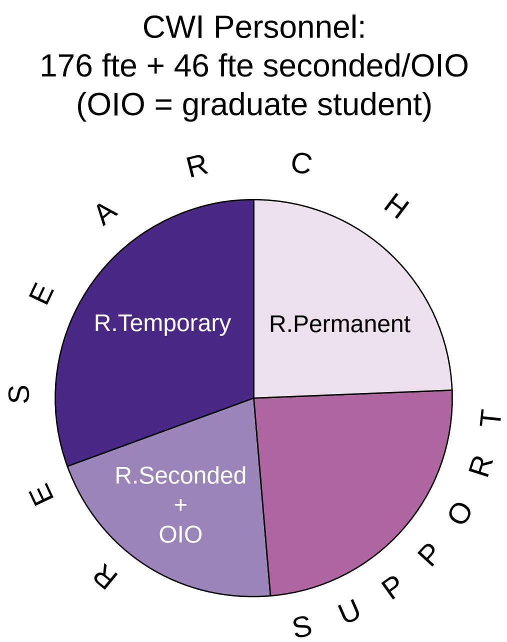

Advisory Board
NWO
GOVERNING BOARD
GENERAL DIRECTOR
RESEARCH CLUSTERS
SUPPORTING DEPARTMENTS
Probability, Networks & Algorithms
Software Engineering
Modelling, Analysis & Simulation
Information Systems
Computer Systems & Telematics
Library & Information Services
Communication & Publication Department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

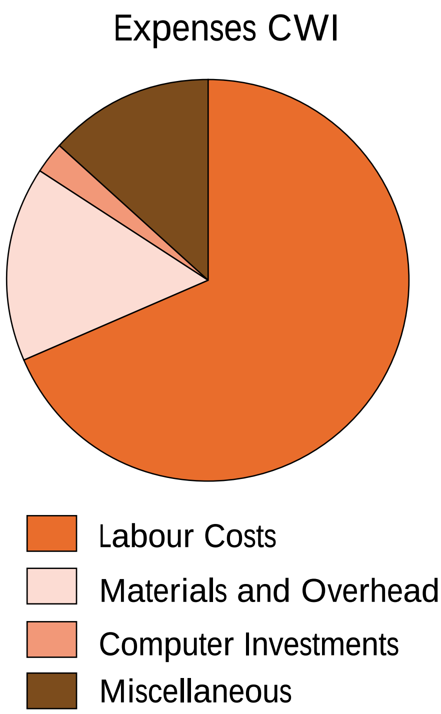
FINANCES, PERSONNEL

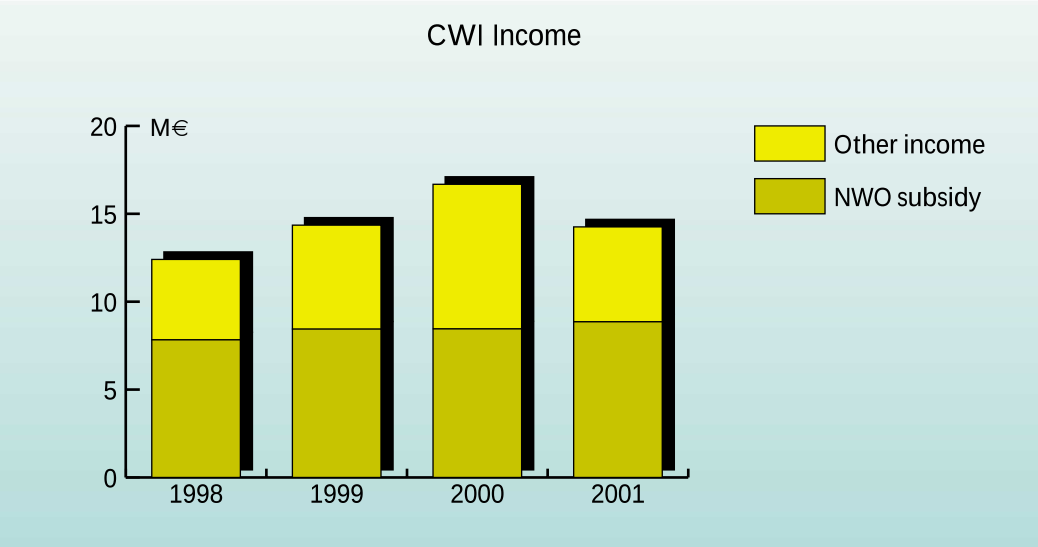
Finances 2001

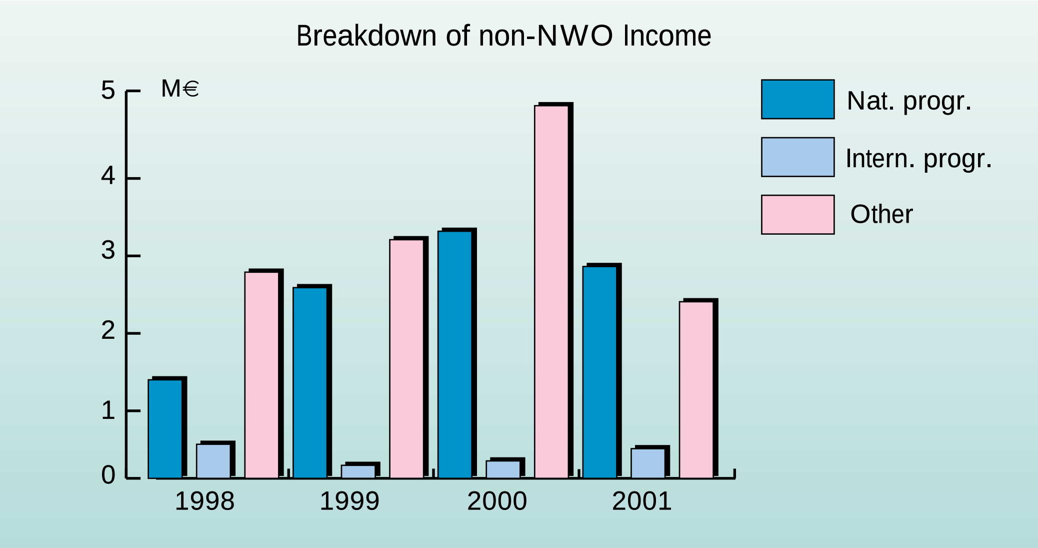
In 2001, CWI spent M€. 14,21. The expenses were covered by a basic subsidy from NWO (M€. 8,86), by income from national projects and programmes (NWO, Telematics Institute, WTCW/ICES-KIS, total M€. 2,73) and international programmes (M€. 0,38), and finally by M€. 2,24 as revenues out of third-party-services and other sources.

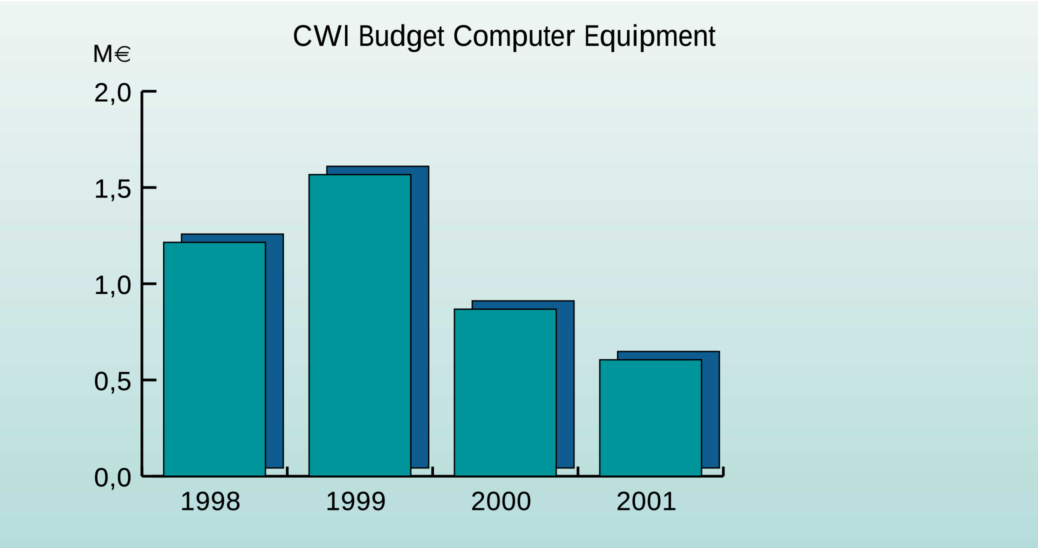







CWI Income
20
15
10
5
0
M€
1998
1999
2000
2001
Other income
NWO subsidy


Breakdown of non-NWO Income
5
4
3
2
1
0
M€
1998
1999
2000
2001
Nat. progr.
Intern. progr.
Other


CWI Budget Computer Equipment
M€
2,0
1,5
1,0
0,5
0,0
1998
1999
2000
2001

CWI PhD THESES

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

S.C.C. Blom
Term Graph Rewriting – Syntax and Semantics
J.W. Klop

M. Genseberger
Domain Decomposition in the Jacobi-Davidson Method for Eigenproblems
H.A. van der Vorst (University of Utrecht)

P.J. 't Hoen
Towards Distributed Development of Large Object-Oriented Models. Views of Packages as Classes
G. Engels (University of Leiden)

B. Lemmens
Iteration of Nonexpansive Maps Under the 1-Norm
M.S. Keane, S.M. Verduyn Lunel (University of Leiden)

R. van Liere
Studies in Interactive Visualization
P. Klint

I W. Mangku
Estimating the Intensity of a Cyclic Poisson Process
M.S. Keane

M.S. Marshall
Methods and Tools for the Visualization and Navigation of Graphs
M. Delest (Université de Bordeaux)

J.R. van Ossenbruggen
Processing Structured Hypermedia: A Matter of Style
J.C. van Vliet (Free University Amsterdam)

M. Pauly
Logic for Social Software
D.J.N. van Eijck, J.K. van Benthem (University of Amsterdam)

B.A.M. Schouten
Giving Eyes to ICT! or How Does a Computer Recognize a Cow?
M.S. Keane

R.M. de Wolf
Quantum Computing and Communication Complexity
H.M. Buhrman, P.M.B. Vitányi

J.H. van Zanten
Martingales and Diffusions – Limit Theory and Statistical Inference
M.S. Keane

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).

Wireless 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, UTMS

The development of queueing theoretic models and algorithms for dimensioning, engineering, and operating integrated-services wireless networks, underlying next-generation mobile communication systems.

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

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 Rew, 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

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.

Discrete algorithms

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

Applied Analysis and Scientific Computing

Theme leader: J.G. Verwer

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.

Analysis, asymptotics and computing

Studies of partial differential equations in connection with applied analysis, asymptotics, special functions and analysis, in particular: symmetries and self-similar structures in diffusion equations, infiltration in porous media with dynamic capillary pressure, sparse-grid methods for time-dependent PDEs, geometric methods and smoothed particle hydrodynamics, collapse behaviour of long elastic structures, asymptotics and special functions, and numerical solution of time-dependent advection-diffusion-reaction equations.

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.

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.

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

Research into applied logic, including dynamic logic, tableau reasoning, construction of electronic textbooks for logic, and interactive information engineering; research on Hopf algebras of noncommutative symmetric functions, and on identification clouds for the automatic indexing of texts; 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 and knowledge discovery

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) and medicine (physiological time series).

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.

Cellular 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
Pilot 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 bio-informatics, particularly the development of a VR desktop 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: P.M.B. Vitányi

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 evolutionary computing

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 statistic, with applications in cognitive psychology. Basic mathematical requirements for performance guaranties of evolutionary programs, using properties of Monte Carlo sampling and rapidly mixing markov chains.

Advanced algorithms and systems

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 (bio-informatics 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,
- cooperation with other institutes,
- CWI project leader(s).

European Programmes

COTIC (23677): Concurrent Constraint Programming for time-critical applications
1997–2001
Universities of Utrecht, Pisa, Lisbon and Kent, SICS, CR&T
K.R. Apt

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

VHS (26270): Verification and control of hybrid systems
1998–2001
U. Joseph Fourier, U. Dortmund, U. Nijmegen, U. Aalborg, INP Grenoble, Chr. Albrechts U. Kiel, Weizmann Inst. Israel, U. Gent, Nylstar Engineering, Sidmar NV, Krupp Uhde GmbH
J.H. van Schuppen

DEDUGIS (28115): Deductive Constraint Databases for Intelligent Geographical Information Systems
1998–2002
CNR/CNUCE, U. Pisa, GMD – First Berlin, U. 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
U. Barcelona, Wasserforschung Mainz GmbH, Czech Acad.Sc., U. Amsterdam
J.G. Verwer

TRIAL Solution
2000–2003
U. Koblenz-Landau, Heidelberger Akad. Wissenschaften, Trinity College Dublin, U. Nice-Sophia Antipolis, FIZ Karlsruhe, Ges. f. Wiss.-Techn. Information, Open University (UK),

TU Chemnitz, U. Köln, Springer-Verlag, Harri Deutsch, Shang IT
M. Hazewinkel

QAIP – Quantum Algorithms and Information Processing
2000–2002
U. Oxford, U. Bristol, U. Aarhus, U. Paris Sud, Hebrew U. Jerusalem, Weizmann Inst., Technion Israel, U. Waterloo, IMCS, MGU Moscow, U. 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 U. 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 U. 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
U. 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 National Supérieure des Mines de Paris (ENSMP-CMM), Association pour la Recherche et le Developpement des Méthodes et Processus Industriels (Armines-CMM), Heinrich-Hertz Institut (HHI), Philips France S.A.S. (LEP), Groupe des Ecoles des Télécommunications (GET-ENST), Universitat Politècnica de Catalunya (UPC), Vrije Universiteit Brussel (VUB), Poznan University 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), Katholieke Universiteit Nijmegen (KUN), Stichting Nationaal Lucht- en Ruimtevaartlaboratorium, Kuratorium OFFIS E.V. (OFFIS), Christian-Albrechts U. Kiel, Weizmann Institute of Science (WIS), France Telecom SA (FT), Centre National de la Recherche Scientifique (CNRS/Verimag), U. Joseph Fourier Grenoble 1 (UYF, Verimag)
F.S. de Boer

TMR

DONET: Discrete Optimization: Theory and Applications
1998–2003
U. Leuven, London School of Economics and Political Sciences, U. Pierre et Marie Curie (Paris), Rheinische U. Bonn, CNR, U. Lisbon, Société Coopérative ALMA, DASH Associates Ltd, Ecole Polytechnique Fédérale de Lausanne
A. Schrijver, A.H.M. Gerards

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

INTAS

Numerical analysis of local and global bifurcations in ordinary differential equations
1999–2001
U. Gent, Russian Acad. Sciences, U. Nizhny Novgorod
M. Hazewinkel

Bilingual English-Russian thesaurus in mathematics
1999–2001
Russian Acad. Sciences, Steklov Inst. of Mathematics, Yaroslav State U., U. Utrecht
M. Hazewinkel

INCO

DEVIEW: Designing and Developing the Viewer Centred Paradigm in Virtual Environments
1998–2001
U. Capetown, U. College London
P.J.W. ten Hagen

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
U. 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

Co-operation with GMD

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

Application of techniques from propositional logic for the verification of processes
1998–2002
U. 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 U., EURANDOM, Lucent Technologies, U. Eindhoven, U. Wroclaw, U. Twente
M.R.H. Mandjes

Foundations of declarative programming
1997–2002
U. Amsterdam, Free U. Amsterdam
K.R. Apt

Dynamic algorithms for on-line optimization
1997–2001
Philips Research
J.A. La Poutré

Quantum Computing and advanced systems research
1997–2001
U. Amsterdam, U. Delft/DIMES, U. Oxford, IBM T.J. Watson Research Centre, LRI-CNR Paris
P.M.B. Vitányi

Learning, cryptography and randomness
1997–2001
U. Amsterdam, U. Twente, U. Waterloo, McMaster U., U. Chicago, UPC Barcelona
P.M.B. Vitányi

CIP – Constraint and Integer Programming techniques
1997–2002
Partners in ERCIM WG on Constraints
K.R. Apt

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

PROMACS: Probabilistic methods for the analysis of continuous systems
1998–2003
U. Eindhoven, Free U. Amsterdam, U. Amsterdam, U. Nijmegen, U. Dresden, Indiana U.
J.J.M.M. Rutten

Sparse grid methods for time-dependent PDE problems
1998–2001
UU/IMAU, RIVM, KNMI, TNO, U. Iowa
J.G. Verwer, B. Koren

Rigid sets
1998–2002
Free U. Amsterdam
J. van den Berg

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

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

GenTrans – Generation of Program Transformation Systems
1999–2001
U. Bergen, U. Utrecht
J. Heering

Component based framework for constraint solving
1999–2001
ERCIM Institutes (in total 10) involved in ERCIM Working Groups on Constraints,
U. Victoria (Canada), U. Singapore, Brooklyn College USA
K.R. Apt

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

Asymptotics and special functions
1999–2001
U. Delft, U. Wageningen, NAM, TNO, U. Leiden
N.M. Temme

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

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

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

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

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

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

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

Dynamo – Semi-automatic hypermedia presentation generation
2000–2004
U. Eindhoven, Philips
H.L. Hardman

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

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

FAST – Large-deviations asymptotics and fast simulation
2001–2004
Lucent Technologies, U. Twente, Free U. 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, U. Leiden, Ioffe-Institute St. Petersburg, U. Amsterdam
U.M. Ebert, W.H. Hundsdorfer

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

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

COCON – Coalgebra and Control
2001–2002
U. Toronto, U. Waterloo
J.H. van Schuppen

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

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

Average-case analysis
2000–2004
P.M.B. Vitányi

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

CoMoLo – Coalgebra Model Logic: Theory and Applications
2001–2003
U. Amsterdam, U. Nijmegen
J.J.M.M. Rutten

Universal learning
2001–2004
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

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

Distributed imperative constraint programming
2002–2004
Russian Research Inst. of Artificial Intelligence Moscow, Institute of Informatics Systems Novosibirsk
K.R. Apt

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

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

Special NWO projects

CAM: Number Field Sieve factoring method
1997–2001
U. Oxford, Australian National U., Citibank New York, San Rafael, U. Groningen, U. Leiden, Macquarie U. Sydney, U. Bordeaux, U. Georgia, U. Giessen, IRI Toulouse
H.J.J. te Riele

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

MPR: Parallel solution of very large eigenvalue problems
1998–2001
U. Utrecht, FOM, U. Delft
H.J.J. te Riele

ALW – Bio-VR: Application of VR in cell biology
1998–2001
U. Amsterdam
R. van Liere

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

ToKeN2000

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

STW (Foundation for the Technical Sciences)

Multiresolution image analysis and synthesis
1998–2002
Johns Hopkins U., TNO, AKZO-Organon, Thales
H.J.A.M. Heijmans

MOBILECOM: mobile communication networks
1999–2003
U. Amsterdam, Free U. Amsterdam, U. Eindhoven, U. 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
U. Juan Carlos Madrid, U. Eindhoven
U.M. Ebert

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

SENTER

RTIPA – Real Time Internet Platform Architectures
1999–2001
Philips, Oratrix, U. Eindhoven, EOLRING Int., France Telecom, GIP RENATER, Hitachi, INRIA, Italtel SpA, LIP6, Politecnico di Milano, Siemens AG, Telebit, Thomson-CSF
H.L. Hardman

WATERLAND – Workflow met semi-automatische metadata extractie bij volledige mediaproductie in Nederland
2001–2005
NOS, TNO-TPD, U. Twente, NOB
A.P. de Vries

NCF

Parallel simulation of the formation of neuronal connections in the nervous system
2000–2001
B.P. Sommeijer

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

EURANDOM

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

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

ICES-KIS Programme

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

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

Distributed virtual reality for cell biology
2000–2001
U. Amsterdam
R. van Liere

Telematica Instituut

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

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

U-Wish: Web-based service for information and commerce
1999–2001
TNO-TM, CTIT
S. Pemberton

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

DRUID: Multimedia indexing and retrieval on the basis of image processing and language and speech technology
1999–2003
TNO, CTIT
M.L. Kersten

Autonomous systems of trade agents in E-commerce
1999–2003
TNO, ING, KPN, IBM, Bolesian
J.A. La Poutré

KNAW

Statistical methods for compound sums
2000–2004
Gadjah Mada U.
R. Helmers