

CWI

Centrum Wiskunde & Informatica

Annual Report 2008





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Centrum Wiskunde & Informatica

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Centrum Wiskunde & Informatica (CWI) is the national research institute for mathematics and computer science in the Netherlands. It is part of the Netherlands Organisation for Scientific Research (NWO).

CWI is a founding member of ERCIM, the European Research Consortium for Informatics and Mathematics. The institute is a member of the World Wide Web Consortium (W3C) and it manages the W3C Office in the Benelux. CWI is located at Science Park Amsterdam.

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1. To conduct advanced research of societal and scientific relevance
2. To act as a breeding ground for academic staff and young researchers
3. To transfer knowledge to society and increase public interest in mathematics and computer science
4. To play a leading role in the Dutch and European mathematics and computer science scene

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Fighting lymph cancer with mathematics

Social yet interactive: new forms of television viewing

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On the road again – with intelligent agents

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The CWI annual report series consists of:

- Annual Report (English), a full colour document giving a general overview of CWI's activities
- Overview Research Activities (English), a comprehensive enumeration of CWI's research
- Jaarverslag (Dutch), a supplement containing the social and financial report and the works councils report

Copies can be ordered at the Communication & Information Department: info@cw.nl

INTRODUCTION

In times of crisis that the world currently experiences, we need to invest in our future even more. We have to construct a solid foundation for tomorrow's society. CWI's scientists are ready for this challenge. We contribute to this common objective by creating new knowledge and turning results into business and welfare for our society.

The year 2008 was very fruitful: the construction of the new wing to our building proceeded as planned, our mid-term evaluation was positive, and the scientific output was substantial.

Let me highlight some results of the past year. Nine CWI researchers were appointed professor. We created two spin-off companies around our innovative MonetDB database system. Our Software Improvement Group spin-off won the national ICTRegie Award 2008 for successful valorization. More appreciation for our results was shown by the many prizes for CWI scientists, such as INFORMS' prestigious Edelman Award for the railway timetable. We cracked the hash function of the MD5 algorithm, which secured digital certificates used for internet security – news that not only reached *NRC Handelsblad* but also *The New York Times*. In July CWI, the University of Amsterdam, and VU University Amsterdam organized the Fifth European Congress of Mathematics, hosting some 1000 mathematicians.

In 2005, our institute was evaluated as 'excellent' by NWO. A CWI Advisory Board committee – chaired by Frank van der Duyn Schouten – performed a mid-term evaluation in the past year. The general conclusion was that CWI maintains its high level of research. We consider this as an endorsement of our general policy and course. However, some issues need attention: increasing the number of PhD students, mobility to industry, external visibility, and governance of the four strategic research themes – earth and life sciences, the data explosion, societal logistics, and software as service. In the Fall we started a new research group in the life sciences.

The large Bsik-ICT programmes BRICKS (with a central role for CWI), MultimediaN and VL-e were rated as being scientifically very successful and most beneficial to society. These projects, funded by the Netherlands natural gas revenues (FES), will end in 2009. Under the auspices of ICTRegie a new proposal is being prepared for the next round of FES. CWI will participate in this proposal. Our institute is flourishing and we have great confidence in the future.

We hope that you will enjoy reading our Annual Report 2008.



Jan Karel Lenstra
General director



CWI Research Clusters

Probability, Networks and Algorithms

Algorithms, Combinatorics and Optimization
Probability and Stochastic Networks
Signals and Images
Cryptology and Information Security

Software Engineering

Interactive Software Development and Renovation
Coordination Languages
Computational Intelligence and Multi-agent Games
Distributed Multimedia Languages and Infrastructures

Modelling, Analysis and Simulation

Dynamical Systems and Numerical Analysis
Scientific Computing and Control Theory
Multiscale Modelling and Nonlinear Dynamics

Information Systems

Standardization and Knowledge Transfer
Database Architectures and Information Access
Semantic Media Interfaces
Visualization and 3D Interfaces
Quantum Computing and Advanced Systems Research

CWI

Founded in 1946, the Centrum Wiskunde & Informatica (CWI) is the Netherlands' national research institute for mathematics and computer science.

CWI conducts pioneering research in mathematics and computer science, generating new knowledge in these fields and conveying it to broader society, and to trade and industry in particular. CWI's research is dedicated to four strategic research themes. CWI obtains around 60% of its funding from the Netherlands Organisation for Scientific Research (NWO). The remaining 40% is obtained through national and international programmes and contract research commissioned by industry.

To achieve its mission, CWI has formulated the following goals:

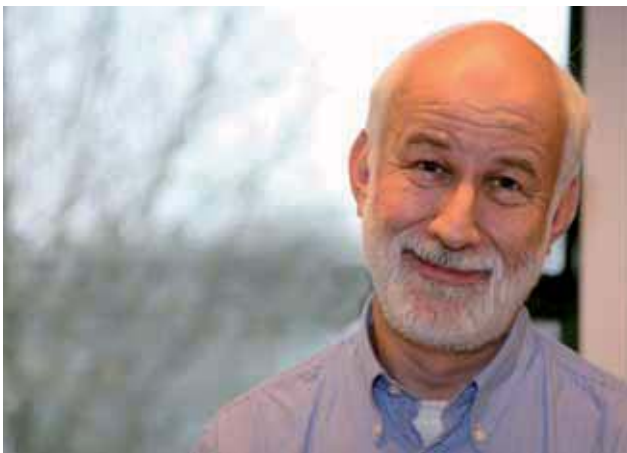
1. To conduct advanced research of societal and scientific relevance
2. To act as a breeding ground for academic staff and young researchers
3. To transfer knowledge to society and increase public interest in mathematics and computer science
4. To play a leading role in the Dutch and European mathematics and computer science scene

1. To conduct advanced research of societal and scientific relevance

CWI concentrates on fundamental questions that are inspired by practical problems. Its strength is the discovery and development of new ideas, and the transfer of knowledge to academia and industry. We study the strongly interrelated core of mathematics and computer science. Numerous prizes and grants show the appreciation for our work.

This section highlights a number of major achievements of the institute and its researchers.

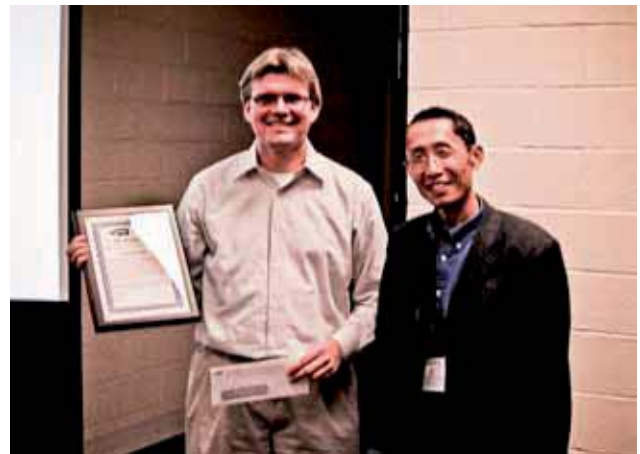
CWI Fellow Krzysztof Apt was appointed CWI Fellow on 1 April. This fellowship is given to outstanding members of CWI research staff, and offers them full freedom in research. At CWI, Apt is member of the research group Algorithms, Combinatorics and Optimization, and he is Professor at the University of Amsterdam. In 2006 he



Krzysztof Apt

was appointed member of the Academia Europæa. He is founder and past Editor-in-Chief of the *ACM Transactions in Computational Logic*. Apt published four books and numerous journal articles in computer science, mathematical logic and game theory. In honour of his appointment CWI organized a symposium on game theory on 27 May.

Erlang Prize In October, Bert Zwart received the prestigious Erlang Prize from INFORMS – the Institute for Operations Research and the Management Sciences in the United States. This award is presented to the best researcher under the age of 36 who has contributed significantly to the field of applied probability. The Erlang Prize is awarded every



Bert Zwart receiving the Erlang Prize from Jim Dai, chair of the jury. picture: INFORMS.

two years, and involves a plaque and one thousand dollars. Zwart was the first person outside the USA to win this prize. The jury praised him for his outstanding contributions to several areas in the interface of applied probability, computer science, and communication networks.

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Innovation Award The train timetable of the Nederlandse Spoorwegen (NS, the Dutch Railways) has won the prestigious Franz Edelman Award. This prize is awarded by INFORMS to excellent operational research with great influence on companies or daily life. It was awarded in April to a team of researchers from NS, Erasmus University Rotterdam, University of Padua (Italy) and CWI. The software to construct the new train timetable for 2007 and onward was developed by Lex Schrijver en Adri Steenbeek of CWI.



Lex Schrijver, Gábor Maróti, Jan Karel Lenstra, Adri Steenbeek, and Leo Kroon (NS Reizigers, on the right). Lenstra holds the Edelman Award.

The schedule of Europe's busiest railway network is based on mathematical models that take many factors into account, like the number of available railway tracks, railway knots, platforms, trains and personnel. The traveller now enjoys the robust timetable with more trains running and fewer delays.



Marjo Wildvank, CEO of SIG (on the right) receives the ICTRegie Award 2008 from Hennie Wesseling, chair of the jury. Source: ICT-Office.

ICTRegie Award In May, the Software Improvement Group (SIG) won the ICTRegie Award. The CWI spin-off SIG analyses any software source code in an automated manner. The company maps out the quality of the system, measures the changeability and assesses the situation, all based on automated analysis of source code. Paul Klint, Tobias Kuipers, Arie van Deursen and Marjo Wildvank are the founders of SIG. The ICTRegie Award is given to a person or group that has been able to convert the results of scientific research into a successful, profitable, or social enterprise.

Philips Mathematics Prize Erik Jan van Leeuwen won the Philips Mathematics Prize for PhD students. He received the award on 17 July during 5ECM – the 5th European Congress of Mathematics, organized in the RAI in Amsterdam. His lecture was entitled 'Geometric optimization for wireless networks and computational biology'. Apart from Van Leeuwen two of the five other finalists also came from CWI: Willemien Ekkelkamp and Robbert de Haan.

Best PhD Thesis Jeroen Wackers won the ECCOMAS Award for the Best PhD Thesis in 2007, in May 2008. The European Community on Computational Methods in Applied Sciences issued this Award to highlight the outstanding achievements of two PhD students. Wackers received a diploma and 2000 euros. He was also invited to give a semi-plenary lecture at the WCCM8 and ECCOMAS 2008 congress in Venice. The committee concluded that his research is “highly innovative and of superior quality, with respect to mathematics and physics”. Wackers received his PhD degree cum laude at Delft University of Technology, with his thesis *Surface Capturing and Multigrid for Steady Free-Surface Water Flows*. At CWI, he worked in a project financed by the research programme BRICKS. Currently, Wackers continues his two-fluid flow research as a postdoc at the École Centrale de Nantes, France.



Jeroen Wackers receiving the ECCOMAS Award.



Ronald de Wolf



Bert Zwart

Two Vidi grants for CWI research Ronald de Wolf and Bert Zwart both received a Vidi grant from NWO. With 600,000 euros each they can develop their own line of research for five years. Mathematician Zwart will use his grant for the project *High dimensional service systems*. This research aims at the analysis of complex systems and procedures in which so many factors are involved that traditional methods cannot be applied. An example is a call centre with hundreds of call agents. If the number of impatient customers increases, more agents are required. The system is too large to analyze. Zwart will develop fundamental models to tackle this kind of problems. Computer scientist De Wolf wants to find other and better applications of quantum computers, machines based on the principles of quantum mechanics. They do not yet exist, but when they do, they will speed up calculations enormously and perform tasks that cannot be done by traditional computers, like cracking specific security codes for internet applications. This theory can also be used to better secure information. De Wolf also wants to study the consequences of quantum computing on traditional computers. He builds on research that he performed with an earlier Veni grant.

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Best Paper Awards At the ACM DocEngineering Symposium in São Paulo, Brazil, in September, CWI researchers Jack Jansen and Dick Bulterman received the Best Paper Award for their SMIL State research. The work described in their paper 'Enabling Adaptive Time-based Web Applications with SMIL State' has been integrated into the new SMIL 3.0 language for interactive multimedia presentations.

At the EuroITV 2008 conference in Salzburg, Austria, Pablo Cesar, Dick Bulterman and Jack Jansen received the Best Paper Award for their interactive television research. Their article 'Usages of the Secondary Screen in an Interactive Television Environment: Control, Enrich, Share, and Transfer Television Content' describes an innovative approach to expanding the interaction possibilities of an end-user in an interactive television framework.



Jack Jansen (CWI, in the middle) accepted the Best Paper Award from Steven Simske (HP Labs, USA, on the left) and David Brailsford (University Nottingham, UK).

At the International Semantic Web Conference 2008 in Karlsruhe, Germany, Michiel Hildebrand received the Best Student Paper Award for research proposals. In his proposal

on intelligent web interfaces *Interactive Exploration of Heterogeneous Cultural Heritage Collections* he investigated how to support end-users in exploring Linked Data on the web. The current Web basically looks like a large document server, whereas in future it will act more like a database, with small pieces of interrelated information. These Linked Data can be utilized much more efficiently. The research is part of the MultimediaN/E-Culture project.



Michiel Hildebrand

ArchiMate team wins NAF-Architectureprize The Dutch Architecture Forum for the digital world awarded the NAF Architecture Prize to the ArchiMate team on 26 November. CWI researchers Frank de Boer and Farhad Arbab are members of this team. It consisted of a broad cooperation from practice (ABN AMRO, ABP, Inland Revenue, Ordina) and science (Radboud University, CWI, Leiden University), under guidance of the Telematica Instituut. ArchiMate was adopted by the Open Source Group, a worldwide consortium of enterprises and knowledge institutions, thus turning a Dutch development into a standard of world stature.

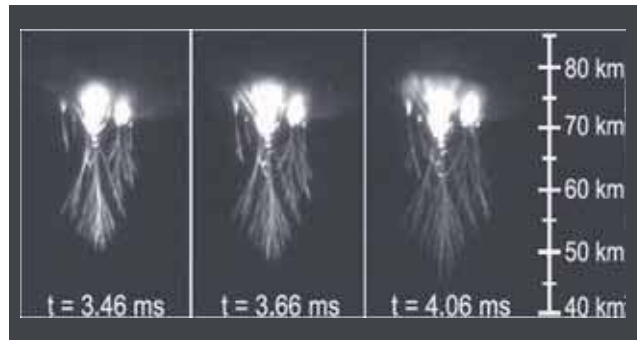


The NAF Architecture prize. picture: Telematica Instituut.

Research projects Many outstanding research projects are being performed at CWI. We highlight three of them here.

Service Optimization and Quality (SEQUAL) ranked first in the IOP Generic Communication funding programme of SenterNovem. Rob van der Mei received 300,000 euros to do research into improving the quality of web services. He cooperates with TNO, University of Twente, IBM Netherlands, Ericsson Netherlands, Ordina and Mobilaria. The research topic fits into the strategic theme *societal logistics*, one of CWI's cornerstones for the coming years. The new project deals with composite services, which combine services of third parties.

Electronic signs on highways should be controlled in a coordinated manner, as should pilotless planes. Five problems of this type are investigated in the project *Control for coordination of distributed systems (C4C)*. Directed by CWI, research-



Attracting and colliding channels in a sprite discharge above a thundercloud. picture: S.A. Cummer et al., *Geophys. Res. Lett.* 33, 4104 (2006).

ers from various European countries join forces in this project, which started in May. The research questions were motivated by several engineering systems including a traffic control network in the Netherlands, communication of small submarines and pilotless planes used for environmental research, and control of complex machines like large printers. CWI mathematician Jan van Schuppen is leader of this project group, with members from four companies and eight academic institutes. The European Commission provided financial support through its Information and Communication Technologies Programme.

In August Alejandro Luque, Ute Ebert, and Willem Hundsdorfer published an article on lightning research in the prestigious *Physical Review Letters*. They explained theoretically how branches in lightning can sometimes reconnect. So far, knowledge only covered growth and branching. Reconnection of lightning branches was detected above thunderclouds and in lab experiments. At CWI, the researchers discovered that attraction and rejection of the heads of two lightning branches depend on the gas density and the proportions of oxygen and nitrogen in the air. The research was co-financed by STW. •

2. To act as a breeding ground for academic staff and young researchers

Researchers at CWI are able to fully concentrate their efforts on their scientific work, and to build an international network of peers. More than half of the permanent research staff maintains close contact with universities as part-time professors. The personal and institutional research networks strengthen our position and attract talent. CWI is a meeting point for researchers around the globe. Our postdocs and PhD students come from more than 25 countries world-wide. This section highlights a number of new professorships and PhD degrees.

Professorships

Bert Gerards Adjunct Professor at University of Waterloo From 1 January 2008 till 31 December 2012 Bert Gerards is appointed



Bert Gerards

Adjunct Professor at the Department of Combinatorics and Optimization of the University of Waterloo, Waterloo, Ontario. It is an honorary position. The department built an exceptional reputation during its 40-year existence. It is renowned in areas like combinatorial optimization, algebraic combinatorics, graph theory, continuous optimization, quantum computing and cryptography. Practically all leading researchers from these areas have worked at or visited this department. Bert Gerards will be working in the area of combinatorial optimization.



Frank de Boer

Frank de Boer Professor of Software Correctness On 15 February Frank de Boer was appointed Professor of Software Correctness at Leiden University. At the Leiden Institute of Advanced Computer Science (LIACS) he is part of the research cluster Foundation of Software Technology. De Boer's research concentrates on the integration of testing and verification techniques for the validation of component-based and

object-oriented software. CWI and LIACS already have well-established relations, and with this appointment both institutes hope to strengthen their associations even more. At CWI Frank de Boer is groupleader of the Coordination Languages research group.



Dick Bulterman

Dick Bulterman Professor of Distributed Multimedia Languages and Infra-structures On 1 March Dick Bulterman was appointed Professor of Distributed Multimedia Languages and Infra-structures at the VU University Amsterdam, where he will work within the Business, Web and Media research group of the Computer Sciences Department. His research concentrates on the development of synchronization languages and interactive infrastructures for supporting a broad range of dynamically distributable multimedia applications on mobile and personal devices. Bulterman's appointment strengthens the ties between CWI and VU, and broadens the position of both organizations within the scientific activity on media

design, analysis and processing in Amsterdam. At CWI Bulterman is head of the research group Distributed Multimedia. He will also remain chair of the SYMM synchronized multimedia working group of the World Wide Web Consortium, W3C.

Barry Koren Professor of Numerical Mathematics On 1 March Barry Koren was appointed Professor of Numerical Mathematics at Leiden University. He combines this position with his work at CWI as head of the research group Scientific Computing and Control Theory, and temporarily with his work as Professor of Computational Fluid Dynamics at TU Delft. The Mathematical Institute of Leiden University: "With over 100 scientific publications and his enthusiastic and skilled training of talented PhD and MSc students Barry Koren is a valued colleague on a national and international level." Koren can strengthen the already existing cooperation between Leiden, Delft and CWI.



Barry Koren

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Arjen de Vries appointed Professor of Multimedia Dataspaces

Arjen P. de Vries was appointed Professor of Multimedia Dataspaces at Delft University of Technology on 1 September. A dataspace – all information belonging to one entity: a person, a community or an enterprise – contains multimedia information, such as web pages, online media, slides, e-mails and attachments. De Vries studies models, algorithms, and system architecture of dataspace support platforms. He sees opportunities for storage and retrieval of unstructured multimedia data by integrating statistical and database techniques. At CWI, De Vries leads the Information Access team that studies the integration of information retrieval and databases. This integration is a prerequisite to creating the next generation of search engines, and handling multimedia and structured data.



Arjen de Vries

Peter Grünwald Professor of Statistical Learning

As of 1 November, Peter Grünwald was appointed Professor of Statistical Learning at the Mathematical Institute of Leiden University. Grünwald holds this position for one day a week and will, among others, set up a class in

Statistical Learning. Statistical learning theory deals with learning from data with as few assumptions about reality as possible. It also has applications in computer science, like self-learning spam filters and speech recognition software. In computer science this discipline is called Computational Learning. Grünwald's chair is part of an exchange programme with Richard Gill, who will do research at CWI for one day a week.



Peter Grünwald

Leen Stougie Professor of Operations Research

On 1 November Leen Stougie was appointed full Professor of Operations Research at the VU University Amsterdam. In Operations Research mathematical methods and models are being developed to solve practical problems, like optimizing railway and school timetables. Stougie thinks that mathematical models are not used nearly enough in solving societal or industrial problems. He performs research in combinatorial optimization with an emphasis on algorithms, with applications in wireless communication, sensor networks, and systems biology. Especially in medicine great new challenges can be found. Stougie started at CWI in

1980, and has been a researcher in the group Algorithms, Combinatorics and Optimization since 2000. He is project leader of the BRICKS project Algorithms and Processes in Life Sciences and a member of the executive committee of the Dutch Network in the Mathematics of Operations Research.



Leen Stougie

Vladas Sidoravicius Professor of Applied Probability On 1 November Vladas Sidoravicius was appointed Professor of Applied Probability at the Mathematical Institute of Leiden University. On 12 December he received the John Von Neumann Prize of the Technische Universität München, a Guest Professorship. In Leiden Sidoravicius will work in the frontier areas of mathematics, physics, and biology, in particular mathematical statistical physics and mathematical population dynamics. Sidoravicius will be involved in national biomathematics activities. Collaboration between CWI and MI is already extensive and successful. Intensifying this through part-time appointments of senior CWI researchers in Leiden improves this cooperation.



Vladas Sidoravicius, picture: Mathematisches Forschungsinstitut Oberwolfach.

Karen Aardal Professor of Optimization

As of 1 September Karen Aardal is full Professor of Optimization at Delft University of Technology, where she becomes head of the Optimization and Systems Theory group. The four preceding years Aardal was a senior researcher at CWI. She foresees many optimization challenges, like improved



Karen Aardal

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ambulance planning, more efficient transport and optimizing the use of operating rooms in hospitals. She also wants to utilize techniques from other mathematical disciplines. From 2005, Aardal had a part-time position at Eindhoven University of Technology. She is Area Editor of *INFORMS Journal on Computing* and Associate Editor of *Mathematical Programming B*, *Networks* and *Operations Research Letters*.

PhDs

Numerical integration Numerous phenomena in science and technology are modelled by systems of ordinary differential equations – ODEs. For their numerical solutions many methods are available, using time steps that are varying in time but are constant over the components. However, there are many problems of practical interest, where the temporal variations have different time scales for different components. To exploit these variations, one needs multirate

methods that use different, local time steps. Large time steps are used for the slow components, and small time steps are used for the fast ones.

In his PhD thesis *Multirate numerical integration of ordinary differential equations* Valeriu Savcenco designed, analysed and tested multirate methods for the numerical solution of ODEs. He developed a self-adjusting multirate time stepping strategy. Savcenco received his PhD on 15 January at the University of Amsterdam. The research has been carried out at CWI and was financed with a Peter Paul Peterich scholarship from NWO. This scholarship is provided once every four years for the best math research proposal.

Supervisor: Prof. dr. J.G. Verwer (CWI and University of Amsterdam), co-supervisor: dr. W. Hundsdorfer (CWI)

Keeping fairness alive In his PhD thesis *Keeping fairness alive. Design and format verification of optimistic fair exchange protocols*, Mohammad Torabi Dashti studied the design and the verification of optimistic fair exchange protocols. The first part of his research deals with a new certified e-mail protocol in which person X can send an e-mail to person Y in exchange for a receipt. With the fair exchange protocol person Y will only receive the e-mail if person X will receive the receipt. Such an exchange is only possible when there is a trustworthy third party involved. The strength of the protocol lies in the use of keychains. Less storage is needed to ensure the fairness.

In the second part Dashti focuses on intruder modelling, which contains thorough fairness restrictions. In this way it becomes possible to verify the liveness aspects of optimistic fair exchange protocols. To prove the empirical effectiveness of Dashti's intruder model he analysed protocols for electronic payments and digital rights. The research was supported by NWO. Dashti received his PhD on 27 February at the VU University Amsterdam.



Valeriu Savcenco



Mohammad Dashti

Supervisors: Prof. dr. W.J. Fokkink (VU University and CWI), Prof. dr. J.C. van de Pol (University of Twente)

Cryptography in a quantum world

Traditional cryptography is concerned with the secure and reliable transmission of messages. With the advent of widespread electronic communication and the internet, new cryptographic tasks have become increasingly important, like constructing secure protocols for electronic voting, online auctions, contract signing and many other applications where the protocol participants do not trust each other. It is impossible to implement such protocols with unconditional security, even using quantum mechanics. Classically, people use the unproven assumption that factoring large numbers is difficult. Once a quantum computer is built, protocols based on this assumption will be broken.

Stephanie Wehner's thesis *Cryptography in a quantum world* proposes a new model for implementing such protocols, making the realistic assumption that storing

quantum states is difficult. Small amounts of noise are being experienced when researchers try to store a quantum state. It is proven that such protocols can indeed be implemented securely under this assumption. On 27 February Wehner received her PhD at the University of Amsterdam. Stephanie Wehner accepted a position at the California Institute of Technology – Caltech.

Supervisor: Prof. dr. H.M. Buhrman (CWI and University of Amsterdam)



Stephanie Wehner

Crosscutting Concerns Magiel Bruntink received his PhD degree with honours on 17 March at Delft University of Technology, for his thesis *Renovation of Idiomatic Crosscutting Concerns in Embedded Systems*. Crosscutting concerns are phenomena that are present in almost any (embedded) software system. They arise if the implementation of a concern – a requirement or design decision – does not fit neatly into the modular decomposition of a software system.

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Magiel Bruntink

A crosscutting concern cannot be confined to a single modular unit and therefore becomes scattered across the system. Automatic identification of such scattered code could be of great help during the maintenance of a software system. Bruntink's approach is one of renovation – a step by step improvement process aimed at easing the evolution of legacy software systems. The studied system was the embedded control software of an ASML wafer scanner, a device used in the manufacturing process of integrated circuits. Bruntink studied whether the use of Aspect-Oriented Programming (AOP) is better than the idiomatic style of implementation used in the ASML software system. The research was carried out as part of the Ideals project under the responsibility of the Embedded Systems Institute, and was partially supported by the SenterNovem TS programme.

Supervisors: Prof. dr. A. van Deursen (Delft University of Technology), Prof. dr. P. Klint (CWI and University of Amsterdam)

Semidefinite Programming Nebojša

Gvozdenović defended his thesis *Approximating the Stability Number and the Chromatic Number of a Graph via Semidefinite Programming* on 10 April at the University of Amsterdam. Gvozdenović investigated two hard combinatorial optimization problems concerning graphs. A graph consists of vertices, of which some are connected by edges. Some practical problems, like scheduling and phone frequency assignment, can be modelled as stable set or colouring problems. Vertex colouring is the assignment of colours to the vertices of a graph in such a way that connected vertices do not share the same colour. In the assignment of cell phone frequencies, the vertices represent the transmitting stations. They are connected by an edge when they are near each other. The least possible number of colours is the minimal number of frequencies that is necessary to communicate without interference. No fast solution method is known for these kinds of problems, and some people even think that there is no solution. Gvozdenović studied a new approach to the problem. He developed a method to find better bounds for the number of colours or the size of a stable set. With



Nebojša Gvozdenovic (in the middle)

this method he provided solutions to several hard problems. This research is part of the NWO Vidi project of Monique Laurent – *Semidefinite Programming and Combinatorial Optimization*.

Supervisor: Prof. dr. A. Schrijver (CWI and University of Amsterdam), co-supervisor: dr. M. Laurent (CWI)

Safer cash withdrawal from ATMs with mathematics Software faults can be expensive – for instance in automated teller machines (ATMs). Quality control should avoid such faults but this is often a cumbersome, expensive and erroneous task. Jens Calamé investigated how to automate this process. He took his PhD on 4 September 2008 at the University of Twente for his thesis *Testing reactive systems with data – enumerative methods and constraint solving*.



Jens Calamé

Calamé used mathematical techniques – constraint solving and formal methods – to find faults in models and implementations of reactive systems with data, such as ATMs or electronic markets. The research challenge is that those

systems can be in millions of possible states. Calamé found a way to reduce this number to a feasible quantity. He accomplished this by making test scenarios depending on the actual system behaviour. To reduce the risks of faults even further, it has to be verified whether the models meet their specifications. This has to be done earlier in the development process. Calamé designed a method to improve this check.

Supervisors: Prof. dr. J.C. van de Pol (University of Twente), Prof. dr. W.J. Fokkink (VU University and CWI)

More effective use of bandwidth with queueing models Bandwidth for internet traffic can be utilized more effectively with queueing models. Pascal Lieshout took his PhD on Friday 5 September at the University of Amsterdam with his thesis *Queueing Models for Bandwidth-Sharing Disciplines*. Modern communication networks like the internet are able to simultaneously support several applications, like data (e-mail), speech (VoIP), and



Pascal Lieshout

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video applications (YouTube). The generated network traffic places different demands on the handling. In data traffic only a few details may be missed. In speech, however, some noise (loss of data) is not too bad but speed reduction is. As the different kinds of traffic have different requirements, it is important to distinguish the bandwidth allocated to each traffic class. Lieshout examined methods to achieve this. To map their performance he applied queueing theory. With the results network providers can improve their capacity in so-called multi-service networks, and save money. In 2006 Lieshout received the prestigious ACM Sigmetrics/Performance best student paper award for his research.

Supervisors: Prof. dr. M.R.H. Mandjes (University of Amsterdam and CWI), Prof. dr. ir. S.C. Borst (Eindhoven University of Technology)

Mathematics to select best model

Scientists have a strong desire to catch real life in models. But which model is the best? Steven de Rooij researched model selection with computational techniques in his thesis *Minimum Description Length Model Selection – Problems and Extensions*. On 10 September he received his PhD at the University of Amsterdam. The results can be applied to the prediction of share prices, filtering of unwanted e-mail, data compression, economic models, and climate change research.

A model can be seen as a theory, or concise description of reality. It can represent a scientific hypothesis, a text comprehended by speech recognition programs, or impressions from the outside world. The issue with such models is that many alternatives are at hand. It is not immediately clear how to choose the best model. When models are specified exactly, based on observations, the Minimum Description Length principal is a good method for selection. Until now it was not taken into account, however, that it changes in time

which model is most suitable, for instance due to changing circumstances. De Rooij found a way to make existing models dynamic. This way the best model can be selected even if circumstances changed.



Steven de Rooij

Supervisor: Prof. dr. ir. P.M.B. Vitányi (CWI and University of Amsterdam, co-supervisor: dr. P.D. Grünwald (CWI and Leiden University)

Predicting Moore's Law limit Components on computer chips increasingly diminish in size. This trend cannot go on forever: When the components get the size of atoms, quantum effects will play a role. This can cause errors. In his quantum computer research Falk Unger calculated the number of errors that normal, classical computers can deal with. He took his PhD on 18 September at the University of Amsterdam with his thesis *Noise in Quantum and Classical Computation & Non-locality*. Unger's results can help to predict the limit of Moore's Law. Moore's Law states that by technological improvement the number of electronic

switches on a computer chip doubles every two years. Modern computers experience so little noise that error correction is still negligible. In 2005 Shekhar Borkar (Intel) estimated that within the next ten years the increasingly smaller electronic switches will become too faulty. Using his research Unger could calculate a limit for this effect. Computer chips can still perform well with 8.856% failing bits. Higher failing rates will make a chip useless. Unger also investigated the effect errors have on quantum computers – computers using effects of quantum mechanics. Quantum computers can break the security of many internet data in no-time – in theory. In practice things are more unmanageable. Building a proper quantum computer is very difficult due, e.g., to the small size of the components and the impossibility to amplify signals. Surprisingly, computations with some noise appeared to be no problem. The attained limits for precision are important for hardware designers of quantum computers.

Supervisor: Prof. dr. H.M. Buhrman (CWI and University of Amsterdam)



Falk Unger



Jarek Byrka

Better positioning of facilities How can two banks be merged efficiently? Which offices should close and which not? Where should people build new energy plants? To answer these kinds of questions Jarek Byrka studied mathematical approximation techniques. He defended his PhD thesis *Randomized Approximation Algorithms: Facility Location, Phylogenetic Networks, Nash Equilibria* at Eindhoven University of Technology on 13 October. The trade-off between costs for building new facilities and servicing clients at a certain distance is difficult. In mathematical terms this facility problem is called NP-complete. For this kind of problems no efficient algorithms are known. Researchers even believe that they do not exist. Byrka designed an approximation technique and proved that his method can bring town planners closer to the optimal solution than before. This could considerably economize large building projects.

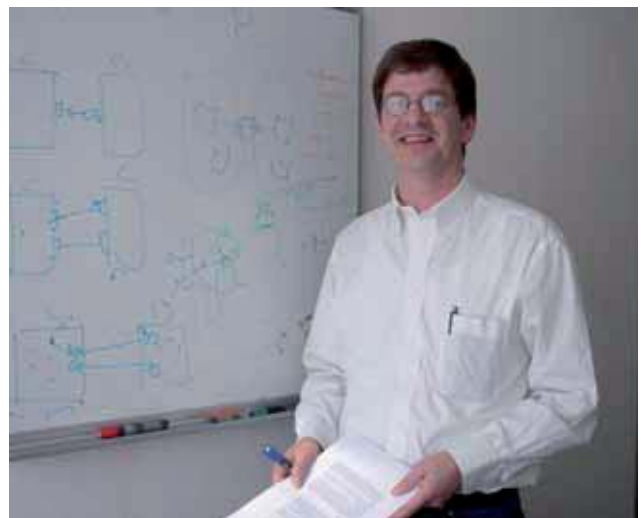
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Byrka also studied problems in the field of Nash equilibria – a topic in game theory. In a Nash equilibrium a player cannot benefit by changing his or her strategy while the other players keep theirs unchanged. Computer scientists and economists are debating whether the market or a computer program is better in determining the location of a Nash equilibrium. Byrka studied this problem with constant factor approximations.

Supervisors: Prof. dr. ir. K.I. Aardal (Delft University of Technology and CWI), Prof. dr. M.T. de Berg (Eindhoven University of Technology)

Industry benefits from modelling On Thursday 13 November Joost Jacob received his PhD for research on models to describe software systems. Jacob defended his thesis *Domain Specific Modelling and Analysis* at Leiden University. He studied various kinds of models and the way they are build. Industry can benefit from his findings.

System models are used in software development. A programmer uses a model that schematically describes what he should build, something like the floor plan of a constructor. Like in construction where an electrician needs other plans than a plumber, software projects have different types of models. This diversity in models can create problems with project members simultaneously working on software. Jacob models differently. He does not select a standard type of model beforehand, but starts with the language that builds the model: the fixed terms describing the model. Jacob first defines a new language. For this he uses terminology from the specific domain in which the model will be used. Next he builds the model with this new language. Members of the project will better understand that model, because it uses their own terminology. In composing a correct new language, connecting to other languages, math-



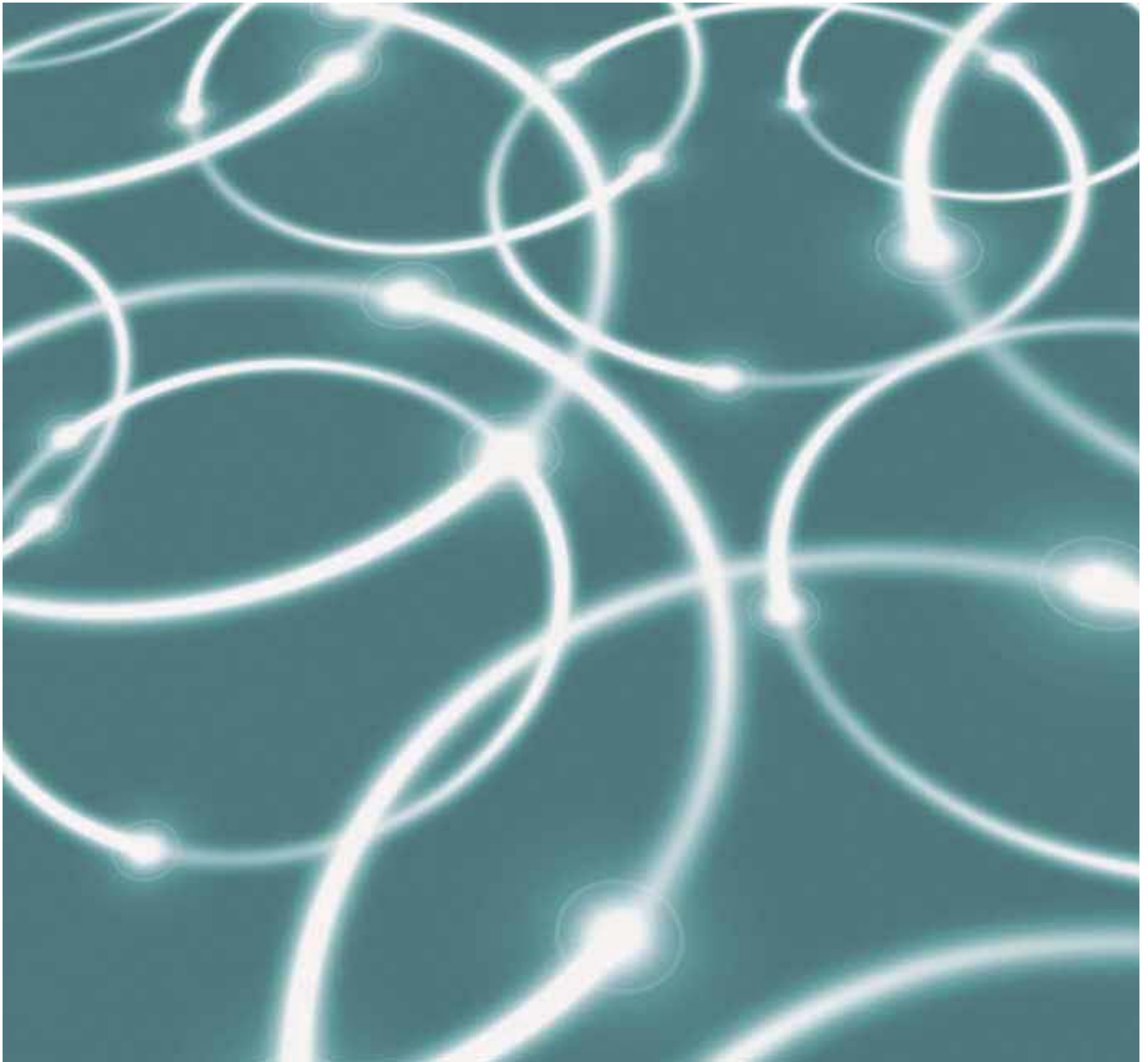
Joost Jacob

ematicians can play an important role. Jacob's ultimate goal is to clarify models so that all persons involved comprehend them. With that he bridges science and industry.

Supervisor: Prof. dr. F.S. de Boer (CWI and Leiden University), co-supervisor: dr. M.M. Bonsangue (Leiden University and CWI)

CWI Internships programme

To strengthen its mission and international position CWI launched a new programme: the CWI Internships. This programme facilitates 3-month visits to CWI by excellent PhD students from abroad. Each year at least one third of the internships is granted to a female researcher. There are two application rounds each year, in March and September. •



3. To transfer knowledge to society and increase public interest in mathematics and computer science

There are many ways to disseminate scientific results to society, other than by scientific publications: cooperation with industry, grant licenses, establishing spin-off companies, organizing meetings for a general public, and maintaining a website are just a few examples of activities to raise public and industrial awareness. This section highlights some means of knowledge valorization.

New spin-off MonetDB To stimulate commercial applications and to disseminate scientific research, CWI founded MonetDB B.V. This independent company markets software products to enhance societal and economic impact of research results. It facilitates the efforts of scientific personnel and stimulates joint ventures in specific market segments.



Founders of MonetDB B.V.: Peter Boncz (left), Dick Broekhuis (on behalf of CWI) and Martin Kersten (right). Not in the picture are founders Stefan Manegold, Sjoerd Mullender and Niels Nes. picture: Nan Tang, CWI.

MonetDB B.V.'s primary task is to control, maintain and spread the open source database management system MonetDB, developed at CWI for over a decade. The system works with SQL and XQuery. Applications can be found in forensic research, scientific databases (e.g., in astronomy) and in the world of finance. MonetDB is available on a large number of platforms and can be used through standard interfaces. More information: www.monetdb.com

W3C Benelux Office The Benelux W3C Office is hosted by CWI. Its mission is to promote adoption of W3C recommendations – such as (X)HTML and SMIL – among developers, application builders, and standards setters in the Netherlands, Belgium and Luxembourg. It encourages participation of organizations in the creation of future recommendations by joining W3C. As of 1 September, Fons Kuijk succeeded Martine Roeleveld as Manager of the W3C Benelux Office. Contacts with ISOC and Accessibility were renewed.

See www.w3c.nl

Cracking the code on Science Day On Saturday 18 October, during the national 'October Science Month', Science Park Amsterdam was open to the public.





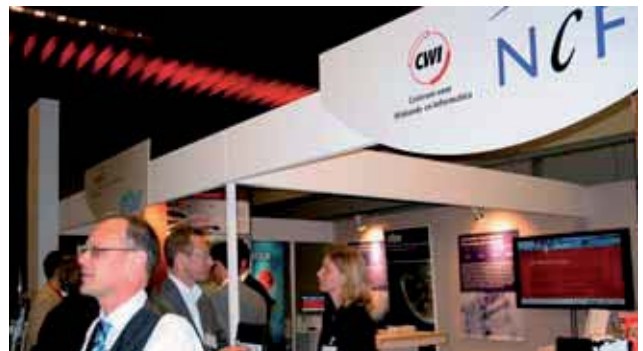
Impressions of the Science Day at CWI.

CWI participated and challenged the visitors to crack the code of a safe, using mathematics. CWI organized a number of entertaining activities around the theme 'Crack the Code'. Apart from cracking the safe, CWI offered mini-lectures to discover more about the secrets of codes, and a lecture on security in internet banking. The goal of the event was to introduce a broad public to science and technology. About 300 people visited CWI.

SIGMA Prize 2008 for DisWis The education project DisWis won the SIGMA Prize during the Lowlands pop festival on 16 August. The jury was unanimous: DisWis

is this year's most magnificent project to connect mathematics to real world applications. The prize winning project was founded by Spinoza Prize winner Lex Schrijver (CWI and UvA) and 'De Praktijk' – a project agency for science education and communication. It included a series of 40 lessons on discrete mathematics, given by mathematics students. Pupils learned about work after studying maths, and visited companies. The goal of DisWis is to increase the number of mathematics students.

Opgelost nominated for best popular science book 2008 The book *Opgelost* (Solved!), written by Bennie Mols, was nominated for the Eurekaprize for the best popular science book 2008. This publication was jointly financed by CWI and the NWO Spinoza Prize of Lex Schrijver (CWI and UvA). The book takes a light-hearted look at the role that mathematics and computer science play in our daily lives. Four other books were nominated. The winner was announced by NWO on 26 May: Floris Cohen with his book *De herschepping van de wereld*. *Opgelost* was also presented at the ICTDelta Conference.



NWO and CWI at the ICTDelta Conference.

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Turtles, deserts and stars – CWI research in book NWO In October the Netherlands Organisation for Scientific Research (NWO) published the popular science book *Experiment NL, wetenschap in Nederland* about science in the Netherlands. It contained stories on the most remarkable, brilliant, funny and exciting research projects of the last year.



CWI research was presented in the popular science book *Experiment NL*.

Three of them came from CWI. Eric Pauwels helps biologists with automatic recognition of skin or shield patterns on whales and turtles. Individual animals can be traced in

the wild, matching new pictures with the ones in a database. Arjen Doelman describes vegetation patterns on the edges of deserts with mathematics. Finally, he hopes to help in forecasting whether or not an area will be in danger of permanently changing into a desert. Finally, Martin Kersten explains new database techniques developed at CWI to 'dig for treasures in the sky', to seek interesting patterns in the giant amount of data from telescopes.

Grünwald in Tumult Debate On 12 November scientists and lawyers discussed the position of scientists in criminal justice in the Tumult Science Café (Kenniscafé) in Utrecht. Lucia de B. lawyer Stijn Franken, Professor of clinical and forensic toxicology Donald Uges, criminal judge Jos Silvis, and Peter Grünwald, statistician and researcher at CWI participated. In court, sciences like toxicology, psychology, and statistics are needed to judge fairly. However, the role of the expert can be criticized, and judges cannot always correctly interpret scientific results. The meeting was organized by Utrecht University and VPRO Noorderlicht for an audience of about 80 people – scientists, students, journalists and the general public. They had a lively discussion, and agreed that there should be some control of the way judges interpret the experts' conclusions in court.

Knowledge on Sunday As part of the October Knowledge Month, Lex Schrijver spoke about his research and debated with the public at the Knowledge on Sunday (Kennis op Zondag) meeting in science center Nemo. He lectured on the mathematics for the 2007 train timetable in the Netherlands. After the lectures there was a casual Meet & Greet with Schrijver and twelve other top researchers. Kennis op Zondag, organized on 12 October, was initiated by KNAW, NWO, Nemo and De Volkskrant.

CWI sponsors Junior Mathematics Olympiad

CWI sponsored the first Dutch Junior Mathematics Olympiad, organized on 3 October at the VU University Amsterdam. The 90 best pupils of the 78,000 Kangaroo Game participants were invited to compete for great prizes. Young visitors were introduced to fun mathematics and did some research – a pleasant and informative day.

Summer course for maths teachers

Getting fresh inspiration for the next teaching semester was the goal of many participants at the annual Summer Course for Maths Teachers – the ‘Vakantiecursus voor Wiskunde-



Summer course for maths teachers.

leraren’. From 1946 on, CWI organizes these informative meetings in cooperation with the Netherlands’ society of mathematics teachers (NVvW). Topics cover a broad mix of interesting mathematics and recent applications showing the relevance of the field. This year’s theme was *Mathematics*



Summer course book sale.

en profil. Lectures covered, e.g., education of mathematical geniuses, mathematics in court, Fibonacci at universities, and the art of proving. The course took place in Eindhoven on 22 and 23 August and at CWI in Amsterdam on 29 and 30 August. About 150 math teachers attended the course.

CWI in the media

CWI researchers showed their results in many media. Some highlights were: ‘Experts uncover weakness in Internet security’, ‘CWI answers the most intriguing Quest reader’s question’, ‘Twenty years of internet in Europe’, ‘CWI research helps predicting limit



Lex Schrijver was interviewed by NRC Handelsblad.

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Moore's Law', and 'Petition for immediate reopening case Lucia de B.'. Over twenty press releases were published, and many more news items on the website. Le Monde, the NY Times Bits Blog weblog and many others wrote about Marc Stevens' research for internet security, NRC published an elaborate interview with Lex Schrijver, Het Parool wrote on the ambulance project with Rob van der Mei, and Radio 5 broadcasted an interview with director Jan Karel Lenstra. CWI experimented with videos on YouTube and a weblog on the International Mathematics Olympiad. Its website was renewed. Some of the news items are highlighted below.

Experts uncover weakness in Internet security Researchers at CWI, EPFL in Switzerland, and Eindhoven University of Technology together with independent security researchers in California found a weakness in the Internet digital certificate infrastructure. This allowed attackers to forge certificates that are fully trusted by all



Marc Stevens presented a movie on YouTube about the weakness in Internet security. The news of 'cracking https' also reached the *New York Times*.

commonly used web browsers. As a result of this weakness it was possible to impersonate secure websites and email servers and to perform virtually undetectable phishing attacks. By presenting their results at the 25C3 security congress in Berlin on 30 December, the research team hoped to stimulate the adoption of more secure cryptographic standards on the Internet, thus increasing its safety.

When a URL starts with 'https', a small padlock symbol appears in the browser window. This indicates that the website is secured using a digital certificate issued by one of a few trusted Certification Authorities (CAs). To ensure that the digital certificate is legitimate, the browser verifies its signature using standard cryptographic algorithms, like MD5. The team of researchers discovered that MD5 can be misused, by creating a rogue certification authority (CA) that is trusted by all major web browsers. They used advanced mathematics and a cluster of more than 200 game consoles. The major browsers and Internet players – such as Mozilla and Microsoft – were contacted before the presentation. They took action to better protect their users. CWI made a video interview with Marc Stevens (Cryptology Group, CWI), who designed the algorithm. The video was posted on YouTube. The topic received media attention all over the world, like in the Bits Blog of *The New York Times*, *nrc.next*, *NRC*, *Le Monde*, *Computable*, *Automatisering Gids*, *Trouw*, *Tweakers.net*, *Webwereld*, and *Security.nl*.

Radio 5 On 20 August Radio 5 broadcasted an interview of half an hour with general director Jan Karel Lenstra and two researchers in the popular-scientific Teleac programme 'Hoe?Zo! Radio'. Lenstra explained the history of CWI and the significance of mathematics and computer science. After that, researcher Peter Grünwald talked about his passion – statistics – and about the mistakes that are often made by statisticians. Finally, Eric Pauwels illustrated another side of

CWI: He described how computer science can assist biologists in recognizing animals, and the link between computer science and fashion designers in Milan.

Twenty years of European Internet On Monday November 17, it was exactly twenty years ago that Europe was connected to the Internet. That day, at half past two in the afternoon, CWI systems manager Piet Beertema received the historic e-mail that CWI – as first organization



Internet pioneer Piet Beertema celebrated 20 years of European Internet at CWI.

outside the United States – was officially admitted to NS-Fnet, an academic computer network that later evolved to the worldwide internet. Not long after CWI other European academic and research organizations were also connected. In the Netherlands, SURFnet played an important role as well. It was only much later, that commercial businesses followed, and individuals even had to wait until 1993. CWI became an important network interconnection between Europe and the United States. Nowadays, part of the European internet traffic still runs through Science Park Amsterdam, by means of the Amsterdam Internet Exchange (AMS-IX).

CWI made a video interview with Beertema that was posted on YouTube. The news was broadcasted by several Dutch media, such as the NOS Radio 1 Journal, Editie NL (RTL4) television, and the NOS Jeugdjournaal – a news broadcast aimed at young viewers.

Total number of people ever on Earth in Quest magazine How many people have ever been born on Earth? That was the prize-winning question of Quest magazine in December. Peter Grünwald estimated the number: 107.5 billion. His answer could be read in Quest101, a special edition of the popular scientific magazine with the 101 most fascinating readers' questions in 2008. At the magazine's request Grünwald studied an old American model, adapted it and used current numbers, emphasizing that the total number depends on many uncertain elements, like inaccurate birth dates in the past. Quest used the outcome to counter much-ventilated assertions like 'There are more people alive now than ever died'. The news item was broadcasted by Giel Beelen at Radio 3FM, and published by several Dutch media, such as the websites of the NOS Journaal, De Telegraaf and Het Parool.



Peter Grünwald answered the most popular science question in Quest101.

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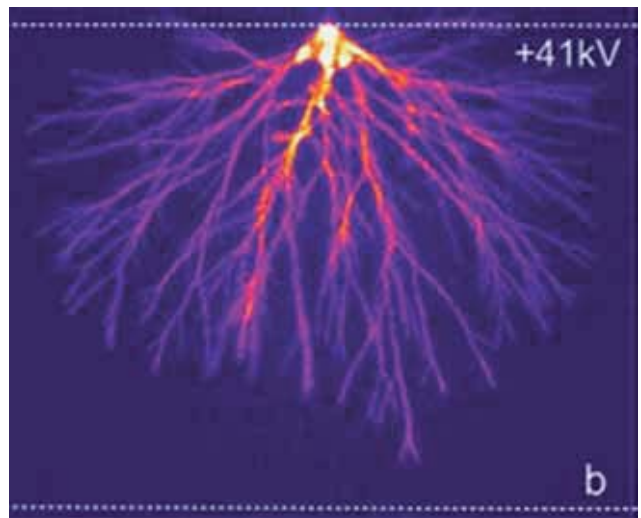
CWI at International Mathematical Olympiad

CWI will be one of the organizers of the International Mathematical Olympiad in 2011 – IMO 2011. In the yearly international contest, pupils under 20 years old try to solve mathematical problems. The 49th International Mathematical Olympiad was held in Madrid, Spain, from 10 to 22 July. In preparation for IMO 2011 in the Netherlands, Teunis van Wijngaarden (CWI) travelled along with the Dutch team and wrote a daily weblog.

Mathematics to save lives How to improve the efficiency of the Amsterdam ambulance services, in order to save lives? In an article in newspaper *Het Parool*, Rob van der Mei gave an interview about one of his projects in the context of societal logistics: developing mathematical models to optimize the planning of ambulance services.

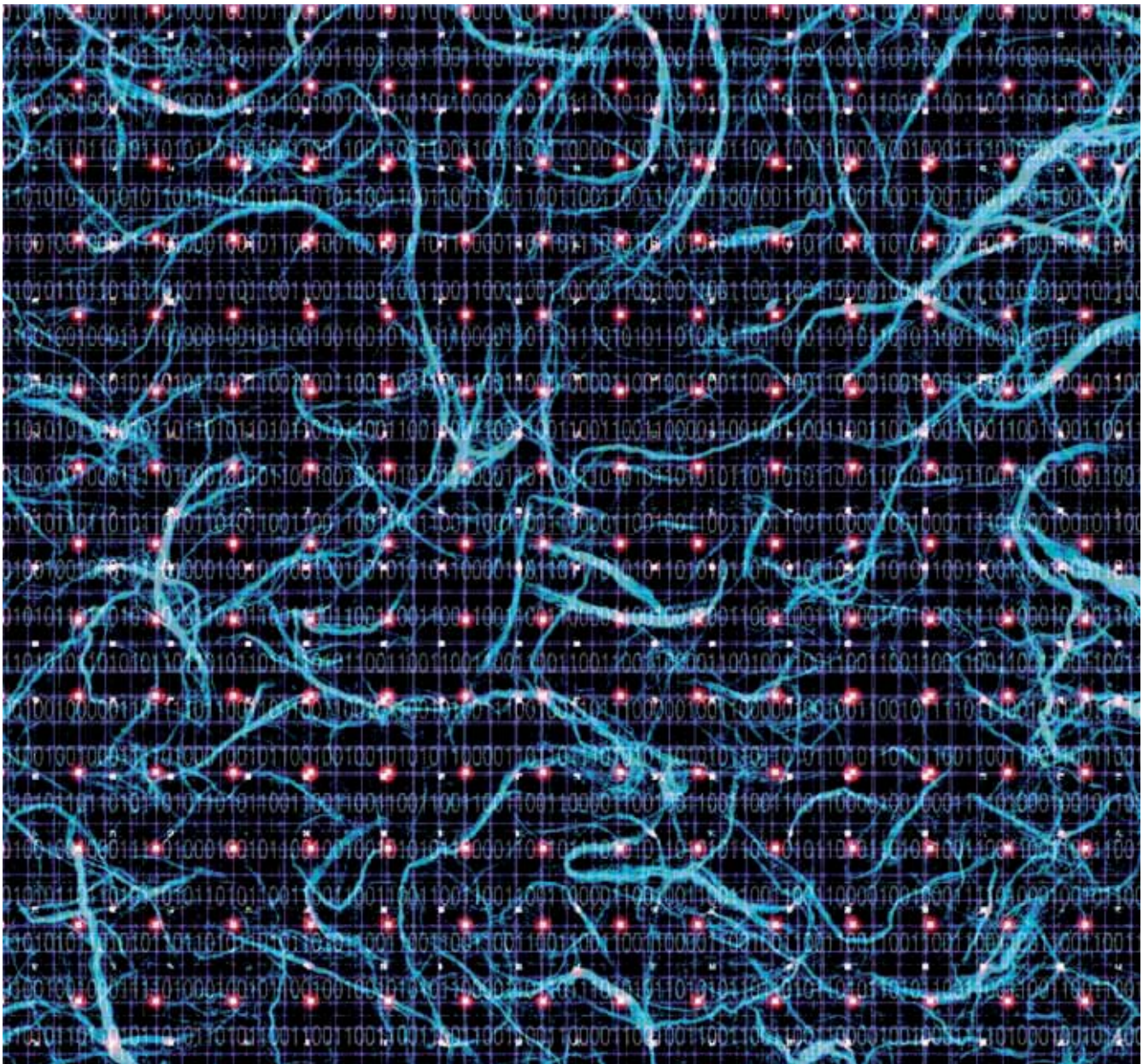


News about CWI improving ambulance planning in newspaper *Het Parool*.



Lightning. picture: Eindhoven University of Technology.

Sparks and lightning ‘Lightning professor’ Ute Ebert and her group appeared several times in the media again. Their work appeared as Research Highlight in *Nature* in September, entitled ‘A bolt from the blue’. Ebert was interviewed for the TV programme *Galileo*, broadcasted on the national channel Nederland 2 on 27 May, and contributed to the popular-scientific *Nieuwslicht* television, broadcasted on channel Nederland 3 on 3 September. She was also interviewed by *Noorderlicht*, Radio 1, on 26 August. The work on merging streamers was described in detail in the national newspaper *NRC Handelsblad* on 6 September, and was explained in the ‘popular-scientific’ magazine *Explore* in October. A large subsidy for their lightning research was mentioned in the *Technisch Weekblad* on 24 October. Ebert coordinated a cluster issue on lightning, *Streamers, Sprites and Lightning* of the *Journal of Physics D: Applied Physics* that appeared on 7 December. Press releases were published on merging streamers and ‘Thick sparks flash faster than thin ones’. •



4. To play a leading role in the Dutch and European mathematics and computer science scene

CWI aims at playing a leading role in setting the national research agendas in applied mathematics and computer science. It contributed, for instance, to the new national agenda for Mathematics – *Concentration and Dynamics*. The institute also continued coordinating the successful national Bsik BRICKS research programme.

Together with other top institutions such as INRIA (France) and Max Planck (Germany) CWI forms the backbone of European research

in mathematics and computer science. The institute is a founder and an active member of ERCIM, the European Research Consortium for Informatics and Mathematics. ERCIM represents about 10,500 European researchers in twenty countries. Bilateral cooperation between INRIA and CWI was continued and extended. CWI organized several conferences, workshops and meetings, and contributed to many others. Some of them are highlighted in this section.



Opening ceremony of the Fifth European Congress of Mathematics.

5ECM in Amsterdam CWI, the University of Amsterdam, and VU University Amsterdam organized the Fifth European Congress of Mathematics (5ECM), from 14 to 18 July in Amsterdam. About 1000 mathematicians from all over the world gathered in the RAI to discuss the latest developments in mathematics. The varied programme was set up by an international Scientific Committee, chaired by Lex Schrijver (CWI, and UvA). The local organizers were André Ran (VU University), Herman te Riele (CWI), and Jan Wiegerinck (University of Amsterdam).

The congress was officially opened by Robbert Dijkgraaf, President of the Royal Netherlands Academy of Sciences. During the opening ceremony ten prizes of the European Mathematical Society and the Felix Klein Prize for Industrial Mathematics were awarded to eleven outstanding young mathematicians.

During the congress, the participants were offered 13 plenary lectures, 35 talks by invited speakers, and 22 mini-symposia. Three science lectures for a general public highlighted



*Robbert Dijkgraaf, President of the Royal Netherlands Academy of Arts and Sciences (KNAW), opened the 5ECM conference.
picture: Peter van Emde Boas*

the important role of mathematics in quantum information theory, predicting climate change, and population dynamics. Two Round Table gatherings were organized, and 200 posters were presented.



Eleven outstanding young scientists were awarded during the 5ECM opening ceremony.



During 5ECM, 1000 mathematicians visited the RAI.

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The 5ECM local organizers were Herman te Riele (CWI, on the left), André Ran (VU University, in the middle), and Jan Wiegnerinck (University of Amsterdam). picture: Peter van Emde Boas

The 44th Dutch Mathematical Congress was also part of 5ECM, including the Brouwer Lecture by Phillip Griffiths (IAS Princeton), an historical lecture on Brouwer by Dirk van Dalen, the Beeger Lecture by Dan Bernstein (University of Chicago) sponsored by CWI, and the Philips



During 5ECM Henk Broer, chair of the Royal Dutch Mathematical Society (on the left) presented the Brouwer Prize to Phillip Griffiths.

Mathematics Prize for PhD students, won by Erik-Jan van Leeuwen of CWI. The participants received a special issue of the *Nieuw Archief voor Wiskunde*, a reprint of *Flatland* by E.A. Abbott (sponsored by CWI and VU University), and a special issue of *ERCIM News* about ‘Mathematics for Everyday Life’.

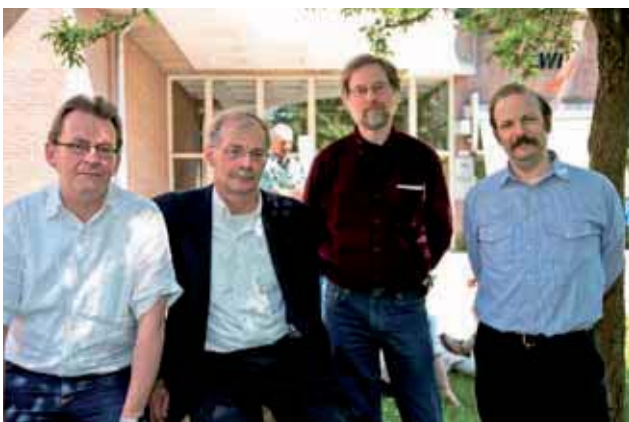
CWI Lectures on Concurrency Theory

On 23 May, the Lectures in Mathematics and Computer Science celebrated the achievements of 25 years of concurrency theory at CWI, and looked ahead to the next 25 years. The CWI group Specification and Analysis of Embedded Systems has played a prominent role in concurrency theory since the early 1980s, with an emphasis on algebraic techniques for the specification and verification of software systems. Five of its consecutive leaders started research groups at Dutch universities. Now that concurrency theory is so well established in the Netherlands, CWI has decided to shift the focus of the group to service-oriented comput-



Visitors at 5ECM.

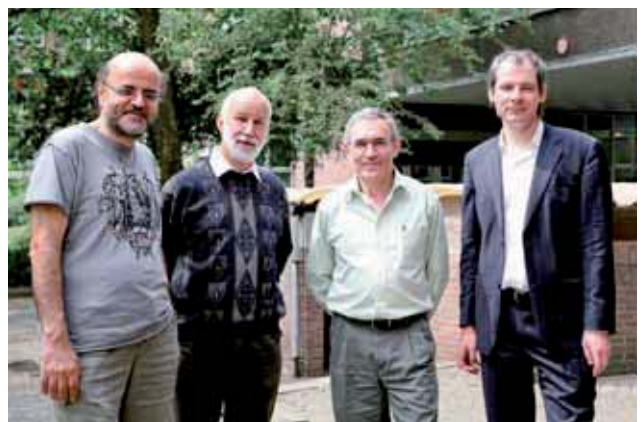
ing. Keynote speakers were Gerard Holzmann (NASA JPL Laboratory for Reliable Software), Moshe Vardi (Rice University), Jos Baeten (TU/e), and Jan Bergstra (UvA and University of Swansea). Concurrency theory researches how various systems can perform several processes at the same time, while mutually communicating. Aim is to execute a combined task. This discipline has applications in parallel and distributed systems, such as the Internet.



(From left to right) Jos Baeten, Jan Bergstra, Gerard Holzmann, and Moshe Vardi were keynote speakers at the CWI Lectures.

Game Theory Day at CWI CWI organized a special day to game theory and its relation with economics and computer science on 27 May. The day was dedicated to researcher Krzysztof Apt (CWI and UvA), who was appointed CWI Fellow in April. Four renowned mathematicians and computer scientists gave lectures on game theory. Speakers were Christos Papadimitriou (University of California at Berkeley), one of the founders of algorithmic game theory, Dov Samet (Tel Aviv University), Han La Poutré (CWI and

TU/e), and Krzysztof Apt himself. Mathematical game theory became a standard tool in economics, to study processes such as competition, cooperation, strategic behaviour, and bargaining. Game theory is also fast becoming an important subject in computer science. There it is used to capture interaction in e-commerce, in particular electronic auctions, strategic behaviour in distributed systems, and, e.g., rational decision making in competitive environments.



(From left to right) Christos Papadimitriou, Krzysztof Apt, Dov Samet, and Han La Poutré gave lectures at the Game Theory Day at CWI.

CWI and Leiden University sign cooperation agreement CWI and Leiden University (UL) expand their cooperation. The Mathematical Institute (MI), Leiden Institute of Advanced Computer Science (LI-ACS) and CWI signed an agreement that makes it possible to exchange part-time researchers between the institutes. At the meeting 'On the bridge between UL and CWI' on 10 April in Leiden several speakers presented their joint research

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projects. Directors Peter Steenhagen from MI, Joost Kok from LIACS and Jan Karel Lenstra from CWI signed the agreement.



Directors Joost Kok (LIACS, Leiden University, on the left), Peter Steenhagen (MI, Leiden University, on the right), and Jan Karel Lenstra (CWI, in the middle) signed a cooperation agreement.

Smalltalk conference

On 25 August the 16th International Smalltalk Joint Conference 2008 started at CWI. Over 150 visitors from all over the world were welcomed by Paul Klint (CWI and UvA) and Stéphane Ducasse (INRIA). The conference was organized by the European Smalltalk User Group – ESUG. Smalltalk is a dynamic, reflexive programming language. Originating in the 1970s it still influences the development of programming languages and technologies. Well over 40 presentations gave the state of affairs for Smalltalk related programming language platforms (such as Newspeak), web frame works (like SeaSide) and model driven engineering (MDE). On 26



Paul Klint (picture) and Stéphane Ducasse opened the Smalltalk conference.

August the Meta Environment, developed at CWI, was presented. The Innovation Awards, sponsored by ABN AMRO, were also granted. The conference ended on 29 August.

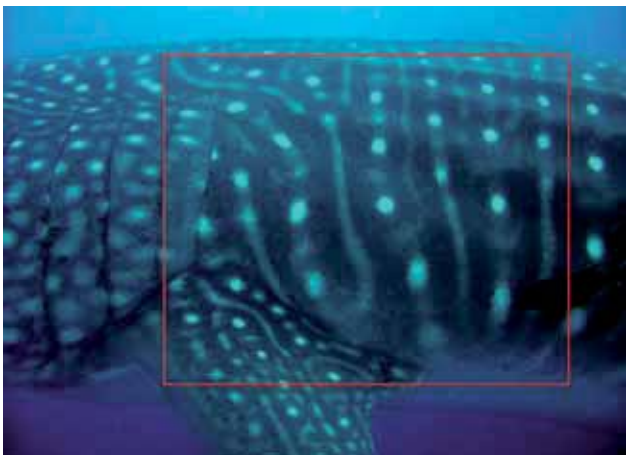


Visitors of the Smalltalk conference at CWI.

Biodiversity, sensors and mathematics

How can computers, cameras and the internet be applied to effectively guard biodiversity? This was one of the topics at the workshop 'Distributed Sensing and Collective Intel-

ligence in Biodiversity Monitoring’, organized by CWI 3 – 6 December. Experts from all over the world gathered to discuss new opportunities offered by sensors, internet and the efforts of volunteers. Marine biologist Brad Norman (Ecocean, Australia) set up a website where divers can upload pictures of the rare whale shark. Lines and spots on the skin of this huge animal are as unique as a human fingerprint.



Recognition of whale shark patterns was discussed at the Bio-DivGrid workshop at CWI. Courtesy: Brad Norman / Ecocean.

Through a large image database the computer can trace the individual. Combined with data like location and time, an observation can be added to the ever growing database. One of the other speakers equipped bumblebees with RFID tags – a miniature version of the security tags used in clothing shops – to register their behaviour. This generates a massive amount of data that must be digitally stored and efficiently queried. *Data explosion* is an important research theme at CWI.



(From left to right) Contributors to the BioDivGrid workshop: Dezheng Song, Erik Pauwels, Ruben Huele, Brad Norman en Wouter Los.

National strategy for Mathematics In

May the new national agenda for Mathematics – *Concentration and Dynamics* was published by NWO Physical Sciences and OOW – the Overleg Onderzoeksscholen Wiskunde. Arjen Doelman (CWI and UvA) chaired the committee that formulated the strategy. The report describes the successes of the national mathematics clusters and discusses the future, e.g., the possibilities of a fourth cluster, dealing with problems in attracting young researchers, and improving mathematics education. Based on this agenda a more concrete plan, the *Masterplan Toekomst Wiskunde*, has been formulated. This masterplan was officially presented at the NWO Physical Sciences Parallel Worlds symposium in December. CWI played a central role in this process, since the two committees involved in drawing up this plan were headed by Jan Karel Lenstra and Arjen Doelman. •

RESEARCH HIGHLIGHTS

Earth & life sciences



Fighting lymph cancer with mathematics

What does a disease like lymph cancer have in common with city heating? This unusual association popped up when CWI researcher Gunnar Klau (age 38) discussed his work with a fellow researcher. It appeared to be a brilliant intuition. Klau now exploits maths originally developed for optimizing heating networks to analyse data of cancer patients. His method appears to be faster and better, even much better than previous ones. Results might help doctors in understanding the disease and hopefully, in the end, contribute to the quest for new, better medicines.

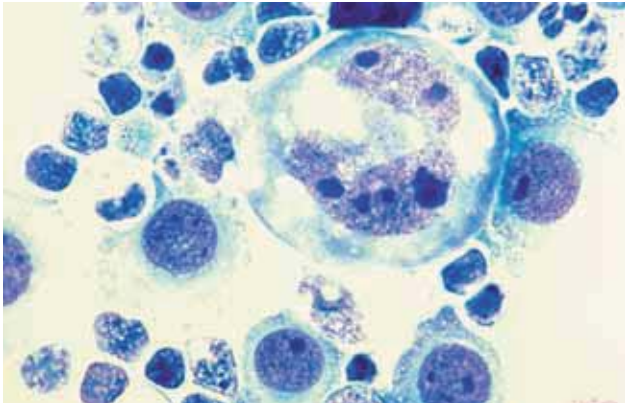
The types of cancer studied by Klau and his colleagues are called non-Hodgkin lymphomas - various malignant cancers originating in white blood cells, spread by the lymph node system. The disease is rather common. Each year, several hundreds of patients in the Netherlands receive this diagnosis. In order to make a good prognosis and treat the disease best, it is important to recognize the specific subtype of cancer that is involved. These cancer subtypes can be distinguished by a different kind of gene expression – that is the way genetic information is converted into functional products like proteins.

In molecular biology, focus of research has recently been shifted from decoding genetic sequences to analysing interactions that take place among genes and proteins.



For new mathematical methods to analyse cancer data, CWI researcher Gunnar Klau used a model for optimizing city heating. picture: Mike1024/Wikimedia.

RESEARCH HIGHLIGHTS



Lymphoma cancer cells. picture: Dr. Lance Liotta Laboratory.

This is part of a new approach called systems biology. It is important to understand these interactions, since proteins do not function in isolation. They interact with each other and with other biomolecules to form molecular machines. These interactions are described by protein interaction networks. Huge amounts of experimental data on these networks emerge from new high-throughput techniques, like microarrays. Finding an active part – a subnetwork – in a big network that might contribute to the disease is like finding a needle in a haystack. When 2000 proteins are involved in a network, up to $4 * 10^{6595}$ candidate subnetworks have to be investigated.

In spite of the apparent impossibility, Gunnar Klau found a new method to do this. How does it work? “Compare it to city heating,” Klau explains. “You can have big houses and small houses, far away or close by. Big houses that are located close by are most profitable for the energy company. Due to their short lengths, the pipelines are not too expensive. On the other hand, a small house far away is not profitable and will probably not be connected to the city heating network at all. Traditional optimization methods only sought the big houses nearby and stopped calculating the moment they noticed a less favourable connection. However, it is possible that just beyond the small house a group of big, profitable houses can be found. Our method can find these kinds of groups.”

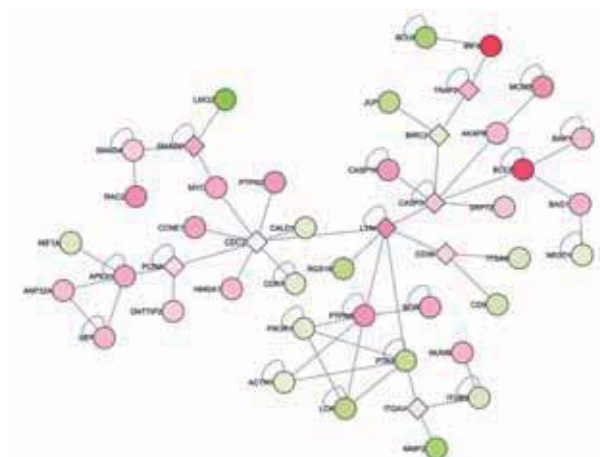
In Klau’s metaphor, a group of big houses stands for an active protein subnetwork. The problem to find these subnetworks is very difficult, or, in mathematical terms, the problem is NP complete. In real, the studied lymphoma networks count about 2000 nodes and 8000 connections. Klau used methods from discrete optimization to avoid looking at the exponential number of all subnetworks. First, he made a mathematical transformation to a known problem, the Prize Collecting Steiner Tree problem. Then the scientist developed, together with statisticians from Würzburg, a toolkit called ‘Heinz’. Using data from medical experts, it surprisingly took Heinz only a few minutes to enumerate possible interesting subnetworks.

Klau and his fellow researchers tested his system with known medical data. Indeed, they found familiar subnetworks with this method, and even possible new interesting ones. The method is already better and faster than existing ones. “We still have to improve its accuracy and robustness,” Klau says. “High-throughput biological data are extremely noisy, and the hidden subnetwork signals are quite weak.”

In future, Klau wants to improve the model by integrating additional data sources to get biologically even more meaningful subnetworks. Klau: “This influences the mathematical model, because also the connections in the network will receive a score, based on co-expression of the two connected proteins. Then, the elegant transformation to the PCST-problem will not work anymore. We deal – mathematically – with a totally new problem, for which own theory has to be developed”.

In the long term, it might be possible to analyse specific patient data faster with his method. The pilot study has shown that it can distinguish between two types of lymphoma cancer. It might also recognize healthy patients from ill ones. “There is still a long way to go before this research can be applied in hospitals,” Klau says. “However, I expect that it can help in studying network properties, identifying disease-related subnetworks, and network-based disease classifications. Ultimately, I hope the subnetworks computed with

my mathematical methods will help to create new biological and medical knowledge which might lead to better cures.”



Biological subnetwork showing differences between two cancer subtypes, computed by Klau’s Heinz Method.

For this research Klau and his fellow researchers won the Outstanding Paper Award at the prestigious ISMB 2008 conference in Toronto, Canada. He cooperates closely with medical research partners like the Nederlands Kanker Instituut (NKI). “CWI finds it important to do this kind of interdisciplinary research,” Klau says. “We start a full Life Sciences Research cluster in 2009, to give this research a boost. I enjoy being part of this development.” •

More information

<http://homepages.cwi.nl/~klau>
<http://www.cwi.nl/lifesciences>

CV

Gunnar Klau

Since 2008: Researcher at CWI, building a group on Algorithmic Computational Biology

2004-2008: Assistant professor at Freie Universität Berlin and member of the DFG Center-MATHEON, Berlin, Germany

2002-2003: Postdoc at the Zuse Institute Berlin (ZIB), Germany

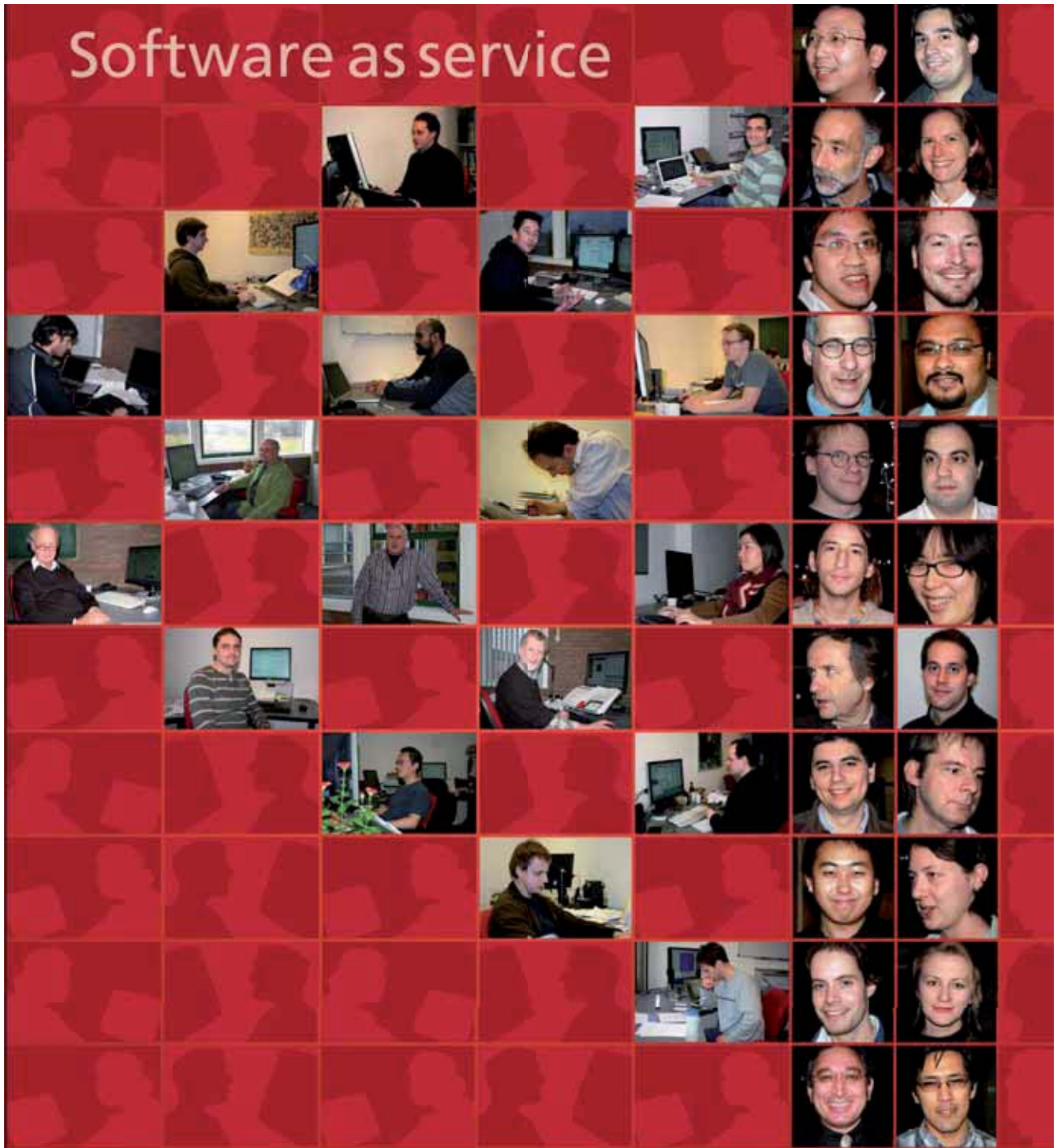
2001-2004: University assistant at Vienna University of Technology, Austria

2001: Postdoc at Mitsubishi Electric Research Laboratories (MERL), Cambridge, MA, USA

2001: PhD thesis in Computer Science in Kurt Mehlhorn’s Algorithm and Complexity Department, Max Planck Institute for Informatics, Saarbrücken, Germany



RESEARCH HIGHLIGHTS



Social yet interactive: new forms of television viewing

What does watching television with your family have in common with surfing the Web on your PC? In the view of Dick Bulterman, Pablo Cesar and Jack Jansen, the answer is: surprisingly little. The social dynamics of informal TV viewing stand in sharp contrast to the active way that users are engaged on their workstations. The CWI trio has been studying new architectures for the control and sharing of media within the home. Their focus is on retaining the social structure of TV while introducing the ability for end-users to enrich and augment TV content from the comfort of the living room couch. This requires both new user interfaces and a home architecture that allows manipulation of content rather than simply content delivery.

The wide acceptance of personal media publishing on YouTube, Flickr and other content-sharing websites has led to a revival of interest in interactive television. In its new incarnation, the emphasis is no longer on the selection of scenes within a programme or even an interface for more efficient home shopping: new research on iTV focuses on enabling the end-user to become a more active participant in the process of selecting, creating and sharing content. Interactive television has become synonymous with social television.

Many of the techniques being applied to social television are based on experiences with media viewing on a desktop PC. The primary concern has been content selection based on automated personal programme guides or via community-based recommendations. These solutions are typically tailored to the needs of an individual, but not to a

wider social group such as a family or the complex extended social networks maintained by household members.

Within CWI's group on Distributed Multimedia, researchers Bulterman, Cesar and Jansen have taken a different path. They have been studying architectures that support end-user content manipulation and personal enrichment as the basis for social sharing of broadcast media content. In particular, the question being studied at CWI is: what types of information sharing architectures are required to enable flexible, context-dependent (and often transient) social interaction with media in a multi-person setting? For example, if one scene in *West Side Story* reminds you of a walk you took with your brother 30 years ago, can you easily share this thought with him while remaining in the context of the movie – that is, not running to your laptop or telephone? And how does his family receive this message on their TV, when they are six time zones away?

The group has been studying support for these micro-personal messages: messages meant for a limited target audience, containing the relevant snippet of the movie plus some graphical, audio or text annotations that communicate an otherwise transient message. Dick Bulterman, the research leader of the group, likes to use the ancient model of a physical book to illustrate the creating and use of micro-personal messages. In the accompanying figure, two pages of a book are shown: one is the original version created by the content author, the other is the version that a specific reader has created for personal use. The base content is the same in both cases, but the page at the right illustrates a transformation from the general to the personal. A key aspect of this transformation is its uniqueness. The notes on each page reflect the personal context of the user, and often need to be evaluated within that context.

RESEARCH HIGHLIGHTS

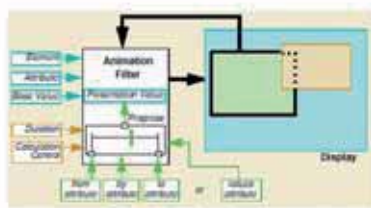


Figure 15-1. MML animation model.

Defining the Target Element

The animation supported by MML is based on the notion of a target attribute within a target element. For most forms of animation control, these target elements will be explicitly specified. They can also be implicitly specified, however, by making the animation a child of the implied target object.

In the following code fragment, the animation target element is defined explicitly:

```

...
animate target element "x" attr "rotation"
  From "10" to "100" dur "10" /
animate target element "y" attr "rotation" left
  From "100" to "20" dur "10" /
...

```

This form of statement can appear anywhere in a MML presentation. The target element can also be defined implicitly, by placing the animation as the child of a parent container:

```

...
animate "x" "y" "z" left "10" height "100" width "100" /
...
animate "x" "y" "z" "w" "v" "u" "t" "s" "r" "q" "p" "o" "n" "m" "l" "k" "j" "i" "h" "g" "f" "e" "d" "c" "b" "a" /
...

```

Animation is implicitly time based, so that an animation duration is also the required. These animations is resolved as a continuous media object. It probably would have been better to have the animation duration default to 0 seconds (the behavior we expect), but at least it would have been consistent with other media.

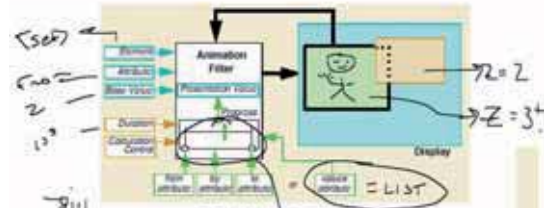


Figure 15-1. MML animation model.

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...

```

Animation is implicitly time based, so that an animation duration is also the required. These animations is resolved as a continuous media object. It probably would have been better to have the animation duration default to 0 seconds (the behavior we expect), but at least it would have been consistent with other media.

This illustration shows two pages of a book – the page at left was selected using a personalized search engine. The page at right was personalized by the end user.

The group uses a service-oriented metaphor for distributed (multi-home) content storage, management and delivery, in which components can be dynamically added or removed from the home environment. Within this metaphor, the group has focused on specification languages and interaction models that allow multiple users to create and share micro-personal messages without corrupting the basic content or violating the rights of the content owner. The architecture allows individuals to send and receive personal messages on private secondary screens, which also serve as a basis for personalized control and navigation through programme content.

In CWI's architecture, all of the media-related devices in the home are modelled as a loosely-coupled distributed system, in which a services architecture is defined across components. When a new device enters the room, it

is provided a set of capabilities based on the nature of the device and the role of its owner within the family. A home controller – which may be a set-top box or a home network interface – manages the interactions with the local devices, and it maintains contacts with a set of directed family and friends members in the home and beyond.

One aspect of the group's work has focused on user interfaces for capturing and delivering micro-personal messages. This work, which was awarded the best paper within its track at this year's ACM Multimedia in Vancouver and was also selected as the top paper for all of the ACM's Special Interest Group on Multimedia conferences in 2008, explores how users can use private secondary screens to create and share micro-personal notes while watching television with others.



A fragment from *West Side Story*: how can an end-user personalize this content?

Having a collection of time-dependent micro-personal notes also requires flexible delivery architectures. Complementary work within the group has focused on the development of SMIL State, a data-model solution for this problem. Unlike other approaches, CWI's work recognizes the special needs of a temporal document, in which the temporal consistency of the presentation structure needs to be maintained. The work on SMIL State won the Best Paper award at this year's Symposium on Document Engineering in São Paulo, Brazil, and it was integrated as a key component of the World Wide Web Consortium's new SMIL 3.0 specification, released in December 2008.

According to Bulterman, the challenge in supporting social television is to recognize that, on the couch, a user may be in different contexts simultaneously: engaged with the content, engaged with his family, and connected – often loosely and asynchronously – with friends near and far. The work in the group is being extended in a new four-year FP7 (EU) project *TA2: Together Anywhere, Together Anytime*. •

More information

<http://www.cwi.nl/sen5>

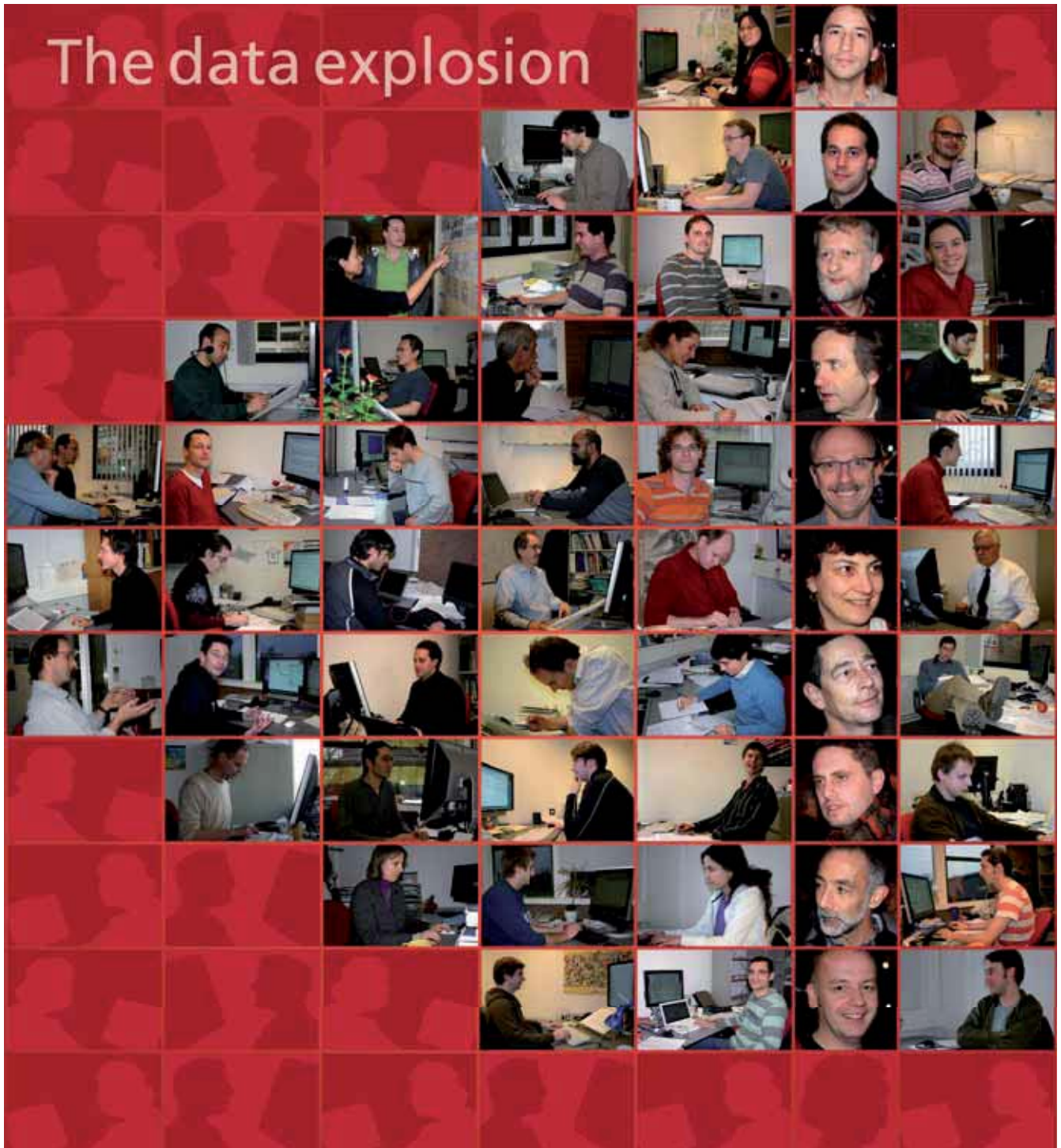
CV

Dick Bulterman

- 2008: Appointed Professor of Distributed Multimedia Languages and Infrastructures at the VU University Amsterdam
- 2002: Head of the Distributed Multimedia Language and Interfaces group at CWI
- 1999-2002: CEO of Oratrix Development BV, a CWI spin-off.
- 1991-1999: Head of the Multimedia and Human-Computer Interaction group at CWI.
- 1988: He started work at CWI.
- 1981-1988: Associate professor of Computer Engineering at Brown University (USA)
- 1982: PhD in Computer Science from Brown University (USA)



RESEARCH HIGHLIGHTS



Ranking the Stars with MonetDB

Wondering at the zillions of stars in a bright night sky, one could dream of having a closer look at these glimmering objects. The international Sloan Sky Server project made this come true with its huge scientific database of celestial bodies. Querying this vast amount of data is a great challenge. Using the MonetDB database system, Milena Ivanova and her fellow researchers implemented the first open source solution that equals the performance of the original one. The MonetDB/SkyServer project now provides a valuable experimentation platform to develop new techniques for scientific data management.

The Sloan Digital Sky Survey (SDSS) started in 2000. It aims to map a quarter of the sky and to obtain observations of 100 million objects, such as galaxies, nebulae and quasars. The SkyServer application gives public access to these data through a website. Both researchers and school children can now easily learn more about temperature,

mass or chemical composition of objects like the Whirlpool Galaxy and Owl Nebula. The survey is immense. In 2007, the sky object catalogue alone contained four terabytes (4000 GB) of information. The data are organized in a relational database, containing tables with millions of rows and hundreds of columns.



The famous Whirlpool Galaxy is one of the many objects in the SDSS database. SDSS acts as a well-documented benchmark for scientific database management. picture: The Sloan Digital Sky Survey.

RESEARCH HIGHLIGHTS

These vast amounts of data stress the capabilities of most database management systems (DBMSs). Efficient querying cannot be done in a mainstream way. The reason is that most modern DBMSs were originally designed about three decades ago for business applications like bank transactions, with many small and fast changing records. Scientific databases, however, have large records, with data that stay unchanged once they have been put in the database. They require a different type of database management.

The original SDSS solution, based on Microsoft SQL Server, was the first to bridge the gap between databases and astronomy. It became a successful showcase of scalable database support for scientific applications. There were several other attempts to port the complete SkyServer application to other commercial and open-source systems, but they did not succeed. That is, until the MonetDB solution was implemented.

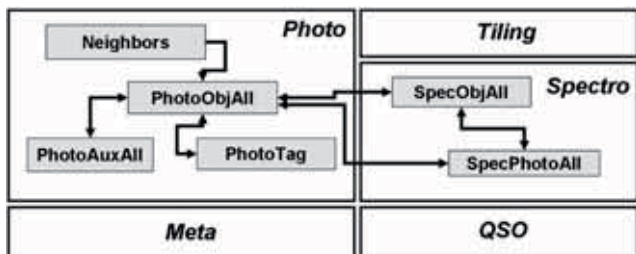
MonetDB is an innovative open-source database system being developed at CWI for over a decade. MonetDB has several advantages, like efficient data access patterns, flexibility with changing workloads, reduced storage needs, and run-time query optimization. It is a column-store database system. Where other systems organize data in rows, MonetDB reads and stores columns. This can be favourable in data analysis applications that need to efficiently retrieve and process large portions of stored data, as in this real-life astronomy application.

The team of CWI researchers – Milena Ivanova, Martin Kersten, Niels Nes, Arjen de Rijke and Romulo Goncalves – intended to examine and demonstrate the maturity of this column-store technology by working on a new version of the SkyServer database that is both scalable to the growing amount of data and more efficient to query. The researchers considered MonetDB the best candidate to act as an experimentation platform, since it enables experimentation at all levels of a DBMS architecture.



The Sloan Telescope, a 2.5-meter telescope at Apache Point Observatory, did all SDSS imaging and spectroscopy. picture: The Sloan Digital Sky Survey.

To make the new SkyServer version, the team members optimized MonetDB for scientific data. They improved its scalability through partitioning and distribution, and made it more efficient. The first functional prototype of MonetDB/SkyServer went live in 2006. It was a 1% subset of the archive, called 'Personal SkyServer', having a size of 1.5GB. The large vendor-specific database schema and its extensive use of a specific SQL functionality required quite some engineering effort. The initial performance was competitive to the reference platform – MS SQL Server 2005. This demonstrated the benefit of column-stored database techniques for scientific database management. The full size version went live at the end of 2008 – a major achievement.



The database schema of SkyServer. The photometric data are stored in the photo-section. The PhotoObjAll table has 454 columns and over 370 million rows. Picture: The Sloan Digital Sky Survey.

The team is currently investigating a number of techniques to increase the system's efficiency, such as parallel load, interleaving of column I/O with query processing, exploitation of commonalities in query batches, and self-organizing indexing schemes like 'crackers'.

Crackers – developed by other members of the MonetDB team, Stratos Idreos and Stefan Manegold – are methods to 'crack' the database into smaller pieces by querying a subset of data, which work fast in columns. For example, when handling a combined query, it is easier

to check the answers on the first question than to read the whole column again. The researchers use the fact that data are not equally important, although it is not known beforehand which ones are important and which not. Instead of ordering the data in a fixed manner, this is dynamically done during the queries.

This project is a good example of one of the CWI key research themes: *the data explosion*. The explosion in the amount of digital data confronts science and society with new questions. How can relevant and compact information be found from this flood of data? There is great need for models, methods and techniques to control it. The MonetDB/SkyServer project contributes to this objective.

The MonetDB SkyServer project was funded by the Bsik BRICKS programme, NWO Focus and MultimediaN. The MonetDB platform was developed in the Bsik programme MultimediaN. •

More information

SDSS – Sloan Digital Sky Survey / SkyServer,
<http://cas.sdss.org>
 MonetDB: <http://monetdb.cwi.nl>

CV

Milena Ivanova

- Since 2006: Researcher at CWI, developing database technology for efficient management and querying of high-volume scientific databases
- 2000-2005: PhD in Computer Science with specialization in Database Technology, Uppsala University, Sweden; PhD thesis on Scalable Scientific Stream Query Processing
- 1996-2000: Senior assistant professor at the Foundations of Computer Science Department of Sofia University, Bulgaria



RESEARCH HIGHLIGHTS

Societal logistics



On the road again – with intelligent agents

Traffic jams increasingly block the Dutch highways, and one of the main reasons is cargo transport. Still, about 30% of all trucks on the road in the Netherlands are empty. Dealing with this inefficiency is one of the goals of the national project *Distributed Engine for Advanced Logistics (DEAL)*. At CWI Valentin Robu and other researchers investigate the use of intelligent software agents to improve efficiency in logistics, in order to reduce costs, traffic jams, and carbon dioxide emissions. One of the case-studies in DEAL explored how to get wine in time from France to the Netherlands.

Common practice for planning in a logistics company is that human planners use an order assignment database and a tool for optimizing routes. In negotiations for orders they have to make choices, such that most parties

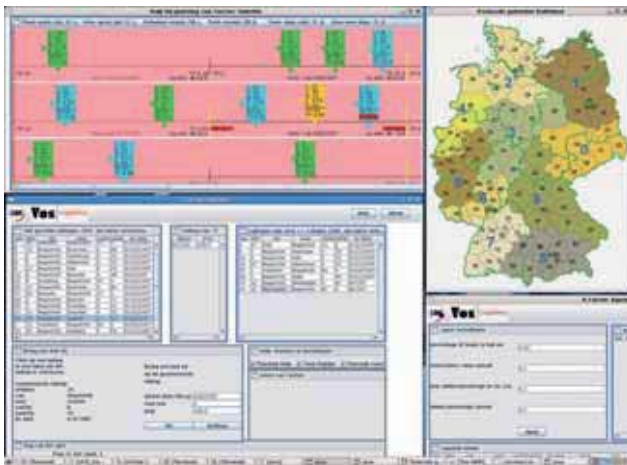
are roughly satisfied with the schedule. The planners try to combine as many loads as possible, in order to avoid losses due to empty driving on their return trips. This is especially important since transport logistics has low margins.



Intelligent agents can prevent trucks waiting empty for their cargo. picture: Vos Logistics.

RESEARCH HIGHLIGHTS

The current approach is time-consuming and has often become sub-optimal during the actual execution of the order. After all, in real-life the market is dynamic: orders continuously appear, while trucks can be delayed by traffic jams or accidents. Besides, optimizing bidding for one's own transport capacity is not necessarily best for the transport network as a whole. There is a lot of uncertainty and lack of cooperation.



CWI designed an auction platform for bidding on loads, in which the strategies of both software agents and human bidders can be tested.

How can these competitive and dynamic environments efficiently be automated? One of the most promising technologies uses multi-agent systems. Originating from artificial intelligence, intelligent agents are autonomous software programs. They are able to make decisions on behalf of their owners and can learn to adapt to their environment. Agents can, for instance, negotiate with humans and each other, or can represent their owner in an auction. Benefits of their use are numerous. Software agents decide much faster than humans in large-scale, repeated transactions, and they can easily be equipped with advanced methods or complex business rules.

Several approaches for optimizing transport logistics with these agents were studied at CWI. Valentin Robu researched the allocation of orders by means of decentralized auctions without a central planner. Agents – representing either individual trucks or different trucking companies – can bid for bundles of transportation orders to optimize their own plans. Such a decentralized, market-based model can be far more adaptable to unforeseen circumstances than centralized pre-planning methods.

To equip agents with efficient and successful bidding strategies, Robu combined several techniques from game theory, artificial intelligence, and machine learning. For example, agents learned to reason about the uncertainty in their plans by building a model of the future, using probabilistic methods, evolutionary computing and other machine learning techniques. Pieter Jan 't Hoen, Valentin Robu and Han La Poutré also studied levelled commitment. This means that bidders are allowed to give an order back while paying a commitment penalty, in order to optimize their loads. This planning flexibility raises the performance of the system.

For a different model, Lonneke Mous, Valentin Robu and Han La Poutré investigated the use of novel market mechanisms, like options. With option contracts, agents pay for the right – but not the obligation – to acquire an order at a future time. They have the freedom to exercise this option if they can obtain other orders needed to fill the truck, thus making a profitable combination. The team of researchers showed that option mechanisms considerably reduced the problem of being exposed to risks for many dynamic settings – of which transportation logistics is a prime example.

So, what about the wine that was mentioned earlier? Jano van Hemert, Peter Bosman and Han La Poutré examined a real-life case-study on transporting wine from France to the Netherlands in time. In this case, a large retail chain

with supermarkets all over the Netherlands sent out many trucks to wine farmers in the south of France to import millions of bottles of wine. It turned out that often the wine was not yet bottled when the truck drivers arrived at their destination. They would have to wait a couple of days at the chateau before they could start their return journey fully loaded. This is very expensive and inefficient.

Inspired by the wine case, a theoretical model for this problem domain was developed, based on the concept of the 'fruitful region'. In the above example an intelligent agent, representing a truck, could have dynamically planned its route to a region with many alternatives – the fruitful region.



With the 'fruitful region' concept, CWI can raise the chance of returning with a load of wine in time. picture: Shutterstock.

If a load were not ready to be transported, the agent could have left the assignment to the next truck, and go for an alternative supplier nearby. The group at CWI developed a theoretical model for the case that a number of orders are known at the start of the ride, while others appear on the fly. The route is pre-optimized by estimating the probability of future loads. By this proactive online planning, chances of returning fully loaded in time are higher, which can provide considerable savings in transportation costs.

At CWI, logistics is an important theme. The DEAL research project is a good example. Starting in 2004, it was funded by SenterNovem, an agency of the Dutch Ministry of Economic Affairs. It combined the efforts of both researchers and industry partners: Almende BV, Erasmus University Rotterdam, VU University Amsterdam, CWI, CarrierWeb, Post-Kogeko, and Vos Logistics. At CWI, the team members were: Han La Poutré, Valentin Robu, Pieter Jan 't Hoen, Jano van Hemert, Peter Bosman, and Koye Somefun. The project ended in 2008. A subsequent project, *DIACoDeM – Distributed Implementations of Adaptive Collective Decision Making*, started in 2007. •

More information

<http://www.cwi.nl/sen4>

<http://homepages.cwi.nl/~han/SEN4Demos>

CV

Valentin Robu

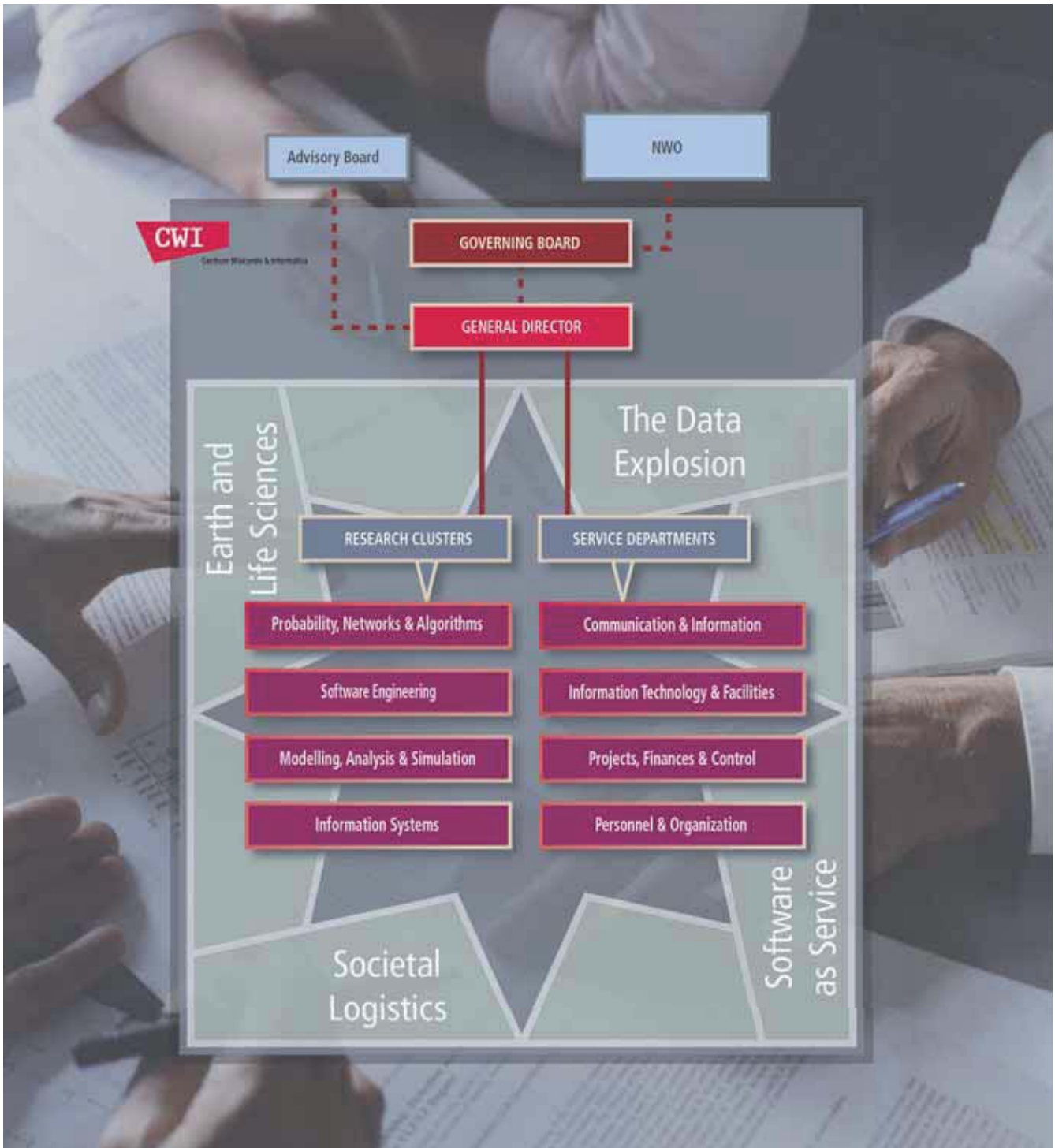
Since 2008: project researcher at CWI, in the Computational Intelligence and Multi-agent games (SEN4) research group, working on the DIACoDeM project

2003-2008: PhD student in SEN 4 on the DEAL project

2003: master degree in Artificial Intelligence from VU University, Amsterdam



APPENDICES



Organization

Research

Cluster

Group

Probability, Networks and Algorithms

Algorithms, Combinatorics and Optimization
Probability and Stochastic Networks
Signals and Images
Cryptology and Information Security

Software Engineering

Interactive Software Development and Renovation
Coordination Languages
Computational Intelligence and Multi-agent Games
Distributed Multimedia Languages and Infrastructures

Modelling, Analysis and Simulation

Dynamical Systems and Numerical Analysis
Scientific Computing and Control Theory
Multiscale Modelling and Nonlinear Dynamics

Information Systems

Standardization and Knowledge Transfer
Database Architectures and Information Access
Semantic Media Interfaces
Visualization and 3D Interfaces
Quantum Computing and Advanced Systems Research

Management

Management Team

Jan Karel Lenstra (general director)
Monique Bekkenutte <November> Judith Coster
Dick Broekhuis
Arjen Doelman
Ids Dijkstra
Bert Gerards
Martin Kersten
Paul Klint
Angelique Schilder

Cluster leader

Group leader

Bert Gerards

Monique Laurent
Rob van der Mei
Eric Pauwels
Ronald Cramer

Paul Klint

Paul Klint
Frank de Boer
Han La Poutré
Dick Bulterman

Arjen Doelman

Jason Frank
Barry Koren
Ute Ebert

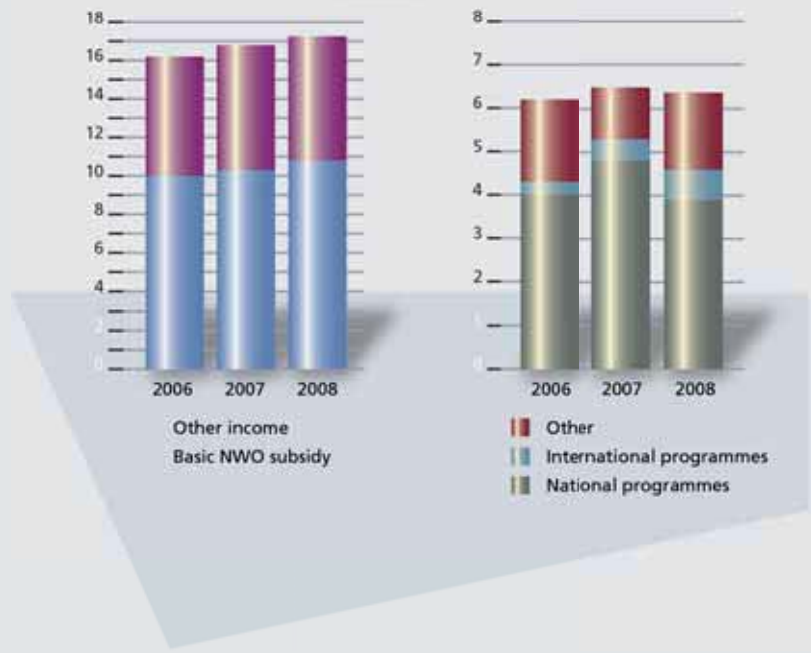
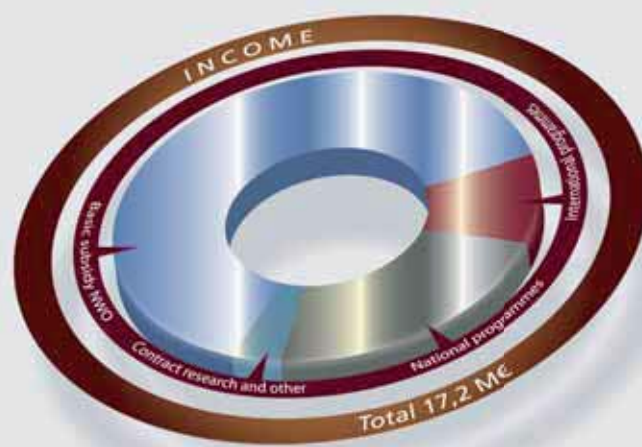
Martin Kersten

Martin Kersten
Martin Kersten
Lynda Hardman
Robert van Lieere
Harry Buhrman

Governing Board

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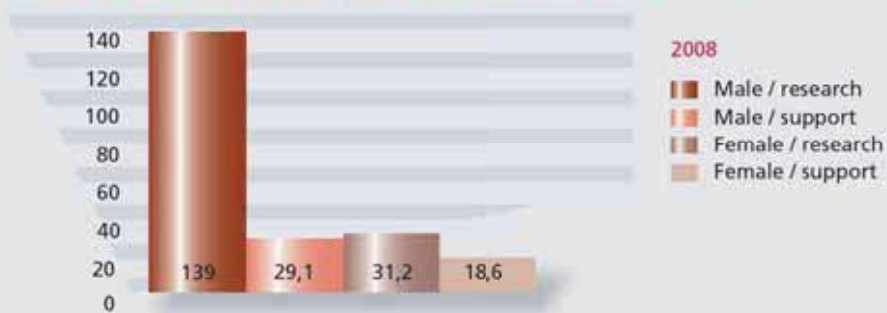
Facts and figures



CWI Staff including other seconded in fte



Male and female research and support staff in fte, including other seconded

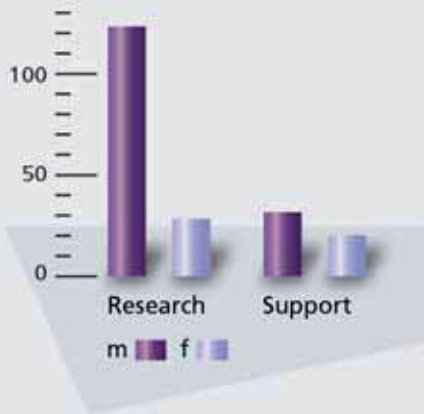


Overview researchers, postdocs and PhD students in fte

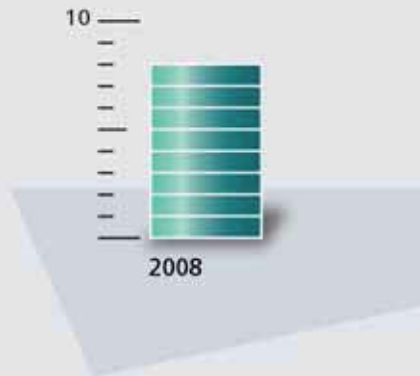


APPENDICES

Male/female staff in fte at the end of 2008 (CWI payroll)



Master students in numbers





International staff in 2008.

Research clusters and groups

PNA - Probability, Networks and Algorithms

PNA does fundamental research motivated by society. It finds its tools in a wide range of pure and applied mathematics and computer science. The main application areas are computer technology, security, telecommunication, logistics and transportation, but applications are also found in areas like the life sciences and the environment. The research covers all four strategic themes.



Cluster leader: Bert Gerards
Bert.Gerards@cwi.nl

Algorithms, Combinatorics and Optimization

This group's fundamental research is motivated by real-world problems, arising for instance in production and transportation planning, routing, scheduling and timetabling, computational biology and network economics.

The goal is to design efficient algorithms. This requires understanding and exploiting the mathematical structure of the problems and using tools and methods from various mathematical areas, including algebra, geometry, discrete mathematics, game theory, complexity, and optimization. This research is relevant for the themes *societal logistics* and *earth and life sciences*.

Highlights

- The train timetable of Nederlandse Spoorwegen (NS), designed by algorithms of Lex Schrijver en Adri Steenbeek (CWI), has won the prestigious Franz Edelman Award.
- Erik Jan van Leeuwen received the Philips Prize at the occasion of 5ECM.
- Krzysztof Apt became CWI Fellow, Lex Schrijver was elected for membership of the Academia Europaea.
- Karen Aardal appointed professor at TU Delft, Bert Gerards appointed Adjunct professor at the University of Waterloo, Canada, and Leen Stougie appointed professor at VU Amsterdam.



Group leader: Monique Laurent
Monique.Laurent@cwi.nl

Probability and Stochastic Networks

Many real-life systems and processes are dynamic and essentially stochastic. Examples can be found in areas like communication and information systems, biology, economics and logistics. This group develops and studies stochastic and statistical models that yield fundamental understanding and enable control and optimization of such systems. Analysis of these models relies on techniques from fundamental probability theory, queueing theory, stochastic scheduling, spatial stochastics and stochastic geometry. This way the group addresses challenging research problems in the context of *societal logistics* and *earth and life sciences*.

Highlights

- Bert Zwart has been awarded the Erlang Prize and an IBM faculty award.
- Bert Zwart has been awarded a Vidi grant.
- Vlasdas Sidoravicius won the John von Neuman Prize and



Group leader: Rob van der Mei
Rob.van.der.Mei@cwi.nl

- the prestigious Clay Mathematics Institute Award.
- Vlasdas Sidoravicius was appointed full professor at Leiden University.

Signals and Images



Group leader: Eric Pauwels
Eric.Pauwels@cwi.nl

The research focuses on two related topics. First, the group investigates mathematical methodologies to generate content specific descriptions of images for efficient retrieval from large image databases. Second, the researchers create semantic meta-data from video and signals generated by camera- and sensor-networks. The aim is to arrive at an appropriate high-level interpretation of observed events. Both topics fit within the strategic theme *the data explosion*.

Highlights

- Renowned speakers visited CWI for the International Workshop on 'Distributed Sensing and Collective Intelligence in Biodiversity Monitoring'.

Cryptology and Information Security

This group's work on the construction of practical cryptosystems as well as the work on cryptanalysis of popular much used systems is in line with the strong need for higher security in the ever expanding digital world. They also research fundamentally new ways to achieve security, including secure multi-party computation and quantum cryptography. All research is closely linked with the themes *the data explosion* and *software as service*.

Highlights

- Chosen prefix MD5 collisions lead to internet security loophole, causing the withdrawal of MD5.
- The Veni project of Dennis Hofheinz started.



Group leader: Ronald Cramer
Ronald.Cramer@cwi.nl

MAS - Modelling, Analysis and Simulation



Cluster leader: Arjen Doelman
Arjen.Doelman@cwi.nl

The research programme of MAS is based on three mathematical research tracks: scientific computing, dynamical systems and partial differential equations, and system and control theory. Recently, there is a growing interest in stochastic systems and molecular dynamics. The research approach of all members of this cluster ranges from fundamental to applied. The application areas include geo- and biosciences, fluid and plasma dynamics, computational finance, and other industrial and technological fields. Altogether, the research covers all four strategic themes.

Dynamical Systems and Numerical Analysis

The group engages in fundamental research on applied dynamical systems theory of PDEs, including asymptotics, low-dimensional dynamics, and stochastic modelling; and numerical analysis, with an emphasis on numerical time integration, geometric integration, and the dynamics of numerical algorithms. The group applies its research to atmosphere and ocean sciences, phytoplankton dynamics, vegetation patterns, biomolecular dynamics, and electromagnetic waves. The work largely contributes to the theme *earth and life sciences*, but can also serve *societal logistics* and *the data explosion*.

Highlights

- Arjen Doelman chaired the writing committees for two national policy documents for the Dutch mathematics field.



Group leader: Jason Frank
Jason.Frank@cwi.nl

Scientific Computing and Control Theory



Group leader: Barry Koren
Barry.Koren@cwi.nl

Scientific computing enables the investigation of phenomena that are too dangerous, too expensive, too difficult or simply impossible to study otherwise. The research contributes to the strategic themes: *societal logistics*, *earth and life sciences* and *software as service*. Control theory is a major factor in the effective functioning of technological systems as well as in modelling and control of biological systems, and in the mathematical analysis of physical systems. This research addresses both *earth and life sciences* and *societal logistics*.

Highlights

- Barry Koren was appointed full professor at Leiden University.
- Jeroen Wackers received the ECCOMAS Award for the best PhD thesis on computational methods in applied sciences in 2007.
- Kees Oosterlee gives inaugural lecture on the occasion of his appointment as full professor Hierarchical Numerical Methods at TU Delft.

Multiscale Modelling and Nonlinear Dynamics



Group leader: Ute Ebert
Ute.Ebert@cwi.nl

This group combines the development of basic methods of nonlinear dynamics and scientific computing for deterministic and stochastic problems with practical, experimentally oriented questions. Subjects are cell and systems biology, atmospheric electricity and closely related subjects of plasma physics and technology. The research fits into the *earth and life sciences* theme.

Highlights

- Studies of interacting sparks were published in renowned journals, they were covered twice on Dutch television and once on radio and extensively in *NRC Handelsblad*.
- Ute Ebert was editor of a cluster issue of the *Journal of Physics D* entitled 'Streamers, sprites, and lightning'.

INS - Information Systems

The research activities of INS focus on various aspects of information systems. Important output of the work is the development of prototypes for demonstrating and experimenting with solutions. The policy regarding their construction is to develop them up to the point that real applications can be built and to support the take up through open-source communities. The work mostly addresses the challenges posed by *the data explosion* but part of the research relates to *earth and life sciences*.

Standardization and Knowledge Transfer

The activities in this group are organized in two dimensions: coordination of World Wide Web activities and development of standards. They play a leading role in coordination and scientific direction of W3C standards.



Cluster and group leader: Martin Kersten
Martin.Kersten@cwi.nl

Database Architectures and Information Access



Group leader: Martin Kersten
Martin.Kersten@cwi.nl

The amount of data managed by database systems and accessed through information retrieval systems is enormous. Information retrieval technology of this group focuses on strategies for structural information retrieval. The scalability issue is addressed using adaptive algorithms at the heart of a modern database system. This clearly connects with the theme *the data explosion*.

Highlights

- CWI founded the independent companies Vectorwise and MonetDB B.V.

Semantic Media Interfaces

The research goal is to support human users in obtaining correct information from the huge amounts available, in the appropriate amount, relevant to the task in hand and presented in an appropriate way. The challenge is to develop methods to explore and confirm models of storage, selection, organization and presentation of information. This research emphasizes the user role in *the data explosion* theme.

Highlights

- Michiel Hildebrand (CWI) received the Best Student Paper Award for research proposals at the International Semantic Web Conference 2008 in Karlsruhe.



Group leader: Lynda Hardman
Lynda.Hardman@cwi.nl

Visualization and 3D Interfaces

Scientific computing is a rapidly growing field and scientists are critically dependent on interactive visual data analysis techniques. This group's focus is to study visualization methods that combine the exploratory nature of discovery with the quantitative nature of science. It contributes to the theme *the data explosion*.



Group leader: Robert van Liere
Robert.van.Liere@cwi.nl

Highlights

- Robert van Liere coauthored the book *Handbook in Visualization, Trends in Interactive Visualization*.
- At the ACM Symposium on Virtual Reality Software and Technology Robert van Liere won a Best Paper Award.

Quantum Computing and Advanced Systems Research

Quantum computers use quantum mechanical effects to drastically and fundamentally speed up certain information processing tasks such as computation, simulations of physical systems, and communication. The researchers develop new algorithms and protocols, and establish the inherent limitations thereof by means of general techniques in the form of no-go theorems.

The work in machine learning and statistics focuses on the realistic case in which all available models describing the data are wrong, still some are useful though, in the sense that they lead to reasonable predictions. This group theoretically analyses this situation and develops new algorithms for it, based mainly on the Minimum Description Length Principle (MDL). MDL states that the best theory or explanation for the data is the one that allows for the shortest description of the data. The research covers *earth and life sciences*, *the data explosion* and *societal logistics*.



Group leader: Harry Buhrman
Harry.Buhrman@cwi.nl

Highlights

- Peter Grünwald was appointed professor at Leiden University.
- Ronald de Wolf received a NWO Vidi grant and Ben Toner received a Veni.

SEN - Software Engineering

SEN focuses its research on various aspects of software engineering, evolutionary systems and multi-media applications. The ambition is to cover the whole range of activities from fundamental concepts and prototype implementations to the application of these concepts in practice. Many activities fit in the theme *software as service*.

Interactive Software Development and Renovation



Cluster and group leader: Paul Klint
Paul.Klint@cwi.nl

Research focuses on the question how the development and renovation of large, industrial, software systems can be supported and improved. Focal points are program understanding, program refactoring, domain-specific languages, large-scale program transformation, and configuration/variability management. It aligns with the theme *software as service*.

Highlights

- The spin-off company Software Improvement Group was awarded the ICTRegie Innovation Award and was ranked 44 on the Deloitte Technology Fast 50.
- Major parts of The Meta-Environment were ported to the Eclipse platform.

Coordination Languages



Group leader: Frank de Boer
Frank.de.Boer@cwi.nl

This group specifically seeks to provide conceptually well-founded technology for the easy and reliable composition

of third-party services into distributed applications. Integral in the approach is the development of solid mathematical foundations on which such technology is to be based. The research fits the theme software as service.

Highlights

- The EU STREP project *Credo: good to excellent* was positively evaluated.
- The ArchiMate team won NAF Architecture prize.
- Trust4All won the ITEA Bronze Achievement Award.
- Lacramioara Astefanoaei and Frank de Boer won the Best Paper Award of the 11th Pacific RIM International Conference on Multi-Agents.

Computational Intelligence and Multi-agent Games



Group leader: Han La Poutré
Han.La.Poutre@cwi.nl

The research focuses on the design and implementation of adaptive solutions and rules for dynamic and decentralized decision making. The group works in the areas of computational intelligence and multi-agent systems. Possible application domains include health care logistics, energy markets, transportation logistics, service markets, and market simulation. In this way, it contributes to the themes *societal logistics* and *software as service*.

Highlights

- Research was started on green energy. A project dealing with increasing decentralized generation thereof was funded in IOP EMVT.
- Han La Poutré was appointed in the Scientific Directorate of Dagstuhl and the computer science advisory board of the Lorentz Centre, and reappointed as chair of the IEEE Technical Committee on Computational Finance and Economics.
- Cooperation started with INRIA on computational intelligence and multi-agent systems.

Distributed Multimedia Languages and Infrastructures

The group's focus is temporal specification languages, declarative interaction models and distributed media delivery and rendering architectures. Combining both analytic and experimental approaches, DMLI studies models for the temporal combination and navigation through heterogeneous media objects, interactive media object synthesis based on socially-driven service-oriented architectures and low-level distribution of media content on non-monolithic, distributed rendering architectures. While our work is related

primary to the *software as service* theme, we also contribute as a significant cause of *the data explosion*.



Group leader: Dick Bulterman
Dick.Bulterman@cwi.nl

Highlights

- Start of the EU projects TA2 (IP) and INEM4U (Strep)
- Best Paper Award, EuroITV 2008 (Cesar, Bulterman, Jansen, et al.).
- Best Paper Award, ACM Document Engineering 2008 (Jansen, Bulterman).
- Best Paper in track Award, ACM Multimedia 2008 (Cesar, Bulterman, Jansen, et al.).
- Best Paper 2008, ACM Special Interest Group on Multimedia (Cesar, Bulterman, Jansen, et al.).
- Publication of W3C SMIL 3.0 Recommendation (Bulterman, co-chair)
- Publication by Springer of the book SMIL 3.0: Flexible Multimedia for Web, Mobile Devices and Daisy Talking Books (Bulterman)
- Dick Bulterman was appointed full professor at VU University, Amsterdam.



International and national research programmes

CWI participates in many national and international research projects. This overview lists all major projects with their duration, partners, and CWI project leader(s).

European programmes

European Union

COMPAS – Compliance-driven Models, Languages and Architectures for Services
2008–2011
Vienna University of Technology, University of Claude Bernard, University of Stuttgart, UT, University of Trento
F. Arbab

CON4COORD – Control for Coordination of Distributed Systems
2008–2011
University Gent, Universidade do Porto, Center for Research and Technology Thessaly, Università degli Studi di Verona, Hesse-Noord Natie, OceanScan, Océ Technologies, Trinite Automatisering
J.H. van Schuppen

CREDO – Modelling and Analysis of Evolutionary Structures for Distributed Services
2006–2009
University Oslo, Christian-Albrechts-Universität Kiel, Rheinische Friedrich-Wilhelm Universität, Bonn, Uppsala University, United Nations University (International Inst. for Software Technology), Almende, Rikshospitalet - Radiumhospitalet HF, Norsk Regnesentral
E.S. de Boer

DISC – Distributed Supervisory Control of Complex Plants
2008–2011
University of Cagliari, University Gent, Technical University of Berlin, University of Zaragoza, INRIA, Akhela s.r.l., Czech Academy of Sciences, Ministry of Flemish Government, CyBio AG
J.H. van Schuppen

EC MOAN – Scalable Modelling and Analysis Techniques to Study Emergent Cell Behaviour
2007–2010
INRIA, VU, Joseph Fourier University, Masaryk University, University of Edinburgh
J.H. van Schuppen

INEM4U – Interactive Networked Experiences in Multimedia for You
2008–2010
Telematica Instituut, Philips Electronics, NEC Europe, Logica CMG, Fraunhofer Gesellschaft, Hewlett Packard, Telenor ASA, Institut für Rundfunktechnik, Philips Consumer Electronics
D.C.A. Bulterman

QAP – Qubit Applications
2005–2009
36 Partners from different countries
H.M. Buhrman

SPICE – Service Platform for Innovative Communication Environment
2006–2008
Telematica Instituut, France Télécom
D.C.A. Bulterman



TA2 – Together Anywhere, Together Anytime

2008–2012

EURESCOM, British Telecommunications, Alcatel Lucent-Bell, Fraunhofer Gesellschaft, Goldsmiths College University of London, TNO, The Interactive Institute II AB, Hasbro, Philips, Limbic Entertainment, JONNAEUM Research Forschungsgesellschaft
D.C.A. Bulterman

VITALAS – Image Indexing and reTrievAL in the Large Scale

2007–2009

EADS Defence and Security Systems, Fraunhofer Gesellschaft, INRIA, Fundacion Robotiker, Institut National de l'Audiovisuel
A.P. de Vries

EU networks

EuroFGI – Design and Engineering of the Future Generation Internet – Towards Convergent Multi-service Networks

2006–2008

Many partners

R. Núñez Queija

K-Space – Knowledge Space of Semantic Inference for Automatic Annotation and Retrieval of Multimedia Content

2006–2008

14 partners

L. Hardman

RESEARCH PROGRAMMES

Life Watch

2008–2011

27 Partners from various countries

E.J.E.M. Pauwels

MUSCLE – Multimedia Understanding through Semantics,
Computation and Learning

2004–2008

38 Partners from various countries

E.J.E.M. Pauwels (scientific coordinator)

PASCAL – Pattern Analysis, Statistical Modelling and
Computational Learning

2003–2008

Partners from various countries

P.D. Grünwald

PASCAL-2 – Pattern Analysis, Statistical Modelling and
Computational Learning

2008–2013

Partners from various countries

P.D. Grünwald

National programmes

NWO

**Adaptive Multisymplectic Box Schemes for
Hamiltonian Wave Equations**

2007–2010

J.E. Frank



Algebraic Geometric Foundations of Cryptology – The Case of Practical and Unconditionally Secure Computation
2007–2011
Vici project
R.J.F. Cramer

Algocrypt – Algorithmic Validation of Widely Used Cryptosystems
2004–2008
Microsoft, TUE, UL
H.J.J. te Riele

Analysis of Distribution Strategies
for Concurrent Access in Wireless Communication Networks
2007–2010
Lucent Technologies
R.D. van der Mei

CellMath – Mathematics and Computation for the System Biology of Cells
2004–2008
VU, UvA, TUE, MAS2 (Van Schuppen)
J.G. Blom

CoCoMAS – Coordination and Composition in Multi-agent Systems
2006–2010
UU
F.S. de Boer

CooPer – Coordination with Performance Guarantees
2005–2009
SEN3 (F. Arbab)
R.D. van der Mei



Computational Topology for Systems and Control
2005–2010
Vidi project
P.J. Collins

C-Quattro – Compositional Construction of Component Connectors
2004–2008
F. Arbab

Cracking a Scientific Database
2006–2009
UU, OMEGACEN/RUG
M.L. Kersten

Critical Percolation and Excitable Media
2005–2008
J. van den Berg

RESEARCH PROGRAMMES

3D-RegNet – Simulation of Developmental Regulatory Networks
2004–2008
UvA
J.G. Blom

DIACoDeM – Distributed Implementations of Adaptive Collective Decision Making
2006–2009
SEN3, SEN4
K.R. Apt

DIAMANT – Discrete, Interactive & Algorithmic Mathematics, Algebra and Number Theory
2007–2010
TUE, UL, RU
A.M.H. Gerards

EFS – Efficient Flow-scheduling in Resource-sharing Networks with Variable Service Rates
2005–2009
R. Núñez Queija

Hefboom-project
2005–2009
Hogeschool Amsterdam, VU, UvA
J.J. Vinju

High Dimensional Service Systems
2008–2013
Vidi project
A.P. Zwart

Infinity – Infinite Objects, Computation, Modelling and Reasoning
2006–2008
VU
J.J.M.M. Rutten

Interactions of Pulses and Fronts
2005–2009
A. Doelman

Learning When All Models Are Wrong
2005–2010
Vidi project
P.D. Grünwald

Mathematics and Computation for the System Biology of Cells
2004–2008
UvA, TUE, VU
J.G. Blom

MBA – Moving Ionization Boundaries and Charge Transport
2005–2008
TUE
U. Ebert

MEMESA – Microbial Ecosystems and Multiple Environment Stoichiometric Analyses
2008–2011
E.J. Bruggeman

Mending the Unending – Machine Assisted Reasoning with Infinite Objects
2008–2011
Veni project
M. Niqui

Mesoscale Simulation Paradigms in the Silicon Cell
2004–2008
UvA
J.G. Blom

MIA – Medical Information Agent
2004–2008
UM
J.A. La Poutré

MON-LM – Monotonicity Preservation for General Multisteps Methods
2007–2010
W. Hundsdorfer

MR-PDE – Multirate Time Stepping for PDEs
2004–2008
W. Hundsdorfer

NA – Task Coordination for Non-cooperative Agents
2006–2010
TUD
H.L. La Poutré



RESEARCH PROGRAMMES

NDNS – Nonlinear Dynamics of Natural Systems

2005–2012

A. Doelman

Pushing the Factoring Boundary to 768 Bits

2008–2012

H.J.J. te Riele

Quantum Computing – Achieving Proofs and Tradeoffs

2005–2008

Veni project

R.M. de Wolf

Quantum Computing – Fault Tolerance,

Communication, and Classical Spin-offs

2008–2013

Vidi project

R.M. de Wolf

Quantum Cryptography – Achieving Provable

Security by Bounding the Attacker's Quantum Memory

2008–2012

S. Fehr

Quantum Information Processing

2004–2011

Vici project

H.M. Buhrman

QUASID – Quantitative Spatial Interaction Design

2005–2011

TUE

R. van Liere

RAPS – Rare-event Analysis of Processor-sharing Systems

2004–2008

Lucent Technologies, TUE

S.C. Borst

RPOS – Realization and Control of National Positive Systems

2005–2009

VU

J.H. van Schuppen

ScaNN – Scalable Reinforcement Learning and Information Processing with Timed Spikes in Scalable Networks of Spiking Neural Networks

2003–2008

Veni project

S.M. Bohte

SPCO – Semidefinite Programming and Combinatorial Optimization

2002–2008

LAAS-CNRS, Univ. Klagenfurt, Univ. Rennes, TUD – Vidi project

M. Laurent

Strengthening Modern Cryptography by Automatable Proving

2008–2011

Veni project

D. Hofheinz

SYANCO – Synthesis and Analysis of Component Connectors

2006–2009

Rheinische Friedrich Univ. Bonn, UL

F. Arbab



Symplectic Integration of Atmospheric Dynamics – Long-term Statistical Accuracy for Ensemble Climate Simulations
2005–2009
J.E. Frank

The Skeptical Minimum Description Length Principle
2006–2009
EURANDOM
P. Grünwald

VEARN – A Visual Exploration Environment for Analysing Gene Regulation in Developmental Processes
2007–2011
UvA, Gutenberg University, James Cook University
R. van Liere

VERMPS – Verification and Epistemics of Multi-party Protocol Security
2006–2010
TUE, VU, UL, UU
D.J.N. van Eijck

WoMaLaPaDia – Workflow Management for Large Parallel and Distributed Applications
2007–2010
TUE
F. Arbab

STW

MoveBP – Electric ‘Fracture’: Growth and Branching of Ionised Channels
2005–2008
TUE, Thomas Stieltjes Instituut
U. Ebert

RESEARCH PROGRAMMES

PASC – Practical Approaches to Secure Computation
2005–2009
TUE
R.J. Cramer

The Start-up of Lightning – Streamer discharges in
Lamp Ignition, Electric Switches and Materials Processing
2008–2012
TUE, Philips
U. Ebert

SenterNovem (including IOP)

BASIS – Biometric Authentication Supporting Invisible
Security
2004–2009
UT, TUE
B.A.M. Schouten

IDEALS – Idiom Design for Embedded Applications on a
Large Scale
2003–2008
ASML, TUE, UT, ESI
P. Klint

IOP-EMVT – Stochastic Methods for Field Computations
in EMC Problems
2004–2008
TNO-FEL, TUE
P.W. Hemker

**Power Modulation and Corona-plasma for
Environmental Purposes**
2007–2010
TUE
U. Ebert



SEQUAL – Service Optimization and Quality
2008–2012

TNO-ICT, IBM, Ericsson, UT, Mobilaria
R.D. van der Mei

Bsik projects

BioRange – Biomathematics in Mass Spectrometry Based
Proteomics and Modelling of Protein Networks
2006–2010

EUR

J.H. van Schuppen

BRICKS – Basic Research in Informatics for Creating the
Knowledge Society
2004–2009

TUD, TUE, UT, UU, NWO

J.K. Lenstra, J.G. Verwer, J.R. van Ossenbruggen, P. Bosman

GeoInfoNed – A Multimedia Geo-database Infrastructure
2006–2008

OTB/TUD/Section GIS Technology

M.L. Kersten

MultimediaN – Multimedia Next Generation
2004–2008

CTIT, LogicaCMG, Philips Research, TI, TNO, TUD, UU,
UvA, VU, V2_, Waag Society

M.L. Kersten

VL-e – Virtual Laboratory for e-Science
2004–2009

see www.vl-e.nl about VL-e consortium partners

R. van Liere

Contract research

Ambulant II

2006–2008

W3C

D.C.A. Bulterman

Implement Forecasting Processes

2008

W. van der Weij

Railway Optimization

2001–2010

NS Reizigers

A.M.H. Gerards

Research Agreement Rabobank International

2008–2012

Rabobank International

C. Oosterlee

**Socially Structured User Behaviour and
Externalities in Sponsored Search Auctions**

2007–2008

Microsoft

S. Bohte

Stagesporen

1998–indefinite

VU, UM

A.M.H. Gerards

RESEARCH PROGRAMMES

XIRAF – XML-based Indexing and Querying for Digital Forensics
2007–2009
NFI
P. Boncz

Telematica Instituut projects

CHIP – Cultural Heritage Information Personalization
2005–2008
TUE, Rijksmuseum
L. Rutledge

Miscellaneous

Digital Repository Infrastructure Version for European Research
2007–2013
A.L. Ong

Molecular Systems Biology at Science Park Amsterdam

2008–2010
AMOLF, SILS
J.H. van Schuppen

Parallelization of Coupled Large-scale Fluid Dynamics and Structural Mechanics

Software
2007–2008
B. Koren

Spinoza Award project

2005–2010
A. Schrijver



Centrum Wiskunde & Informatica (CWI) is the national research institute for mathematics and computer science in the Netherlands. The institute's strategy is to concentrate research on four broad, socially relevant themes: earth and life sciences, the data explosion, societal logistics and software as service.

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June 2009

The logo for Centrum Wiskunde & Informatica (CWI) features the letters 'CWI' in a bold, white, sans-serif font. The text is centered within a red, trapezoidal shape that tapers to the right, creating a dynamic, arrow-like effect.

Centrum Wiskunde & Informatica