CWI

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Colofon

Content

Making the best of fallible models

Statistical models simplify reality, they are not reality itself. Models therefore have flaws. Modern society depends on models nonetheless – from medical research to speech recognition. Peter Grünwald introduces methods derived from pattern recognition and machine learning into statistics. These methods combine frequentist statistics with a Bayesian approach, thus avoiding some of the weaknesses in both. The results lead to a better assessement of the reliability of for instance medical research and can even be used in court.

In speech recognition software a statistical model is used to connect a text on paper to the same text in spoken language. For this the software has to understand how speech functions. However, this is impossible: we don't know how speech really functions. A speech recognition model is therefore unlikely to be true. For practical reasons such a model usually only looks at the two previous words to determine the context for the next word. To look at ten previous words would lead to an unworkable amount of data. A model should be simple; therefore it has to be wrong. This represents a common problem with models, a problem that fascinates Peter Grünwald. On the one hand man doesn't really understand reality, on the other hand one has to oversimplify reality to keep a model running. So to get a grasp on reality we assume for example a linear relation between blood pressure and age, while at the same time we know that the real correlation is far more complex. The fact that models are wrong doesn't make them useless. On the contrary; it only becomes a problem when this leads to wrong decisions or bad predictions in practical situations. And that is likely to occur when models are regarded as reliable.

"The fact that models are wrong doesn't make them useless."

Reliability

One example lies in the field of medical statistics. Connected to every double blind medical research project is a P-value for the significance level. This mark for reliability should be below five per cent. Epidemiology research has however pointed out that the real figure is far higher possibly at even thirty per cent. There are several explanations for this. For one, research results in line with main stream are likely to be published more willingly than contradictory results. Such a mechanism of self-fulfilling prophecy has been unveiled in research into attractiveness. The conclusion that individuals with a symmetrical face are found more attractive was sustained for a long time in many studies. Ultimately it proved wrong.

Right is wrong

The weak spot in the P-value is a sort of baked-in multiplier effect. The significance value could indeed be five per cent, provided that every medical study would live up to the standard. But that is not the case in practice.

An example. Research results with a hundred patients look promising, but fall short to attain the right P-value. So the patient group is extended. Two hundred patients make the results statistically even more significant? With two hundred patients the right P-value can indeed be attained. This means that the very fact that the study was adapted diminishes the model's reliability. Hence the correct P-value should be larger. The procedure does not take into account that the model is wrong, like it should. The P-value should be multiplied with a correction factor representing unreliability. This correction factor can be attained by a 'new' method, combining Bayesian inversion and 'classical' frequentist statistics.

Purely Bayesian methods that output the chance of a conclusion being true rather than a P-value also have too much trust built into them. Grünwald reached a breakthrough in 2010 by coming up with a precise quantification of the correction factor, inspired by a PAC-Bayesian approach derived from machine learning.

Direct feedback

Similar ideas have already been developed in the machine learning literature. The main novelty of Grünwald's research is to adapt these for use in statistics. In this field the fallibility of models is much more widely known and accepted than in statistics. Model failure here directly leads to product failure. In statistics there is no such direct feedback, yet statistics can now also benefit from these new ideas about a model's reliability. The knowledge from machine learning is applied to justifiably dilute the conclusions in statistics. The nature of failures in machine learning differs from those in statistics. In machine learning the problem often revolves around (a lack of) correlation, whereas in (medical) statistics the assumed protocol is wrong, for instance if the research is extended until the results are satisfying. Therefore the methods from machine learning must be adapted before they can be used in statistics. But in both fields the goal is the same: to improve the model by knowing where it goes wrong. In 2010 Grünwald mainly worked on developing a general framework, in which both types of 'wrongness' can be expressed.

Prof. dr. Peter Grünwald heads the information-theoretic learning subgroup in the research group Algorithms and Complexity. He is also part-time full professor at Leiden University. Since July 2010 he heads the NWO Vici project Safe Statistics.

"Extremely fascinating field"

"I was introduced to the world of machine learning through artificial intelligence", says Grünwald. "Every collision of a robot with an object in a room for example helps it to map the room. It is the same with self-learning spam filters; once you feed examples of spam to these filters, they learn to recognize spam ever better. This system of pattern recognition in data is in fact a kind of statistics: extracting useful conclusions from 'data soup'. This is a sort of purification process with philosophical implications. It is tempting to regard conclusions from statistics as pure. In science as well as in the court room it has by now been proven regularly that this – apart from tempting – is also very dangerous. Statistics can tell you that there is a minute chance that a certain nurse is present at the death of a number of patients. Statistics can also tell you that the chance of such a coincidence never to happen, given the number of hospitals around the world, is also very small indeed."

Grünwald here refers to the renowned case of Lucia de Berk, a nurse who was convicted for the murder of several of her patients, based partly on flawed statistical and medical evidence. Using his expertise in statistics, Grünwald has been actively involved in an ultimately successful attempt to reopen the case: in 2010, De Berk was fully acquitted. "Statistics boring? To the contrary, it is extremely fascinating and has implications on an almost unlimited number of topics."

His work got Peter Grünwald a Vici grant from the Netherlands Organisation for Scientific Research (NWO) as well as the prestigious Van Dantzig Award together with Harry van Zanten, both in 2010.

Fundamental research in coalgebra: Being is doing

Coalgebra has a highly fundamental nature. First and foremost, research on coalgebra at CWI is about theorems and proofs. Together these theoretical results form a computational toolset that has a serious impact on the research of theoretical computer scientists and mathematicians worldwide. Ultimately coalgebra has also interesting and relevant applications – for instance, in proving the correctness of software of safety-critical systems in airplanes or medical equipment.

Prototypical examples of coalgebras are streams, which are infinite sequences. Concrete examples of streams can be found in mathematics, such as the stream of natural numbers or the stream of the Fibonacci numbers. Streams also occur in daily life, for instance, in the form of 'interactive' data streams in various forms of electronic communication – for example streams of data sent between WiFi routers and PC's. They are also important to describe the behaviour of present-day computers. Decades ago the computer literally 'computed'. There was input and after some calculation time this lead to output: I/O. Nowadays, this is not the case anymore. The behaviour of many computer processes can be characterised by means of those infinite, interactive streams, for instance data streams between smart phones and telecom antennae, or between the operation system of an airline and its airplanes. Processes like these are meant never to be offline and behave like infinite systems. It is this kind of infinite behaviour that can be modelled mathematically by coalgebra. Such coalgebraic models contribute to a better understanding of these 'infinite' systems and help in their maintenance and design.

Universal coalgebra

The field of coalgebra has its roots in logic. It came to full bloom in the early 1990s, as the result of the interaction between logic with theoretical computer science. Universal coalgebra, the first systematic description of the basic principles of coalgebra, was published in an article by Rutten in 2000. This article became one of the most cited studies from CWI ever and has proved its relevance in various fields of application.

Co-induction

A central notion in coalgebra is co-induction. Induction is a standard mathematical principle that is used to prove properties of finite mathematical structures. Co-induction is a kind of converse formally 'dual' of this principle of induction. It is for infinite structures what induction is for finite structures. For instance, it can be used to prove the equality of infinite streams, leading to new, coherent classifications that bring order into the world of infinite streams. Co-induction can also be characterised by the slogan: being is doing. Streams can be said to 'do as they are', because their behaviour can be seen as the one-by-one outputting of their respective elements. As a consequence, in order to prove that two streams are equal, it suffices to show that they behave in the same way. This elementary 'behavioural' proof principle has far reaching implications.

Applications

In the recent past, coalgebra and co-induction have been used in the semantic modelling of REO, a programming method for the coordination of component-based software, introduced at CWI. Other examples in software engineering are the introduction of new, 'co-inductive' programming features constructs in programming languages such as Haskell. Coalgebra has found its way, from logic and via theoretical computer science, into the world of mathematics as well: at CWI, there is collaboration between the theoretical computer scientists and the mathematicians, who have started using coalgebra in control theory.

Unexpected and surprising applications can be found in economics – in relation with game theory for models of infinite interaction – and even in ecology. In 2010, ecologists at the University of Bayreuth have applied coalgebraic techniques in models explaining the relevance of stress in the breeding behaviour of birds living together in large colonies!

"How often do you hear a renowned scientist say that one only encounters few works of this stature in one's lifetime?"

Kleene coalgebra

The year 2010 has become the most recent milestone in the research on coalgebra in Rutten's group. In December, Alexandra Silva defended her PhD thesis entitled 'Kleene Coalgebra' at the Radboud University Nijmegen. She received her PhD degree with the predicate 'cum laude', awarded by a committee of national and international experts, a distinctive honour. Starting point was Kleene's theorem, which has since long been one of the fundamental results in theoretical computer science. It applies to certain classes of systems such as automata and formal languages. Coalgebra, as a universal theory of the behaviour of systems, made it possible to extend this theory to a large variety of many other classes of systems. The resulting new theory was called Kleene coalgebra. Although in the first place a fundamental theoretical result, it has already led to new applications in the world of process algebra. This is a discipline of theoretical computer science studying the correctness of (computer) processes. As a result, Kleene coalgebra has already contributed to a better understanding of the design and the correctness of new and larger classes of computer programs.

Prof. dr. Jan Rutten (senior researcher at CWI since more than 25 years): "For the sheer beauty of it"

"I love the beauty and elegance of the field of coalgebra. Take for instance the quote 'being is doing'. It might sound simply like a vague philosophical principle. But there is a whole world of very precise mathematics behind it. I also like the surprising fields of application. Coalgebra proves to offer solutions to unsolved problems in a wide variety of specialisations; who would have thought of the breeding conduct in bird colonies? This multidisciplinarity enables useful co-operation with experts worldwide, at institutes such as Imperial College London, Oxford University, Cornell University and various universities in mainland Europe. We saw that the interdisciplinary character of coalgebra has led to applications in many different fields. But admittedly, the use of coalgebra in theoretical computer science is the most important. For co-promotor Marcello Bonsangue and myself, the cum laude dissertation by Alexandra Silva on Kleene coalgebra was a milestone in 2010. How often do you hear a renowned scientist like Dexter Kozen from Cornell University say that one only encounters few works of this stature in one's lifetime? I see this also as a reward for CWI, which, apart from a useful emphasis on societal relevance, also leaves room for our kind of very fundamental research."

Energy at CWI:
Advanced calculation for a sustainable future

It is no secret that oil and gas supplies will run out during our 21st century. One of the biggest challenges at hand is therefore the paradigm shift to a sustainable energy supply by for instance sun, wind and nuclear fusion. These challenges have large mathematics and computer science components. This explains why CWI scientists are very active in contributing to solutions for this societal problem.

Our entire Western economy is driven by supply and demand. However, sustainable energy sources like sun and wind don't obey demand. Their energy yield varies and is supply-driven. This phenomenon complicates the energy supply chain and asks for smart energy grids, adapted to bi-directional energy transport. CWI has several research projects on energy, such as Computational Capacity Planning of Electricity Networks (CoCaPlan), IDeaNeD – for decentralized control in energy systems – and Computational Energy Systems (CES).

Energy auctions

A software regulated auction system could contribute to solving the problem of varying power supply. It could reconcile supply and demand through autonomous consumer choice, for instance with 'price blocks' per half hour. Such a system with constantly fluctuating price levels becomes increasingly relevant. Consumers get more appliances, like electrical cars, with an energy consumption that can be planned in time. The car owner buys electricity when the price is right. He doesn't do that by himself, but through decentralized software like intelligent software agents that can take decisions by themselves. The software acts within the price, comfort and time limits set by the consumer. This may sound simple, but the interconnected subjects of economy, informatics and grid capacity are highly complicated. One of these subjects concerns the stability and reliability of the software, which must be fully guaranteed. Another subject concerns the capacity of the network: should everybody use the same software that makes the same decisions at the same time, they would all start charging their car battery at 20:00 hours. This would be the opposite of the desired stable spread in supply and demand; it would challenge the capacity of the network. The CWI CES projects looks into this.

Adaptation

One solution would be not to offer total supply in one sequence of half an hour blocks, but to hold several parallel auctions with a slightly shifted starting time.
A crucial task within the CES project therefore lies in developing technology for optimized software agents within the boundaries set by agent systems, market mechanisms and game theory. In order to keep a sound planning and bidding conduct, these agents should be adaptive. They should not only be driven by hard 'if this, than that' decisions, but be empowered to adapt their software autonomously to rapidly react to changing market conditions or user data. This adaptive agent asks for the keen algorithms with computational intelligence on top that CWI now develops.

Nuclear fusion

Apart from sun and wind there is another energy source with virtually no raw material costs, no CO_2 emission and only minor nuclear waste problems. It is nuclear fusion, the process that takes place in the core of the sun. The experimental nuclear fusion reactor ITER in the South of France is expected to be operational by 2025. It will be the first fusion reactor to generate more energy than goes into it. 'Key to the reaction process is a plasma of 150 million degrees Celsius with as many deuterium and tritium atomic nuclei as possible. Numerical mathematics and simulation are needed to explain the behaviour of this plasma, which has the tendency to start vibrating unstably, causing damage and system downtime.'

Sensible thrift

The first step is an analysis of the influence of parameter variation in the plasma, as done by the French mathematician and 2010 Fields Medal recipient Cédric Villani.
This is input for the CWI task of detailed computations of plasma changes over time, representing the 'computational heart' of the project. It involves a combination of two 19th century mathematics classics: Maxwell's equations and the Navier-Stokes equations.

The 21st century translation of these equations into state-of-the-art computational magnetohydrodynamics involves challenging new mathematics and also informatics. The problem is multiscale, as the phenomena to be studied vary over wide ranges in both space and time: from several meters to micrometers or smaller and from several minutes to fractions of seconds. This whole variation has to be carefully simulated.
The entire space inside the reactor is represented by a grid of 3D, non-overlapping, small cells. Per cell, single starting values are set for temperature, density and the separate components of the velocity and magnetic field. These starting values will in general differ from cell to cell. With these values in all cells known, it is possible to estimate their influence on neighbouring cells.
Locations with large gradients are interesting. They are selected for locally refining the grid by dividing the local space there into more cells. This is no trivial job, as over-refining may cost loads and loads of extra computing time, whereas under-refining

carries the risks of missing the point. It all boils down to sensible thrift with the grid, to reach a good trade-off between detail and efficiency in the approximate spatial representation of the plasma.

To the limit

Computing the temporal variation of the plasma requires the computation of the ingoing and outgoing mass, momentum, energy and magnetism over all cell faces, leading to updated values of these quantities for each cell.
The update requires a series of small steps in time, minor time laps in order to guarantee the real-life and real-time fraction-of-a-second vibration phenomena not to be missed. The whole simulation should eventually represent a much longer period though, in order to understand phenomena that last for minutes. This gives a hint of the amount of calculations that is needed to carry out this task: mathematics at an enormous computing-intensive scale.
CWI invents and develops the computing heart and tests it to its limits with experimental data from the Joint European Tokamak (JET) reactor in England. To further prove the reliability of the simulation outcomes, where possible, rigorous mathematical analyses are carried out. If this finally leads to a 'quality stamp', in the form of articles in leading international scientific journals and PhD theses, the task of CWI is done.

"One of the fascinations of working on nuclear fusion is the elegance of the concept, running on water and rock only."

Prof. dr. ir. Han La Poutré is group leader Multi-agent and Adaptive Computation. He works at CWI since 1997.

"The technology of agent systems and decentralized IT has an excellent fit to the electricity world. This is cause for professional satisfaction. Even more important is the societal relevance of

this research. Supply and demand problems have to be solved to give sustainable energy sources the market share they deserve. The attention from the energy market is a proof of the commercial relevance of this research."

Prof. dr. ir. Barry Koren is leader of the research cluster Modelling, Analysis and Computing (MAC). He works at CWI since 1987.

"One of the fascinations of working on nuclear fusion is the elegance of the concept, running on water and rock only. For a small country it is a challenge to contribute to a project in which so many countries participate. The math is cutting edge. It is numerical simulation taken to extremes."

The two-way street between computer science and IT practice

Modern society depends on advanced data management. Organizations now base their operational decisions on analysis of the vast amounts of data they have been collecting. This is known as data warehousing and business intelligence (BI). The phenomenon has permeated many areas, including transportation, healthcare and even science itself. As data collections grow, demand for fast data search as a key to insight and efficiency increases. CWI spin-off VectorWise applies vectorized database search to make full use of the speed and capacity of present computer technology. Spin-off Spinque makes it easy for organizations to create their own tailor-made, domain-specific search engine. CWI benefits from the spin-off activities as well: they lead to many new academic collaborations, thus increasing the quality and quantity of the CWI research output.

One of the areas of expertise of the database group of CWI is the interaction of database algorithms and modern hardware. Modern computer processors (CPUs) have become very fast thanks to parallel computation, by offering multiple processing 'cores' on one chip, but also through parallelism within a single core. Whereas in the past a core would execute one machine instruction at-a-time, modern cores can execute many instructions simultaneously. Regrettably, current database systems cannot exploit these capabilities of modern hardware well, as they work on one record at a time, which prevents them from profiting fully from parallelism. CWI scientists have now invented methods that allow complex database operations to be expressed fully in vector operations. This allows to calculate query results for thousands of records simultaneously, and makes database query processing much akin to scientific computations, where this principle was more easily applicable. The new method therefore allows database queries to run much faster on common modern hardware.

Market success

CWI has put a lot of effort into this line of research, which first became known for the work on its open-source database system MonetDB. This was recognized in 2009 by the scientific community through the prestigious VLDB 10-year Best Paper Award. The follow-on vectorized database research had by that time already led to spinning off VectorWise in 2008. From the start VectorWise has been working with long-time US database company Ingres, in order to integrate its techniques into the Ingres database system. This resulted mid-2010 in the launch of Ingres VectorWise, a database product aimed at business intelligence. It provides very high query performance, recently giving Ingres the lead in the TPC-H data warehousing industry benchmark. The successful market introduction convinced Ingres to fully acquire VectorWise and its technology at the end of 2010. CWI profits from the success of VectorWise as well: it has led to new collaborations with scientists in the US, Germany, Switzerland, Scotland and Spain.

Combined search

In the meantime, database technology led to another CWI spin-off in 2010. The rise of the Semantic Web – a 'web of data' that enables machines to

understand the semantics, or meaning, of information on the World Wide Web – is driven by the assumption that searching would become better and easier once more enriched information is available. A lot of organisations started to enrich their data with annotations, only to find out that it is actually far from trivial to realize a consistently better search process using this additional structure in annotated data; especially when the original unstructured data remains important. Organizations with large data collections like multi-nationals or patent offices would therefore welcome better means of combined searching in structured as well as unstructured information. During a research project CWI developed a search engine on behalf of an Austrian party owning a patent corpus. Reactions were enthusiastic, but unfortunately the company went out of business. The search engine under construction was aimed at performing combined searches in databases as well as full texts; it was able to handle enriched information as well as 'flat' information. As this possibility is interesting to all organisations with professional search activities, it was decided to proceed with product development anyway. This led to the start of Spinque.

Two stage searching

The Spinque toolset enables to specify tasks involving search, for instance 'list patents on topic X assigned to competitors Y, and explore the results'. Once satisfied with the results of such a *search strategy*, the smart part comes: a second stage. The user can instruct Spinque to generate a tailor-made search engine to support the task. The number of possible search engines is infinite, thanks to what happens 'under the bonnet'. Spinque stands out as the first search toolset to use a probabilistic database as core engine: an extension to standard relational databases, adding a score to every element in the database representing a chance. This database ability to handle chance provides the toolset its versatility and flexibility.

The field of application is wide. Apart from a toolset for search professionals, Spinque can also be used as a dedicated search engine connected to a website or family of websites. At the moment Spinque is at the verge of a breakthrough with several customers. The performance during the 2010 PatOlympics has helped in this respect. PatOlympics is the international competition for

search in patent literature. The goal is to find the highest number of relevant patents. Spinque's two-stage approach proved its value here. One 'fixed' search engine initially seemed better than Spinque. But when the Spinque possibility of on-the-fly-search-engine-adaptation came in, competitors were crushed. Spinque eventually found five times as many relevant patents as the number two.

Prof. dr. Arjen de Vries, at CWI since 1999, now group leader Interactive Information Access and CEO of Spinque B.V.: "Helping to solve the prospect's bottle necks".

"I like the idea of running my own business together with colleagues. In your work as a scientist you are fenced off from all sorts of supporting tasks like contracts or taxes. Now you have to do these varied activities yourself and I enjoy that. Furthermore, the Spinque environment is not exactly a product to be explained during a thirty second elevator pitch. A pitch also asks for sensitivity, because you ask your counterpart to say goodbye to his present in-house search technology. It is a nice challenge to convince prospects that the added value is high enough to do so."

Dr. Peter Boncz, at CWI since 2002, researcher in database architectures and founding father of VectorWise B.V.: "Spin-off activity has increased the quantity and quality of science".

"The great appeal of computer science is that high-quality foundational research has very often an immediate relevance in practice. In the database field, having shown the value of vectorized query processing in the market, boosts the credibility and stature of our publications. The fact that we have working technology has also led to many new academic collaborations. Scientists in Yale, Tübingen, Zurich, Edinburgh and Barcelona use the software for further research in collaboration with CWI. While some people may fear that spin-off activities come at the expense of science, in the case of VectorWise it has actually increased the quality and quantity of our research output."

Societal and scientific relevance

CWI concentrates on fundamental questions that are inspired by practical problems. Very important is the transfer of knowledge to society. This knowledge is of very high quality as is shown in this section, by means of a number of major achievements of the institute and its researchers.

Grants

NWO Meervoud Grant for Anne Fey-den Boer

In December, Anne Fey-den Boer (CWI/TUD) received an NWO Meervoud grant for an assistant professor position at Delft University of Technology. The subsidy, granted by the Netherlands Organisation for Scientific Research (NWO), is meant to stimulate the promotion of female postdocs to higher academic positions. It guarantees a permanent position at a university.

Fey has investigated mathematical sandpile models. Although the rules are simple, the wide-ranging behaviour emerging from them is fascinating. They can, for instance, be interpreted as simplified models to investigate neural networks. Another practical application is the modelling of movements in the Earth's crust. Fey will use the grant for her research project 'Sandpile mathematics, Self-organization and Neuronal Networks'. She hopes to extend the mathematical knowledge of these models to make it more applicable to neuroscientific research.

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Vici grant for Peter Grünwald

Peter Grünwald has received a prestigious Vici grant from the Netherlands Organisation for Scientific Research (NWO). With 1.4 million euro he can develop his own line of research and research group in the next five years. Grünwald will use his grant to investigate new methods in statistics and

pattern recognition. Existing statistical methods are built on the assumption that models are correct. Applied scientists often make use of practically useful but incorrect models for their statistical analyses. New methods will provide us with sharper and better conclusions, based on less data. They can be applied in widely different areas including machine learning (self-learning computers), software such as spam filters and for statistics in court.

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Van Dantzig Award for Peter Grünwald and Harry van Zanten

The jury of the prestigious 'Van Dantzigprijs', the highest Dutch award in statistics and operational research, has chosen unanimously to honour two winners: Peter Grünwald (photo: left) (CWI and Leiden University) and Harry van Zanten (photo: right) (Eindhoven University of Technology and EURANDOM). They received the prize at VU University Amsterdam. The award is given every five years to a young researcher who has contributed significantly to developments in statistics and/or operational research. Grünwald is specialized in computer science (or machine learning) and statistics. His new insights add to the synthesis between the Bayesian and frequentist statistics, and to the renewal of 'machine learning' (self-learning software).

More information
http://vvs-or.cpu.nl/

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ERC Starting for provable security against physical attacks

Krzysztof Pietrzak (CWI) was awarded an ERC Starting Grant of 1.1 million euro from the European Research Council for his proposal 'Provable Security for Physical Cryptography'. In this project he will develop methods to design cryptographic schemes which are provably secure against all types of physical attacks, such as side-channel attacks, where an adversary exploits information leakage from the physical implementation of a cryptosystem, e.g. by measuring the power-consumption of a smartcard. Even modern security notions do not take physical attacks into account, and as a consequence many 'provably secure' schemes get broken once an adversary can attack their physical implementation. In the future the 'leakage-resilient' schemes developed in this project can be used on lightweight cryptosystems, such as smart cards, RFID tokens or mobile phones, which are particularly susceptible to physical attacks. The grant, which started November 2010 and runs for five years, pays for two postdoc positions and two PhD students.

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Vidi grant for Roeland Merks

Roeland Merks was awarded a Vidi grant for his research project 'Reconstructing the interactions between cells and extracellular matrix during angiogenesis'. The outgrowth of new blood vessels is a crucial step in, for instance, wound healing and tumour growth. A better understanding of the mechanisms of blood vessel growth will help us to steer and control it better in the future. This requires research not only on the molecular level, but also into the multi-scale interactions between the molecular level, the cellular and the tissue level. Self-organization is an important mechanism:

blood vessel cells coordinate their movements by deforming a surrounding protein network, called the extracellular matrix (ECM), and depositing signalling molecules into it. Merks will develop new numerical techniques to simulate the ECM dynamics and the cell-cell interactions that the ECM coordinates. Merks collaborates with the VU University Medical Center and heads the core modelling group of the Netherlands Consortium for Systems Biology (NCSB).

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Vidi grant for Joost Batenburg

Joost Batenburg received a Vidi grant for his research project 'Quantitative electron tomography by simultaneous parameter estimation and reconstruction'. Electron tomography is a mathematical technique for creating three dimensional images of microscopic objects such as biological cells and nanomaterials. The electron microscope takes several pictures of the specimen, from varying angles. Next, these images are processed in a complex calculation yielding a three dimensional image. In practice, these computed images are often blurred because of a variety of distortions during recording; for example, the specimen may shift during recording.

In his research project Batenburg will develop computational models that are able to determine the distorting influence of these effects and by which three-dimensional images can be made much more accurate. These models will help to create sharp images of nanomaterials. Knowledge of the structure of these materials is essential in developing more efficient solar cells and computer chips.

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NWO TOP grant for Paul Klint

Our society depends on software. A major problem is that the size of software systems is rapidly increasing. As a result software development and maintenance are becoming more and more expensive. CWI started a research project to develop methods that make software smaller. This will lead to a higher productivity and higher software quality. To reduce software size, researchers mine existing software for common concepts and use them to develop domain-specific languages (DSLs). A DSL is a dedicated programming language to solve problems in a clearly delineated domain, such as auditing, databases or forensic investigation. Using DSLs, future software development is expected to be 10 to 50 times faster. The research is conducted by the CWI research group 'Software Analysis and Transformation', headed by Paul Klint. It was made possible by the Top grant program of NWO, which offers top researchers "the opportunity to innovate their lines of research, to create room for groundbreaking science of superb quality".

Rubicon grant for Wouter Koolen

Wouter Koolen received a Rubicon grant for his research project 'Game-Theoretically Optimal Online Learning: From Conflicting Advice to High-Quality Decisions'. The Rubicon program encourages talented researchers to gain experience at a top research institute outside the Netherlands. The focus of Koolen's research is online learning, an emerging discipline on the interface between computer science, information theory and statistics. It concerns recurring decision problems with conflicting expert advice, for instance on stock prices. The new computer programs that Koolen will develop automatically learn to make high-quality decisions. They execute the optimal strategy in which the opinions of all available experts are combined. The computer programs of Koolen also know exactly when to switch between different experts over time. Koolen is going to do his research at the Computer Learning Research Centre at Royal Holloway, University of London, internationally recognized for its research into machine learning problems.

Veni grant for Christian Schaffner

Christian Schaffner has been awarded a Veni grant. He received this grant for his project 'Quantum Cryptography Beyond Key Distribution', which deals with new applications for quantum cryptography (security obtained by quantum computing techniques). It is technically very challenging to store information in quantum particles like photons. Schaffner investigates if he can use this technical difficulty as an advantage in the development of provably secure systems. He studies communication and computations between two parties that do not trust each other, e.g., during a merger of companies or in electronic auctions. The results can be applied to secure identification and e-voting.

Best Paper Awards

Best Presentation Award for Jeroen Hazewinkel

At the annual meeting of the J.M. Burgers Centrum (the Research School for Fluid Dynamics) Jeroen Hazewinkel (photo: 2nd right) has been awarded the first prize for his presentation on tomographical reconstructions of internal water waves (waves under the water surface). Research groups in fluid dynamics from all Dutch Universities presented their most recent research on 13 January at Twente University. The presentation by Jeroen Hazewinkel was awarded because of the scientific relevance of his topic and his appealing performance for a broader audience. Hazewinkel investigates pattern formation of three-dimensional internal water waves. For this research it is required to perform measurements in a fluid without disturbing it. The newly developed tomographic method allows for such measurements and will lead to better understanding of 3D internal wave patterns. Understanding the formation of these patterns could lead to better insight in the underwater wave dynamics in lakes and oceans.

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Best Paper Award for Van Liere, Liu and Martens

Lei Liu, Robert van Liere (CWI and TU/e) and Jean-Bernard Martens (Eindhoven University of Technology) won a Best Paper Award on 21 March for their article 'Revisiting Path Steering for 3D Manipulation Tasks'. The award was presented at the fifth IEEE Symposium on 3D User Interfaces (3DUI 2010) in Waltham, Massachusetts, USA.

The winning paper was chosen out of nine nominations and a total of 60 papers. Liu, Van Liere, and Martens investigated path steering tasks in 3D virtual environment. They showed that apart from path length and path width (the two dominant factors) path curvature and orientation also have significant influences on the path steering time. Results of the research can be used for designing higher level interactive desktop manipulation techniques in Human-Computer Interaction.

More information:
http://conferences.computer.org/3dui/3dui2010/index.html

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Eurocrypt Best Paper Award for Kiltz, Hofheinz, Cash and Peikert
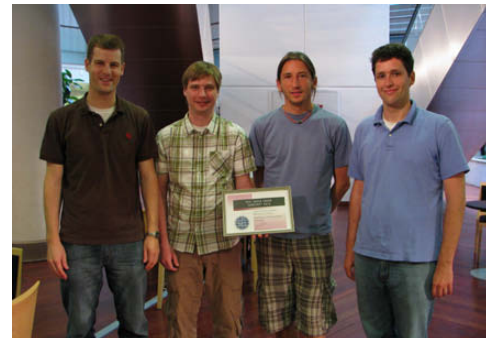
Eike Kiltz (photo: 2nd right) (CWI) received the Best Paper Award from the EuropCrypt 2010 Conference in Monaco and Nice – one of the two premier international conferences in cryptography. He and co-authors Dennis Hofheinz (photo: 2nd left), David Cash (photo: right) and Chris Peikert (photo: left) were honoured for their joint paper 'Bonsai Trees, or How to Delegate a Lattice Basis'. The work deals with lattice-based cryptography, a relatively new kind of cryptography that has the promise of resistance to attacks by quantum computers, unlike almost all other cryptography that is currently used in industry. In a quantum era many communication systems that are, for example, currently used by banks, would be rendered completely insecure and important data such as credit card numbers or PIN codes could be leaked.

Kiltz also presented his award-winning research at the workshop 'Public Key Cryptography and the Geometry of Numbers'. This took place in May at the Royal Netherlands Academy of Arts and Sciences (KNAW) in Amsterdam and was organized by Ronald Cramer (CWI) and David Mandell Freeman (Stanford University, USA).

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Best Paper Award for Peter Bosman

Peter Bosman (CWI) has won a Best Paper Award during the Genetic and Evolutionary Computation Conference 2010 in Portland, Oregon (USA) – one of the most out-standing conferences in Evolutionary Computation. Bosman received the prize for his publication 'The Anticipated Mean Shift and Cluster Registration in Mixture-based EDAs for Multi-Objective Optimiza-tion'. Estimation of Distribution Algorithms (EDAs) are advanced genetic algorithms that are mainly used for general optimization problems. Bosman focused on optimizing multiple, often conflicting objectives at the same time, such as, for example, the costs and quality of a product. Bosman's research is part of the CWI research group Multi-agent and Adaptive Computation (SEN4). EDAs were recently used during the study of adaptive bed planning in hospitals. They will likely be deployed in other projects, for example in research for revenue management and energy systems.

More information:
http://www.sigevo.org/gecco-2010/

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Jarek Byrka wins Lipski Award

Jarek Byrka, who worked in PNA1 (and gave a lecture in September at CWI) won the prestigious Lipski Award. The award is given annually to a Polish computer scientist under the age of 30 'for the best scientific achievements in computer science and its applications'.

More information:
http://nagrodalipskiego.
mimuw.edu.pl/prize.html

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Spinque wins Best Presentation Award at ESAIR 2010

At the Third Workshop on Exploiting Semantic Annotations for Information Retrieval (ESAIR 2010) Arjen de Vries, Wouter Alink, and Roberto Cornacchia from Spinque and CWI have been given the Best Presentation Award for their 'Search by Strategy' presentation and demo. The third ESAIR workshop was held on 30 October in Toronto. Its topic was semantic annotations, which refers to linguistic annotations, user annotations, and other related information added to textual or other objects. Out of seventeen poster presentations Spinque was chosen by the audience, showing the appreciation in the science community of its unique view on search technology. Spinque is a CWI spin-off company. It has been founded by three researchers from the Interactive Information Access research group. Spinque develops search tech-nology for information specialists, combining the key advantages of databases and information retrieval.

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Best Paper Award for Bert Zwart

Bert Zwart (CWI and VU University) has won a Best Paper Award at the Performance 2010 conference in Namur, Belgium, in November. He received the prize for his paper 'Tail-robust scheduling through limited processor sharing', which he wrote with

Jayakrishnan Nair and Adam Wierman from the California Institute of Technology (Caltech), USA. Zwart also gave an invited lecture about 'Fluid and Diffusion Approximations and Bandwidth-Sharing Networks'.

The Performance conference is one of the leading international conferences in the field of Computer Performance, Modelling, Measurements and Evaluation.

More information:
http://performa.ulb.ac.be/

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Best Paper Award Florian Simatos

Florian Simatos has won a Best Paper Award for his paper 'Load Balancing Via Random Local Search in Closed and Open Systems' at the ACM SIGMETRICS conference 2010. In future wireless networks, it is expected that clients will be able to dynamically change the frequency that they use.

Simatos' research is concerned with enhancing the performance of such networks by investigating how clients may share a set of frequency bands in a distributed manner. SIGMETRICS is the flagship conference of the SIGMETRICS community, the ACM Special Interest Group for the computer systems performance evaluation community.

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Breeding ground

Researchers at CWI are able to fully concentrate on their scientific work. More than half of the permanent research staff maintains close contact with universities. The personal and institutional research networks attract talent from all over the world. The metamorphosis of the CWI building facilitates contact between researchers in an energizing and sociable atmosphere. This section highlights the new professorships and PhD degrees of 2010.

Opening

To create more space for researchers, a new wing was added to CWI's building, and the old building was completely renovated. At the opening ceremony for the new wing on 11 November there were speeches by Jan Karel Lenstra (General Director CWI), Peter van Laarhoven (chair of the CWI Governing Board) and Jos Engelen (Chairman NWO), followed by an acrobatic act – symbolizing the beginning and growth of activities in the new wing.

Positions

Guido Schäfer appointed Professor at VU University Amsterdam

On 1 January Guido Schäfer was appointed Professor of Algorithmic Game Theory at the Faculty of Economics and Business Administration at the VU University Amsterdam. Schäfer's research focuses on algorithmic game theory – a rather new and interdisciplinary research field at the intersection of mathematics, computer science and economics. It addresses several real-world phenomena, such as lack of coordination, data uncertainty and limited resources. Examples of application areas are traffic, network routing and auctions. Schäfer's vision is to advance the field of algorithmic game theory by performing frontier research and to demonstrate its societal impact by doing joint research with partners from industry. For four days a week, Schäfer continues his work at CWI in the Algorithms, Combinatorics and Optimization group, where he is one of the coordinators of the algorithmic game theory project.

Joost Batenburg appointed Professor at University of Antwerp, Belgium

On 1 March Joost Batenburg was appointed Professor of Physics at the University of Antwerp. With Jan Sijbers, he co-leads the research group ASTRA (All Scale Tomographic Reconstruction Antwerp), part of the Vision Lab. Batenburg works in Antwerp for one day per week, and at CWI for the remaining days. His research focuses on the development of theory, algorithms and numerical solution techniques for large-scale inverse problems in imaging, an interdisciplinary field with aspects from Mathematics, Computer Science and Physics. By augmenting his CWI research on computational aspects of image reconstruction with expertise in imaging physics from Antwerp, new algorithms developed at CWI can immediately find their way towards various imaging applications in medicine, industry and science.

More information:
http://astra.ua.ac.be

Han La Poutré appointed Professor at Utrecht University

Han La Poutré was appointed Professor of Computer Science at the Faculty of Science of Utrecht University on 1 April, holding a chair in Adaptive Decision Making with Uncertainty. It is a part-time appointment for one day a week. La Poutré's research will focus on decision making in which uncertainty and dynamics play important roles, and where often multiple parties are involved. Application areas include energy networks (smart grids), transportation networks and patient logistics. At CWI, La Poutré is head of the research group Multi-agent and Adaptive Computation. He is a member of several international councils, including the Scientific Directorate of Schloss Dagstuhl – the Leibniz Center for Informatics – and the editorial board of ACM Transactions on Internet Technology. La Poutré was previously Professor at Eindhoven University of Technology.

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Rudesindo Núñez-Queija appointed Professor at University of Amsterdam

On 1 June, Sindo Núñez-Queija was appointed Professor of Industrial Mathematics by special appointment at the Korteweg-de Vries Institute, the mathematical research institute of the University of Amsterdam (UvA), for one day a week. The chair was installed by the Stichting Bèta Plus (Science Plus Foundation). He also remains affiliated as Associate Professor of Operations Research with the UvA Faculty of Economics and Business (since November 2008). At CWI, Núñez-Queija is a researcher in the Probability and Stochastic Networks group.

Núñez Queija's research on mathematical queuing theory focuses on the design, management and analysis of complex computer and communication networks. He previously worked as a researcher at the Institut National de Recherche en Informatique et en Automatique (INRIA) in France. Besides CWI, he has held positions at Eindhoven University of Technology and at TNO Information and Communication Technology. Núñez Queija is associate editor of Mathematical Methods of Operations Research and Performance Evaluation.

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Inaugural lecture Dick Bulterman

Photo by Peter Lowie

On 14 October Dick Bulterman gave his inaugural lecture at VU University, entitled 'Creating, managing and verifying multimedia interactions: the temporal dimension'. Within the current decade, raw video transfer will account for more than 80% of Internet traffic. Watching video will consume a large percentage of our network use, and supporting video will consume a great deal of the physical power required by the Internet infrastructure. What can we do with video to make it more accessible, to make it more social, and to make it a basis for synchronous and asynchronous communication. Bulterman argued that meeting these requirements will require advances in the open processing and structuring of multimedia content. He noted that many current trends in media support are actually impediments rather than catalysts for real progress.

At CWI, Bulterman is leader of the Distributed and Interactive Systems research group.

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Inaugural lecture of Barry Koren

On 22 October Barry Koren gave his inaugural lecture at Leiden University, entitled 'Numerical Mathematics: Science and Tool'. In this lecture, he addressed the history of numerical mathematics and its current research applications.

Numerical analysis is the heart of computer simulation, which latter is of vital importance to today's and tomorrow's society. It enables the simulation of processes, phenomena and systems that cannot be investigated with real experiments, because these are too dangerous, too expensive, unethical or simply technically impossible. The challenge is to ensure that numerical algorithms take full advantage of tomorrow's computers. With the increasing realism in computer simulations, and thus increasing complexity, numerical robustness and efficiency are increasingly important properties. Current research topics of Barry Koren are wind-farm aerodynamics (for wind-energy conversion at the North Sea) and tokamak magnetohydrodynamics (for the International Thermonuclear Experimental Reactor at Cadarache, France).

PhDs

Chris Kruszynski

PhD: 25-01-2010, Eindhoven University of Technology

Interactive Measurements of Three-Dimensional Objects

Supervisor: Prof. dr. ir. R. van Liere
URL: http://www.cwi.nl/2010/1047/inter-active-3D-measurements-of-objects

Joost Geurts

PhD: 03-02-2010, Eindhoven University of Technology

A Document Engineer-ing Model and Processing Framework for Multime-dia Documents

Supervisor: Prof. dr. L. Hardman (CWI/UvA)
Advisor: Dr. J. van Ossenbruggen (CWI)
URL: http://www.cwi.nl/2010/1052/model-developed

Christina Unger

PhD: 10-03-2010, Utrecht University

A computational approach to the syntax of displace-ment and the semantics of scope

Supervisor: Prof. dr. D.J.N. van Eijck (CWI/UU)
Advisor: Prof. dr. E.J. Reuland (UU)
URL: http://igitur-archive.library.uu.nl/dis-sertations/2010-0624-200156/unger.pdf

Willemien Ekkelkamp

PhD: 03-02-2010, Eindhoven University of Technology

On the Amount of Sieving in Factorization Methods

Supervisor: Prof. dr. R. Tijdeman (Leiden Univer-sity), Prof. dr. A.K. Lenstra (EPFL, Switzerland)
Advisor: Dr. ir. H.J.J. te Riele (CWI)
URL: http://oai.cwi.nl/oai/asset/16869/16869A.pdf

Jonathan Zvesper

PhD: 09-03-2010, University of Amsterdam

Playing with Information

Supervisor: Prof. dr. K.R. Apt (CWI/UvA), Prof. dr. J.F.A.K. van Benthem (UvA)
URL: http://www.illc.uva.nl/Publications/Dissertations/DS-2010-02.abstract.txt

Michiel Hildebrand

PhD: 03-04-2010, University of Amsterdam

End-user support for access to heterogeneous linked data

Supervisor: Prof. dr. L. Hardman (CWI/UvA)
Advisor: Prof. dr. A.T. Schreiber (VU), dr. J.R. van Ossenbruggen (CWI)
URL: http://www.cwi.nl/2010/1068/linked-data-EN

Janina Brenner

PhD: 17-05-2010, TU Berlin

Truthful Mechanism Design for Cooperative Cost Sharing and Congestion Games Language

Supervisor: Prof. dr. G. Schäfer (CWI/VU)
URl: http://opus.kobv.de/tuberlin/volltexte/2010/2836/pdf/ brenner_janina.pdf

Anke Hutzschenreuter

PhD: 26-05-2010, Eindhoven University of Technology

A Computational Approach to Patient Flow Logistics in Hospitals

Supervisor: Prof. dr. J.A. La Poutré (CWI/UU)
Advisor: Prof. dr. ir. J. W.M. Bertrand(TU/e), dr. P.A.N. Bosman (CWI)
URL: http://www.aamas-conference.org/Proceedings/aamas08/proceedings /pdf/industrial_application_track/AAMAS08_IndTrack_17.pdf

Svetlana Dubinkina

PhD: 28-05-2010, University of Amsterdam

Statistical Mechanics and Numerical Modelling of Geophysical Fluid Dynamics

Supervisor: Prof. dr. ir. J.E. Frank (CWI/UvA)
Advisor: Prof. dr. J. Verwer (CWI/UvA)
URL: http://www.cwi.nl/2010/1076/Prediction-of-climate-behavior

Stratos Idreos

PhD: 24-06-2010, University of Amsterdam

Database Cracking: Towards Auto-tuning Database Kernels

Supervisor: Prof. dr. M.L Kersten (CWI/UvA)
Advisor: Dr. S. Manegold (CWI)
URl: http://www.cwi.nl/2010/1082/databasecracking

Ying Zhang

PhD: 08-07-2010, University of Amsterdam

XRPC - Efficient Distributed Query Processing on Heterogeneous XQuery Engines

Supervisor: Prof. dr. M.L. Kersten (CWI/UvA)
Advisor: Dr. P.A. Boncz (CWI)
URL: http://www.cwi.nl/2010/1083/Ying_Zhang

Ignacio Cascudo

PhD: 25-07-2010, Universidad de Oviedo

On asymptotically good strongly multiplicative linear secret sharing

Supervisor: Prof. dr. R.J.F. Cramer (CWI/LU)
Advisor: Prof. C. Martinez Lopez (Universidad de Oviedo)
URl: http://www.cwi.nl/2010/1086/Techniques_improve_ performance_secret_sharing_applications

Yanjing Wang

PhD: 21-09-2010,
University of Amsterdam

Epistemic Modelling and Protocol Dynamics

Supervisor: Prof. dr. D.J.N. van Eijck (CWI/UU)
URL: http://www.cwi.nl/node/2926

Tim van Erven

PhD: 23-11-2010,
Leiden University

When Data Compression and Statistics Disagree: Two Frequentist Challenges for the Minimum Description Length Principle

Supervisor: Prof. dr. P.D. Grünwald (CWI/LU)
URl: http://www.cwi.nl/news/2010/statistical-methods-improved-data-compression-techniques

Alia Amin

PhD: 08-12-2010,
University of Amsterdam

Understanding and Supporting Information Seeking Tasks among Multiple Sources

Supervisor: Prof. dr. L. Hardman (CWI/UvA)
URl: http://www.cwi.nl/news/2010/novel-interfaces-support-complex-search-tasks-across-multiple-sources

Fang Fang

PhD: 08-12-2010, Delft
University of Technology

The COS method: An efficient Fourier method for pricing financial derivatives

Supervisor: Prof. dr. ir. C.W. Oosterlee (CWI/TU Delft)
URl: http://cermics.enpc.fr/cnf/Fang.pdf

Andreas Grüner

PhD: 10-12-2010, Leiden
University

Testing Object Interaction

Thesis cover

Supervisor: Prof. dr. F.S. de Boer (CWI/LU)
Advisor: Prof. dr. M.M. Bonsangue (LU)
URL: http://www.informatik.uni-kiel.de/~ang/

David Costa

PhD: 13-12-2010,
VU University

Formal Models for Component Connectors

Supervisor: Prof. dr. J.J.M.M. Rutten (CWI/VU/RUN)
Advisor: Prof. dr. F. Arbab (CWI/LU), Dr. M. Niqui (CWI), Dr. D.G. Clarke (Katholieke Universiteit Leuven)
URL: http://www.cwi.nl/news/2011/research-guarantees-proper-integration-of-software-components

MohammadMahdi Jaghouri

PhD: 20-12-2010,
Leiden University

**Time At Your Service:
Schedulability Analysis of
Real-Time and Distributed
Services**

Supervisor: Prof. dr. F.S. de Boer (CWI/LU)
URL: http://homepages.cwi.
nl/~jaghouri/Files/PhDthesis.pdf

Alexandra Silva

PhD: 21-12-2010, Radboud
University Nijmegen

Kleene coalgebra

Supervisor: Prof. dr. J.J.M.M. Rutten (CWI/VU/RUN)
Advisor: Prof. dr. M.M. Bonsangue (LU)
URI: http://www.cwi.nl/news/2011/cum-laude-
thesis-kleene-coalgebra-improve-software-quality

Transfer to Society

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

In the media

In 2010 CWI issued almost fifty press releases about its researchers and gathered a wide range of media coverage, from daily newspapers to technical trade publications.
Some highlights: The new factorization record, which demonstrated the vulnerability of 768-bit RSA keys for internet security, gained national media exposure in newspapers *NRC Handelsblad* and *NRC Next*, and in numerous technical publications.

The research on building the digital infrastructure for a virtual observatory to detect forest fires was featured by *De Telegraaf* and on prime time at TROS Nieuwsshow on national radio. *NRC Handelsblad* also featured the developments on energy, covering an interview with Han La Poutré on smart grids. CWI software engineering researchers and audit experts joint forces to combat fraud; this news was published in *Automatisering Gids*, *Computable* and various accountancy publications. Paul Klint was also interviewed by radio BNR

Denktank! on investing in a new supercomputer or not.
Finally, CWI organized the meeting 'Mathematics and Industry 2010', which resulted in two radio interviews at Hoe?Zo! Radio with Rob van der Mei about mathematical solutions to questions from industry. During this event, the mathematicians shared their experiences in a blog.

CWI organizer of 72nd Study Group Mathematics with Industry

From 25–29 January seventy mathematicians from all over the world gathered at CWI for the 72th annual Study Group Mathematics with Industry. During a week they worked on solving five problems from various businesses. These problems were: design an optimization algorithm to keep a ship at sea fixed in place (Maritime Research Institute Netherlands MARIN), how many solar panels can neighbours install before causing a power outage (KEMA), model the flow of poultry through a meat processing unit (Stork Food Systems), optimize algae growth for the removal of fertilizer from greenhouse run-off (Phytocare), and compute the absolute positions of terminals like PDAs in an indoors navigation system, given a few absolute and many relative positions (European Space Agency – ESA).

As a remarkable result, the mathematicians developed a new model that figured out the maximum amount of energy an average household could produce, using alternative energy sources. They also solved the other problems.

More information:
http://swi2010.cwi.nl/

Catching digital butterflies Catching digital butterflies – IT Project for pupils

Pupils from three Amsterdam high schools worked on the 'Large Computer Science Project' in their final year. Expert jury members Harry Buhrman (CWI and UvA) and Paul Klint (CWI and UvA) assessed the results on 19 April, mainly looking at the presentation and originality of the projects. "We were very impressed with the quality and creativity," says Buhrman. Winners were Saskia Ebing and Mees de Vries of the Sint Ignatius Gymnasium. They made the 'The Catchgame' for a Multitouch table – a table with a large touchscreen. The game involves two teams digitally capturing butterflies and bees. Buhrman: "They made innovative use of this new multi-touch technology, with all its difficulties". For this project the pupils learned a new programming language and programmed a flash game.

More information:
http://www.itsacademy.nl/download/nieuwsbrief_mei_2010.pdf
http://www.studeren.uva.nl/beta-bachelors/scholierensite.cfm/27882A6B-31AA-4CFC-8426CB14A0976EBD

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Famous cryptographer Ron Rivest lectured at CWI

On 4 May, Ron Rivest, one of the foremost cryptographers in the world, gave a lecture on the 'Security of Voting Systems'. Rivest, also known as the 'R' from the famous RSA public-key cryptosystem, discussed recent trends in the reliability of voting systems and new approaches, including some based on cryptography. According to Rivest, these new developments help to resolve problems and conflicts inherent to voting processes.

Rivest is Professor of Computer Science at the Massachusetts Institute of Technology (MIT, USA). One of his research highlights is the design of the RSA public-key cryptosystem, which he invented in the 1970s together with Adi Shamir and Len Adleman. They have been awarded the 2002 ACM Turing Award – the 'Nobel Prize in Computing'.

The lecture was organized by Ronald Cramer, leader of the CWI Cryptology group, which focuses on fundamental cryptographic questions from a broad scientific perspective.

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New CWI spin-off: search technology company Spinque

In May CWI researchers Arjen de Vries (photo: 2nd right), Wouter Alink (photo: right) and Roberto Cornacchia (photo: left) established Spinque – a new spin-off company from CWI. Spinque develops search technology for information specialists, combining the key advantages of databases and information retrieval. It introduces a novel approach to search, 'Search by Strategy'. This allows users to search through multiples sources simultaneously, irrespective of size, and to easily determine connections between different types of information. With success: during the PatOlympics 2010, an international competition between researchers, Spinque received the highest award in the category 'Cross-Lingual Retrieving'.

The establishment of spin-off companies is an important instrument for CWI to transfer

technology and knowledge to society and industry. Spinque has developed search technology in the area of scalability, quality and stability while its commercial activities raise new fundamental questions that can be addressed by CWI.

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DisCoTec at CWI

The Foundations of Software Engineering group, headed by Frank de Boer, organized this year's DisCoTec – the 5th International Federated Conferences on Distributed Computing Techniques. This year the main conferences took place at CWI from 7–9 June.

Some highlights: The first day Joe Armstrong (Ericsson Telecom AB) gave a keynote speech on Erlang-style concurrency. The second day Gerard Holzmann (Jet Propulsion Laboratory, USA) discussed the question: "Formal Software Verification: how close are we?". The third and last day Joost Roelands (Director of Development Netlog) presented the problem area of distributed social data. Lucca Cardelli (Microsoft Research Cambridge, UK) was a keynote speaker during the CS2Bio'10 workshop that was affiliated with DisCoTec.

In addition, the program included a joint technical session consisting of one paper from each of the conferences and an industrial session with presentations by Andries Stam (Almende B.V.) and Marcel Verhoef (CHESS), followed by a panel discussion.

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Summer course for mathematics teachers

From 1946 on, CWI has organized informative and inspiring annual summer meetings for mathematics teachers – the 'Vakantiecursus voor Wiskundeleraren' – in cooperation with the Netherlands' society of mathematics teachers (NVvW). The theme of the 64th edition was 'Mathematics: The Challenge' ('Wiskunde: de uitdaging').

The goal of this year's summer course was to make clear that wherever and whatever the problem is, it is almost always a challenge to mathematics. Lectures covered mathematics and statistics in court, forecasting the weather, embarrassing mathematical questions, Diophantine equations, mathematical challenges in industry, internet security, and surprising problems used at contests such as the Mathematics Olympiad.

The course took place in Amsterdam on 27 and 28 August and in Eindhoven on 3 and 4 September. About 135 teachers participated. The summer course is sponsored by NWO, the Netherlands Organisation for Scientific Research. It aims to keep mathematics teachers up to date and to enthuse pupils for mathematics through their teachers.

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Junior Mathematics Olympiad

On 8 October the Dutch Junior Mathematics Olympiad took place at the VU University in Amsterdam. During the kick-off researcher Rob van der Mei (CWI and VU) gave a lecture for 90 young participants and their parents about applications of mathematics in real-life. In March of that year, thousands of students nationwide had participated in the Kangaroo Contest for Mathematics. The 90 pupils with the highest scores were allowed to participate in the Junior Mathematics Olympiad.

After Van der Mei's lecture the contest started, consisting of multiple choice and open questions,

and followed by mathematical workshops. Besides being a contest, the Junior Mathematics Olympiad is also a chance to make acquaintance with fun mathematics and to do own mathematical research.

More information:
http://www.few.vu.nl/nl/voor-het-vwo/docenten/ activiteiten-voor-scholieren/junior_olympiade/index. asp

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October - Open Day at CWI

Science Park Amsterdam opened its doors for the general public on 9 October. This year's theme was 'Long Live Variation', about variation in science.

At CWI three lectures on recent research topics were given: 'Tomography: The World Inside Out' by Joost Batenburg, 'Treasure Hunting in Software' by Paul Klint and 'The Making and Disappearance of Patterns in Ecosystems' by Sjors van der Stelt.

Children could participate in the Pretlab for Girls and the General Pretlab. At CWI, visitors could also enjoy contributions of Vierkant voor Wiskunde (puzzle market and a large maze), and Arabesk (mathematical puzzles).

More information:
http://www.scienceparkamsterdam.nl/nieuws/ open-dag

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Barry Koren at Klokhuis Science Day

On 14 November the popular-scientific tv pro-gramme Klokhuis organized the 'Klokhuis Vragendag' in science center Nemo. During this day children could ask their questions to scientists

– for example: How does a satellite work? Why does a rubber ball bounce? Do twins share the same DNA? Barry Koren from CWI was one of the researchers to answer the childrens' questions.

More information:
http://www.hetklokhuis.nl/algemeen/Vragendag
http://www.e-nemo.nl/?id=1&s=40&d=589

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CWI in Bedrijf on Energy, Mathematics & Computer Science

The conversion and distribution of renewable energy cannot do without mathematics and com-puter science. CWI performs various energy-related research projects, in collaboration with companies and other research institutes on 11 November. Algorithms for simulation and control are being developed, tailored to applications like nuclear fusion, offshore wind farms and smart energy systems.

After a welcome and introduction by Jan Karel Lenstra (CWI) and Barry Koren (CWI), Tony Donné (FOM Rijnhuizen, TU/e) gave a presenta-tion on controlled nuclear fusion, Peter Eecen (ECN) on wind energy, Peter Vaessen (KEMA) on transport and distribution of electrical energy and Rob Aalbers (CPB) on economical aspects of climate change. The meeting was rounded off

with a panel discussion, led by Maria Henneman. Panel members were: Niek Lopes Cardozo (FOM, TU/e), Wim Sinke (ECN, Utrecht University), Sjef Peeraer (SP Innovation, Atoomstroom) and Gijs van Kuik (TU Delft, Duwind).

More information:
http://www.cwi.nl/inbedrijf2010

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Spin-off company VectorWise sold to Ingres Corporation

High-tech spin-off company VectorWise from CWI was sold to Ingres Corporation (USA), a leading open source database management company. VectorWise develops analytical database technology and was founded in 2008 by CWI researchers Peter Boncz, Marcin Zukowski, Sándor Héman and Niels Nes. Ingres has funded the spin-off company since its inception.

VectorWise is based on scientific research results and derives its strength from a completely new approach on data processing, making use of vector processing, tailored to modern processors. Possible applications areas include businesses, logistics, science, medicine and healthcare, all depending on the analysis of very large data volumes.

The research behind VectorWise stems from earlier work at CWI on its open-source database system MonetDB, which is being used worldwide. Vector-Wise is a good example of a CWI spin-off that has successfully transferred scientific knowledge to the market and that, in return, has raised new fundamental scientific questions.

Briefly after this, Ingres VectorWise made waves in the data warehousing market by capturing a decisive lead in the TPC-H industry benchmark.

More information:
http://www.cwi.nl/news/2011/cwi-spin-company-vectorwise-sold-ingres-corporation
http://www.ingres.com/products/vectorwise

Leading role

CWI aims at playing a leading role in setting the national research agendas in mathematics and computer sciences. Together with other top institutions such as INRIA (France) and the Max Planck Institute (Germany) CWI forms the backbone of European research in mathematics and computer science. Some of the results are highlighted in this section.

New factorization record demonstrates vulnerability cryptographic keys

In January CWI researchers – together with partners from Germany (BSI and Bonn University), France (INRIA Nancy), Japan (NTT) and Switzerland (EPFL) – broke a 768-bit RSA key by finding its prime factors. To achieve this, they used advanced mathematics and a vast amount of computing power. In a distributed computing project thousands of CPUs were deployed during 2.5 years. RSA keys (named after inventors Rivest, Shamir and Adleman) are commonly used to exchange confidential data and sign electronic documents on the internet. The new record demonstrated the vulnerability of 768-bit RSA keys and underlined the importance to phase out the usage of 1024-bit RSA keys in the next decade.

CWI has a long tradition in large computing projects. In 1999 it played a major role in breaking the first 512-bit RSA key and in 2008 the MD5 internet security system was broken, demonstrating the vulnerability in the infrastructure of digital certificates. This research helps making the internet safer.

More information:
Technical summary: http://documents.epfl.ch/users/l/le/lenstra/public/papers/rsa768.txt
Preprint paper: http://eprint.iacr.org/2010/006.pdf
Press release: http://www.cwi.nl/node/2152

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Workshop on side-channel attacks

Side-channel attacks – attacks that use physical leakages to break the security of electronic devices like smart cards or RFID chips – are becoming a major problem. For instance, by measuring the power consumption or electromagnetic radiation, criminals might extract information from banking cards and electronic car keys.

For a long time, side-channel attacks were seen as a practical problem. However, recently new cryptographic principles were discovered against all known or unknown side-channel attacks, making only minimal assumptions on the hardware.

In February, cryptographers and hardware engineers gathered at the workshop 'Provable Security against Physical Attacks' to develop new methods and tools. CWI, Leiden University, MIT, the K.U. Leuven and ENS Paris organized this event at the Lorentz Center in Leiden. Scientists from over 40 universities and institutes participated at the workshop, the first in Europe in this format.

More information:
http://www.cwi.nl/2010/1054/side-channel-attacks

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YouTube Movie Room for Women at 'Talent to the Top' Charter

In March, CWI signed 'Talent to the Top' Charter, highlighting the objective of the national task force to increase the number of women in senior positions.

To illustrate this, CWI created the short film 'Room for Women'. In this film four female scientists – Ute Ebert, Lynda Hardman, Martina Chirilus-Bruckner and Sara Ramezani – tell about their lives, research and ambitions, as role models for a new generation of scientific talent. The movie was posted on YouTube and shown at CWI. Guest of honour at the premiere was Constance van Eeden, the first female scientist at

CWI in 1954 and now Honorary Professor at the University of British Columbia.

At present, CWI has 16 percent women in its research staff. CWI implements measurable targets to have more women on top positions. The ambition is to increase the number of women at CWI in 2016 with 30 percent in general.

More information:
http://www.cwi.nl/general/room-for-women
CWI Youtube:
http://www.youtube.com/user/CentrumWI

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Research on efficient use of renewable energy

CWI has started a large multidisciplinary project exploring the efficient use of renewable energy sources. In the project 'Computational Energy Systems', scientists from various disciplines conduct basic fundamental research about our future energy grid. The research project was designed in collaboration with Keuring Elektrotechnische Materialen Arnhem (KEMA). Results can be utilized by governments, policy makers, network providers and energy suppliers.

CWI researchers examine sustainable energy issues in logistics, production, distribution and consumption. They focus on the transition to alternative energy sources, distribution over the electrical network with uncertain decentralized supply and storage, the development of smart grids and the degree to which smart buildings can contribute to saving energy.

CWI stimulates collaborations between different disciplines so that knowledge can be widely employed. Broad research as described here is a good example of this.

More information:
http://www.cwi.nl/2010/1074/renewable-energy

CWI Lectures in Mathematics and Computer Science 2010 Data Intensive Research

On 25 June CWI organized its annual CWI Lectures. The keynote speakers gave their vision on Data Intensive Research: Hector Garcia-Molina (Stanford University, USA), Alex Szalay (Johns Hopkins University (USA), Stratos Idreos and Daan Crommelin. Discovery based on data-intensive science is becoming more and more important: A Fourth Paradigm (J.Gray). The data-centric setting requires a new look at computing architectures, algorithms and strategies to exploit the accumulation of data.

During the CWI Lectures, Garcia-Molina discussed the opportunities for large scale text analysis. Szalay gave a lecture on data intensive research in numerical data, such as the Sloane Digital Sky Server – the world's largest database of astronomical data. Idreos and Crommelin showed examples of data intensive research in database architectures and modelling from earth and life sciences. The CWI Lectures were organized by Martin Kersten.

More information:
http://www.cwi.nl/en/lectures2010

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Woudschoten Conference

The Thirty-fifth Woudschoten Conference of the Dutch & Flemish numerical analysis communities was held on 6 8 October in Zeist, The Netherlands. Hundred and fifteen participants attended this annual event, which was organized by the Werkgemeenschap Scientific Computing (WSC). CWI, the Netherlands Organisation for Scientific Research (NWO), Nonlinear Dynamics of Natural Systems

(NDNS+), and the Research Foundation Flanders (FWO-Vlaanderen) supported this meeting.

Themes of the conference were parallel numerical linear algebra and immersed boundary methods and Cartesian grids. Keynote speakers were Patrick Amestoy (Université de Toulouse, France), Peter Arbenz (ETH Zurich, Switzerland), Alex Pothen (Purdue University, USA), Gianluca Iaccarino (Stanford University, USA), Petros Koumoutsakos (ETH Zurich, Switzerland), Rajat Mittal (Johns Hopkins University, Baltimore, USA).

CWI actively contributes to WSC, thereby stimulating young talent and the communication within the research community. Jan Verwer (1946–2011) was chair of the WSC Committee; Margreet Nool is secretary of both the WSC Committee and the Woudschoten Conference Committee.

More information:
http://wsc.project.cwi.nl/woudschoten/2010/conferentieE.php

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Symposium Large-Scale and Uncertain Optimization

In November CWI organized the symposium 'Large-Scale and Uncertain Optimization', in honour of Aharon Ben-Tal, currently visiting CWI as 'Distinguished Scientist'. Ben-Tal is professor and head of the Minerva Optimization Center at the Technion-Israel Institute of Technology. He has developed mathematical methods and computational algorithms to solve optimization problems arising in medical applications and civil and aerospace engineering.

Optimization problems stemming from applications like medical imaging, radiation therapy, machine learning, or shape design of mechanical structures in engineering, pose severe challenges due to the large number of decision variables and the uncertainty affecting the problems' parameters. For instance, in radiotherapy, the actual tumor size and location are uncertain due to slight movements of the patient. Safer and more effective treatment programs can be designed using Robust Optimization, a relatively new methodology which takes uncertainties a-priori into account.
The four speakers at the symposium, Aharon Ben-Tal, Marco Campi (University of Brescia), Dick den Hertog (Tilburg University) and Arkadi Nemirovski (Georgia Institute of Technology), presented state-of-the-art methodologies and computational schemes addressing the above challenges.

CWI Distinguished Scientist

In 2010 the Distinguished Scientist Programme started at CWI. Once a year CWI invites a prominent scientist from abroad as a distinguished guest for a period of three to six months on a basis of 'most expenses paid'. The scientist is honoured with a one-day symposium for a broad scientific audience and is encouraged to give lectures in the Netherlands. The first Distinguished Scientist to visit CWI was Professor Aharon Ben-Tal.

More information:
http://homepages.cwi.nl/~monique/Optimization-Symposium-Day/

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CWI and ERCIM

ERCIM, the European Research Consortium for Informatics and Mathematics, fosters collaboration between researchers in Europe and co-operation with European industry. Members are leading research institutes from nineteen European countries. In November the Board of Directors chose three Vice Presidents: CWI's general director Jan Karel Lenstra, Andreas Rauber (AARIT, Austria) and Keith Jeffery (STFC, United Kingdom). President is Michel Cosnard (INRIA, France).

In 2010 the ERCIM ABCDE project started, supported by the European Commission to co-invest in the ERCIM Alain Bensoussan Fellowship programme. With the subsidy, young talented researchers can extend their fellowship in ERCIM institutes with three months. They will also be trained in a range of non-scientific skills.

Dick Broekhuis from CWI is member of the steering committee.

The ERCIM News magazine published four issues, two of which were co-coordinated by CWI researchers. ERCIM News 81 on 'Computational Science: Simulation & Modelling for Research and Industry' was coordinated by Ulrich Trottenberg (SCAI, Germany) and Han La Poutré (CWI); ERCIM News 82 on 'Computational Biology' was coordinated by Gunnar Klau (CWI) and Jacques Nicolas (INRIA, France).

More information:
http://www.ercim.eu

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W3C and CWI
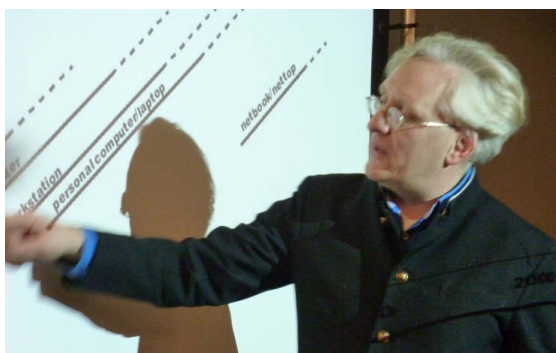
CWI plays an active role in the World Wide Web Consortium (W3C), which develops technologies to lead the Web to its full potential. Several CWI research groups (Distributed and Interactive Systems, Interactive Information Access) actively participate in the W3C Working Groups. Some researchers have special positions within W3C. Ivan Herman is Semantic Web Activity Lead, coordinating all W3C Semantic Web related work world-wide. Steven Pemberton (photo) chaired the

XHTML2 Working Group, and is Forms and HTML Activity Lead.
Ivan Herman organized the RDF Next Steps workshop at Stanford (USA), resulting in a new RDF Working Group. Another major output was the publication of RIF (Rule Interchange Format), as well as the continuing work on RDFa (together with Pemberton), or SPARQL.

W3C Benelux Office

CWI hosts the W3C Benelux Office (W3C-Benelux), the regional contact point for Belgium, the Netherlands and Luxembourg. It is managed by Fons Kuijk and cooperates with the Dutch and Belgium Internet Society (ISOC). On 14 January W3C-Benelux and many ICT-related organizations jointly organized a new year's event at science center NEMO in Amsterdam. In June W3C-Benelux supported the First Amsterdam Semantic Meetup, bridging academic research to business applications. In November the Second Semantic Meetup with the W3C Benelux Office took place, where Ivan Herman presented the newest Semantic Web (SW) technologies.

To improve the quality and accessibility of websites, W3C-Benelux and the Bartiméus Accessibility Foundation coordinated the Dutch translation of the 'Web Content Accessibility Guidelines version 2' (WCAG), which was published in December. Twenty-four organizations participated. A seminar on the translation was organized in Zeist in December. CWI speakers were Steven Pemberton and Fons Kuijk.

Translation: http://www.w3.org/Translations/WCAG20-nl/

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Software Freedom Day 2010

CWI facilitated a Dutch Software Freedom Day 2010, which took place on 17 September at CWI. The goal of this annual day is to educate people on free and Open Source Software (OSS). CWI plays an active role in developing open internet recommendations (W3C), and has since long been involved in the open source community.
The programming language Python created at CWI is a good example. In September, several speakers from international companies, universities and the government gave presentations on open source software.

Speakers from CWI were: Jurgen Vinju on Rascal (a domain specific language for source code analysis and manipulation), Jack Jansen on SMIL (W3C's Synchronized Multimedia Integration Language), Jacco van Ossenbruggen on the MultimediaN Eculture project (providing multimedia access to distributed collections of cultural heritage objects) and Fabian Groffen on MonetDB (an open-source database system for high-performance applications).

More information:
http://www.softwarefreedomday.eu/2010/index.html

Appendices
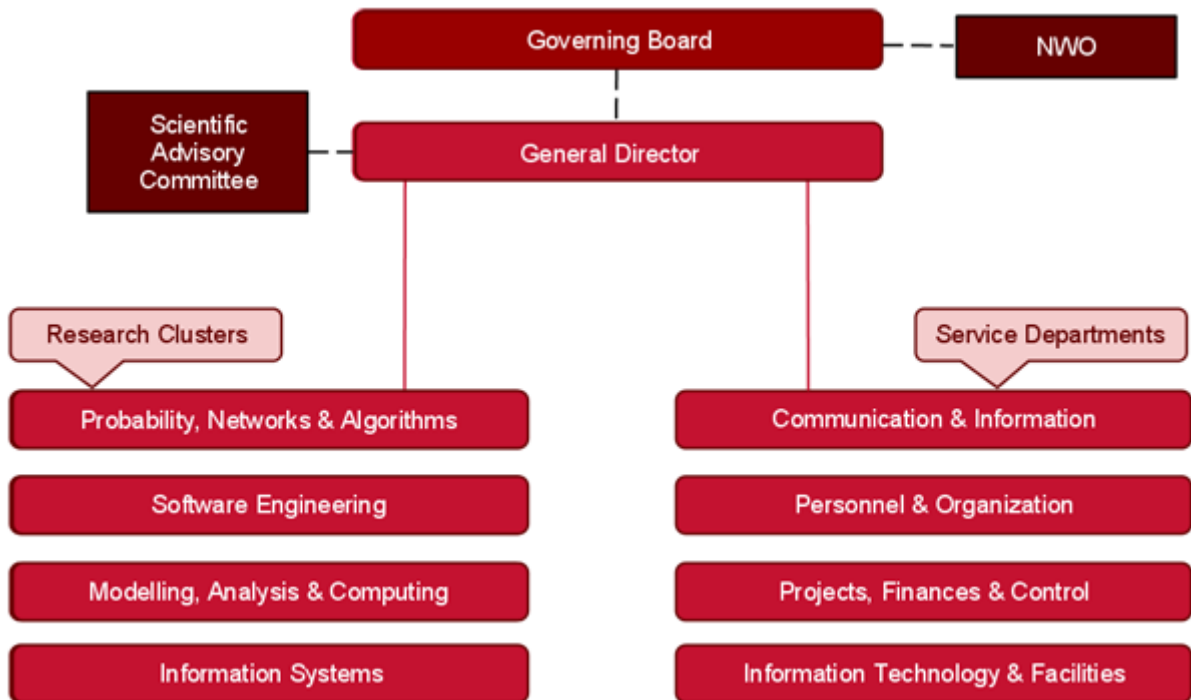
Organization

Research

Cluster	Cluster leader
Group	Group leader

IProbability, Networks and Algorithms — **Rob van der Mei**

Algorithms, Combinatorics and Optimization	Monique Laurent
Probability and Stochastic Networks	Bert Zwart
Cryptology and Information Security	Ronald Cramer
Algorithms and Complexity	Harry Buhrman

Software Engineering — **Paul Klint**

Software Analysis and Transformation	Paul Klint
Foundations of Software Engineerin	Frank de Boer
Multi-agent and Adaptive Computation	Han La Poutré
Distributed and Interactive Systems	Dick Bulterman

Modelling, Analysis and Computing

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

Barry Koren

Jason Frank
Kees Oosterlee
Ute Ebert
Gunnar Klau

Information Systems

Database Architectures
Interactive Information Access
Visualization and 3D Interaction

Martin Kersten

Martin Kersten
Lynda Hardman
Robert van Liere

Management

Management Team

Jan Karel Lenstra (general director)
Dick Broekhuis
Martin Kersten
Paul Klint
Barry Koren
Rob van der Mei
Niels Nes
Angelique Schilder
Marga Sutherland

Governing Board

Peter van Laarhoven (Group Director Strategy TNT), chairman
Anton Franken (Radboud University Nijmegen)
Frank den Hollander (Leiden University)
Joost Kok (Leiden University)
Sylvia Roelofs (ICT~Office)

Research clusters and groups

PNA

Probability, Networks and Algorithms

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

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: *earth and life sciences*, *the data explosion*, *societal logistics* and *software as service*.

Algorithms, Combinatorics and Optimization

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

This group works on developing new algorithmic methods for problems in combinatorics, optimization and algorithmic game theory, motivated by real-world applications like transportation planning, timetabling, scheduling, network routing, traffic control, internet auctions, and social networks. The goal is to design efficient algorithms. This requires understanding and exploiting the mathematical structure of the problem and using tools and methods from various areas of mathematics and computer science, including algebra, geometry, probability, discrete mathematics, game theory, complexity and optimization. The research is relevant the theme *societal logistics*.

Highlights

- Aharon Ben-Tal was guest researcher as Distinguished Scientist.
- Krzysztof Apt edited and contributed to the book *Lectures in Game Theory for Computer Scientists*.
- Fernando de Oliveira Filho was awarded an NWO Rubicon grant for research at the TU Berlin.
- The group has co-organized many workshops, including: Advances on Algorithmic Game Theory and a Symposium day on Large-Scale and Uncertain Optimization at CWI, High Performance Optimization Techniques in Tilburg, Graphs and Metroids in Maastricht, Graph Theory in Oberwolfach and the Oberwolfach Seminar on Semidefinite Programming.

Probability and Stochastic Networks

Group leader: Bert Zwart
Bert.Zwart@cwi.nl

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, queuing theory, stochastic scheduling, spatial stochastics and stochastic geometry. The group is also interested in new research areas of societal relevance, such as revenue management and pricing, ambulance planning, and forensic science.

Highlights

- Florian Simatos and Bert Zwart receive Best Paper Awards at prestigious conferences (Sigmetrics, Performance).

- Bert Zwart was keynote speaker at the Performance conference.
- Rob van der Mei received a grant for the project 'Realization of Reliable and Secure Residential Sensor Platforms.'
- Vladas Sidoravicius was invited to organize an ESF conference and a Clay summer school.

Cryptology and Information Security

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

This group's work on the construction of practical cryptosystems as well as the work on cryptanalysis of popular much used systems 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. In addition, there is special focus on interplays with algebra, number theory, geometry, combinatorics, probability theory, complexity theory, formal methods, quantum physics and information theory, as advances in modern cryptology increasingly rely on deeper understanding of these interplays.

Highlights

- ERC Starting Grant: Krzysztof Pietrzak.
- EUROCRYPT 2010 Best Paper Award won by David Cash, Eike Kiltz, Dennis Hofheinz and Chris Peikert.
- RSA-786 Factored (record).
- Eike Kiltz won the Sofya Kovalevskaya Award from the Alexander von Humboldt Foundation, Germany.

Algorithms and Complexity

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

Our group focuses on quantum computing, learning theory, complexity & information theory and computational biology. We design and analyse new algorithms and communication protocols, study fault tolerance, and develop quantum cryptographic protocols. Our group also works on statistical and machine learning, prediction and model selection. We focus on the realistic situation in which all models are wrong, yet some are useful. Within this context we mainly study information-theoretic approaches such as the Minimum Description Length (MDL) principle. We address the origin of early proteins and the genetic code, researching the robustness and fault tolerance in the genetic code. Application areas include DNA sequences, computation devices and the evolutionary origin of the sleeping sickness parasite. We collaborate with various international experimental groups.

Highlights

- Grunwald obtained a prestigious Vici grant and was awarded the Van Dantzig Prize.
- Buhrman, Cleve, Massar and De Wolf published: *Nonlocality and communication complexity Reviews of Modern Physics 82*, 665–698, 2010.7
- Buhrman, Chandran, Fehr, Gelles, Goyal, Ostrovsky, and Schaffner published: *Position-Based Quantum Cryptography: Impossibility and Constructions* (Plenary talk Quantum Information Processing).
- Buhrman, Regev, Scarpa, and De Wolf: Near-optimal and explicit Bell inequality violations (featured presentation Quantum Information Processing).

SEN

Software Engineering

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

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. Activities fit in the themes *software as service*, *the data explosion* and *societal logistics*.

Software Analysis and Transformation

Cluster 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 analysis and understanding, program refactoring, domain-specific languages (DSLs), and large-scale program transformation.

Highlights

- Cambridge University Press published the book *Computational Semantics with Functional programming* by Van Eijck and Unger.
- New results on ambiguity checking of context-free grammars.
- An NWO TOP grant was awarded to the project 'Domain Specific Languages: A Big Future for Small Programs'.
- The NWO/Jacquard project Next Generation Auditing: Data Assurance as a Service was awarded.

Foundations of Software Engineering

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

This research group develops models, formal methods, and tools for engineering and analysis of software intensive systems, including object oriented and component based systems, compositions of distributed services, and multi-core programming. Developing solid coalgebraic models of computation on which such technology is based is integral to SEN3's approach.

Highlights

- PhD defences: David Costa, Andreas Grüner, Mahdi Jaghoori and Alexandra Silva (cum laude).
- New NWO proposal (Open Competition) Behavioral Differential Equations (Jan Rutten).
- Final review en successful completion EU FP6 project Credo (coordinator: Frank de Boer).
- Final review en successful completion DFG/NWO bilateral project Syanco (coordinator: Farhad Arbab).

Multi-Agent and Adaptive Computation

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

The research focuses on the design and implementation of adaptive solutions for dynamic and decentralized decision making. The group works in the areas of computational intelligence, multi-agent systems, and sensor networks. Application domains include energy networks, transportation logistics, health care logistics, and market simulation.

Highlights:

- A Best Paper Award for Peter Bosman at the Genetic and Evolutionary Computation Conference (GECCO-2010).
- Awarding of four PhD positions on smart energy systems, within the projects Computational Capacity Planning in Electricity Networks (NWO, Smart Energy Systems program) and Computational Energy Systems (NWO Dynamization Program/CWI, and KEMA).
- Han La Poutré was appointed Full Professor at Utrecht University, at the department of Information and Computing
- Start of the project SUPPORT (Supporting and Strengthening Logistic Networks in and around the Rotterdam Port; Agentschap.nl/Pieken in de Delta program.

Distributed and Interactive Systems

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

The group's focus is the study of how users (and user agents) interact in distributed, time-constrained environments. We study: languages for capturing user interaction, languages that contain temporal specifications, network architectures and systems for time-sensitive media delivery and open-source interfaces to (possibly linked) webs of data. Combining both analytic and experimental approaches, the group studies models for interactive media object synthesis based on socially-driven service-oriented architectures and low-level distribution of media content on non-monolithic, distributed rendering architectures. Our application areas include social sharing of multimedia content and the development of frameworks for the semantic web.

Highlights

- Dick Bulterman, Inaugural Lecture at VU University.
- Pablo Cesar, Appointed Member of EU Future Media Internet Architecture Think Tank.

- Dick Bulterman, Distinguished Lecture at KU-Leuven.
- Pablo Cesar, Invited Lecture at MIT Media Lab.

MAC

Modelling, Analysis and Computing

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

The research programme of MAC is based on three mathematical research tracks: (i) scientific computing, (ii) dynamical systems and partial differential equations (PDEs), and (iii) 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, computational tomography, and other industrial and technological fields. Altogether, the research covers all four strategic themes of CWI: *earth and life sciences*, *the data explosion*, *societal logistics* and *software as service*.

Dynamical Systems and Numerical Analysis

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

The group engages in fundamental research on computational, stochastic and analytical methods for continuous dynamical systems (ordinary and partial differential equations). Applied research addresses problems in atmosphere and ocean sciences, phytoplankton dynamics and vegetation patterns, energy technology and electromagnetics. Specific research projects include computational methods for internal waves, statistical accuracy of climate simulations,

stochastic subgrid scale modeling of convection processes, traveling waves and pattern formation, and electrical power network dynamics in the presence of decentralized generation and storage.

Highlights

- Jason Frank was appointed Adjunct Professor of Numerical Analysis and Dynamical Systems at the University of Amsterdam.
- Peter van Heijster was awarded the Stieltjes Prize for best mathematics thesis of 2009.
- Svetlana Dubinkina successfully defended her PhD thesis 'Statistical Mechanics and Numerical Modelling of Geophysical Fluid Dynamics'.
- MAC1 acquired three new projects via: the NWO Open Competition, the internal CWI project competition, and an ERCIM fellowship round.

Scientific Computing and Control Theory

Group leader:
Kees Oosterlee
C.W.Oosterlee@cwi.nl

Scientific Computing relates to the numerical solution of mathematical equations on state-of-the-art hardware. Advanced discretization and solution methods are developed to handle a next generation of applied problems. The emphasis is currently on computational energy systems, with a focus on nonlinear partial differential equations, as well as on economic decision-making and financial engineering, which is at the intersection of numerics and stochastics. Computerized Tomography, in particular the mathematics of inverse problems, has become a research topic with the arrival of Batenburg. Control and System Theory research focuses on fundamental control and realization problems for hybrid systems, rational positive systems, and nonlinear stochastic systems. In addition, research has been done on computational topology for dynamical and hybrid systems. Common research is on the optimal control of dike height to balance the expected cost of flooding and dike increases.

Highlights

- Van Schuppen was appointed CWI Fellow.
- NWO Vidi grant for Batenburg.
- Paper on nano-structures with Batenburg as co-author accepted in Nature.
- Best Poster Awards for Sanderse on wind farm wakes, and Haverkort on instabilities in tokamak plasmas.

Multiscale Modelling and Nonlinear Dynamics

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

The group develops basic methods in nonlinear dynamics, pattern formation, scientific computing, and multiscale modelling and applies them to practical problems. Nonlinear partial differential equations play a central role; methods include numerical analysis and scientific computing as well as model reduction and analysis of coherent structures. The scope is extended to hybrid models coupling stochastic particle and deterministic density approaches and to stochastic differential equations. Most applications are in multiscale plasma modelling: transient discharges in lightning and other atmospheric discharges and closely related phenomena in plasma technology and pulsed electric power, as well as fusion physics. Other applications include population and vegetation dynamics in ecology.

Highlights

- With four papers in geoscientific journals in 2010, the group has further established its geophysical expertise.
- Theory shows that the feathery structure in certain discharges is the signature of single electron stochastics.

Life Sciences

Group leader:
Gunnar Klau
Gunnar.Klau@cwi.nl

The Life Sciences group at CWI performs fundamental research on algorithms, theory, models and simulations to help understand the overwhelming complexity of living systems. Research concentrates on modelling and simulation of biological processes and the analysis of biological data using discrete algorithms and statistical techniques. The group carries out highly interdisciplinary research and therefore maintains strong links to cooperation partners from biology and biomedicine, including the Netherlands Cancer Institute (NKI) and the VU University Medical Center (VUmc) Amsterdam. CWI is also one of the four partners within the Netherlands Institute for Systems Biology (NISB) and hosts the modelling core group of the Netherlands Consortium for Systems Biology (NCSB).

Highlights

- Gunnar Klau co-edited a special issue of ERCIM News on 'Computational Biology'.
- Roeland Merks won a NWO Vidi grant.

INS

Information Systems

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

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*.

Database Architectures

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

The research activities of the group center around the design and development of system architectures, data management algorithms, data structures, and optimization techniques to cope with the data explosion happening in many fields of science, information systems and data warehouses for business intelligence. Innovations at all levels of the software architecture of database management systems (DBMS) are called for to cope with the scalability, performance, extensibility and fault tolerance requirements.

Coordination Languages

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

Dataspaces refer to all information associated with an entity, e.g. a person or an enterprise. Information within a dataspace is scattered, fragmented and administratively controlled by different bodies, but needs to be organized to be delivered succinctly, compactly and informatively to users. The research goal is to advance scientific knowledge on interactive information access to dataspaces, with models, methods and tools focused on discovery, exploitation and human interaction with semi-structured elements. The ultimate goal is to redesign information access tools in a way that users feel that they, rather than the system, are in control of the search process.

Highlights

- The BSIK project MultimediaN E-Culture was brought to a close with the publication of two PhD theses by Michiel Hildebrand and Alia Amin

on providing interactive user support for the exploration of multiple semi-structured information sources.
- Research on high-level support for specifying search strategies resulted in the creation of the spin-off company Spinque.
- An FP7 project Fish4Knowledge was acquired. This will initiate research on interactive search support for biologists exploring a large collection of video of marine ecosystems.

Visualization and 3D Interaction

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

The goal of INS3 is the development of quantitative methods for assessing the quality of interactive data visualizations. Central to the group's vision is the notion of model driven visualization, in which only features of interest are extracted from data and their properties are used for visualization analysis. We apply model driven visualization to research automated template matching methods for cryo-electron microscopy applications and functional data analysis methods for imaging mass spectrometry applications.

Since research in interactive visualization is by definition multidisciplinary, the group combines the development of basic methods of interactive scientific visualization with practical questions in structural biology, e.g. coral morphology from CT data, structural cell biology from CET data, and protein identification from imaging mass spectrometry data. Close collaborations with research groups at FEI Optics, AMOLF and TUE have been established.

Highlights

- Robert van Liere, Lei Liu and Jean-Bernard Martens (TU/e), won a Best Paper Award for their article 'Revisiting Path Steering for 3D Manipulation Tasks' at the fifth IEEE Symposium on 3D User Interfaces (3DUI 2010) in Waltham, Massachusetts, USA.

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

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

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

DISC – Distributed Supervisory Control of Compex Plants
2008–2011
University of Cagliari, Ghent University, 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 University, Joseph Fourier University, Masaryk University, University of Edinburgh
J.H. van Schuppen

EMILI – Emergency Management in Large Infrastructures
2010–2012
Fraunhofer IAIS, Skytec AG, ASIT AG, Aplicaciones en Informática Avanzada, Ludwig- Maximilians-University Munich, Institute Mihailo Pupin
M.L. Kersten

Firesense
2009–2012
Centre for Research and Technology Hellas, Bilkent Universitesi, Ecole Supérieure des Communications de Tunis, Xenics nv, Marac Electronics S.A., Bo aziçi University, Hellenic Ministry of Culture, Titan Bina Elektronik Sistemleri, Teknoloji Sanayi ve Ticaret, Consiglio Nazionale delle Ricerche
E.J.E.M. Pauwels

Fish4Knowledge – Supporting humans in knowledge gathering and question answering w.r.t. marine and environmental monitoring through analysis of multiple video streams
2010–2013
University of Edinburgh, Università di Catania, National Center for High-Performance Computing (Taiwan)
H.L. Hardman

HATS – Highly Adaptable and Trustworthy Software using Formal Methods
2009–2013
Chalmers Tekniska Högskola, Universitetet I Oslo, Kunglia Tekniska, Universodad Politécnica de Madrid, Technische Universität Kaiserslautern, Alma Mater Studiorum, Università di Bologna, Norsk Regnesentral Stiftelse, Fredhopper B.V. Fraunhofer, Katholieke Universiteit Leuven
F.S. de Boer

LOD2 – Creating Knowledge out of Interlinked Data
2010–2014
Inst. für Angewandte Informatik e. V. an der Universität Leipzig, Digital Enterprise Research Institute, Freie Universität Berlin, Openlink Ltd, Semantic Web Company, TenForce, Exalead, Wolters Kluwer Deutschland, Open Knowledge Foundation
P.A. Boncz

PSPC – Provable Security for Physical Cryptography
2010–2015
ERC Advanced Grant
K. Pietrzak

QCS – Quantum Computer Science
2010–2013
Latvijas Universitate, University of Bristol, Université Paris-Sud XI, Tel Aviv University, Université Libre de Bruxelles, Institut de Ciències Fotòniques, Fundació Privada, The Chancellor, Masters and Scholars of the University of Cambridge
H.M. Buhrman

QAP – Qubit Applications
2005–2010
36 Partners from different countries
H.M. Buhrman

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

TELEIOS – Data Management, Integration and Knowledge Discovery for Earth Observation Applications
National and Kapodistrian University of Athens, Fraunhofer Gesellschaft zur Förderung der Angewandten Forschung E.V. Deutsches Zentrum für Luft – und Raumfhart E.V., National Observatory of Athens, Advanced Computer Systems
M.L. Kersten

VITALAS – Video & image Indexing and reTrievAL in the LArge Scale
2007–2010
EADS Defence and Security Systems, Fraunhofer Gesellschaft, INRIA, Fundación Robotiker, Institut National de l'Audiovisuel
A.P. de Vries

EU networks

ECRYPT II
2008–2012
Katholieke Universiteit Leuven, Ecole Normale Supérieure, Ruhr-Universität Bochum, Royal Holloway and Bedford New College, Università degli Studi di Salerno, University of Bristol, France Telecom S.A., IBM Research GMBH, Eindhoven University of Technology, Technische Universität

Graz, Ecole Polytechnique Féderale de Lausanne
R.F.J. Cramer

Life Watch
2008–2011
27 Partners from various countries
E.J.E.M. Pauwels

PASCAL-2 – Pattern Analysis, Statistical Modelling and Computational Learning
2008–2013
Partners from various countries
P.D. Grünwald

PlanetData
2010–2014
University of Innsbruck, École Polytechnique Fédérale de Lausanne, Foundation for Research and Technology Hellas, Freie Universität Berlin, Jozef Stefan Institute, Karlsruhe Institute of Technology, Semantic Technology Institute International, Universidad Politécnica de Madrid
M.L. Kersten

Plantsysmodel – Integrating modelling into plant systems biology: Applications to auxin-driven plant morphogenesis
2008–2011
R.M.H. Merks

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
2007–2012
Vici project
R.J.F. Cramer

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

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

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

CoRE – Coinductive Calculi of Regular Expressions
2010–2015
M. Bonsangue

DIAMANT – Discrete, Interactive & Algorithmic Mathematics, Algebra and Number Theory
2007–2010
Eindhoven University of Technology, Leiden University, Radboud University Nijmegen
A.M.H. Gerards

Dijkstra – Dijkstra's Impact on Design and Verification of Systems and Programs
2010-2015
K.R. Apt

GrammarLab – Foundations for a Grammar Laboratory
2010–2014
P. Klint

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

Inequalities and Random Spatial Processes
2009–2013
J. van den Berg

Influence of a new stochastic convection parameterization on cloud - climate feedbacks
2010–2014
D. T. Crommelin

KISEN – Knowledge and Interaction in Social and Economic Networks
2010–2014
D.J.N. van Eijck

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

MatE – Matroid Structure – for Efficiency
2009–2011
A.M.H. Gerards

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

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

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

NA – Task Coordination for Non-cooperative Agents
2006–2010
Delft University of Technology
J.A. La Poutré

NDNS – Nonlinear Dynamics of Natural Systems
2005–2012
A. Doelman

NGA – Next Generation Auditing: Data-assurance as a Service
PriceWaterhouseCoopers, Belastingdienst
2010-2015
P. Klint

Phase Transitions in Random Nearest Neighbour Graphs
2009–2012
Veni project
T. Müller

Pushing the Factoring Boundary to 768 Bits
2008–2012
H.J.J. te Riele

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
Eindhoven University of Technology
R. van Liere

Querying while Transforming Large Graph Databases
2009–2013
P.A. Boncz

Safe Statistics
2010–2015
VICI-project
P.D. Grünwald

SEGMAO-PMF – Segmentation and motion analysis using polygonal Markov field
2009–2013
M.N.M. van Lieshout

Stochastics cluster STAR
2010–2012
R.D. van der Mei

SYANCO – Synthesis and Analysis of Component Connectors
2006–2010
Rheinische Friedrich-Wilhelms University Bonn, Leiden University
F. Arbab

Talmas – Teaching and Learning in Multi Agent Systems
2009–2013
S.M. Bohte

Thermostat closures for inviscid fluids
2010–2014
J.E. Frank

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

VEMPS – Verification and Epistemics of Multi-party Protocol Security
2006–2010
Eindhoven University of Technology, VU University, Leiden University, Utrecht University
D.J.N. van Eijck

WoMaLaPaDia – Workflow Management for Large Parallel and Distributed Applications
2007–2010
Eindhoven University of Technology
F. Arbab

STW

CleanAir – Transient plasma for air purification
Eindhoven University of Technology
2010–2014
U. Ebert

Revocable Privacy
TNO-ICT, Radboud University Nijmegen, ICTU
2010–2013
R.J.F. Cramer

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

Understanding Lightning: From Terrestrial Gamma-Ray Flashes to Lightning Protection
2010–2014
Eindhoven University of Technology
U. Ebert

Agentschap NL (formerly SenterNovem)

IDeaNeD – Intelligent and local management of networks and data
2009–2012
Alfen B.V., Continuon, Eneco Infra, Eneco NetBeheer, Kema, Phase to Phase, Eindhoven University of Technology
J.A. La Poutré

Power Modulation and Corona-plasma for Environmental Purposes
2007–2010
Eindhoven University of Technology
U. Ebert

RRR – Realization of Reliable and Secure Residential Sensor Platforms
2010–2014
University Twente, ADT Fire & Security, Munisense BV., Stichting Kinderopvang Voorzieningen Goeree Overflakkee, Thales Nederland B.V.
R.D. van der Mei

SEQUAL – Service Optimization and Quality
2008–2012
TNO-ICT, IBM, Ericsson, UT, Mobilaria
R.D. van der Mei

Support – to support and reinforcing logistical networks in and for the Rotterdam port
2010–2013
Almende, APM Terminals BV, Delft University of Technology, De Rijke Trucking BV, Peeman Transport BV, Deal services BV, Hebra Containervervoer BV
J.A. La Poutré

Bsik projects

BioRange – Biomathematics in Mass Spectrometry Based Proteomics and Modelling of Protein Networks
2006–2010
EUR
J.H. van Schuppen

Contract research

Computational Methods for Decision Problems in Economics
Joint operating agreement with CPB
2010–2014
C.W. Oosterlee

Forensic Language Engineering
Joint operating agreement with Netherlands Forensic Institute
2009–2013
P. Klint

Optimal Dike-Height Control
2009–2010
Deltares
B. Koren

Positive Numerical Solution of Differential Equations
Szechneyi Istvan University, University of Massachusetts Darmouth
(KAUST Global Research Programme)
2010–2013
W.H. Hundsdorfer

Research Agreement Rabobank International
2008–2012
Rabobank International
C.W. Oosterlee

Miscellaneous

ABCDE - Alain Bensoussan Career Development Enhancer
Several ERCIM partners (inclusive CWI)
2010–2014
coordinated by ERCIM

Molecular Systems Biology at Science Park Amsterdam
2008–2010
AMOLF, SILS
J.H. van Schuppen

Spinoza Award project
2005–2010
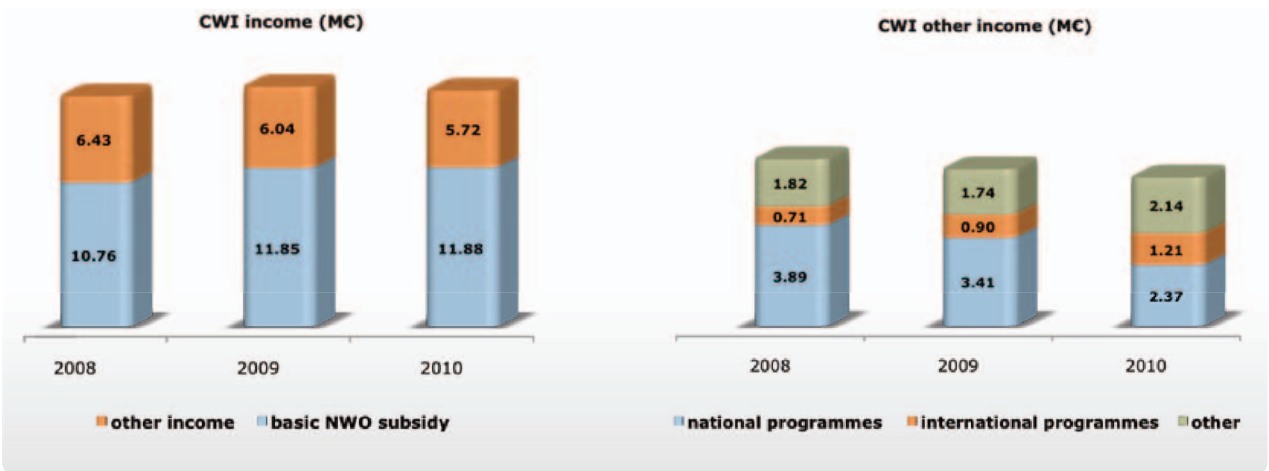A. Schrijver

CWI 2010 Facts & figures

Founded in 1946, Centrum Wiskunde & Informatica (CWI) is the national research institute for mathematics and computer science in the Netherlands. It is located at the Science Park Amsterdam and is part of the Netherlands Organisation for Scientific Research (NWO). The institute is internationally focused and renowned for its high quality research.

Over 150 researchers conduct pioneering research and share their acquired knowledge with society. Thirty-four researchers are also employed as professors at universities. The institute has generated twenty-one spin-off companies.
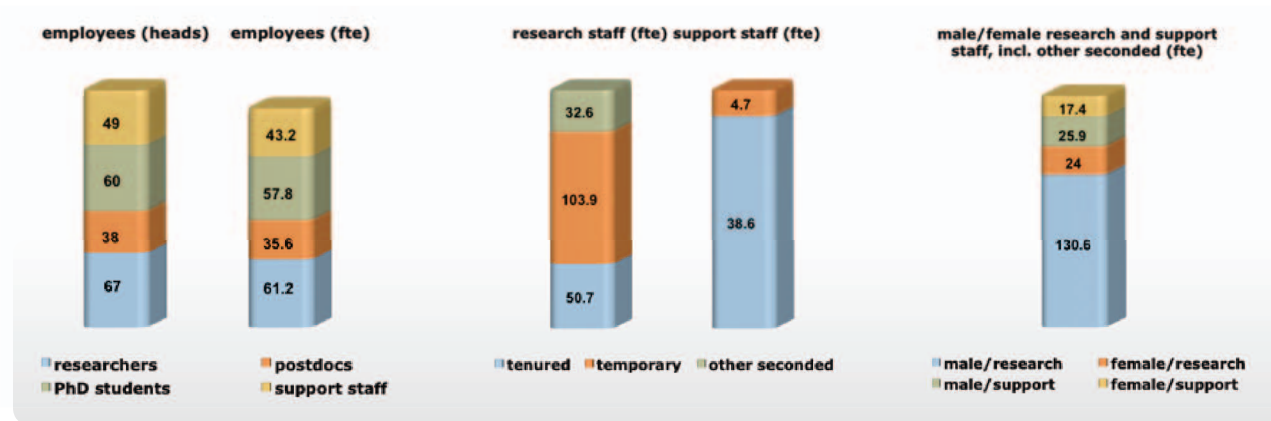
Figures

The figures present a selection of data from the Centrum Wiskunde & Informatica, concerning budget and staff. The reference date is 31 December 2010.

Budget

total income 2010 (%)

12.2
6.9
13.5
67.5

- basic NWO subsidy
- national programmes
- international programmes
- contract research and other

CWI income (MC)

	2008	2009	2010
other income	6.43	6.04	5.72
basic NWO subsidy	10.76	11.85	11.88

- other income
- basic NWO subsidy

CWI other income (MC)

	2008	2009	2010
other	1.82	1.74	2.14
international programmes	0.71	0.90	1.21
national programmes	3.89	3.41	2.37

- national programmes
- international programmes
- other

Staff

employees (heads) — researchers 67, PhD students 38, 60, 49

employees (fte) — 61.2, 35.6, 57.8, 43.2

research staff (fte) — 50.7, 103.9, 32.6

support staff (fte) — 38.6, 4.7

male/female research and support staff, incl. other seconded (fte) — 130.6, 24, 25.9, 17.4

- researchers
- PhD students
- postdocs
- support staff
- tenured
- temporary
- other seconded
- male/research
- male/support
- female/research
- female/support

Total national and international staff

Country	Count	Country	Count
Armenia	1	Italy	2
Austria	1	Latvia	1
Belarus	1	Lithuania	1
Belgium	2	Netherlands	137
Brazil	1	Poland	2
Bulgaria	1	Portugal	2
Canada	1	Russia	3
China	3	Spain	5
France	4	Sri Lanka	1
Germany	18	Czech Republic	1
Greece	4	Switzerland	2
Hungary	1	Turkey	1
India	2	UK	5
Iran	4	USA	5
Israel	1		

CWI