

# Annual Report 2014

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The current debate on public funding of scientific research stresses that research should result in practical applications for society and economy. I believe that fundamental research and practical results are two sides of the same coin. Since our foundation in 1946 CWI has pursued a dual mission of pioneering research and contributions to society. During my career I have seen purely fundamental research lines develop into highly relevant and fashionable applications, sometimes only decades later. Of course, all these years of pioneering research were needed to arrive at these applications, even though we did not always plan these beforehand.

Our task is to develop the research lines of today that could be the answer to the societal challenges of tomorrow. Due to our high flexibility we are able to regularly take on new research fields such as quantum computing, computational biology, bioinformatics, neuroinformatics or computational imaging in recent years. We can only speculate what new applications will arise from these fields, but I do know that they will contribute to future societal challenges.

In 2014, we have been able to add new achievements to our growing list of our contributions to fundamental research and societal relevance. This Annual Report gives a summary of our efforts, and accounts for what we have done with the resources entrusted to us by society and our public and private partners. This document is intended to be browsed in no particular order. In it, you will find four articles where we highlight our research on cloud computing, mapping genome variation, statistical analysis of large data sets and complex networks. In five overviews, we further present a bird's eye view of our work on the research themes Software, Information, Life sciences, Logistics and Energy. These texts are interwoven with snippets of information concerning other events and activities at CWI in 2014 and facts and figures about our institute.

I hope you will enjoy reading and browsing through our Annual Report 2014.

**Jos Baeten**

General director

# About Centrum Wiskunde & Informatica

## Mission

Centrum Wiskunde & Informatica (CWI) is the national research institute for mathematics and computer science in the Netherlands and is part of NWO, the Dutch Science Council. The mission of CWI is to conduct pioneering research in mathematics and computer science, generating new knowledge in these fields and conveying it to trade and industry and society at large.

## Vision

Results of mathematics and computer science are the invisible driving forces behind our economic growth and welfare, and are instrumental to developments in other scientific disciplines. They provide new insights and powerful tools for societal problems in energy, health care, climate, communication, mobility, security and many other domains. As national

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## Research theme

### Software

#### Banking software

Large banks usually maintain an ever growing body of software essential for managing their complex products and services. CWI has started a collaboration with one of the leading banks in the Netherlands to apply domain specific language (DSL) technology to adapt their software to ever changing circumstances, such as new products and new markets, with focus on optimizing of cost-of-ownership and quality-of-service.

#### Error prevention

Writing new features for existing software can easily lead to errors, since the new code interacts in many different places in the software. Code from one feature can silently overwrite that of another one. This causes bugs, leading to later appearance of new software and more costs. To solve this problem, CWI researchers developed the abstract delta modeling technique. The resulting modular software is easy to maintain, and is also suited for multiple software editions. The research results are interesting for software engineers in both academia and the industry.

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platform for mathematics and computer science  
CWI wants to expand its position in safeguarding the interests of these research fields and playing a leadership role in science policy. To achieve this, CWI is in the forefront of developing new lines of long-term research in high risk areas, inspired by problems in society and industry. We also serve as a breeding ground for academic staff and young talented researchers, and give high priority to knowledge transfer. This is not only achieved by scientific publications and public lectures, but also through training PhD students to become high-potential researchers in science and industry, founding spin-off companies, collaboration with private and public partners and making innovative software tools available for researchers, companies and the general public.

## Milestones

CWI has a unique talent pool of researchers. Since its foundation in 1946, more than 190 of its researchers have become **full professor**. In 2014, our researchers included a **Spinoza Prize** winner, 17 researchers with one or more **NWO Innovational Research Grants**, two **KNAW**-members, four members of the **Academia Europaea**, two members of the **Koninklijke Hollandsche Maatschappij der Wetenschappen**, a **SIAM Fellow**, an **AMS Fellow** and two **honorary doctorates**.

CWI has a long-standing tradition of excellence in research that is both fundamental and societally relevant. CWI's track record includes building the **first computer in the Netherlands**, computing the **dike heights for the Dutch Delta Works**, connecting Europe to the **internet**, developing the **Python** programming language, computing the **train timetables for the Dutch Railways**, breaking factorization records of **RSA encryption** for internet security and developing the open source database system **MonetDB**. Recent highlights include analyzing the **Flame** malware, using domain specific programming languages in forensic research, investigating **smart energy networks** and modelling and simulating phenomena such as **lightning, ocean currents, financial products, wind parks, proteins** and **quantum computing**.

CWI plays a central role in various programs and organizations, including the **W3C Benelux Office**, **Platform Wiskunde Nederland**, **EIT ICT Labs**, **ERCIM** and **Informatics Europe**. Since its foundation CWI has commercialized its research in the foundation of **22 spin-off companies** that have generated millions of turnover to date.

## Research theme Software

### Internet security

Digital signatures and other cryptographic standards are crucial for Internet security. They ensure the authenticity of e.g. documents, e-mails, software updates, downloads and payments. CWI investigates a new additional security layer that protects against flaws in widely used standards. By making use of a new counter-cryptanalysis method designed at CWI, it enables the continued use of weak cryptographic standards in a secure way. It detects and counters threats, such as the forged digital signatures found in the Flame super malware. This research is funded by the Veni grant of Marc Stevens.

### OpenDocument Format

The OpenDocument Format (ODF) is increasingly popular as standard for office applications like texts (.odt), presentations (.odp) and spreadsheets (.ods). Several governments have adopted ODF for reasons of cost, system interoperability, software flexibility and promises of document longevity. ODF contains many W3C technologies, several of which CWI contributed to: SMIL, RDFa, XForms, MathML, SVG and parts of XHTML. CWI also hosts the W3C Benelux Office, which welcomed four new Members in 2014: Logius (Dutch Government), CORVE (Flemish Government), standards organization GS1 and Rabobank.

### Code complexity

Cyclomatic complexity, a quantitative measure of source code complexity based on the number of path-splitting choices, was long believed to correlate linearly with the number of lines in the source code (SLOC). After extensive study of large bodies of Java and C source code, CWI software engineering researchers were able to refute this belief. This landmark result shows that cyclomatic complexity should be used alongside SLOC as a measure for code complexity in the daily practice of software quality assessment and bug prediction.

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# Networking for the future

Travelling, shopping in well-supplied stores, using the Internet, a house and office full of electrical devices: virtually everything we do relies on networks. The transportation, traffic, communication and energy networks we developed can rightfully be called the backbone of modern society. The more we rely on these complex networks, the better we need to understand them.

## Networks consortium

No matter how well designed, networks are inherently variable and unpredictable. Understanding how networks can be designed and used more efficiently, and how congestions or even breakdowns can be prevented, is of fundamental importance for the functioning of our society now and in the future. For this reason, the Networks consortium

## cwi in 2014

### Amsterdam Economic Board

In 2014, CWI joined the Network Council of the Amsterdam Economic Board (AEB). The AEB stimulates and supports collaboration, innovation and growth in the Amsterdam Metropolitan Area. The Network Council is formed by managers of the core supporters of the AEB. Together with AEB, VU and UvA, CWI regularly organizes speed-dating sessions for science and industry. Topics of sessions organized in 2014 include technology enhanced learning, security, data science and digital simulation.

## cwi in 2014

### Scientific Advisory Committee

CWI has appointed a new Scientific Advisory Committee (SAC) to advise CWI on strategic questions. The SAC will meet for the first time in 2015. Its new members are:

- Prof.dr.ir. Hans van Duijn (TU Eindhoven)
- Prof. Carole Goble (University of Manchester)
- Prof. Michael Wellman (University of Michigan)
- Dr. Claude Kirchner (Inria)
- Prof.dr. Jürgen Sprekels (Weierstrass Institute)
- Prof. Stefan Vandewalle (University of Leuven)
- Prof. Shafi Goldwasser (MIT CSAIL)
- Dr. Marie-France Sagot (Inria)

## cwi in 2014

### Cooperation with Xinhuanet

At the China Holland Business Summit 2014 in Beijing, CWI and Chinese online news provider Xinhuanet signed a cooperation agreement to develop a user experience research program. CWI will help Xinhuanet to build the first advanced user experience laboratory in China. Both institutions will explore the use of sensor technology to better assess the user experience during media consumption. The Mayor of Amsterdam Van der Laan, who led the trade mission to China, called the cooperation 'a very interesting example of the potential for creative cooperation between the Netherlands and China'.

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was selected at the end of 2013 for a Gravitation grant (see text box) of 22.7 million euros, spread over 10 years, to investigate the challenges posed by large-scale networks. The consortium consists of mathematicians and computer scientists of CWI, University of Amsterdam, Eindhoven University of Technology and Leiden University, and focuses on the modelling, understanding, controlling and optimizing of complex networks, with the ultimate goal to build self-organizing and intelligent networks.

### Graph limits

The programme started mid-way 2014 and aims to build a strong community that positions the Netherlands as the worldwide centre of excellence in networks research. Lex Schrijver, CWI Fellow in the Networks & Optimization group, is one of the eleven core researchers in Networks. “My expertise is in algorithmics and optimization,” says Schrijver. “I have worked for many years on problems that are too large and complex to find an exact solution.”

Large-scale networks are a typical example. For instance, you cannot find the most efficient way to deliver all packages in a city by calculating all possible routes and selecting the shortest. Already for 15

packages there are more than a billion possibilities. Schrijver: “I work on algorithms that approximate the optimal solution for such problems. One approach, which I will further develop in the Networks programme, is that of the graph limit theory. In this theory, you view a large network as a continuous space instead of a discrete set of connected elements. A road is filled with individual cars, but on a network of dense roads it might be more useful to describe traffic as a continuous flow with varying size and speed. In such networks, a random subset can be selected that represents the properties of the entire network, making it easier to make computations on very large networks. The so-called graph limit theory investigates how large a subset you should take to guarantee that it represents the entire network.”

### Quantum networks

A different research line carried out at CWI within the Networks programme is that of quantum networks. Quantum computers are the next generation computing devices based on the laws of quantum mechanics. They can be used to implement quantum algorithms, which are able to perform some computations much faster than classical algorithms. Researcher Harry Buhrman of

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## cwi in 2014

### CWI .nl registrar

In 2014 CWI became a .nl registrar. The move completed the circle connecting SIDN and CWI – the organization that gave birth to the .nl domain. Eighteen years ago in 1996, CWI formally handed over responsibility for administration of the .nl domain to SIDN, the Foundation for Internet Domain Registration in the Netherlands – newly formed to fulfil that role. Eighteen years on, SIDN administers more than five million registered .nl domain names. CWI remains the registrant of the first .nl domain name ever to be registered: cwi.nl.

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## cwi in 2014

### Vision on smart energy

In the European vision document ‘Towards a European Smart Energy System’, researchers Han La Poutré and Felix Claessen from CWI’s Intelligent Systems group addressed the technological requirements for the transition to a sustainable European energy market. The report has been conducted in collaboration with international industry experts, policy makers and scientist with support of EIT ICT Labs. It formulates a joint input to the European goals on ICT and Smart Energy Systems, and for the innovation activities of EIT ICT Labs.

## cwi in 2014

### SEN symposium

In December 2014, CWI hosted the first annual national conference on Software Engineering in the Netherlands (SEN). The conference was visited by 125 researchers and provided an opportunity for students, researchers and engineers to interact. Nine leading software researchers in the Netherlands explained their vision on the future of the field. Forming a strong community increases the visibility and impact of software engineering in the Netherlands. The day was appreciated by the participants and plans are already under development for another SEN symposium in 2015.

## Gravitation programme

With the Gravitation ('Zwaartekracht') programme, the government encourages excellent research in the Netherlands. The programme is for scientific consortia that have the potential to rank among the world's best in their field. The programme is a form of direct government research funding. In the 2013 round, 6 research consortia received a total of 153 million euros. Along with the Networks consortium, grants were awarded to research in microbiology, immunology, climatology, nanotechnology and renewable energy. According to Minister Bussemaker of Education, Culture and Science, "these are scientists that the Netherlands can be proud of and belong to the world top. The teams will put Dutch science on the international map and show that you can realise ground-breaking research that can improve the lives of many people through collaboration at the highest scientific level."

CWI's Algorithms & Complexity group investigates such quantum algorithms: "Where regular bits are either 0 or 1, qubits are 0 and 1 at the same time. A collection of qubits therefore can be in a tremendous amount of states at the same time, as their number grows exponentially. Twenty qubits are already in more than a million states at the same time, two to the power twenty. Algorithms

that exploit this property of qubits can, for certain problems, solve very large instances very fast." Finding such algorithms is however very hard. In the Networks programme, Buhrman will apply the theory of random walks, a powerful algorithm for solving classical network problems, to quantum networks. A proper understanding of quantum random walks might reveal surprising new quantum algorithms and new applications.

### Expertise

The Networks programme is diverse and covers a wide range of fundamental problems and applications bridging mathematics and computer science. Next to graph limits and quantum networks, CWI researchers are also involved in other research lines of the programme, ranging from algorithmic game theory in networks that involve economic decision making to the stability of future energy grids based on renewable energy. The developed knowledge, the scientific experts that will be trained, and the courses developed at universities is expected to make the Netherlands a major international player in the field of network theory and algorithms.

<http://thenetworkcenter.nl/>

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## Research theme

# Information

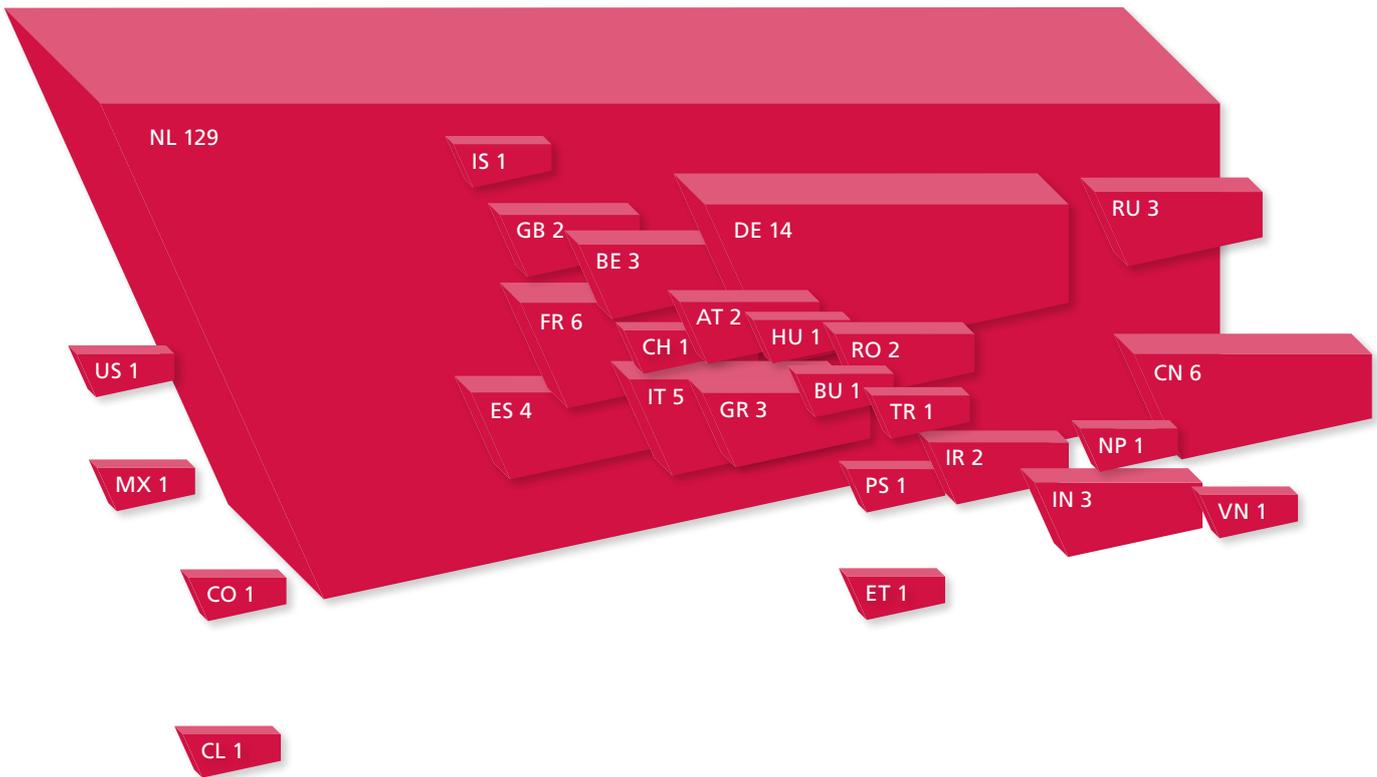
### Distributed theatre

In 2014, CWI contributed to a unique theatre performance. Miracle Theatre from Falmouth (UK) performed a single play of *The Tempest* between two theatres, each with their own audience. Live footage of the venues was combined into a single experience for all audiences. CWI helped developing the technological infrastructure. The main research challenges were seamless integration of live audiovisual footage with minimal delay, and semi-automatic editing of material from various camera angles and microphones into a single experience, simulating the live experience as close as possible.

### Improve industrial processes

LIACS, CWI, database company MonetDB, Tata Steel and BMW have joined forces in a four-year research project that is aimed at developing a new system for controlling and optimizing industrial production processes. The project is part of the NWO Data Science program Challenging Big Data. In this project the Database Architectures research group of CWI will develop new models and technologies to integrate the various data sources, including numerous types of sensors that provide numerical as well as image data, in order to store, process and analyse the data using modern database technology.

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## Research theme Information

### Precision farming

In the European research project Linked Open Earth Observation Data for Precision Farming (LEO), CWI, the University of Athens and industry partners join forces to develop a new application for precision farming. The new application is based on remote sensing and geospatial data that are increasingly made publicly available by organizations such as ESA and NASA. In the project, the CWI researchers combine and convert the various data sources using MonetDB database technology from CWI. This allows the data to be transferred into RDF format and published as Linked Open Data.

### Evaluating search systems

Accurate evaluation metrics are the basis for designing and developing effective search systems. Standard search evaluation metrics do not take into account the complex user interface features of modern search engines. They assume that all users use the search engine the same way and share the same preferences, irrespective of domain or search expertise. CWI investigates an evaluation approach that blends traditional benchmarking with simulations to better capture the variability in user search behaviours. The project is funded by the Veni grant of Jiyin He, awarded in 2014.

### LinkedTV exhibition

At the Ibero American Biennial of Design (BID) in Madrid, CWI researchers Lilia Pérez and Michiel Hildebrand have been awarded an honorary mention in the category Digital Design for the concept and interaction design of LinkedTV News. LinkedTV News is a second screen companion for watching the news based on semantic web technologies. The project was selected out of six hundred submissions and reached the top 5 in its category. LinkedTV News was featured in the international exhibition of the Biennial in Madrid and will further tour in Spain and Latin America throughout 2015 and 2016.

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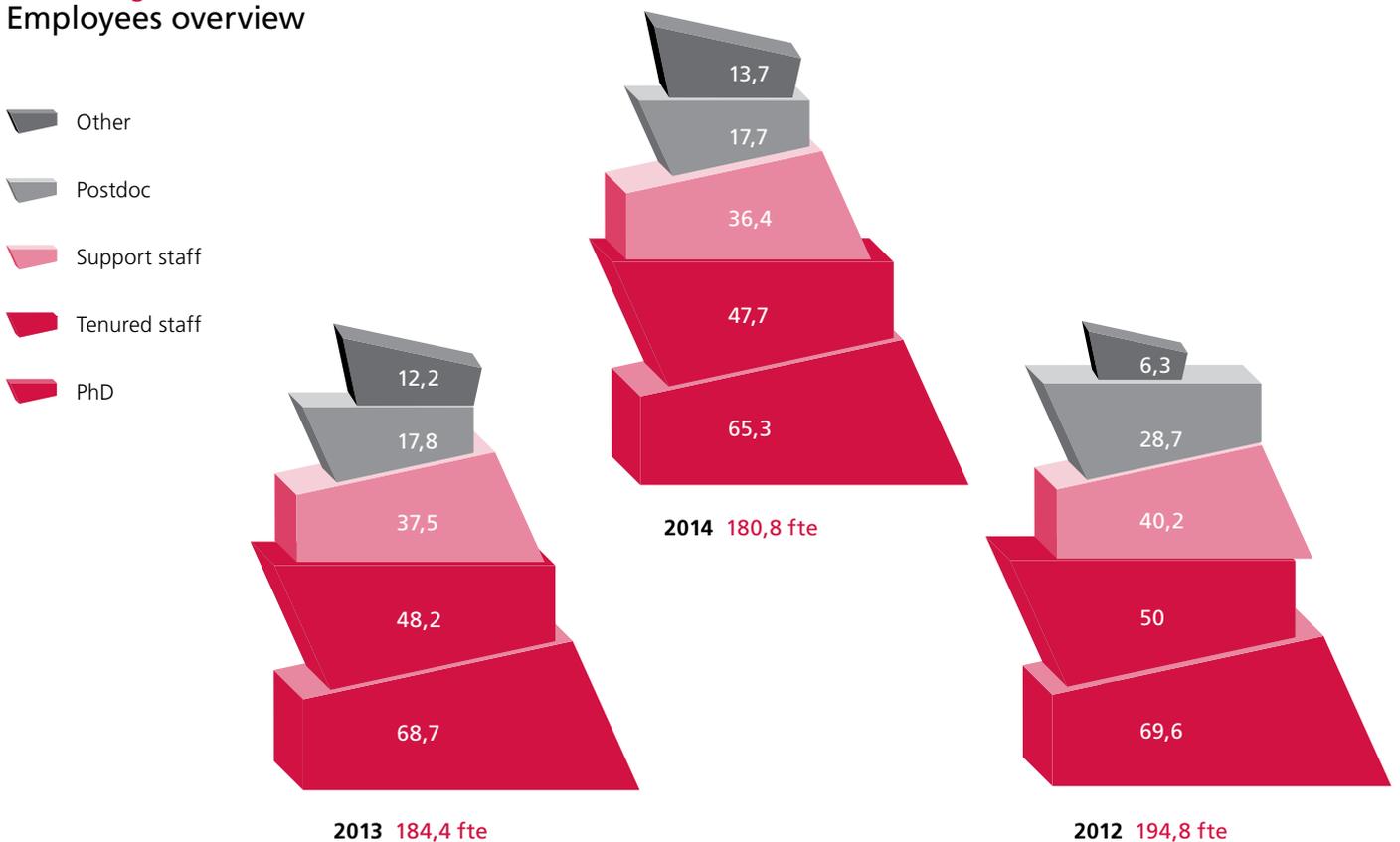
# Working together on database technology

Public-private research is not just for large companies. Last year, CWI started a joint research with The Hague-based startup BeDataDriven, which has 5 employees. Researcher Hannes Mühleisen from CWI's Database Architectures group will research how database optimization techniques could be brought to "Renjin", a fast interpreter for the widely used statistical programming language 'R'. The project is funded through the IPPSI-KIEM program of NWO, which helps fund innovative public-private partnerships in ICT.

### Renjin

BeDataDriven develops the open source software Renjin (from 'R-engine'), an interpreter for programming language R. R is widely used for statistical software and data analysis,

## Facts & figures Employees overview



from astronomers to online marketers. Renjin is an implementation of the R language optimized for the use of big data sets. “We want Renjin to be the fastest and most powerful tool for statistical analysis”, says Maarten-Jan Kallen, managing director at BeDataDriven. “To achieve this, we are particularly looking to accelerate the processing of large data sets.” Kallen met Mühleisen on a conference of R developers. Mühleisen presented his research on fast integration between data management systems such as MonetDB and statistical languages like R. “We decided that we should work together, and when the opportunity came in the form of research vouchers provided by CWI (see text box), we went for it.” Funded by the voucher budget, Mühleisen was able to perform an initial investigation into the possibilities of integrating CWI’s software MonetDB and BeDataDriven’s Renjin. “To deal with complex statistical analysis, Renjin turns an R program into a graph.” says Mühleisen. “From a data management perspective, this graph represents a query. We have experience in optimizing such queries, so I could see the potential.’ To make it work the cooperation had to continue in a much larger project, and that came along in the form

## CWI in Bedrijf research vouchers

Once every two year CWI organizes CWI in Bedrijf, a networking event for researchers and industry. CWI researchers demonstrate their work and companies can discuss their challenges directly with experts in mathematics and computer science. In the 2013 edition, CWI introduced research vouchers as an incentive for cooperation. When submitted together with a CWI researcher, the voucher provided the company with one research month to be spent on a proposed challenge. Eight research vouchers were submitted after the event, including the BeDataDriven research project.

of the IPPSI-KIEM program of NWO, which is specifically intended for public-private partnerships between a company and a research institute. In the project titled ‘R as a query language’, CWI and BeDataDriven agreed that Mühleisen would spend one full year on this project. The costs will be covered partly by the company, and partly by NWO through the program. “The tools used by statisticians are not optimized for large datasets and complex analyses such as those required for machine learning techniques,” says Mühleisen. “Renjin smartly circumvents this by building a graph structure of the analysis

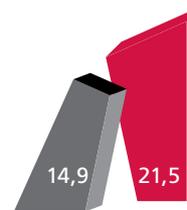
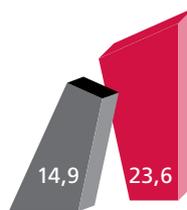
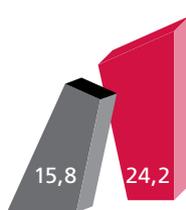
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## Facts & figures

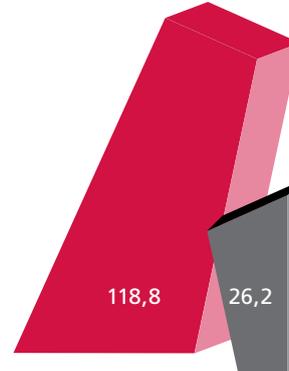
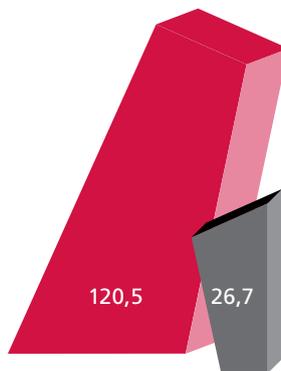
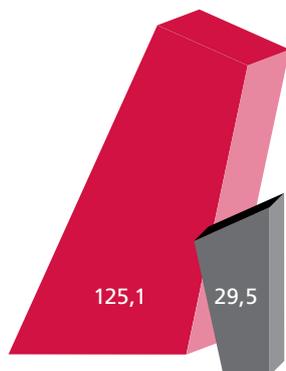
### Employees male / female

■ male  
■ female

Support staff



Research staff



2012

2013

2014

script, compiling this graph into code for Java Virtual Machine, which is able to execute the code much quicker than the original R implementation. We will investigate how to change the graph prior to compilation based on the properties of the data. In addition, we are investigating how to efficiently ship parts of the data analysis towards MonetDB's highly optimized data crunching operators. We expect this to speed up statistical analyses by several magnitudes." One of the datasets that will be used as a test case is the American Community Survey. Mühleisen: "This annual survey consists of about 200 questions answered by millions of participants in the US. They have been doing this for 30 years, so the data

volume is quite large. Researchers are very interested in analyzing these results in terms of demographics, regional differences and progression over the years. Conventional statistical software cannot handle complex questions such as how someone's gender and location affect their income. If we will be able to answer such questions with Renjin and MonetDB, this will open a whole new area of possibilities in the field of statistical analysis." The results of the project are expected to greatly improve the commercial attractiveness of both Renjin and MonetDB, and subsequently into business opportunities for their commercial support by BeDataDriven and MonetDB Solutions – the CWI spin-off company founded in 2013 that provides consultancy for the MonetDB database. "We are very glad that we are able to integrate state-of-the-art knowledge from data science into our product," says BeDataDriven's Maarten-Jan Kallen. "We have just started the project, but we already impressed by the creativity and ideas that arise through discussions and by working together. Hannes brings the results of 30 years of experience with large-scale database research with him. It is an investment that I expect to be well worth the money."

## MonetDB

Researching data management architectures for data-intensive science and applications is a major research topic at CWI. Results of this research are regularly included in the Open Source database management software MonetDB. New modules are often added, such as the integration with R developed by Mühleisen.

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## Research theme

### Life sciences

#### RETHINK big

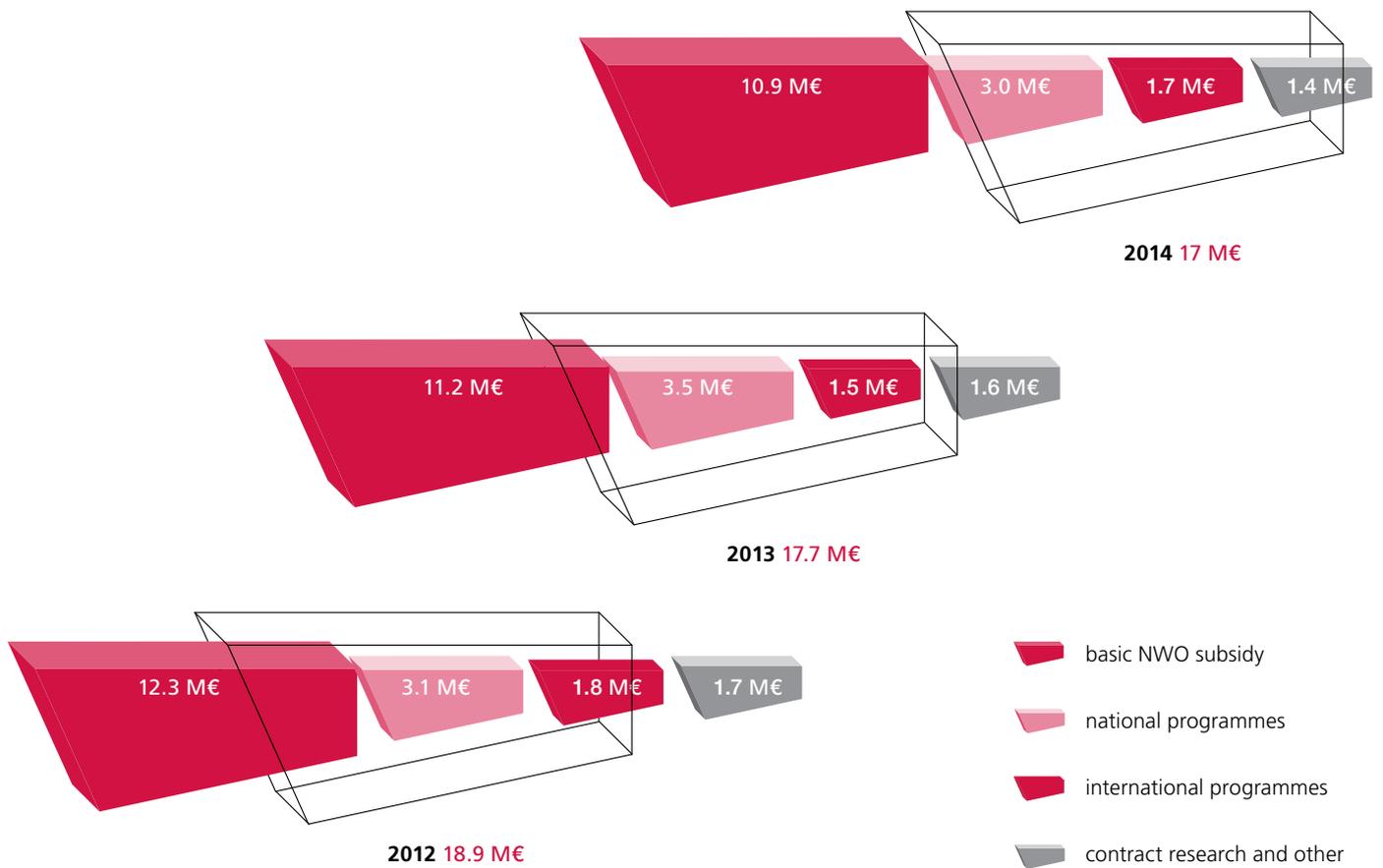
The life sciences are a major producer and consumer of big data, for instance in large-scale experiments or simulations. In the RETHINK big Project, aimed at increasing the European competitiveness in the processing and analysis of big data over the next 10 years, CWI life sciences researcher Gunnar Klau leads the Life Sciences application working group. RETHINK big brings together the key European hardware, networking, and system architects with the key producers and consumers of Big Data. CWI's database researcher Stefan Manegold leads another group on enabling technologies.

#### Spiking neural networks

Modern artificial intelligence (AI) is based on so-called deep neural networks. This form of AI is already being used by companies like Google and Facebook in speech and image recognition. However, these neural networks are only based on a rough model of how brains work. In a new project, CWI aims to develop more powerful and more efficient neural networks based on advanced models of the building blocks of our brains: spiking neurons. With spiking neurons, more powerful neural networks can be applied in for instance person or object recognition in smartphones, or direct translation of speech.

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Facts & figures  
Income



Research theme Life sciences

**Embryonal development**

The development of an embryo from a single cell to a complex organism is still not fully understood. Most research focuses on the differentiation of cells in organs and tissues through chemical communications. Recent experiments have revealed the key role of mechanical forces. By pushing and pulling the extracellular matrix in which the cells are embedded, individual cells affect the movement and orientation of their neighbours. CWI has developed a computer model that simulates the growth of a blood vessel structure on a cellular level solely based on mechanical forces between cells.

**Volume structure in 3D**

A crucial question when investigating biological specimens like subcellular structures and organelles is how the three-dimensional structure of microscopic particles is organized in large volumes. CWI researchers will develop new volume reconstruction methods to enable high-throughput imaging at nanometer resolution. These tomographic methods will also be useful for investigating nanomaterials in other fields. This research is funded by the Veni grant of Xiaodong Zhuge, received in 2014.

**Blood vessel hollowing**

A key step in blood vessel development is lumen formation: the hollowing of blood vessels for perfusion. Experimental observations of lumen formation resulted in two alternative, hypothetical mechanisms, which since 1856 has sparked a scientific debate on the mechanisms of blood vessel hollowing. CWI researchers now developed a model that includes both mechanisms and reproduces the experimental observations, suggesting that both mechanisms function synergistically. The model thus provides a possible explanation for the contradictory experimental observations in the debate.

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# Improving cloud-based marketing

The cloud is very attractive for its flexibility. Getting a new virtual server – cloud provisioning – can literally be done within minutes, without the need for investing in own hardware. At the same time, using the cloud is not always profitable due to high costs of bandwidth and data storage. The Formal Methods group at CWI developed new techniques for advanced monitoring and controlling cloud software. To test and implement them in practice, CWI and global company SDL joint forces in a public-private partnership project on improving cloud-based marketing. With success.

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## Research theme

### Logistics

#### Impatient Internet users

When a large number of customers use a service like mobile Internet on the same network, the service rate may drop so low that users become impatient and abort. This user behaviour is a significant problem for the quality of service, as resources have already been spent to serve such users. Impatient customers are usually not considered in protocols that direct Internet traffic, but they can have a huge impact, especially in overload situations. CWI researchers developed new methods that are able to assess the performance of protocols in overloaded systems with user impatience.

#### Altruistic behaviour

Consideration for others doesn't always lead to the best outcome – that is, when applied in game theory. In conventional models players are only interested in themselves, but in real life people are also influenced by others. CWI researchers studied the impact of cooperation, friendship and animosity on games. They concluded that altruistic behavior of players can make traffic or data flows become worse. With their more realistic models researchers and policy makers can make better qualitative predictions. The results can be applied to networks and GSP auctions such as used by Google Adwords.

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In webshops, the amount of online shoppers typically fluctuates a lot – think of the busy Christmas time – so hiring external, off-premise servers to host online catalogue software can be a very efficient solution. Of course, there is a trade-off. To limit the costs, not too much server space should be reserved. On the other hand there should always be enough to keep the software running, also during popular sales weeks, to meet the various service level agreements (SLAs). Currently, allocation of server space is often done by hand on a 24/7 basis. Businesses have been very interested in CWI's research to find real-time optimal allocation more automatically.

At CWI, researcher Stijn de Gouw studies formal support of cloud provisioning, both for assigning optimal server space and for finding bugs. He explains: 'It is important that these kinds of issues are solved in a formal way. For instance, a server should never break down during a busy peak. If the performance of the online catalogue system is not always good, the client will lose customers and turnover. Further, clients shouldn't pay too much for server space due to bugs. When space

## CWI and SDL: inspiring sparring partners

Collaboration between the international translation and e-commerce company SDL (operating behind the scenes of over 300 of the world's largest web shops) and CWI started in 2009, and has become quite intensive since. A master student and two former group members of Frank de Boer's Formal Method research group at CWI started working for Fredhopper. It was later acquired by SDL, where one of them is now Vice President SaaS Development & Innovation. In 2013 CWI and SDL lined up within two EU projects – HATS and Envisage. In 2014 they started the current public-private partnership project to improve cloud-based software for marketing purposes. CWI researcher Stijn de Gouw now works part-time for SDL, and is equally paid by both SDL and CWI. De Boer says: "I'm pleased that such a solid basis of multi-level contact has been established with SDL. We also collaborate with companies like Philips, Thales, and PriceWaterhouse Coopers. If other companies are interested, too, in improving their cloud related software, they are welcome to contact us."

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## Research theme Logistics

### Personalized travel advise

Congestion can be prevented by coordinating the travel plans of individual road users. In a pilot project within the Amsterdam Smart City initiative, CWI cooperates with company TrafficLink to create the digital road coordinator 'De Digitale Wegbeheerder'. In the project, traffic data of public and private parties is combined to give commuters of IJburg a personalized travel advice. Participants leave their homes at the allocated 'time slots' that are based on real-time and predicted traffic density on the road. 'De Digitale Wegbeheerder' can even adapt the behaviour of traffic lights if needed.

### Tax routes

Mathematical analysis of a data set collected by Centraal Planbureau (CPB), revealed new information on how bilateral tax treaties can be exploited to form 'tax routes' that minimize profit taxes. CWI developed network analysis algorithms to investigate the network formed by the tax treaties between 108 countries. This confirmed earlier conclusions of CPB that the Netherlands is among the top five intermediary countries on tax routes of the world. It also showed that there exists a group of 64 countries between which companies can freely transfer their profits, without paying any taxes.

### Mathematics saves lives

In case of life threatening fire incidents, the ability of firefighters to arrive at the site within a few minutes can make the difference between survival and death. However, the development and growth of cities has altered the travel times from base locations to fire incidents. CWI and regional firefighter departments have collaborated in a research project on the optimization of the locations of fire stations in urban regions. The research showed that only small adjustments in the spatial distribution of locations can strongly improve the travel times to fire incidents.

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## SAGA

At CWI, Stijn de Gouw developed a specification language (SAGA) that can describe the software on a high abstraction level. It was implemented with RASCAL into an open source runtime verifier for Java programs and other software. Frank de Boer: "There are no other tools that support new techniques on new versions of Java. To keep your tools up-to-date is a real challenge".

is automatically being assigned, a bug can literally cost millions of dollars. Now, with our research, services using cloud computing can run in a much more effective, efficient and reliable manner, thus lowering the costs and optimizing the profit.'

"How do we do this?" De Gouw explains: "We combine the traditional method of run-time assertion checking with a new, event-based approach. When a customer searches an article on a website, this is, in software terms, an event. Under the hood, my SAGA checker intercepts this event to see if it meets its requirements. In online catalogues, search results are

often mixed with ads. We are monitoring this process real-time, and look at things like: is it done right and quick enough, and aren't calls waiting for each other? One can't see if this is right from the static software alone. In our approach, we are looking at literally millions of events. We specify series, detect bugs, look for unwanted interactions between software components and external factors, and then make visualized bug reports for our clients' developers."

This approach is currently being developed and tested in a joint public-private partnership project with SDL Ecommerce optimization (formerly known as Fredhopper). The overall objective of this project is to give more insights in the compliance on the SLA's between SDL and customers. The preliminary results of this research are very promising. De Gouw says: "One of the nice things of combining science and business, is that you do research with inspiring, innovative people and see immediate results of your work. I'm very happy to contribute to the dissemination of new knowledge to society."

## cwi in 2014

### ERCIM 25 years

The 25<sup>th</sup> anniversary of ERCIM was celebrated in Pisa in October. Since its start, ERCIM – the European Research Consortium for Informatics and Mathematics – has funded 500 postdoc fellows, rewarded 21 Cor Baayen Awards and has published 100 issues of ERCIM News magazine. It gave strategic advice to the EU and participated in over 70 EU projects. Nowadays, it has 22 institutional members and reaches over 16,000 researchers. It hosts the European W3C headquarters. ERCIM promotes cooperation in research, technology transfer, innovation and training. CWI was one of its co-founders.

## cwi in 2014

### Awards and honours

A selection of awards and honours received by CWI researchers in 2014:

- ACM Distinguished Member (Lynda Hardman)
- Huijbregtsen Prize - nomination (Stochastics group)
- Honorary Mention Digital Design category Ibero-American Design Biennial (Lilia Pérez and Michiel Hildebrand)
- Invited Speaker at International Congress of Mathematicians (Monique Laurent)
- SIGMOD Edgar F. Codd Innovations Award (Martin Kersten)
- Stieltjes Prize 2013 (Benjamin Sanderson)

## cwi in 2014

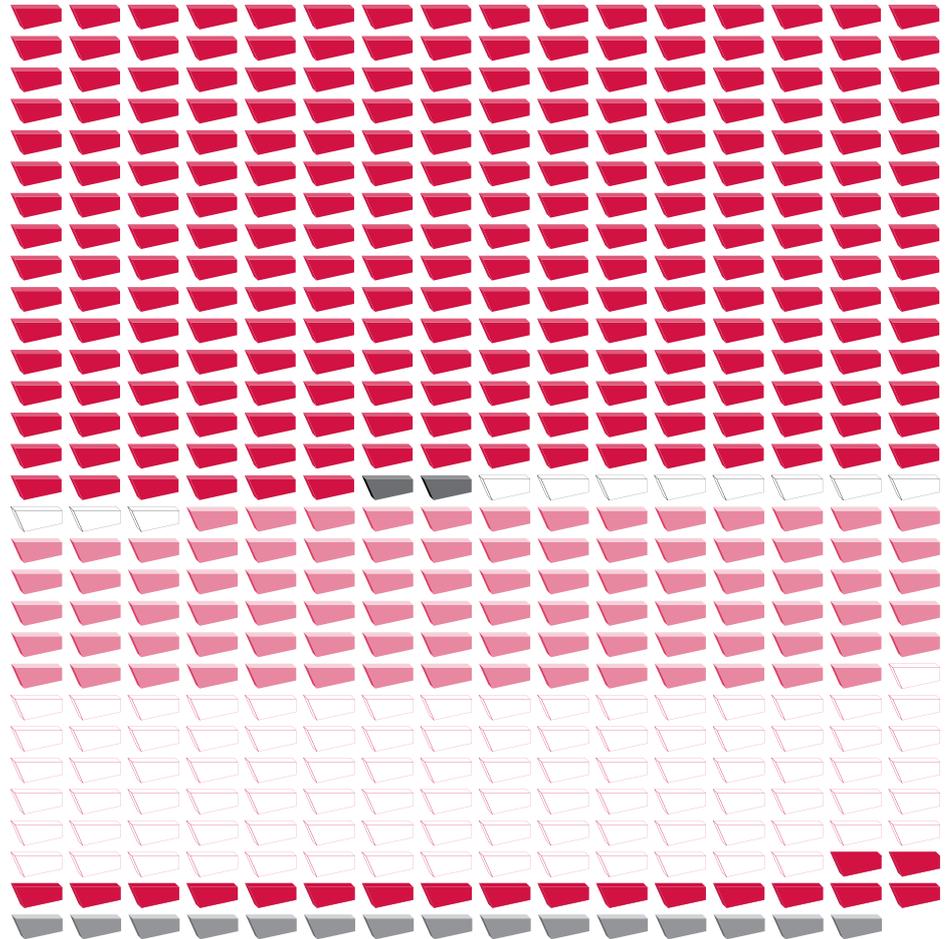
### Professorships

The following CWI researchers were appointed for the first time as professor in 2014:

- Daan Crommelin (Professor by special appointment of Numerical Analysis and Dynamical System at University of Amsterdam)
- Stefan Manegold (Professor of Data Management at Leiden University)
- Roeland Merks (Professor of Multiscale Mathematical Biology at Leiden University)
- Jurgen Vinju (Professor of Automated Software Analysis at TU Eindhoven)

## Facts & figures Output 2014

	Papers	246
	Books	2
	Book chapters	11
	Media appearances	92
	Lectures	95
	Software products	18
	PhD theses	15



### cwi in 2014

#### Five Veni grants

In 2014 CWI received no less than five NWO Veni grants. A Veni allows researchers who have recently obtained their PhD to conduct independent research and develop their ideas for a period of three years. They were awarded to:

- Jop Briët (quantum data protection)
- Jiyin He (information retrieval)
- Wouter Koolen (machine learning)
- Marc Stevens (digital security)
- Xiaodong Zhuge (3D imaging)

### cwi in 2014

#### Media appearances

In April 2014, Rob van der Mei featured in NTR TV show *De Kennis van Nu*, which covered CWI's research on dynamic planning of emergency services. In December 2014, Peter Grünwald performed a statistical analysis of the 'Nationale Oliebollen-test' for KRO tv show *De Rekenkamer*. CWI researchers also appeared in other media, including *BNR Radio* (Han La Poutré), radio show *De Kennis van Nu* (Sander Bohte, Rob van der Mei and Jurgen Vinju), *NTR Akademie Radio* (Lex Schrijver) and newspapers *NRCQ* (Krzysztof Apt), *Trouw* (Peter Grünwald) and *de Volkskrant* (Barry Koren).

### cwi in 2014

#### Multimedia lectures

The CWI Lectures 2014 were organized around the theme of Socially-Aware Multimedia. It covered the areas of Multimedia Systems, Content Analysis, Human-Computer Interaction and Hypermedia. Eight internationally recognized speakers highlighted past achievements and reflected on future possibilities for new research challenges. The event on 22 May was organized in recognition of CWI's researcher Dick Bulterman. After nearly 25 years of tenure at CWI, he became President of the FX Palo Alto Laboratory (FXPAL) in California in 2014.

# No two people are exactly the same: mapping DNA differences

While our DNA uniquely identifies us as human, it is not exactly the same between individual human beings. Up to 1.5% of DNA differs from individual to individual. The Genome of the Netherlands project mapped these differences for 769 people in family settings, making it one of the most concise analysis of DNA differences ever. Alexander Schönhuth of the Life Sciences group at CWI developed the algorithms that locate the exact differences in the genomes. The resulting DNA catalogue provides valuable insights in the role of genetic variation in illnesses.

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## Research theme

### Energy

#### Energy data

The interaction of sensor-equipped buildings and neighbourhoods with smart grids is expected to produce huge amounts of data that track how these complex systems interact and co-evolve. Unlocking the hidden value of this data is the key to the effective and efficient control of the various (sub)systems. In the STW project mentioned before, CWI also investigates novel methodologies for visual and analytic exploration of this data. Applications include forecasting over different timescales to better anticipate and exploit fluctuations in production and demand, as well as predictive maintenance.

#### Smart energy

New ways of production and consumption of energy calls for new technologies that make buildings handle energy supply and demand more efficiently. CWI investigates the development of market based supply and demand matching mechanisms, including ancillary services. This is part of the large scale STW Perspective programme Smart Energy Systems for the Built Environment, which also includes industrial partners such as Thales, TenneT, Enexis and Alstom.

continued on p.17

## Mapping DNA

Comparing the DNA of two individuals is not as easy as it might appear at first. The human genome consists of approximately 3 billion letters. Due to this size it has to be cut up in fragments, which are mapped to a whole-length reference genome to determine their origin. After mapping all the fragments of the two genomes that are being compared, their differences can be determined in terms of reference coordinates. Very large deletions and insertions of over 100 letters are relatively easy to spot, as the differences make statistically significant effects. Very small differences under 30 letters are again relatively easy, because their detection is possible using well-known alignment techniques. Middle-sized differences however do neither make statistically significant effects, nor do they allow to be detected using standard techniques because this would require too much computational run-time. Alexander Schönhuth of the Life Sciences group at CWI developed novel data techniques that fill in this gap. "My algorithms are fast enough to perform enhanced statistical tests, allowing to perform computations within realistic run-time. Making the discovery of mid-size differences

## Life Sciences research at CWI

The research of Alexander Schönhuth is part of the Life Sciences research group at CWI. An interdisciplinary research team works on mathematical and computational techniques to help understand the complexity of living systems. Life science research is applied in a wide range of topics such as cancer research, pharmacology, cell biology and developmental biology and contributes to the understanding of the fundamental processes of life. In 2013, Schönhuth was awarded a Vidi grant by the Netherlands Organisation for Scientific Research to develop a research line on statistical models for genetic variation during a period of five years.

possible, a 'blind spot' in genetic variation discovery has been eliminated that had been standing for more than 5 years." This method was a huge success: no less than 98.4% of all variations the techniques found in the bandwidth of 30 to 100 letters were new and previously unknown.

### Personalized medicine

By sampling a large population from a relatively small geographic location, the researchers were able to focus on rare variations on the individual level. This genetic profile allows to investigate the

continued on p. 18

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## Research theme Energy

### Antimatter from lightning

Lightning is a natural particle accelerator. Ahead of growing lightning flashes electrical fields can become so high, that electrons are accelerated to extremely high energies. When these electrons collide with air molecules, they can create not only X-rays and gamma rays, but even antimatter, namely positrons, as was measured in 2011. CWI researchers now modelled the electric fields and how these fields accelerate particles. They also simulated for the first time how thunderstorms create positrons as well as protons and neutrons, showing that neutrons from lightning can even reach the ground.

### Wind at sea

When developing large-scale wind parks at sea, poor understanding of uncertainties associated with wear and tear can lead to costly and unnecessary large safety measures. In a large-scale project with several academic and industrial partners, researchers investigate the uncertainties associated with wind farms in order to reduce high development costs, making wind energy a more attractive source of durable energy. CWI investigates the correlation between wind and waves, and combining different sources of uncertainty.

### Nuclear investments

A new generation of nuclear fission reactors is expected to be highly sustainable and safe, featuring a substantial reduction in fuel and waste. Another benefit is that they can be built in small and medium size. An important question is how the economy of scale of large reactors compares to the economic flexibility of several smaller reactors. Researchers of CWI, TU Delft and NRG have developed a tool that determines the optimal policy for nuclear power plant investments. It uses advanced techniques from financial mathematics to determine the economics of a new generation of nuclear reactors.

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## Genome of the Netherlands

The Genome of the Netherlands is an unique large-scale research project that aims to develop a genetic profile of the Netherlands. The researchers have mapped the DNA sequences of 250 family trios, consisting of two parents and one child, across the Netherlands. It is the first time that the genes of healthy persons have been analyzed in this number and with this precision. The project is initiated by BBMRI-NL, a collaboration between biobanks in the Netherlands, and supervised by Cisca Wijmenga of the University Medical Center Groningen (UMCG). Alexander Schönhuth of CWI provided the fast algorithms for comparing full DNA sequences. Other institutes involved include UMC Utrecht, Leiden UMC, VU University Amsterdam, AMC Amsterdam, UMC St. Radboud Nijmegen, Erasmus MC in Rotterdam, and a number of foreign research groups.

role of genes in the development of chronic and age-related diseases. Analysis has shown that the role between genes and diseases is more complex than previously thought. Every participant in the project turned out to have an average of twenty mutations that were thought to cause rare diseases, although the participants were perfectly healthy. The resulting data provides enough material for follow-up research in the years to come. Links between DNA and diseases were found in various

occasions, such as a single letter flip associated with diabetes. Further research is necessary to reveal the how and why of these types of correlations. A promising application of these new DNA sequence comparing techniques is to discover the role of genome differences in the effectiveness of treatments. Some medicines have a very different effect from individual to individual. Mapping DNA differences could provide the key to understanding these effects. This might pave the way to personalized medicine, where the type and dose of drugs is customized for optimal effect. Schönhuth also sees potential for his techniques in cancer research. "Now that our techniques start to become much more detailed, we could try to apply them to compare the genome of individual cells of the same person. Cells become cancerous through DNA mutation, so comparing the genome of cancer cells with healthy cells could reveal valuable information on how cancer develops on the genome level."

## Facts & figures

### Research partners

### Public institutions

Belastingdienst NL Centraal Planbureau NL CSIC ES  
 CNRS FR GGD Amsterdam NL De Verkeersonder-  
 neming NL GGD Flevoland NL KNMI NL  
 Koninklijke Bibliotheek NL NL Ministry of Defense  
 NL Politieacademie NL RAV Gooi- en Vecht-  
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ABB CH Actian Corporation US Alcatel Lucent FR Almende NL Alstom FR Arcadis NL ARM GB Atbrox AS NO  
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 Sound and Vision NL Open Knowledge Foundation GB  
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**Centrum Wiskunde & Informatica (CWI)** is the national research institute for mathematics and computer science in the Netherlands. The institute's strategy is to concentrate research on five broad, societally relevant themes: Software, Information, Life Sciences, Logistics and Energy.

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#### Design

Kitty Molenaar

#### Printing

Drukkerij Palteam

#### Publication date

April 2015

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#### Credits

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Deelman, Paul	10-11
Kranen, Hay	19
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