# 70 CWI

th
anniversary

# Annual Report
# 2016

**Credits**

**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, Data,
Networks, Computation and Quantum.

**Contents**

The Mathematisch Centrum at the 2ᵉ Boerhaavestraat 49 in Amsterdam

# Preface

2016 was a year of looking forward as well as looking back. We celebrated the institute's 70th birthday, and we were proud to pay tribute to a number of historical successes, such as the registration of the top level domain .nl 30 years ago. Of course, we also commemorated the 100th anniversary of the birth of Adriaan van Wijngaarden, a trailblazing pioneer who was involved in the introduction of the computer in the Netherlands.

CWI's numerous past successes make it a pleasure to reminisce. However, looking forward is arguably even more exciting. The fields of mathematics and computer science are vibrant and of undeniable importance to society. This is illustrated by some of the research highlights of 2016. For instance, CWI researchers developed market mechanisms to align electricity supply and demand. Their work can be used to balance the demand in future grids for sustainable energy. 2016 was also the year of the 'ambulance study': CWI researchers developed smart forecasting and planning methods for ambulance services. This led to a new spin-off, Stokhos Emergency Mathematics, which provides software solutions for proactive relocation of emergency vehicles.

These examples illustrate CWI's dual mission: to conduct pioneering research and to contribute to society. CWI is proud of its many collaborations with academic and industrial partners. A prime example is the QuSoft research institute, an initiative of CWI, UvA and VU. This year, the importance of quantum computing was acknowledged by the European Commission, which proposed to invest one billion euros in a large-scale European research program: the Quantum Flagship. Today, the scientific landscape is rumbling with change. In January 2017, the Netherlands Organisation for Scientific Research (NWO) adopted a new organisation structure. The new NWO stimulates cross-disciplinary collaboration. In 2016, as well as in any other year, CWI has proven to be ready and willing to break through disciplinary boundaries. For instance, CWI researchers developed real-time 3D tomography, which is used in medical scanners. And CWI collaborated with biologists to describe how a cell decides what type of function it will adapt after cell division.

Of course, the backbone of CWI's excellence is, and always will be, the dedicated researchers and supporting staff. Thanks to their commitment, CWI looks towards the future with confidence. This document gives an account of their efforts in the previous year. I hope you will enjoy this Annual Report 2016.

**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. Our mission is to conduct pioneering research in mathematics and computer science, generating new knowledge in these fields and conveying it to industry and society. CWI is part of the Netherlands Organisation for Scientific Research (NWO).

**Vision**

CWI conducts long-term research in mathematics and computer science, inspired by real-life needs in energy, climate change, healthcare, security and other areas. As the national platform for mathematics and computer science, CWI aims to safeguard the interests of our research fields and play a leadership role in science policy. CWI nurtures young research

talent and is a pioneer in new lines of long-term research in high risk areas. Knowledge transfer is an important part of our work. We collaborate with public and private partners and we foster spin-off companies. We make our software tools available to researchers, companies and the general public.

## New themes

To focus our efforts, CWI research is clustered in broad, societal-relevant themes. In 2016, these were updated to the following themes: software, data, networks, computation and quantum.

## valorisation

In 2016, a Valorisation Team was appointed, which monitors valorisation activities within the institute, keeps track of new funding and partnership opportunities and mobilizes CWI researchers to act upon these opportunities. Awareness of societal relevance has grown within the institute and this has resulted in new collaborations and applications.

## Milestones

CWI has a unique talent pool of researchers. Since its foundation in 1946, around 200 of its researchers have become **full professors**. In 2016, our researchers included a **Spinoza Prize** winner, 21 researchers with one or more **NWO Innovational Research Grants**, two **ERC Grant** holders and three **KNAW**-members.

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 launching the **QuSoft** research centre for quantum software, showing the practical **vulnerability of the SHA-1 standard** for internet security, developing proactive planning methods for **ambulance**, **firefighters** and **police services**, investigating **smart energy networks** and modelling and simulating phenomena such as **lightning**, **ocean currents**, **financial products**, **wind parks** and **proteins**.

CWI plays a central role in various programs and organizations, including the **W3C Benelux Office**, **Platform Wiskunde Nederland**, **EIT Digital**, **ERCIM** and **Informatics Europe**. Since its foundation CWI has commercialized its research in the foundation of **24 spin-off companies** that have generated millions of turnover to date.

# Software

## Optimal coverage of emergency services

CWI and TU Delft developed models for optimizing the logistics of emergency response vehicles. In his models the researchers focus on the location of the stations, routing of non-emergency rides (for ambulance services) and shift scheduling. By quantifying the process it can be shown that making small changes can lead to a better quality without adding capacity. Ambulances have to accommodate planned transport of non-emergency patients between healthcare institutions. For these planned rides, the researchers developed a tool that allows ambulance services to schedule rides as efficiently as possible.

## Parallel programming made easier

With the increase of multi-core processors used in smart phones and other computers, parallel programming has become even more important. To prevent software errors in these programs, concurrent calculations must always exactly be executed in the correct order. This is not easy, as existing techniques – interaction protocols – are very hard to use. CWI researchers investigated a new programming method to simplify this, making it easier for programmers to program and reuse interaction protocols. This improves the quality of parallel software, for instance in the coordination of drones.

## Software quality

There is an urgent need for new, auto-mated techniques to analyze software and to guarantee its quality, argued part-time professor of Automated Software Testing and CWI group leader Jurgen Vinju in his inaugural speech at Eindhoven University of Technology on Friday 12 February 2016. The quality of software is an insidious problem. When mistakes come to light or software is completely incomprehensible, it is often too late and the damage already suffered. The enormous complexity of software makes that errors lack visibility and adjustments are made without being clear what consequences this has for the quality. According to Vinju the solution must be sought in better automated software analysis.

## MonetDB for Java and Python

When a database grows into millions of records spread over many tables, which is often the case for businesses or for scientific purposes, a column-store database management system is called for. In column-based database systems, data tables are stored as columns rather than rows. This provides a scalable solution without having to resort to substantial hardware investments. CWI is the breeding ground of the open-source column store database technology MonetDB. The product is constantly evolving, improving and growing: in 2016, MonetDBLite versions were introduced for Java and Python (NumPy).

## Connecting Fashion, Senses, and Spaces

During Amsterdam Dance Event 2016, CWI and the textile studio ByBorre explored the future of club culture at the exclusive RedBull At Night Playrooms event. CWI supported the event with innovative technology, orchestrating a unique immersive club experience. While the guests partied, a system of sensors, especially designed by CWI for this event, was seamlessly gathering and processing in real-time data from the attendees, understand-ing their experience and identifying their most meaningful moments. Combining research on multimedia systems and machine learning artificial intelligence, the whole event was orchestrated, gathering over 50 million data points from 900 party-goers.

Sensored wristband that collects user data

## Facts & figures
## Research partners

| | public institutions | companies | non-profit organizations |
|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| | Actian Corporation **US** | Alcatel Lucent **FR** | Almende **NL** | Alstom **FR** | Arcadis **NL** |
| ARM **GB** | Atbrox **NO** | BBC **UK** | BeDataDriven **NL** | BMW **DE** | Brainport Development **NL** |
| BT **UK** | Centric Netherlands **NL** | ChyronHego **UK** | Cisco International **UK** | CityGIS **NL** | Cofely **NL** |
| CEA **FR** | Connexxion **NL** | CTVrede **NL** | De Verkeers-onderneming **NL** | Descartes **CA** | DNV **NO** |
| DNV GL **NL** | Eaton **NL** | Elekta **SE** | Endinet **NL** | Enexis **NL** | Engineering Igegneria Informatica S.p.A **IT** |
| EuroCottage **NL** | European Archive **NL** | ExxonMobil Chemical **US** | FEI **US** | Fredhopper **NL** | GGD Amsterdam **NL** |
| GGD Flevoland **NL** | Illuminations **FR** | Imagine Optic **FR** | ING Bank **NL** | Koninklijke Bibliotheek **NL** | Kropman Installatietechniek **NL** |
| Locamation **NL** | LogIT Systems **NO** | MAIOR **IT** | MonetDB **NL** | Net2Grid **NL** | NEWlab Research Den Haag **NL** |
| No Rack **FR** | NXP Semiconducter Belgium **BE** | Parstream **DE** | Philips **NL** | Prorail **NL** | Rabobank **NL** |
| RAV Gooi-en Vechtstreek **NL** | RAV Utrecht **NL** | Rovecom **NL** | Stedin **NL** | Stichting KiKa **NL** | Stichting Sensor City **NL** |
| Tata Steel **IN** | Teezir **NL** | TenneT **NL** | Textkernel **NL** | Thales **NL** | TomTom **NL** |
| Trinite Automatisering **NL** | Vabrema **NL** | VORtech **NL** | Xinhuanet **CN** | | |

CWI's research group Computational Imaging

# Real-time computational imaging

3D imaging has incredibly useful applications in many different fields. A key challenge is how to create 3D images of processes underneath the surface, invisible to the naked eye. In such cases, high quality images need to be computed from limited data, obtained in a very short time. This is one of the problems that CWI's research group Computational Imaging, newly founded in 2016, is addressing. Their long-term goal: to be able to produce 3D images in real-time, during the scanning process.

"Tomography by itself is a very old technique", group leader Joost Batenburg admits. "Last century, scientists discovered how to convert several 2D images taken from different angles to one 3D image." But these methods either require a vast amount of measurements, or they take a long

time to compute. Batenburg: "We want to be able to make high quality 3D images from just a few measurements, in just seconds of computing time."

## Quantitative 3D imaging

Batenburg's group develops algorithms for creating 3D images that allow quantitative data analysis of the scanned object. "The trick is to consider the different steps involved in computing a 3D image, such as physical scanning, image reconstruction, and data analysis, as a complete pipeline, instead of focusing on just one of the steps", says Batenburg. For instance, in a collaboration with the Rijksmuseum, scientific staff member Robert van Liere and his colleagues are examining a small ivory sphere from the 18th century. "It's an incredibly interesting object that I have put my heart and soul into", says Van Liere. "It consists of nine concentric spheres, all engraved with intricate geometric patterns. Using computer tomography data, we try to find tool marks on the inner spheres, to determine how these spheres were made." To this end, not just the reconstruction, but also the data analysis required for extracting the nine surfaces must be performed in a quantitative way.

## From static objects to dynamic processes

But computational imaging is not just about static objects anymore. The group also wants to be able to produce 3D, real-time movies of dynamical processes. Batenburg gives some examples: "One could study how oil flows through a drill core or watch chemical reactions in a nano sample." Using real-time tomography, researchers could change the processing parameters during the scanning process, or zoom in on a section of interest. "This is very different from how it is done now", Batenburg explains. "Right now, researchers put an object into a scanner, the scanner is turned on for a while, and then afterwards they study the observations." Last year, an important first step towards real-time tomography was realized. Together with scientists from Forschungszentrum Jülich in Germany, the Computational Imaging group used a reconstruction algorithm to produce a 3D image of a carbon nanotube. "By combining a fast scan with our reconstruction methods, this process took just three seconds of scanning time, while it would usually require a scan of about an hour to reconstruct an image of similar quality", Batenburg says. "Right now, we are working on the next step, which is to make a 3D movie of nanomaterials under a microscope."

Another point of interest for the group is the large amount of data modern scanning equipment can produce. "Sometimes there are so much data, the only thing you can do is store them", says Van Liere. "We are trying to find ways to interpret all of the data in real-time using advanced algorithms, so you can benefit from them when they are generated, instead of months later."

**Bridge between theory and practice**

To work on specific applications, having the ability to scan in-house is crucial. Therefore, in May 2017 the group will get its own CT scanner. "It is a scanner with unique capabilities, built specifically for our computational imaging research", Batenburg clarifies. The FleX-ray CT scanner will bring theory and practice even closer together than they already are – which fits in nicely with Van Liere's and Batenburg's vision for Computational Imaging. "We want to bridge theory and practice", says Batenburg. "A lot of groups either consists entirely of mathematicians or of physicists", Van Liere says. "We combine the spectrum of mathematics, computer science and physics, and train people in all of those fields."

The group's goals are ambitious, but they are backed up by substantial funding through a broad portfolio of fundamental and applied projects. Also, Joost Batenburg obtained a Vici grant from NWO in February 2016, which meant 1.5 million euros worth of extra funding for the group. "This gave our group a lot of momentum right from the start", Batenburg says.

Left: 18th century artifact from the Rijksmuseum collection, consisting of 9 concentric spheres carved from a single piece of ivory
Right: 3D digital model of the object, obtained by CT scanning and advanced digital postprocessing

CWI  annual report 2016

The European Grid-Friends project will help the Amsterdam building project Schoonschip become the most sustainable floating neighbourhood in Europe

# Data

### Data exploration

Database management systems rely on an implicit pact with the user. They give correct answers, but only if they get precise questions, expressed in a query language. This is a problem when a user wants to find interesting new facts hidden inside the data, while having no prior knowledge of the data. CWI researchers have now developed new 'database assistants' to explore large databases. Among other things, the assistants help refine queries by allowing users to select clusters of objects, and show what makes a selection of objects unique.

### Mapping 'dark matter' of human DNA

CWI researchers have made a big step towards a better understanding of the human genome, in collaboration with an international team. By identifying complex and difficult-to-discover DNA variants in 250 Dutch families, the researchers have shed light on much of the 'dark matter' in human genomes. For their discovery CWI has developed an ultra-fast algorithm. The new data enable researchers to study the correlation between DNA variants and genetic diseases or potential health risks, a major step towards personalized medicine. The findings were published in Nature Communications.

**Probability for random events**

CWI developed new insights for probabilistic systems influenced by random events. Imagine an ice cream parlour at the beach. Sales are heavily influenced by the weather, making it very hard to predict sales on a specific day in the future. However, if you zoom out on a larger time scale, you can recognize patterns and make useful approximations. CWI showed that this scaling will eventually produce known probability distributions. The results are applicable in various contexts, such as the production of molecules in a cell or data transfer over the internet.
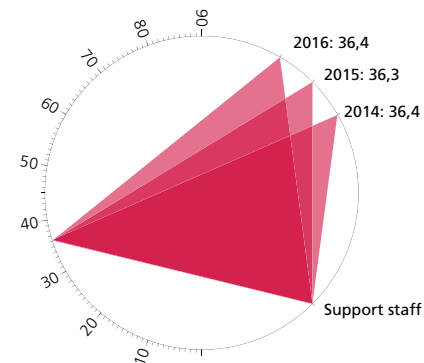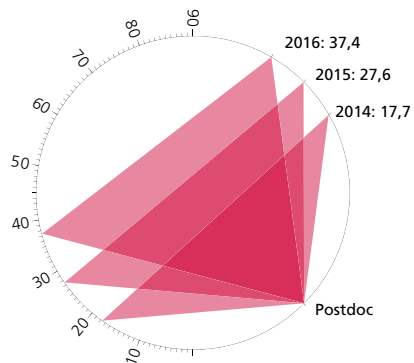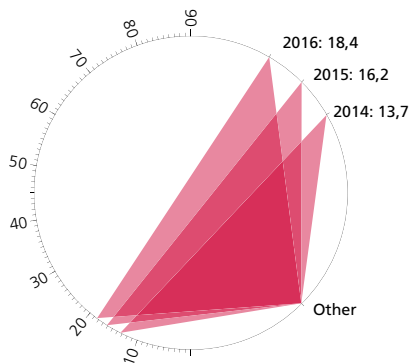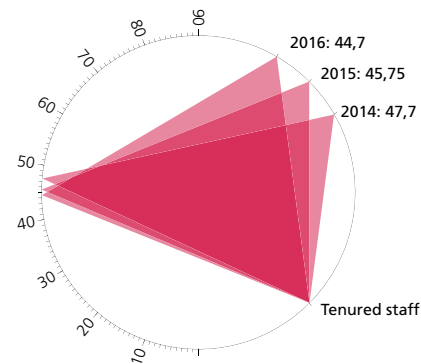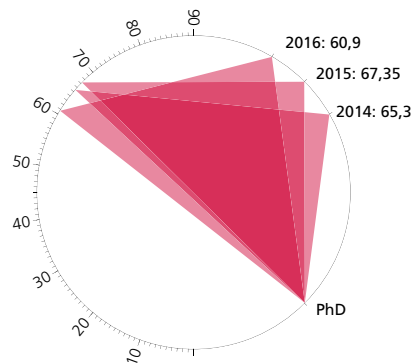
**VRE4EIC**

Launched in 2015, the VRE4EIC project is a Horizon 2020 research and innovation programme that addresses key data and software challenges in supporting multidisciplinary data driven sciences. CWI is a partner of VRE4EIC, and in 2016, three new researchers were recruited thanks to VRE4EIC funding. Combining both symbolic and statistical methods, two PhD candidates together with their senior programmer will work on methods and infrastructure to improve algorithmic transparency, trust and security in virtual research environments.

**Better ranking for big data**

Ordering results is important for companies analyzing data without a natural order, like user ratings. This is usually done with classification and clustering methods. CWI researchers studied a third technique: seriation, ranking objects according to their pairwise relative similarities. For large data sets this is very practical: it is, for instance, easier to compare two movies than to decide which film is number 71 of your top-100 favourite movies. The new algorithm can be used for better and faster ranking of big data in machine learning and data analysis.

# Employees overview



PhD
- 2016: 60,9
- 2015: 67,35
- 2014: 65,3

Tenured staff
- 2016: 44,7
- 2015: 45,75
- 2014: 47,7

Other
- 2016: 18,4
- 2015: 16,2
- 2014: 13,7

Postdoc
- 2016: 37,4
- 2015: 27,6
- 2014: 17,7

Support staff
- 2016: 36,4
- 2015: 36,3
- 2014: 36,4

# Employees male / female



**2016**

support staff female: 16,1

support staff male: 20,4

research staff female: 23,6

research staff male: 137,9

**2014**

support staff female: 14,9

support staff male: 21,5

research staff female: 26,2

research staff male: 118,8

**2015**

support staff female: 13,9

support staff male: 22,5

research staff female: 29,7

research staff male: 127,3

The new seriation method developed at CWI makes ranking results better and faster

CWI published the book Geheugentrommels, written by Erik Verhagen, about the development of the first computers in The Netherlands

# Networks

### Sharing energy

Renewable energy from sun and wind has natural fluctuations, and the demand for electricity is also subject to change. Therefore, a neighborhood can only be energy neutral and self-sustaining with the help of a smart grid: an intelligent grid that coordinates the storage and distribution of energy between households. The European Grid-Friends project, led by CWI researchers, will launch a pilot for the implementation of such a grid in the Amsterdam building project Schoonschip: 47 households which aim to form the most sustainable floating neighborhood in Europe.

### Dynamic pricing

Energy supply and demand are currently balanced through coordinated generation in power plants. However, future energy grids will depend on renewable sources, such as solar panels and wind turbines, that are owned by various parties. Therefore, new mechanisms need to be developed to balance supply and demand. CWI researchers have created several market mechanisms and pricing strategies for this purpose: these mechanisms enable the planning of consumption and generation of energy ahead of time and encourage short-term adaptations. This research was funded by the Netherlands Enterprise Agency (RVO).

### Firefighters better in position

If multiple fire stations are busy fighting a major fire, where should vehicles of other stations go to for optimal coverage? CWI, Delft University of Technology and the Fire Department Amsterdam-Amstelland collected data, such as the local fire risk, and developed a mathematical model that enables firefighters to optimally position. Based on the results a fire department makes a decision to reposition and how. This is an example of how maths can lead to further improvement of the quality of emergency services, which could possibly save lives.

### Improved sensor networks

It is important to improve sensor networks, as the number of sensors is growing and their networks become crowded. CWI and VU optimized the throughput of ZigBee sensor networks with mathematical techniques. This resulted in a promising new technique, making sensor networks able to contribute to better decisions, such as choosing the best emergency exit. With business partners they also studied indoor climates and improved them by tackling the problem that one sensor could dominate the others. This is relevant for applications in the Internet of Things.

### Call center efficiency

Call centers should base their staff planning on the number of unique callers instead of the total number of calls. Furthermore, introducing a system that gives redialers priority over fresh callers both reduces the average waiting time and improves the fairness of the system. This can be concluded from a study on call center management conducted by CWI. The study resulted in a staffing model that includes the flow of redialing and reconnected callers and a call-back system, in which long-waiting callers are suggested to call back some time later if the system is congested.

CWI's research group Machine Learning

# Machine Learning: from cochlear implants to online ads

**Machine learning is not just about computers recognizing patterns in images. Scientists at the Machine Learning research group, founded in 2016, work on a great many subjects – ranging from questions on how much data is needed, to biologically plausible neural networks used to improve cochlear implants.**

"Machine learning is a hot topic", group leader Peter Grünwald says. "It seems like every week a new machine learning group is founded somewhere." An example of machine learning is a computer determining how to recognize malignant tumours on pictures of human lungs. What is the minimal

amount of images labelled by doctors a computer would need to achieve this feat? That is the kind of question Grünwald focuses on. Grünwald is especially interested in situations in which our models of reality are far from perfect, yet useful enough for making predictions. Recently, he received a NWO TOP-grant for this research.

A related research topic concerns a surplus of data. "Sometimes a researcher has the option to use more data than was initially planned. Currently, you have to decide how many data you will use before you start", Grünwald explains. "If you change this, your conclusions are not reliable anymore." However, Grünwald and his colleagues are working on a method that does allow researchers to continue taking data if the opportunity presents itself. Also, it enables them to change their hypotheses along the way.

**Multi-armed bandits**
Another example of a machine learning topic is a so-called multi-armed bandit problem. In these problems, a gambler has access to several slot machines, some of which provide bigger or more frequent rewards than others. What strategy should

the gambler chose to maximize profits? Suppose a machine seems to pay quite well, should the gambler stick with that machine? While this might sound like a textbook problem, there are many similar real-world problems. Grünwald: "Google cannot show me a thousand adverts at the same time, so the company has to decide which ones work best. Say I respond well to an advert showing a remedy against hair loss. Should Google show more of these? Or should they try others that might work even better?"

Bandit problems are examples of online learning and prediction, in which information arrives sequentially in time and a learner constantly has to adapt future predictions. Group member Wouter Koolen's work in this field has gained a lot of interest. In December 2016, Koolen was chosen to present his paper in a talk at the influential Conference on Neural Information Processing Systems (NIPS) – an honour that is bestowed to only two percent of the papers submitted.

**Spiking neural networks**
Colleague Sander Bohté's work focuses on another topic, namely that of biologically plausible neural networks: artificial networks that try to emulate the

way a human or animal brain works. This will have applications in recognizing and predicting patterns, but Bohté is not satisfied with a network that simply learns how to classify images. "We are working on problems involving time", he says. "Videos, for instance. Or the act of writing something down, or going to a supermarket."

To tackle these problems, Bohté uses spiking neural networks. The neurons in these networks emulate real neurons by using short electric pulses, or spikes, to communicate. A promising application of these neural networks is cochlear implants. "The problem with current cochlear implants is that they have a very bad dynamic range", Bohté says. "A sound is experienced by users as either loud or quiet, but nothing in between. We are working with researchers at the Leiden University Medical Center to fix this problem."

Another approach Bohté and his team are working on, is deep reinforcement learning. "Learning by trial and error", Bohté explains. Recent examples are Google DeepMind's algorithms learning how to play classic Atari computer games, and AlphaGo beating a professional human go player in 2015. The CWI

group focuses on a different class of problems: the kind of cognitive tasks that monkeys perform while their neuron activity is being measured.

**Collaborations**

"We work closely with the Netherlands Institute for Neuroscience and the Psychology and Neuroscience departments of the University of Amsterdam", says Bohté. Also, the group requires a lot of computational power, so it regularly employs the Dutch supercomputer Cartesius and the new 'mini-supercomputer' Little Green Machine II at Leiden University.

"In the near future, we think our research can make a contribution to the medical world", Grünwald says. "All of the areas of machine learning that we work on can readily be applied in the medical domain. For instance, we can use our work to recognize skin diseases on images, to adjust treatments as new data come in, and to minimize the amount of data needed to get reliable conclusions."

## cwi in 2016

# Van Wijngaarden Year

2 November marked the 100th anniversary of the birth of Adriaan van Wijngaarden. He was head of the calculation department of the Mathematisch Centrum (now CWI) and was directly involved in the introduction of the computer in the Netherlands.
CWI was founded on 11 February 1946 to help rebuild the Netherlands after World War II and marked its 70th anniversary year as 'Van Wijngaarden Year'. CWI commemorated these two special occasions with the publication of a book and an exhibition about van Wijngaarden and the first years of Dutch computer history.

## cwi in 2016

# Professorships

In 2016 Tijs van der Storm acquired a new position as professor of Software Engineering at the University of Groningen.

## cwi in 2016

# Awards and honours

A selection of awards and honours received by CWI researchers in 2016:
- ACM Fellow (Martin Kersten)
- 2016 ACM SIGMOD Systems Award (Martin Kersten)
- 2016 Internet Defense Prize (Léo Ducas)
- ACM Distinguished member (David A. Shamma)
- Google Security Privacy and Anti-abuse Applied Award (Marc Stevens)
- CWI Fellow & chair of the computer science department of VU Amsterdam (Dick Bulterman)

CWI presented a small exhibition with rare computer hardware. The masterpiece of the exhibition was an original Enigma machine

To conclude the anniversary celebrations, Jos Baeten revealed an artwork with photos of CWI-personnel and Aad van Wijngaarden in the background

Van Wijngaarden was fascinated by randomness and random movement also inspires the work of Mark Bischof. During the Lectures, he gave a live demonstration of some of his work

The winners of the 2016 Van Wijngaarden award, Xavier Leroy and Sara van de Geer, surrounded by members of the Van Wijngaarden family

**cwi in 2016**

## Emmy® Award for Timed Text

W3C received a 2016 Technology & Engineering Emmy® Award for its work on the Timed Text Mark-up Language standard. This makes video content more accessible with text captioning and subtitles. CWI contributed to this in the past, and is still being very active in W3C standardization today – for instance in XForms, RDF and Digital Publishing. It also houses the W3C Benelux Office, which hosted and co-organized several W3C meetings, such as on SVG, XProc and Smart Vocabularies. New W3C Members in the Benelux are DTL Data Projects, Taxonic and Trust1Team.

**cwi in 2016**

## Van Wijngaarden Awards

Mathematician Sara van de Geer and computer scientist Xavier Leroy received the Van Wijngaarden Awards 2016. These awards are intended for scientists who contributed significantly to their field and are awarded once every five years. It is the third time the Van Wijngaarden Awards were awarded. Sara van de Geer is a Dutch mathematician interested in statistics and statistical learning theory. Xavier Leroy is a senior research scientist at Inria where he leads the Gallium project team.

**cwi in 2016**

## CWI Lectures

On Thursday 3 November, CWI organized the CWI Lectures. A special programme in honour of Adriaan van Wijngaarden was put together and several internationally renowned speakers, Samson Abramsky, Alexandra Silva, Tanja Vos, Lambert Meertens, Gilad Bracha and Mark Bischof, explored the legacy of Van Wijngaarden in both mathematics and computer science.
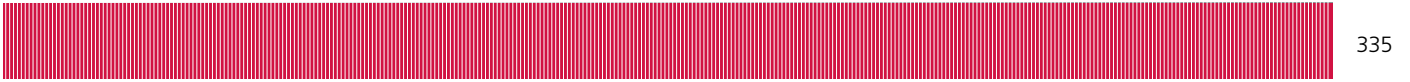
Each year, CWI opens her doors to the general public during the Amsterdam Science Park Open Day

# Facts & figures
## Output

Papers

335

Books

3

Book chapters

17

Media appearances

319

Software

26

PhD theses

13

CWI's research group Software Analysis and Transformation in action

# Making sense of software

Software specialists are having trouble managing software's exponentially increasing complexity. It is especially difficult for users to make sense of an already existing code base. Analyzing existing source code requires its original context in order to trace back its meaning and purpose. Researchers of CWI's Software Analysis and Transformation group (SWAT) are working on such context-specific analysis methods. Their ultimate aim is to better understand existing software complexity, and to find new ways to prevent, manage and mitigate it.

Software is becoming ever more important. The sheer volume of software is growing rapidly due to new applications, as well as extensions to existing systems. Meanwhile, software's complexity grows even faster than its volume.

During the lifetime of a typical program, bugs need to be fixed, some components are exchanged for others, new functionalities are incorporated, and existing code is reused in other packages. Software development is often an evolutionary

process; code bases are growing organically. The tools required to analyze a code base that was developed in this fashion are difficult to develop. "These tools need to extract the meaning and purpose of the source code, qualities that mostly existed only in the heads of the original programmers", explains SWAT group leader Jurgen Vinju. "These people worked their way through the requirements to understand the what, how and why of the program; they interacted with customers, users and colleagues; and they were probably busy getting things done rather than meticulously logging every administrative detail of the process. In general, reading the resulting code and making sense of it becomes harder and harder as the software changes over time and its original context fades into history." It should come as no surprise that unmanageable complexity leads to errors, which lead to extra costs at best and accidents at worst.

**Context matters**

"The solution to this problem is to incorporate a new type of knowledge into the analysis phase of our reverse engineering tools", says Vinju. "This includes technical information on the interfaces and coding standards used, as well as business information on terminology and processes. This additional input is specific to a particular sector or industry, or even to an individual organization or development process. The result will be an advanced software analysis tool that is domain-specific or context-specific. These tools will allow us to see not only what the source code says, but also what it means."

The SWAT group is a pioneer on this largely unexplored path. Vinju: "What we are trying to accomplish is to separate the reusable 'heavy lifting' in analysis tools from the hopefully light weight specializations needed for specific contexts. To do this, we first transform source code into reusable abstract objects and relations, and then analyze these models in conjunction with context-specific information. Examples of the latter are knowledge about which specific APIs, platforms and coding standards are being used, along with the professional terminology and idioms.  That requires us to link up to particular sectors and industries, which often have this type of knowledge available. Think, for example, of domain-specific languages (DSLs), which provide specialized features for particular domains, and unified modeling language (UML) code, representing software systems, workflows

CWI  annual report 2016

and business processes. Reaching out to specific sectors, finding industry partners, and talking to experts are important parts of our quest. Collaboration between software researchers and software engineers is crucial. Making sense of software is eminently a multidisciplinary affair."

In 2016, the idea was born to launch a spin-off company called SWAT.engineering. When companies find that the complexity of their software slows down their pace of innovation and business development, they can contact SWAT.engineering for a tailor-made analysis of their existing software. The results can be used to generate new software or to update the existing code base. 'We give our customers back control over their software', reads the SWAT.engineering mission statement.

**Rascal**
For their work, the SWAT group relies on Rascal, a self-developed meta-programming system aimed at code analysis, code transformation, and the implementation of domain-specific languages. Reading source code and transforming this into abstractions for analysis can already be done for Java and PHP. The SWAT group is currently starting on

the connectors for C and C++. "The main research questions lie around the analysis phase", says Vinju. "How do we incorporate context-specific knowledge in our tools, and how do we process the resulting information? At the other end we need to find out how to query these abstractions in a smart and fast way. The latter is a scientific challenge in itself." "Context-specific analysis will eventually allow researchers and users to ask context-specific questions", says Vinju. "Those answers will be more relevant than any current state-of-the-art software tool can provide, and will facilitate higher-quality software at lower cost."

# Computation

### Vascular growth

Researchers at CWI and AMC used large-scale computer simulations to discover how cell types work together to form new blood vessels. Understanding vascular growth is essential for understanding and manipulating processes such as tumour growth, wound healing, and a number of eye diseases. Computational modelling and simulations are increasingly important in the life sciences. They allow for the development and testing of hypotheses in much more complex situations than lab experiments. They can be repeated many times with varying properties to generate large amounts of data in which new discoveries can be made and various hypotheses can be tested.

### Cloud formation

Clouds play a major role in weather and climate, but are hard to include in predictions due to their chaotic nature and small scale. Even modern supercomputers are not powerful enough to simulate the global atmosphere in so much detail that individual clouds can be resolved. Therefore, cloud formation must be represented in a simplified way in simulations. CWI researchers have developed a new, probabilistic method to represent cloud processes, accounting for the randomness that stems from the chaotic nature of cloud formation.
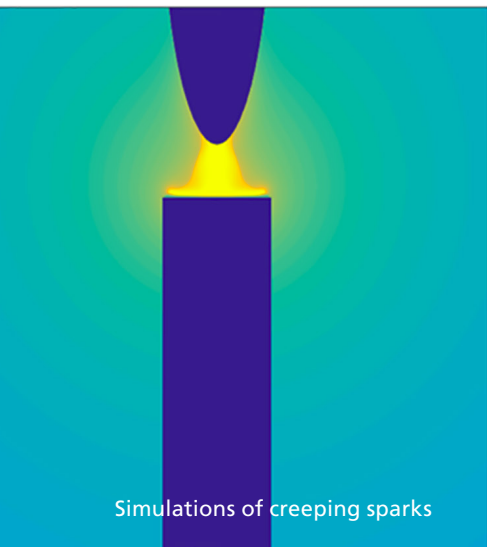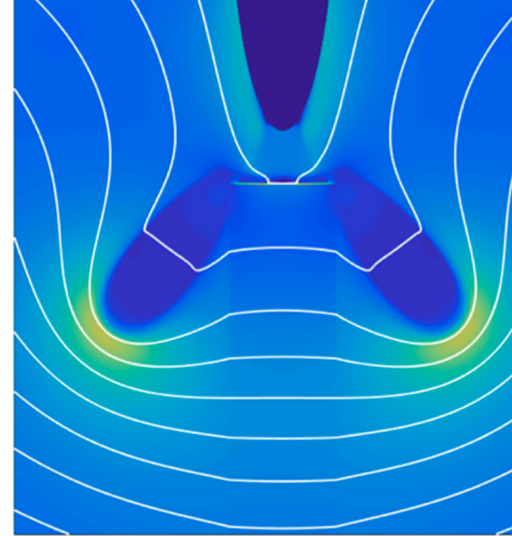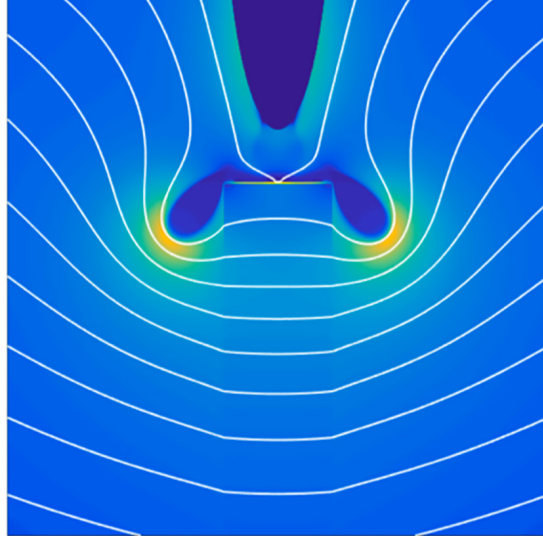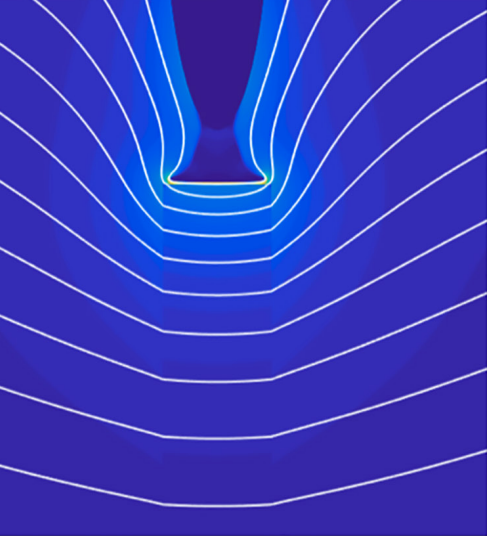
### Towards new electricity nets

Renewable energy requires new electricity grids, as green energy is often generated in remote areas. A general problem in such networks is that often sparks occur on the surface of insulating materials, causing permanent damage to the equipment. Until now, not much was known about such 'creeping sparks' – such as when they occur and how they will move. CWI developed new mathematical models to predict the behaviour of these sparks. The results can help to improve and renew the architecture of high-voltage networks in the future.

### Future fate of cells

How does a cell make a decision about his future, on what type of cell it will be after the cell division? This process is described by CWI researchers, together with a Japanese team of biologists. The researchers discovered that the cell shape before its division (co-)determines the functions of the daughter cells. Although a cell will lose its form before its division, becoming round, the information about the original form turns out to be preserved.

### Faster computation of 3D images

CWI has developed new algorithms for computer tomography (CT) for fast computation of high-quality three-dimensional images. This increases the practical use of this technology in areas such as material sciences and biomedical research. In many applications, it is useful to look inside an object without destroying it, such as medical examination or product quality assessment in industry. This is possible with a CT-scan, that results in several X-ray images with varying angles. A mathematical algorithm uses these two-dimensional images (projections) to create a three-dimensional image of the object's internal structure.

Simulations of creeping sparks

CWI annual report 2016

# Facts & figures
## Income

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

**2016**                                                          **Total 18,4 M€**

11,5 M€     4 M€     1,7 M€   1,2 M€

**2015**                                                          **Total 17 M€**

11,2 M€     3,3 M€     1,3 M€   1,2 M€

**2014**                                                          **Total 17 M€**

10,9 M€     3 M€     1,7 M€   1,4 M€

# Short
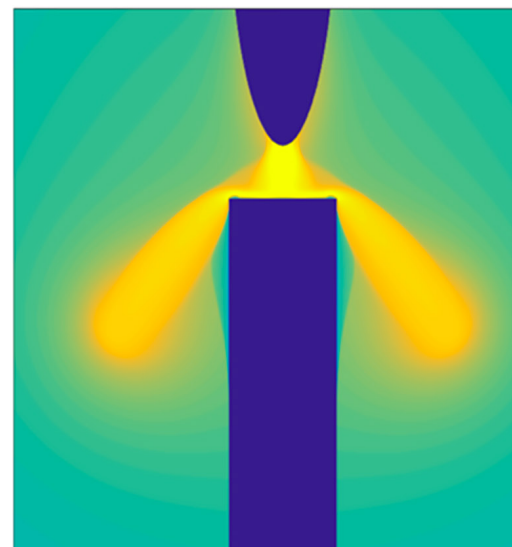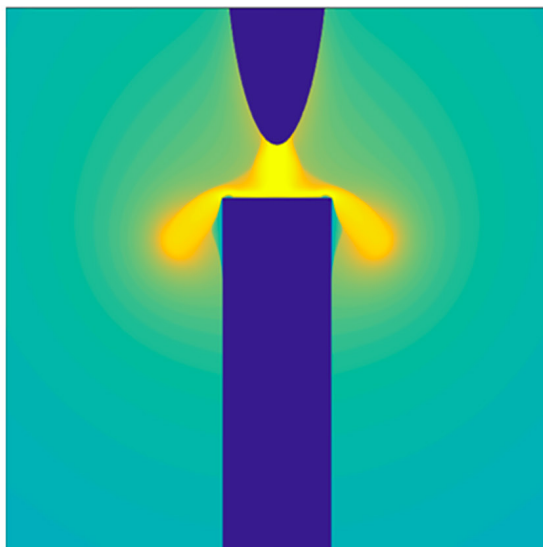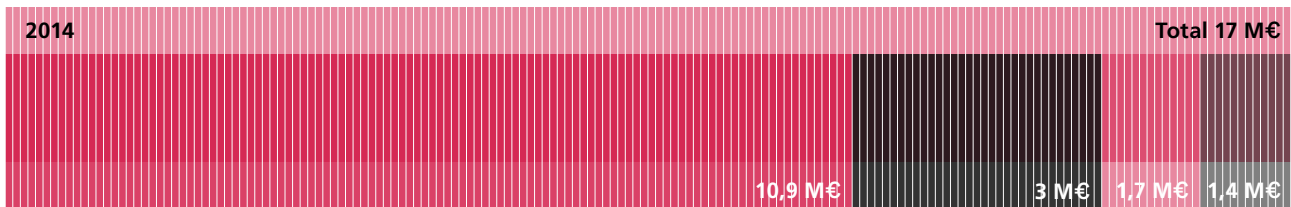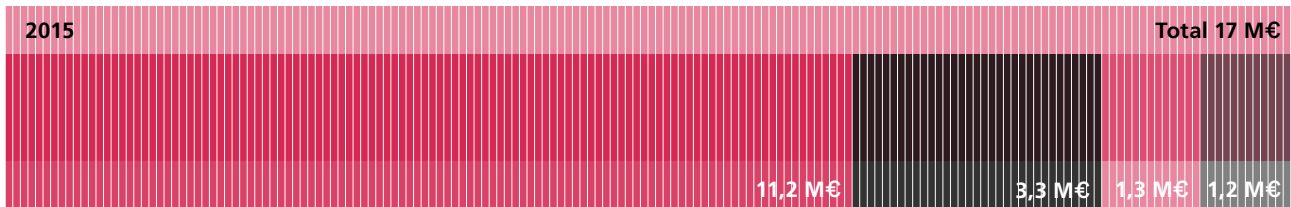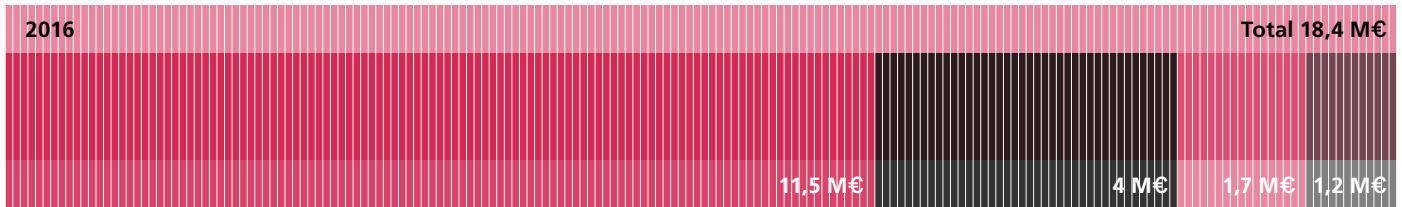
## cwi in 2016

### Two Veni grants

In 2016, CWI researchers Léo Ducas and Johannes Köster were awarded Veni grants from NWO. Veni grants, which are part of the NWO Innovational Research Incentives Scheme, allow researchers who have recently obtained their PhD to conduct independent research and develop their ideas for a period of three years. Ducas will use the grant to develop cryptography resilient to attacks by quantum computers; Köster will develop a framework for reproducible data analysis that can handle big data in the cloud.

## cwi in 2016

### Media appearances

National newspapers such as de Volkskrant, Trouw, NRC and Het Parool featured a variety of CWI topics, such as artificial intelligence, 30 years of .nl, and quantum software research. De Volkskrant published our open letter on open access and CWI was mentioned as 'a lifesaver' in de Telegraaf. Vrij Nederland magazine dedicated an article to Python, De Ingenieur treated the sharing of renewable energy, and AGConnect featured CWI's software. CWI also appeared in several video productions, such as a Mongolian TV interview and a documentary from The People's Cloud.

## cwi in 2016

### Universiteit van Nederland

CWI researcher Rob van der Mei lectured in an episode of the TV programme 'Universiteit van Nederland' (University of the Netherlands). Rob and four other scientists from different disciplines contributed to a series of five episodes themed 'Contingency Plan!' on the origin, prevention and handling of disasters. Rob's talk focused on how we make sure that an ambulance can reach your home even faster. The recordings took place in October, and the programme was broadcasted on TV in January 2017. It is also available online and via YouTube (http://bit.ly/2i9AZTu).

Lecture by Rob van der Mei in an episode of 'Universiteit van Nederland'

Jos Baeten (General director CWI) and Antoine Petit (CEO Inria) shaking hands after signing the partnership agreement

**cwi in 2016**

## NWO transition

In 2016, a large-scale transition for the NWO organization was brought into effect to make NWO more effective and more focused on collaboration, and thus more flexible to respond to developments in science and society. The new NWO has a structure with an Executive Board, a separate NWO Institutes Organisation and three domains: Sciences, Applied and Engineering Sciences, and Social Sciences and Humanities. As a NWO institute, CWI is closely involved in this process and is preparing to join the Institutes Organisation in January 2018.

**cwi in 2016**

## New spin-off companies

CWI announced the foundation of its new spin-off Stokhos Emergency Mathematics. Stokhos provides software solutions which enable the proactive relocation of emergency services based on predictions of future demand.
CWI also launched spin-off company SEITA (Sustainable Energy Is Totally Achievable), a service provider focused on the energy sector. SEITA advises suppliers of renewable energy in the area of 'demand response' using flexible energy tariffs.

**cwi in 2016**

## Partnership agreement CWI and Inria

CWI and Inria have signed a partnership agreement at the festive 70th anniversary of CWI in Amsterdam. Inria invited CWI to set up an Inria International Lab (IIL) together. The purpose of such Inria International Labs is to fund and develop partnerships and collaborative research with international first-class institutions. Inria regards CWI as being one of the best players in the field internationally and has thus selected the institute as a long-term strategic partner.

Dr.ir. Jok Tang (VORtech), Dr. Dirk Scevenels (ING bank), Drs. Sandy Kalisingh (STW), Drs. Kees de Graaf (PhD student, UvA), Dr. Drona Kandhai (ING Bank, UvA), Prof.dr.ir. Kees Oosterlee (CWI, TUD), ir. Qian Feng (PhD student, CWI), Dr. Diederik Fokkema (EY)

# Better estimation of financial risk with applied mathematics techniques

Since the financial crisis of 2008, regulations for banks and pension funds have been sharpened. Financial institutions are obliged to retain sufficient buffers and to map the risks of their financial products very thoroughly, to be able to cover the financial risks in extreme situations. To carry this out, accuracy is essential. Inadequate buffers will either lead to irresponsible risks or will slow down the economy. In a research project led by Kees Oosterlee of CWI's Scientific Computing group, new calculation methods have been developed. With the help of these calculations highly accurate estimations can be made in order to assess the extent of the necessary buffers needed to mitigate financial risks.

Professor Yuying Li was at CWI for two weeks during the project to train the researchers in the area of Big Data in finance. Professor Li is appointed at the University of Waterloo in Canada and is a leading expert in this field. "In North America we invested in connecting with the Wall Street companies on the topic of computational finance, but it is very difficult to come close to the open atmosphere that I experienced here, it is refreshing. I think that this is made possible by having the people at key positions who are really good at making the connection between academia and industry. Also, I understand that research funding in the Netherlands often directly connects academia and industry, making it possible to have a direct transfer of results to society, which is wonderful. The CWI graduate students have so many opportunities to benefit from these contacts. I encountered interesting research questions myself during the stay that I would like to work on when I'm back home."

Qian Feng, PhD student from CWI, modeled CVAs and designed a new algorithm that can help banks estimate the risks more precisely, so they can take appropriate measures if necessary. The resulting algorithm can compute the risk of high losses more precisely. In an interview Qian Feng said: "Since the recent financial crisis, financial modelling and risk management have changed. The Basel Committee on Banking Supervision has introduced new documentation with banking regulations. Banks should reserve a certain amount of capital to buffer for the default risk of all counterparties in their portfolios. The use of models that take this so-called counterparty credit risk into account, results in an increased computational demand within banks. This is a very critical problem. Within my research I have focused on the computational problems in pricing and measurements aspects of the counterparty credit risk. I have developed an efficient algorithm, based on the Stochastic Grid Bundling Method, for credit valuation adjustment. I hope that the industry will be interested in the algorithm. My dream is that banks will apply the algorithm widely."

CWI collaborated with UvA, ING, EY and VORtech in the project 'Advanced Estimation of Credit Valuation Adjustment'. The researchers worked on state-of-the-art computational techniques that align with the financial questions that organizations are dealing with. New mathematical techniques can cope with more complex calculations and will for example estimate the effect of a bankruptcy on the complete portfolio of financial products instead of the effect on individual products. This will help banks to meet the required standards and to be able to grant credits at the same time.

The private partners are very pleased with the results of the project. Drona Kandhai, head of the Dutch branch of the Front-Office Quantitative Analytics team of ING and active academic partner (from the Computational Science Lab of UvA) of the project comments: "the cooperation between the academic researchers and ING went very well and is of great added value to our bank. The jointly developed techniques are very relevant and will be integrated in our valuation- and risk-systems on short notice. After four years of intensive, high-level research, we can conclude this is a very successful example of valorization."

Facts & figures
Nationalities

Finland 1
Russia 5
United Kingdom 2
Netherlands 131
Poland 4
Belgium 2
Germany 16
Switzerland 1
Austria 2
France 6
Romania 2
Hungary 1
United States 5
Bulgaria 1
Spain 4
Italy 9
Greece 5
Israel 1
Iran 4
China 7
South Korea 1
Mexico 1
India 3
Vietnam 1
Colombia 1
Chile 1
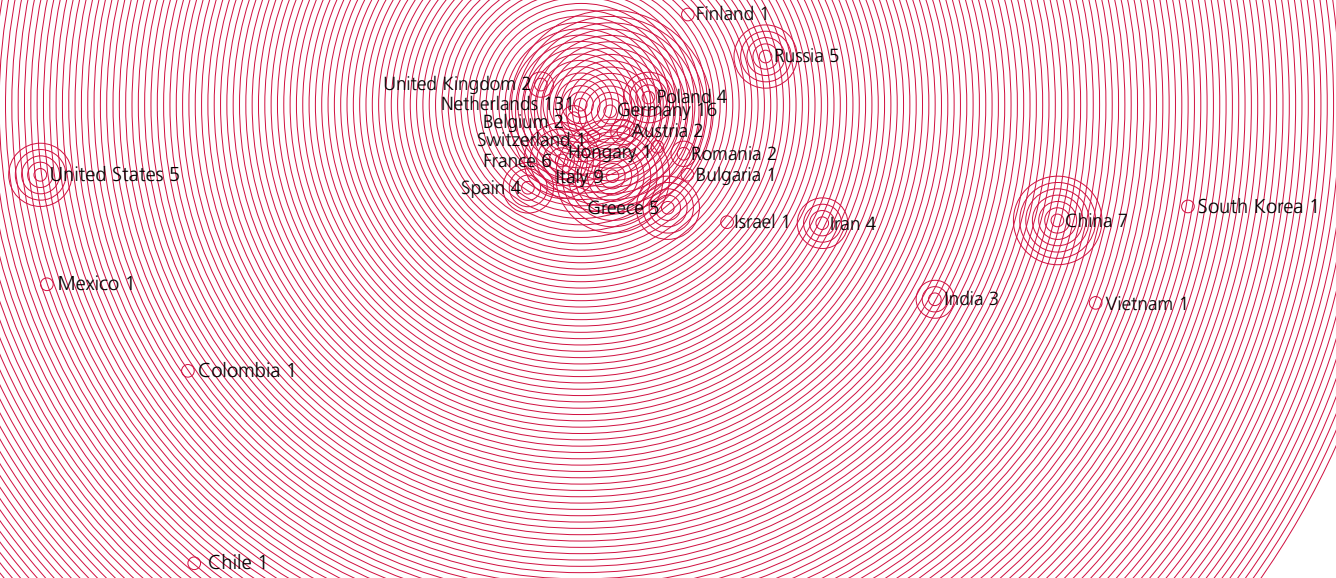
Yfke Dulek presenting at the 'Quantum Software in the Netherlands' symposium

# Quantum

## Secure communication

How can you be sure that a message is, in fact, from the person you think it is from? The sender's location might provide an answer. Although classic location-based methods were already proven to be unsafe, location-based quantum cryptography still seemed to have a chance. However, CWI researchers now studied quantum attacks with teleportation techniques, and showed that some of the location-based protocols were unsafe even from practical attacks (i.e. attacks with a realistic number of entangled states). The challenge thus remains to find a truly safe protocol.

## Entanglement

CWI researchers have investigated the impact of quantum mechanics on communication tasks, such as the transmission of information. They found that information transmission can be made more efficient using quantum entanglement. To quantify the impact of entanglement, they developed new techniques combining tools from combinatorics and optimization. They found that quantum entanglement can sometimes give an exponential advantage over classical communication systems. The work provides a more unified mathematical framework to study the power of entanglement, which can be used to explore the potentials of future quantum computers.

### Nonlocality

An international team that includes CWI and QuSoft researchers has proven that quantum communication is based on nonlocality. The team provided a universal method which derives a violation of Bell's inequality in every case in which there is a (sufficiently large) quantum communication advantage. This means that whenever quantum communication is more efficient than classical communication, it must be possible to find a nonlocal correlation somewhere. The work deepens the understanding of the link between non-locality and quantum communication protocols.

### 2016 Internet Defense Prize

Léo Ducas (CWI) and three co-authors won the 2016 Internet Defense Prize for their improved cryptosystem 'NewHope', designed to resist attacks by future quantum computers. Quantum computers would have a devastating impact on the security of our current protocols – sometimes referred to as the 'Cryptocalypse'. Google integrated this NewHope into TLS and HTTPS, two security protocols used by web-browsers, as an experiment toward post-quantum security. This was featured in Wired. Facebook created the Internet Defense Prize in 2014 through a partnership with USENIX. It consists of 100,000 dollar.

### Quantum Software Symposium

It is no longer a question of if, but when the quantum computer will come. And when it comes, what will humanity do with it? The scientific field of quantum software is working on answers to this question. In November 2016, the symposium 'Quantum Software in the Netherlands' was organized and hosted by QuSoft, the joint research institute for quantum software, founded by CWI, UvA and VU. The symposium showcased a sample of the diverse topics that quantum software researchers from academia and industry in the Netherlands are working on.

# Facts & figures
## Organogram

2016

### Governing Board

Peter van Laarhoven
Anton Franken, HU University of Applied Sciences Utrecht
Lorike Hagdorn
Frank den Hollander, Leiden University
John Koster, ASML
Rineke Verbrugge, University of Groningen

N𝑊O
Netherlands Organisation for Scientific Research

### General Director

Jos Baeten

Scientific
Advisory
Committee

### Management Team

Dick Broekhuis
Lynda Hardman
Han La Poutré
Monique Laurent

### Service Departments

**Communication**
Peter Hildering

**Financial Administration**
Edwin de Boer

**Information & Documentation**
Lieke Schultze

**IT & Facilities**
Niels Nes

**Personnel & Organization**
Angelique Schilder

**Secretariat**
Hans Hidskes

### Research Groups

| | | |
|---|---|---|
| **Algorithms & Complexity** | A&C | Harry Buhrman |
| **Database Architectures** | DA | Stefan Manegold |
| **Information Access** | IA | Jacco van Ossenbruggen |
| **Life Sciences** | LS | Gunnar Klau |
| **Machine Learning** | ML | Peter Grünwald |
| *supervised by Lynda Hardman* | | |
| | | |
| **Computational Imaging** | CI | Joost Batenburg |
| **Distributed & Interactive Systems** | DIS | Pablo César |
| **Formal Methods** | FM | Frank de Boer |
| **Intelligent and Autonomous Systems** | IAS | Eric Pauwels |
| **Software Analysis & Transformation** | SWAT | Jurgen Vinju |
| *supervised by Han La Poutré* | | |
| | | |
| **Cryptology** | CR | Ronald Cramer |
| **Multiscale Dynamics** | MD | Ute Ebert |
| **Networks & Optimization** | N&O | Guido Schäfer |
| **Scientific Computing** | SC | Daan Crommelin |
| **Stochastics** | ST | Bert Zwart |
| *supervised by Monique Laurent* | | |