Annual Report CogniGron 2020
Annual Report
CogniGron
2020
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CogniGron has finished the third year of its existence, and what a year!

The pandemic has forced us to stop scientific visits, one of the CogniGron jewels, and the number of discussion meetings and seminars has been reduced due to the saturation of online meetings that we have experienced. Most of us had to dedicate additional time to teaching in a completely new way, as well as to coaching our group members, especially the youngest ones, dealing with the uncertainty about getting their degrees on time and non-optimal personal situations. Particularly difficult it has been for the new staff and students, who had just arrived or were arriving in Groningen when the social distancing began and have had to initiate their contacts virtually and start their labs, but also finding houses or schools, under very challenging circumstances. Especially for those, we cannot wait to get back to normal so that we can have coffee regularly together while talking science face to face.

Despite all the difficulties, in 2020 CogniGron has continued its groundwork. Our PhD students have organized online meetings, inviting the speaker of their wishes and discussed among themselves. They have been able to continue with their projects. Our Program Board meetings have taken place once a month, with the same frequency as in previous years, and we have managed to stay connected. The hiring of new professors has gone on, with online interviews, and in two cases, we have successfully concluded the entire process and appointed new colleagues. We are indeed very close to accomplish the ambitious goal that we set: 12 new professorships on CogniGron-related disciplines. If the pandemic has taught us something, is that life quality and a liveable city are tremendous assets. We are extremely pleased of being able to offer a city like Groningen to our staff.
The scientific and technological interest in cognitive computing is booming all around the world and in this third year, we have put large efforts in connecting with others starting similar initiatives. CogniGron has coordinated an ambitious proposal aimed to lay the mathematical foundations for computing with physical systems, together with the BRAINS centre (University of Twente) and the Universities of Nijmegen, Amsterdam and Eindhoven, organizing more than a dozen joint meetings in 2020. We have also participated in other related national proposals. CogniGron staff and students have joined the European network meetings of the related initiatives MANIC and NEUROTECH.

All in all, one can say that, despite the social distancing, CogniGron has become better connected with a scientific, but also social, environment that shows increasing understanding for the urgent needs of developing energy-efficient ways of computing. A fitting colophon for this year was the Dutch national TV and radio spreading the news of the generous donation that has enabled CogniGron to be a reality.

Steal a look inside on the 2020 CogniGron journey and stay in touch!

Beatriz Noheda, CogniGron Director
CogniGron: Born to Make a Difference
The face of computing is about to change forever. Our society is increasingly dependent on the ever larger and more complex streams of data that we generate, and we are well aware of the game-changing solutions that could be found if we analysed all the data, we have access to in a global, safe and meaningful manner: the Internet of Things (IoT), autonomous driving, rapid disease diagnosis, personalized medical treatments, national security or forecasting of natural disasters are some examples of what the future may bring.

Existing computer technology is, however, not well equipped to extract useful information from unstructured data, resulting in a highly inefficient process. Supercomputers are needed to handle big data and this has already led to the IT sector being responsible for over 10% of world energy consumption. Therefore, we need new computers that can view, prioritize, combine and analyse data, as well as generate new suggestions, using only a small portion of the energy consumption of the current technology. To achieve this goal, the human brain and its amazingly energy-efficient ability for pattern recognition and information processing has been used as inspiration to develop what is known as the neuromorphic or cognitive computer.

A holistic approach that coordinates efforts in materials science, physics, mathematics, computer science and artificial intelligence is needed to achieve a breakthrough in the field. To this end, the University of Groningen has created the Groningen Cognitive Systems and Materials Centre, CogniGron for short, to make the necessary fundamental breakthroughs. The efforts of different disciplines are combined here, with the goal of developing novel architectures for cognitive computing.

CogniGron Scope

The era of Moore’s law, which predicts the doubling of processing power for computers every two years, has come to an end, and we are reaching the physical limits of device miniaturization that can be achieved with the current technology. The emergence of the internet in the mid-1990s has ultimately shaped a new era. Digitized or digital information can easily be shared worldwide via the touch of a button and the internet also provides automated access to huge collections of data. The rapid increase in the use of sensors and the rise of the Internet of Things also provide big sources of streaming data that will open a wealth of new application perspectives.

Extracting information from this deluge of digital data requires new methods that can deal with uncertainty and variability in the data, such as deep learning, which allows the detection, classification and prediction of patterns in data. This can be used, for example, for facial recognition in video surveillance, recognition of traffic patterns in camera data for self-driving cars or the prediction of epidemics based on Google search requests for specific symptoms. Advanced computer technology is essential, moreover, to make further steps forward in industry, science or society at large today.
Currently, successful methods from the field of artificial intelligence rely on neural networks or other brain-inspired algorithms and software. These are then implemented on traditional hardware (a computer) that is not optimized for neural functionality and also lacks plasticity, that is, the ability to learn. This results in a very high energy demand for the efficient handling of data and has led to the current energy consumption of the Information and Communication Technology (ICT) field accounting for 10% of world electricity consumption. Consequently, there is a need to process information/computation more efficiently but also to develop the hardware to do so.

Current computer technology demands so much power because information needs to be continuously shuttled between the memory and the processing units. The most energy-efficient system on earth is our brain. This is mainly due to the fact that neurons, and the synaptic connections between them, are both memory and processing units. Although computers can make a single calculation faster and more accurately than our brain, our brain can make more calculations per second than the fastest supercomputer. Moreover, our brain is more efficient in pattern recognition and is able to incorporate sensation in the computational process. In addition, our brain has the ability to adapt (i.e., plasticity), which allows for learning. More importantly, our brain does this only at a fraction of the energy consumption required by a supercomputer: a system that can approach the cognitive functioning of a human being consumes ~80 kW, both for computing and communication functions. By comparison, the human brain with around 9x10^10 neurons and 1.5x10^14 connections (synapses) consumes less energy than a light bulb (20 W).

This means that performance improvement for information processing by several orders of magnitude is possible. In this context, it is obvious that significant investments in science and technology are needed to address the future demands of cognitive computing.

CogniGron Mission

Technological and theoretical innovations are needed to advance the field of cognitive computing. Therefore, CogniGron is creating the conditions for researchers from materials science (physics and chemistry), computer science, artificial intelligence and mathematics to work closely together with a common mission: to develop materials-centred systems paradigms for cognitive computing based on modelling and learning at all levels: from materials that can learn to devices, circuits and algorithms.

The main goal of CogniGron is to create self-learning materials that will perform the tasks that are currently assigned to thousands of transistors and complex algorithms in a more efficient and straightforward manner, thereby forming the basis for a new generation of computer platforms for cognitive applications, such as pattern recognition and analysis of complex data. To the best of our knowledge, CogniGron is the first initiative of such a kind that unites expertise from the disciplines of physics, materials science, mathematics, computer science and artificial intelligence.
Our programme in cognitive systems and materials aims to discover and develop physical building blocks (i.e., materials) with intrinsic cognitive functionality via cross-linked networks at the nanoscale, allowing more efficient and denser circuits than those of state-of-the-art solutions (e.g., the neuromorphic chip TrueNorth™). CogniGron will also investigate and design the optimal implementation of such new material structures at the system level.

Management Team
The Scientific Director, the Programme Board and the Coordinating Office form the daily management team of Groningen Cognitive Systems and Materials. The Supervisory Board is responsible for long-term strategic planning, in collaboration with the Programme Board.

- The **Scientific Director** is responsible for the scientific programme and chairs the Programme Board. The director functions as the official representative of the centre.
- The **Programme Board** is responsible for determining scientific strategy, for the daily running of the scientific programme, the allocation of the budget, as well as the recruitment of new staff.
- The **Supervisory Board** approves the budget and, in collaboration with the Programme Board, reviews the long-term strategy of the programme on a yearly basis. It also supervises and discusses significant changes in focus and implementation with the Programme Board.
- The **Coordinating Office** assists the Scientific Director and the Programme Board in all aspects of management, outreach and communication activities.

CogniGron also has an international **Scientific Advisory Panel**. The role of the Scientific Advisory Panel is to advise the Scientific Director and the Programme Board on the scientific merits of research plans and assist in delineating new scientific directions.

Programme Board
The Programme Board is chaired by the **Scientific Director**. The founding Scientific Director of CogniGron is Prof. Beatriz Noheda.

Beatriz Noheda received her PhD in Physics from the UAM in Madrid. After holding various positions at the Saarland University, the Clarendon Laboratory in Oxford, the Brookhaven National Lab in New York and the Vrije Universiteit in Amsterdam, in 2003 she was awarded a Rosalind Franklin Fellowship by the University of Groningen, where she is now Full Professor. Noheda is a Fellow of the American Physical Society and recipient of the IEEE Robert E. Newnham Ferroelectrics Award. She has served as member of numerous national and international committees and several editorial boards. She is the author of more than 100 publications and receives more than 10 invitations a year to speak at international conferences. Noheda’s research focuses on understanding the relationship between the structure and functionality of thin films of ferroelectric, piezoelectric and multiferroic materials, often used as memory elements. Her research, although fundamental in nature, is inspired by two main application areas that she believes will enable the next technological revolution: piezoelectric energy harvesting for low power electronics and the development of novel materials for adaptable electronics and neuromorphic computing.
The Programme Board includes the following members:

Prof. dr. Tamalika Banerjee  
Professor Physics of Nanodevices, University of Groningen.

Prof. dr. Kanat Camlibel  
Associate Professor Systems and Control and vice-chair of the Bernoulli Institute for Mathematics, Computer Science and Artificial Intelligence, University of Groningen.

Prof. dr. Georgi Gaydadjiev  
Professor Innovative Computer Architectures

Prof. dr. Maria Antonietta Loi  
Professor Photophysics and Optoelectronics.

Prof. dr. Lambert Schomaker  
Professor Artificial Intelligence, University of Groningen.

Prof. dr. Niels Taatgen  
Professor Artificial Intelligence and Chair of the Board Bernoulli Institute for Mathematics, Computer Science and Artificial Intelligence, University of Groningen.

Prof. dr. ir. Caspar van der Wal  
Professor Physics of Quantum Devices and Director Zernike Institute for Advanced Materials, University of Groningen.

Prof. dr. ir. Ton Engbersen - Advisor to the Program Board  
University of Groningen, Netherlands

Changes to CogniGron Program Board  
In 2020 Prof. dr. Georgi Gaydadjiev replaced Prof. Jos Roerdink, as member of the Program Board. Prof. dr. Jos Roerdink retired this year from his positions as Professor Scientific Visualization and Computer Graphics and Director Bernoulli Institute for Mathematics, Computer Science and Artificial Intelligence, University of Groningen. Prof. dr. Jos Roerdink has been a key contributor for the realization of CogniGron from the start and he is co-responsible for the successes obtained thus far. CogniGron would like to thank Jos for all the efforts in getting CogniGron where it is today. We will miss Jos Roerdink but wish him all the best for the future.

Prof. dr. Jos Roerdink is substituted in the program board by Prof. dr. Georgi Gaydadjiev (Professor Innovative Computer Architectures), one of our new members, as the computer science representative.
Supervisory Board

Drs. Hans Biemans
Member of the Board of the University of Groningen

Prof. dr. Jasper Knoester
Dean of the Faculty of Science and Engineering, University of Groningen.

Dr. mr. Esther Marije Klop
Managing director of the Faculty of Science and Engineering, University of Groningen.

Changes to CogniGron Supervisory Board
In 2020 Dr. Dick Veldhuis, former managing director of the Faculty of Science and Engineering (University of Groningen) and member of the CogniGron Supervisory Board retired. He has been replaced, both at the Faculty as well as in the CogniGron Supervisory Board, by Dr, Esther Marije Klop. We would like to thank Dick for all his efforts and wish him all the best for the future.

Coordinating Office

Dr. Jasper van der Velde
Scientific Coordinator CogniGron, University of Groningen.

Scientific Advisory Panel

Prof. dr. Giacomo Indiveri
Professor Neuromorphic Cognitive Systems and director Institute of Neuroinformatics
UZH / ETH Zurich, Switzerland

Prof. dr. Julie Grollier
Professor Nanodevices for Bio-Inspired Computing and chair of the interdisciplinary research network GDR BioComp
CNRS/Thales, France

Dr. Heike Riel
IBM Fellow, Department Head Science & Technology
IBM Zurich, Switzerland

Prof. dr. Ivan Schuller
Professor Nanoscience and director QMEENC (Quantum Materials for Energy Efficient Neuromorphic Computing)
Department of Physics and Centre for Advanced Nanoscience, University of California, San Diego
Prof. dr. Rainer Waser
Professor of Electrical Engineering and Information Technology at RWTH Aachen University, Germany and director Peter Grünberg Institute, Julich, Germany

Dr. Yoeri van de Burgt
Assistant Professor in the Microsystems group at TU/e as well as a member of the Institute of Complex Molecular Studies (ICMS) 
TU/Eindhoven, Netherlands

Prof. dr. ir. Wilfred van der Wiel
Professor of Nano Electronics and director centre for Brain-Inspired Electronics (BRAINS) 
University of Twente, Netherlands

Prof. dr. Chris Eliasmith
Professor Philosophy and Systems Design Engineering, and cross-appointed to Computer Science and director Centre for Theoretical Neuroscience 
University of Waterloo, Canada

Prof. dr. Susan Stepney
Professor of Computer Science 
University of York, United Kingdom

The daily management team of CogniGron.
The minds of CogniGron
Materials with nanoscale functionality
- Oxide electronics
- Carbon electronics
- Molecular electronics
- Spintronics
- Valleytronics
- Phase change materials
- Memristors
- Optoelectronics
- Ionic transport

P1. Cognitive devices
P2. Neuromorphic circuit design
P3. Computational neuroscience

- Machine learning
- Computer vision
- Neuroscience
- Network behaviour
- Neuromorphic computing
- Cognition

P4. Multi-Agent Decision Making
P5. Continuous machine learning
P6. Innovative computer architectures
P7. Computer networks

- Network visualization
- Systems engineering
- Neuromorphic computing
- Image processing/Computer vision
- Pattern recognition/Machine learning

P8. Theory of computation
P9. Topological data analysis and Data Science

- Complex networks
- Dynamical systems
- Statistical networks
- Statistical mechanics
- Materials modeling
- Computer algebra
- Network synthesis theory

Material Science

Artificial Intelligence

Mathematics

Computer Science
**In-house Expertise**

The strength and uniqueness of CogniGron lies in the physical systems that are investigated (with scalability potential beyond current solutions) and in the multidisciplinary character of the approach. Therefore, collaborations beyond disciplinary boundaries are a number one priority. CogniGron brings together expertise from two prominent institutes within the Faculty of Science and Engineering, the Zernike Institute for Advanced Materials and the Bernoulli Institute for Mathematics, Computer Science and Artificial Intelligence, building on their strengths in various disciplines: materials science, physics, mathematics, computer science and artificial intelligence. Thereby, CogniGron is creating an environment that encourages creativity and open communication to solve scientific questions more efficiently.

Figure 1 presents the existing expertise related to CogniGron and the relevant disciplines, highlighting the excellent position of CogniGron to make progress in the field of cognitive computing. Over the last two years, CogniGron has attracted new expertise on the borders of various disciplines, aiming to increase the synergy and collaborative efforts and providing a communicative bridge between the existing expertise in materials science, AI, mathematics and computer science.

As mentioned above, two institutes within the Faculty of Science and Engineering have taken on a leading role, bringing the following expertise with them:

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**On the left page Figure 1.**

*Sketch of the originally existing expertise within the four disciplines involved in CogniGron (four circles and black font topics), as well as that of the new professor positions (P1-P12), with interdisciplinary character (in red font), The new profiles are located in between the disciplines whose interaction they aim to strengthen (represented by the overlapping areas). The themes that are of common interest are displayed in the centre of the figure.*
The initial guidelines for CogniGron defined its focus on ‘Cognitive Materials’. Several material systems and areas of expertise were already being studied within the Zernike Institute. The researchers working on these topics are therefore central participants, with leading roles in current research. The materials science contributions aim to explore, study and further design (opto-) electronic materials that can both transfer signals over short timescales and exhibit learning effects over long timescales (e.g., as is present in established memristor functionality). Thereby, the material is suited to the cognitive processing of information, with learning features (adaptivity/plasticity). The long-term learning dynamics may come from effects such as ion displacement and phase changes, while short-term signal transfer typically concerns electronic or optical transport properties. Operating modes with low-energy consumption and toggling (gradual) between learning modes and operational modes, may occur via the tuning of the spiked character of signals or via the gating of field-effects in the material.

We aim to explore this functionality in various materials systems and devices: i) where both aspects are intrinsically present at the nanoscale within a material; ii) in hybrid systems where part of the functionality is in the material, while additional transistors are present for feedback routes and tuning; iii) through a fully device-based approach, particularly relevant to devices that have the prospect of dense integration and very low power consumption. In this regard, we are building on our expertise in materials with tuneable conducting domain walls, skyrmions, functionalized carbon nanotubes, phase change or ferroic materials, as well as expertise on optoelectronics, spintronics, thermoelectrics, polymer self-assembly, nano-ionic and device physics.

Materials Science Principal Investigators:

Prof. dr. Tamalika Banerjee
Spintronics of Functional Materials

Prof. dr. Elisabetta Chicca
Bio-Inspired Circuits and Systems

Prof. Dr. Maria Loi
Photophysics and Opto-Electronics

Prof. dr. ir. Bart Kooi
Nanostructured Materials and Interfaces

Prof. dr. Beatriz Noheda
Nanostructures of Functional Oxides

Prof. dr. George Palasantzas
Physics - Surface interactions and Nanostructures
Artificial Intelligence Expertise

The University of Groningen holds a strong position in artificial intelligence (knowledge-based and multi-agent systems), pattern recognition/machine learning and cognitive modelling/data-science engineering. We have expertise in neural networks, both in artificial and natural systems, in cognitive neuro-scientific modelling and computational neuroscience. Problems in cognitive systems range from analysing the response of the computing materials to high-level cognitive mechanisms and applications.

In recent years, the availability of large data sets and computing power have led to a revolution in machine learning, notably in the area of ‘Deep Learning’ with neural networks (Bengio, 2009; Bengio et al., 2015). Improvements in learning algorithms now allow for neural networks with more layers and parameters (weights) than ever before. For patterns in 2D or 3D arrays, the use of convolution kernels allows a saving in the number of coefficients and a gain in terms of robustness against pattern variation. The concept of a ‘universal function approximator’ has been mathematically supported (Cybenko, 1989; Hornik, 1999).

This state of the art leads to opportunities and challenges. Deep learning now allows the detection, classification and prediction of spatiotemporal patterns in continuous and discrete data. This allows for a functionality that is now called Cognitive Computing, aimed at uncovering meaningful knowledge from raw data. However, there are also several challenges. First, it should be noted that current neural-networking methods are implemented on Turing/Von Neuman machines with a very high-energy demand, both for computing and communication functions. At the same time, the human brain, with 9x1010 neurons (1.5x1014 connections), uses less energy than a light bulb. Current GPUs for neural-network training may be 1000 Watts each, and their information-processing capacity is still limited in comparison to the human brain. Notably, a snapshot of electrical brain activity will reveal that most neurons are silent. The neuron can be considered a spike oscillator (point-process generator), firing only when necessary.

To discover and exploit new materials with nonlinearity and adaptive connectivity, it is necessary to determine the fundamental classes of computing that are suitable candidates for neuromorphic computing, using both mathematical theory and simulation. Finally, despite the success of deep learning, there are theoretical and practical challenges: How do we prevent and detect
inappropriate instances of learned models? How do we learn from raw data with a minimum of training examples? In close cooperation with the materials scientists, we will develop models and methods facilitating the search for materials that are suitable for neural computing due to their electrical nonlinearity and ability for trace formation. In this way, we can cover the full range from low-level modelling to cognitive principles. Our strong national and international connections with researchers at the CWI (Centrum voor Wiskunde en Informatica) in Amsterdam (Sander Bohté) and at the University of Waterloo (Chris Eliasmith, member of our Advisory board) are highly beneficial in this endeavour.

Artificial Intelligence Principal Investigators:

Prof. dr. Sander Bohté
Neural Computation

Dr. Jelmer Borst
Artificial Intelligence

Prof. dr. Davide Grossi
Cognitive Multiagent Systems

Prof. dr. Herbert Jaeger
Computation in Cognitive Materials

Prof. dr. Lambert Schomaker
Artificial Intelligence

Prof. dr. Niels Taatgen
Artificial Intelligence

Dr. Marieke van Vugt
Cognitive Modelling

Computer Science Expertise

In terms of its existing expertise, Computer Science at the University of Groningen is well positioned to make a significant contribution to CogniGron. There are several groups working in Image Processing & Computer Vision that are developing state-of-the-art morphological image operators for feature extraction and description from very large images and image sequences. This expertise can be harnessed to develop efficient image analysis algorithms to analyse conductivity levels and conduction paths in images of nanomaterials.
Computer Science has a long tradition in developing biologically motivated and brain-inspired pattern recognition and machine-learning methods, which is directly relevant to Cognitive Computing. Expertise in Computer Graphics, Visualization and Visual Analytics can be applied to the visualization of computational infrastructure (system, pipelines and networks), processes and data in order to support the interactive design of cognitive materials and gain insight into the complex processes and structures involved. Systems engineering expertise is available for the design of very complex, scalable and/or distributed systems-of-systems, such as cognitive systems that comprise heterogeneous and operationally independent constituent systems.

In Fundamental Computing, the expertise covers areas such as logic, discrete structures, advanced algorithms and data structures, and the formal modelling of communicating systems. This knowledge is needed to develop new computing paradigms, algorithms and programs for the new cognitive systems, and to understand the computational complexity of such systems in a precise mathematical sense.

There are also cross-links with complementary expertise in AI in relation to machine learning, automated reasoning and human-computer interaction. Collaboration with the materials scientists has been established for the design of cognitive materials (efficient image analysis algorithms for analysing conductivity levels and conduction paths during network training). Other direct contributions will involve the use of machine learning and pattern recognition in cognitive system design, interactive network and system visualization and parameter inference in complex systems.

Computer Science Principal Investigators:

Prof. dr. Michael Biehl
Intelligent Systems

Prof. dr. ir. Georgi Gaydadjiev
Innovative Computer Architecture

Prof. dr. Boris Koldehofe
Computer Networks

Prof. dr. Jos Roerdink
Scientific Visualization and Computer Graphics

Dr. Michael Wilkinson
Digital image analysis and computer vision
Mathematics Expertise

The mathematics expertise present at the University of Groningen covers a broad spectrum (Statistics & Stochastics, Systems & Control, Computational Mathematics and Dynamical Systems). Mathematics is already closely connected to the computer sciences, for example at the systems and engineering level, through Systems & Control. Other contributions to the Centre involve the modelling of the large-scale behaviour of stochastic systems; control analysis of large-scale complex systems; and large-scale simulations and numerical analysis.

An overarching theme of the mathematics department is the analysis and control of dynamic systems. These systems can be autonomous or open to interaction with other systems. The subject involves a variety of mathematical theories ranging from analysis and algebra to geometry and measure theory. Statistical, stochastic and algebraic aspects of network dynamics also play an important role. Dynamic systems theory and systems and control theory are used throughout the natural and engineering sciences, from mathematical physics to the earth and life sciences, and from fluid dynamics to power networks. Another important theme across the department is computational and algorithmic mathematics, linking mathematical and physical modelling, the simulation of dynamics, geometric computing and analysing networks.

Dynamic systems theory is concerned with the behaviour of systems that evolve over time. Above all, this concerns the long-term behaviour that comprises stationary, periodic, multi-periodic and chaotic dynamics, but transient behaviour is also of interest. Moreover, bifurcations or transitions between asymptotic states – in particular transitions between regular and chaotic motions – under the variation of parameters are of great importance. Mathematics in Groningen is developing mathematical tools using methods from analysis, geometry and measure theory to grasp, study and develop the structures involved. Moreover, it is developing methods to detect and understand the dynamics in specific models, employing numerical and visualization tools and computer algebra.

Algorithmic and constructive methods also play an important role. If the number of degrees of freedom is huge, then such systems are best described by statistical means. Statistical mechanics deals with the question of how global observables, such as temperature, can be explained based on microscopic behaviour. There is a close relationship with dynamic systems theory, in particular with regard to random and chaotic behaviour and what are called ‘non-equilibrium systems’. When viewing such systems from an experimental point of view, the old paradigm of many observations relative to the number of predictors is obsolete. New high-dimensional inference methods based on sparsity and borrowing strength have become essential to face such challenges. The analysis, control and optimization of such complex systems are studied in the highly esteemed Systems, Control & Optimization group. There are significant opportunities for close collaboration between materials engineering and mathematics in Groningen, both through fundamental mathematical research and in collaboration with colleagues from engineering and the natural sciences.
Computer Science Principal Investigators:

**Dr. Bart Besselink**  
Systems and Control Theory

**Prof. dr. Kanat Camlibel**  
Systems and Control Theory

**Dr. Christian Hirsch**  
Topological Data Analysis and Data Science

**Prof. dr. Arjan van der Schaft**  
Applied Analysis

**Dr. Alef Sterk**  
Dynamical Systems Theory

**Prof. dr. Holger Waalkens**  
Dynamical Systems Theory

**Prof. dr. ir. Fred Wubs**  
Numerical Mathematics
The Young Scientists Driving CogniGron

PhD Students and Postdoctoral Researchers
The staff members are encouraged to submit joint PhD proposals with PIs from different disciplines. These proposals lead to CogniGron-funded PhD positions. Brainstorming and discussion sessions are organized to develop the research plans for these positions. PhD students funded by other means but whose work is closely related to CogniGron also take part in CogniGron activities and are listed below, together with their research theme.

CogniGron funded

Dr. Shuyan Shao (2018-2019)
Organic memristors
Photophysics and Opto-Electronics

Dr. Oleksandr Zheliuk (2020-2021)
Enhanced Learning Efficiency of Synaptic Devices for Neuromorphic Computations
Device Physics of Complex Materials

Anouk Goossens (2018-2021)
Nanoscale memristors for new computing paradigms
Spintronics of Functional Materials

Ruben Hamming Green (2021-2025)
Combined volatile/non-volatile memristive ferroelectric arrays.
Nanostructures of Functional Oxides

Anne-Men Huijzer (2019-2023)
Memristor Networks
Systems and Control Theory Research Group

Azminul Jaman (2020-2024)
Towards a cognitive computer architecture based on memristive devices: developing Short- and Long-Term Memory
Spintronics of Functional Materials

Julien van der Ree (2020-2024)
Nanoparticle based percolating networks towards neuromorphic computing
Physics - Surface interactions and Nanostructures
Jan Rieck (2019-2019)
Memristor networks from self-assembled domain walls in oxides
Nanostructures of Functional Oxides

Saad Saleh (2020-2024)
New switching architectures with memristors for neuromorphic computing
Computer Networks

Thomas Tiotto (2020-2024)
Towards a cognitive computer architecture based on memristive devices: developing Short- and Long-Term Memory
Artificial Intelligence

Karolina Tran (2020-2024)
Carbon nanotube-based neuromorphic electronics
Photophysics and Optoelectronics

Daniel Willhalm (2020-2024)
Large deviations in stochastic geometry
Topological Data Analysis and Data Science

Associated PhD students and Postdocs

Dr. Celestine Lawrence (2020-2023)
Theory of neuromorphic computing – This project has received funding from the EU Horizon 2020 Research and Innovation programme under the grant agreement (Grant agreement No. 871371).
Computing in Cognitive Materials

Dr. Cynthia Quinteros (2018-2020)
Exploration of ferroic domain walls assemblies in BiFeO3 for neuromorphic implementations
Nanostructures of Functional Oxides

Dr. Pavan Nukala (2018-2020)
Multiscale investigations on Si-integrable Ferroelectric Hafnia-Zirconia systems (FERHAZ) – This project has received funding from the EU’s Horizon 2020 programme under the Marie Sklodowska-Curie Actions Individual Fellowships (MSCA-IF-2017) (Grant agreement No. 794954)
Nanostructures of Functional Oxides

Sanne Berg (2018-2021)
Self-assembled networks of functional metal oxides for neuromorphic materials
Nanostructures of Functional Oxides
Silvia Damerio (2018-2021)
**Thin films of modulated multiferroic oxides as adaptable systems for cognitive computing**
Nanostructures of Functional Oxides

Philipp Klein (2018-2022)
**Learning in neuromorphic systems**
Bio-inspired Circuits and Systems - external PhD student
(employed at Bielefeld University, Germany)

Alexander Kugele (2018-2022)
**Event-based Vision for Automated Driving**
Bio-inspired Circuits and Systems - external PhD student (employed at Bielefeld University, Germany)

Mian Li (2020-2024)
**Morphological Image Analysis of Conduction Maps** – This project has received funding from the EU’s Horizon 2020 programme under the Marie Skłodowska-Curie grant agreement (Grant agreement No. 861153)
Scientific Visualization and Computer Graphics

Michele Mastella (2020-2024)
**Neuromorphic Embedded Processing for Touch** – This project has received funding from the European Research Council (ERC) under the European Union’s Horizon 2020 research and innovation programme (Grant agreement No. 813713)
Bio-inspired Circuits and Systems

Guillaume Pourcel (2020-2024)
**Theory of neuromorphic computing** – This project has received funding from the EU Horizon 2020 Research and Innovation programme under the grant agreement (Grant agreement No. 871371).
Computing in Cognitive Materials

Ole Richter (2020-2024)
**Neuromorphic Integrated Systems for network stability and homeostasis**
Bio-inspired Circuits and Systems

Jan Rieck (2020-2024)
**Memristor networks from self-assembled domain walls in oxides** – This project has received funding from the EU’s Horizon 2020 programme under the Marie Skłodowska-Curie grant agreement (Grant agreement No. 861153)
Nanostructures of Functional Oxides
Mart Salverda (2018-2019)
Neuromorphic phenomena in thin film perovskite oxides
Nanostructures of Functional Oxides

Thorben Schoepe (2018-2022)
Neuromorphic Sensorimotor Systems
Bio-inspired Circuits and Systems - external PhD student
(employed at Bielefeld University, Germany)

Willian Soares Girão (2020-2023)
Neuromorphic Circuits for Novel Devices – This project has received funding from the EU’s Horizon 2020 programme under the Marie Skłodowska-Curie grant agreement (Grant agreement No 861153)
Bio-inspired Circuits and Systems

Wytse Talsma (2018-2020)
Neuroplasticity in neural networks utilising semiconducting single-walled carbon nanotube inks
Photophysics and Opto-Electronics

Master Students
In addition, several Master projects have been designed to test CogniGron ideas and their suitability to become PhD projects. The Master students involved in CogniGron for the year 2020 are listed below:

Manvi Agarwal (supervisor: Lambert Schomaker & second supervisor: Tamalika Banerjee)
Credit assignment for surrogate-gradient learning rules in spiking neural networks
Artificial Intelligence

Eric Brand (supervisor: Beatriz Noheda)
Ferroelectric field effect transistors (FeFETs) for memresistive applications
Nanostructures of Functional Oxides

Swaraj Dalmia (supervisor: Lambert Schomaker)
Constraint-Based Circuit Design Using Generative Adversarial Networks
Artificial Intelligence

Pilani-Goa – Exchange student BITS, India (supervisor: Tamalika Banerjee)
Nb doped SrTiO3 memristors as prospective devices for neuromorphic architectures
Spintronics of Functional Materials
L. de Jonge (supervisor: Christian Hirsch)
Percolation in reinforcement-based models for synaptic plasticity
Topological Data Analysis and Data Science

Miina Leiviska (supervisor: Tamalika Banerjee)
Investigating the magnetic properties of SrRuO3 in complex oxide heterostructures for spin-orbit torque applications
Spintronics of Functional Materials

Avinash Pathapati (supervisor: Lambert Schomaker & second supervisor: Alexander Balatsky (Nordita))
Bandgap prediction for molecular crystals using Geometric Deep learning
Artificial Intelligence

Daan Sijbring (supervisor: Jelmer Borst)
Fine-Tuning Input Selection while Learning Associative Memories in a Spiking Neural Network
Artificial Intelligence

Vasiliki Vamvaka (supervisor: Bart Besselink)
Synchronization in electrical circuits with memristive
Engineering Mathematics

Jie Yan (supervisor: Lambert Schomaker/ Yulia Sandamirskaya (ETH Zurich))
Path Integration and Map Learning with a Spiking Neural Network for Neuromorphic Computing
Artificial Intelligence

Bachelor’s Students
As with the Master projects, also several Bachelor projects have been designed to test CogniGron ideas. The Bachelor students involved in CogniGron for the year 2020 are listed below:

Loran Knol (supervisor: Jelmer Borst)
Dynamic coding in a large-scale, functional, spiking-neuron model
Artificial Intelligence

Arsenity Nikonov (supervisor: Jelmer Borst & second supervisor: Niels Taatgen)
Simulating Prescribed Error Sensitivity learning using memristors
Artificial Intelligence

Chiel Wijs (supervisor: Jelmer Borst)
Dynamic coding in a neural model of activity-silent working memory
Artificial Intelligence
CogniGron Welcomes New Professors
CogniGron is an interdisciplinary programme that takes advantage of know-how in materials synthesis and characterization, device design, self-organizing networks, complex and emergent behaviour, network analysis, control design, phase transitions, bifurcations and tipping points in deterministic systems, randomness and stochastic behaviour, adaptability and learning strategies and the theory of computing. This know-how comes from the disciplines of physics, mathematics, computer science and artificial intelligence, and is applied to one common goal: the design of novel physical platforms for low power cognitive computing.

Figure 1 highlights how Groningen is excellently positioned for the development of this programme. However, to increase the synergy and raise collaborative efforts to the next level, we have created twelve new professor positions. These new staff members will provide additional links and bridge existing gaps in order to bolster interaction between our experts in materials science, AI, mathematics and computer science. Selecting these new colleagues has been one of the main focuses of CogniGron since its official start.

Visionary academics were invited to apply for one of the following positions:

1. Cognitive Devices
2. Neuromorphic Circuit-Design
3. Computational Neuroscience
4. Cognitive Multi-Agent Systems
5. Continuous Machine Learning
6. Innovative Computer Architectures
7. Computer Networks
8. Theory of Computation
9. Topological Data Analysis and Data Science
10. Computational Mathematics
11. Engineering Mathematics
12. Stochastics

We are delighted to report that highly talented staff have already been appointed for nine of these positions.
Introduction of New CogniGron Staff

Significant efforts have been made to advertise the CogniGron positions to reach as many people as possible and ensure that excellent candidates for the various vacant positions were aware of the opportunity. A general brochure that included the mission of CogniGron and summaries of the vacancies was widely advertised through a range of channels: CogniGron website, the University of Groningen website, Dutch newspapers (4 weekend editions of the NRC and Volkskrant; 8 weeks in Die Zeit online and academics.de/.ch.at for Germany, Austria and Switzerland) and several scientific platforms (NatureJobs, ResearchGate, Academic Transfer, LinkedIn and Academic Positions). The scientific staff of CogniGron were also employed as ambassadors to advertise the positions. Additionally, the scientific coordinator of CogniGron, in close synergy with the HR department of the UG, attended several career fairs for recruitment activities (NatureJobs Career Expo Dusseldorf 2017 and 2018, MIT European Career fair Boston 2018, 2019 and 2020, Nature Careers Expo London 2019 and Faculty of Science and Engineering Career Day 2019).

The following excellent researchers have been appointed have already started in Groningen (in inverse chronological order of their appointments)

Prof. Elisabetta Chicca – Bio-inspired Circuits and Systems research group

Elisabetta Chicca has been appointed as Professor Bio-inspired Circuits and Systems at the Zernike Institute for Advanced Materials within CogniGron. Her position has been designed to bridge the gap between material science, Computer science and Artificial intelligence. Her aim is to identify the principles of neural computation and implement them in fully parallel and low-power neuromorphic systems that offer the opportunity to overcome the limitations of traditional digital architectures. Hereby she develops biologically inspired learning, sensing and acting systems, which allow us to test current theories of neural computation. The physical substrate of these implementations consists of CMOS technology and novel materials.

Elisabetta Chicca obtained a “Laurea” degree (M.Sc.) in Physics from the University of Rome 1 “La Sapienza”, Italy in 1999, a Ph.D. in Natural Science from the Swiss Federal Institute of Technology Zurich (ETHZ, Physics department) and in Neuroscience from the Neuroscience Centre Zurich, in 2006. E. Chicca has carried out her research as a Postdoctoral fellow (2006-2010) and as a Group Leader (2010-2011) at the Institute of Neuroinformatics (University of Zurich and ETH Zurich) working on development of neuromorphic signal processing and sensory systems. From 2011 to 2020 she was leading the Neuromorphic Behaving Systems research group at Bielefeld University (Faculty of Technology and Cognitive Interaction Technology Centre of Excellence, CITEC). In 2020 she was appointed as professor at the University of Groningen leading the Bio-inspired Circuits and Systems research group. Her current interests are in the development of VLSI models of cortical circuits for brain-inspired computation, learning in spiking VLSI neural networks and systems based on memristive device, bio-inspired sensing (olfaction, active electrolocation, audition, visually guided navigation) and motor control.
**Prof. Boris Koldehofe – Computer Networks**

Boris Koldehofe has been appointed as Professor in Computer Networks at the Bernoulli Institute for Mathematics, Computer Science and Artificial Intelligence, within CogniGron. His position has been designed to bridge the expertise gap between mathematics, computer science and Physics. His research contributes to mechanisms and methods for distributed and self-adaptive intelligent systems. This comprises methods and mechanisms that account for i) the tremendous volume of available data, ii) help utilizing resources like the network infrastructure and processing resources efficiently, iii) provide information in a consistent and reliable way, and iv) account for several constraints e.g., privacy of information, quality of data and QoS.

Boris Koldehofe obtained a Diplom in Informatik at Universität des Saarlandes, Saarbrücken, Germany in 1999 and a Licentiate degree of philosophy at Chalmers University of Technology, Göteborg in 2003. He received his Ph.D. degree in 2005 at Chalmers University of Technology, Göteborg – Sweden. Boris Koldehofe has carried out his Postdoctoral research (2005-2006) at the Swiss Federal Institute of Technology in Lausanne (EPFL), Switzerland. Afterwards he became a senior researcher and Lecturer at the Institute for Parallel and Distributed Systems (IPVS) at Universität Stuttgart, Germany, where he headed the Adaptive Communication Systems research group until 2014. From 2014 to 2020 he was appointed as senior researcher and Lecturer, Multimedia Communications Lab (KOM) at the Technische Universität Darmstadt, Germany. Since 2017 he is also the Principal Investigator of the DFG Collaborative Research Centre 1053 MAKI. In 2020 Boris Koldehofe was appointed as professor at the university of Groningen to lead the computer networks research group. His current interest are Networked and Distributed Systems, Middleware and Event-based Systems.
Dr Christian Hirsch – Topological Data Analysis and Data Science

Christian Hirsch has been appointed as an Assistant Professor in Topological Data Analysis and Data Science at the Bernoulli Institute for Mathematics, Computer Science and Artificial Intelligence, within CogniGron. His position has been designed to bridge the expertise gap between mathematics and computer science. Hirsch is especially interested in applying mathematical principles in seemingly unrelated contexts, in collaboration with engineers and physicists. His research interests lie in the domain of spatial random structures, i.e., random structures that come with an embedding into a Euclidean space. These structures give rise to fascinating research questions within mathematics as well as in application domains ranging from materials science to neuroscience. For example, Hirsch is working on random network models to explain phenomena related to synaptic plasticity. Understanding such mechanisms holds the promise of yielding insights not only into the inner workings of learning in the brain, but also into artificial neural networks.

In recent years, topological data analysis has emerged as one of Hirsch’s methods to analyse randomly organized structures in materials science. One of his research goals is to build up a firm statistical underpinning by proving central limit theorems for persistent Betti numbers and related quantities.

Christian Hirsch studied mathematics at LMU Munich, Germany, before pursuing a PhD (Summa Cum Laude) at Ulm University, Germany, on the connectivity and percolation properties of stochastic networks. After obtaining his PhD he held a position as postdoctoral researcher at the WIAS Berlin, Germany, where he applied techniques of stochastic geometry, large deviations and statistical physics in the analysis of next-generation wireless networks. Subsequently, he was a postdoctoral researcher at Aalborg and Munich, Germany, working on more interdisciplinary topics, before he was appointed as an assistant professor at the University of Mannheim, Germany. From 1 January 2020, Christian Hirsch will take up his position as Assistant Professor in Topological Data Analysis and Data Science.
Prof. Georgi Gaydadjiev – Computer Architectures

Georgi Gaydadjiev has been appointed as a Full Professor in Computer Architectures at the Bernoulli Institute for Mathematics, Computer Science and Artificial Intelligence within CogniGron. His position as been designed to bridge the expertise gap between artificial intelligence and computer science. Gaydadjiev is a Computer Engineer with over 30 years of industrial and academic experience. He has worked on various designs of embedded systems (even before such systems were given this name). He has also performed research on Computer Architecture and Microarchitecture for reconfigurable, highly customized and safety critical computing systems. In 2014, Georgi joined Maxeler Technologies Ltd in London, an appointment that led to the creation of Maxeler IoT-Labs BV in Delft. At Maxeler, Georgi led the Dataflow Software Engineering division as one of the company’s vice presidents and focused on the research and development of highly customized High-Performance Computing (HPC) systems. Some of these systems were able to outperform TOP-500 supercomputers in very specific tasks while using only a fraction of the electrical energy required. In August 2019, Georgi joined us as Professor in Innovative Computer Architectures. His focus will be on research in advanced (digital and non-digital), highly customized computing systems, based on cognitive materials and devices.

Georgi Gaydadjiev obtained his degree in control systems engineering at Voenmeh (currently the Baltic State Technical University) in Leningrad, Soviet Union, and subsequently worked designing personal computer I/O peripherals at System Engineering Ltd in Pravetz (Bulgaria). He later joined Pijnenburg Microelectronics and Software in Vught, the Netherlands, working on various designs of embedded systems. One of the products developed by his team won the Design and Engineering showcase award at the Consumer Electronics Show (CES) in Las Vegas in 1999. While working at Pijnenburg M&S, he also enrolled at TU Delft and successfully completed a Master of Science in Electrical Engineering. In 2002, Georgi joined the Computer Engineering (CE) laboratory at the Faculty of Electrical Engineering, Mathematics and Computer Science (EEMCS), TU Delft, as a faculty member. His research was funded by STW, the European Commission, point.one, CenterNovem/BSIK and Google Inc. In 2011, he received a personal grant from the Swedish Research Council (VR) and joined Chalmers University of Technology, holding the professorial chair in Computer Systems Engineering. In 2014, Georgi joined Maxeler Technologies Ltd (London), which led to the creation of Maxeler IoT-Labs BV in Delft in December 2017. At Maxeler, Georgi led the Dataflow Software Engineering division as one of the company’s vice presidents.
Herbert Jaeger has been appointed as a Full Professor in Computation in Cognitive Materials at the Bernoulli Institute for Mathematics, Computer Science and Artificial Intelligence within CogniGron. His position has been designed to bridge the expertise gap between artificial intelligence, computer science and materials science. Jaeger is internationally recognized for pioneering the field of ‘reservoir computing’ (RC). In this non-standard approach to computer chip design, computing can be non-digital and does not necessarily use transistors as basic computing elements. Instead, a randomly structured lump of nonlinear material (possibly nano-scale) is used as a ‘reservoir’ of dynamic phenomena. The input data are fed into this material reservoir and ‘excite’ high-dimensional response dynamics within it, from which the desired output is distilled with machine learning methods. This can be done not only with electrical forms of input signals, but also with optical, chemical, mechanical, or magnetic signals, or mixtures of them. Due to this universality, and also because RC has some fascinating similarities with how biological brains work, reservoir computing has become an important approach to making computing more ‘cognitive’ and also more energy-efficient than is possible with standard digital hardware. Herbert’s research has revolved around questions concerning the modelling of ‘cognitive’ information processing systems.

This quest has led him down a diverse path through classical AI, robotics, signal processing, computational neuroscience, machine learning and neuromorphic computing. In all of these fields, he aims to find mathematically beautiful descriptions and efficient modelling/learning algorithms. For his future work at CogniGron, he wants to assist in the working out of mathematical/algorithmic bridges between the CogniGron pillar disciplines of AI, machine learning, CS, mathematics, materials science and neuroscience. Building bridges between these fields means developing new ‘cross-cultural’ formalisms and models, a wonderful challenge both for the most abstract theoretical/conceptual process of thinking, as well as for the most concretely useful algorithm design.

Herbert Jaeger studied mathematics and psychology at the University of Freiburg and obtained his PhD in Computer Science (Artificial Intelligence) at the University of Bielefeld in 1994. After a five-year postdoctoral fellowship at the German National Research Centre for Computer Science (Sankt Augustin, Germany) he headed the Intelligent Dynamical Systems group at the Fraunhofer Institute for Autonomous Intelligent Systems AIS (Sankt Augustin, Germany). In 2003, he was appointed associate professor for Computational Science at Jacobs University Bremen, where he led the Modelling Intelligent Dynamical Systems (MINDS) group (http://minds.jacobs-university.de/) until his CogniGron appointment as Professor of Computing in Cognitive Materials on 1 August 2019.
Prof. Bart Besselink – Engineering Mathematics

Bart Besselink has been appointed as an Assistant Professor in Engineering Mathematics at the Bernoulli Institute for Mathematics, Computer Science and Artificial Intelligence, within CogniGron. His position has been designed to bridge the expertise gap between mathematics and materials science. Besselink’s research interests are in the analysis and control of large-scale dynamic systems with emphasis on nonlinear systems and model reduction problems. Currently, he focuses on the development of modular techniques for the analysis and control of such systems, including the analysis of large-scale electrical circuits with nonlinear elements such as memristors. Memristive devices are regarded as promising elements for cognitive computing as, first, they have dynamics that make them suitable for acting as synapses in artificial neural networks and, second, have natural nanoscale implementations in specific materials. Within CogniGron, this research line targets the analysis of large-scale electrical circuits with memristive elements as models of neuromorphic materials, with the aim of understanding material behaviour as well as guiding the design of material network structures. Such analysis requires the development of novel mathematical tools to analyse the robustness of electrical circuit behaviour with respect to non-uniformity in the electrical components, then to synthesize the desired behaviour, and finally, study the scalability of such networks.

Bart Besselink received his MSc and PhD degrees in Mechanical Engineering from Eindhoven University of Technology, Eindhoven, the Netherlands, in 2008 and 2012, respectively, both with a focus on systems and control theory. He was a short-term visiting researcher at Tokyo Institute of Technology, Tokyo, Japan, before becoming a postdoctoral researcher at the ACCESS Linnaeus Centre and Department of Automatic Control at KTH Royal Institute of Technology, Stockholm, Sweden, between 2012 and 2016.
Prof. Davide Grossi – Cognitive Multi-Agent Systems

Davide Grossi has been appointed as an Associate Professor in Multi-Agent Decision-making at the Bernoulli Institute for Mathematics, Computer Science and Artificial Intelligence within CogniGron. His position has been designed to bridge the expertise gap between artificial intelligence and computer science. He works on foundational topics in artificial intelligence and multi-agent systems. His main research focus concerns the question: How do different autonomous (human or artificial) entities make good decisions as groups? Examples of processes of this type are elections, referenda, deliberative committees and assemblies, information markets, and consensus protocols. Grossi is currently exploring whether tools from computational economics (e.g., game and social choice theory, network theory) can be used to gain insights into how groups of relatively simple entities (e.g., neurons) can (self-)organize to support computational processes.

Davide Grossi studied Philosophy (with distinction) at the University of Pisa and obtained his PhD in Computer Science at the University of Utrecht in 2007. After undertaking postdoctoral research at the University of Luxembourg and the University of Amsterdam he became a lecturer (assistant professor) in the Department of Computer Science at the University of Liverpool, where he was promoted to senior lecturer (associate professor) in 2015. In 2017, he was appointed associate professor at the Bernoulli Institute for Mathematics, Computer Science and Artificial Intelligence, within CogniGron. Grossi has authored over 60 peer-reviewed articles published in international journals and presented at international conferences, including top-tier journals and conferences in artificial intelligence. He has been the recipient of grants from research agencies in the UK (EPSRC) and the Netherlands (NWO), among other countries.

Two more professors to start in 2021

In 2020 we were able to appoint two more professors; on the “Stochastics” position (Dr. Gilles Bonnet) and the “Theory of Computation” position (Dr. Revantha Ramanayake). Both of which will start during 2021. For two more positions (Cognitive devices and Computational Neuroscience) the process is on the negotiation phase with excellent candidates.
Ongoing Research Projects
Cross-Disciplinary PhD Projects

Staff can participate and contribute to the CogniGron research programme by having a PhD student funded via this programme. A requirement is that staff and team members fully commit to the scientific goals and work plan of CogniGron. In addition, projects that strengthen the collaboration between different disciplines are prioritized. A 4-page proposal is submitted for each PhD. The proposal should clarify how the research directly addresses the main goals of CogniGron and how it will contribute solutions beyond the state of the art. In addition, the proposal should explain how it will make use or enhance the collaboration between different disciplines/institutes. The proposals are reviewed by the CogniGron Supervisory Board and, if needed, the Scientific Advisory Panel of external experts.

Running projects awarded in 2020:

Nanoparticle based percolating networks towards neuromorphic computing
– Awarded in 2020

Nanoparticle (NP) percolating networks exhibit interesting switching behaviour and potentiation in response to applied voltages, which are characteristics of the brain with neurons and synapses. A key feature in metal nanoparticle assemblies is the coexistence of two resistance-switching regimes. One shows complex switching patterns in a small resistance range and is generally associated with a switching activity spread over a network of junctions. The other corresponds to Low-to-High-Resistance bistable switching due to the breaking and reconnection of single junctions. For phase change material NPs, we expect a richer network activity via local amorphous to crystalline phase change transformations. Thus, we could obtain a switching behaviour from both the collective behaviour of nanoparticles and on the level of the individual NPs. The experimental study will be carried in close synergy with the mathematical analysis of synchronization in oscillator networks, which serve as biological models of neurons and cognitive functions implemented by synchronization processes between brain neurons. Here the random geometry will be inspired by the random deposition of NP percolation networks from the physics part, and the connectivity will be determined by the local synchrony of adjacent oscillators in order to mimic the formation and destruction of local conductance junctions in the NP networks. The aim of the mathematics part is to obtain rigorous results on synchrony dependent percolation type phenomena capitalizing from very recent results on models of this type with a simpler network geometry. For the physics study, we will start from metallic NPs that will serve as a reference system. The final objective will be to understand in close synergy with mathematical modelling of synchronization the potentiation behaviour of phase change material NP assemblies around the percolation threshold, where they exhibit complex switching behaviour due to the formation and annihilation of atomic junctions within the network tunnel gaps.

Project leaders: George Palasantzas, Bart Kooi, Holger Waalkens and Daniel Valesin
Running projects awarded before 2020:

‘Nb-doped SrTiO3 memristive interfaces for bio-inspired computing’ – Awarded in 2019
This project, involving researchers from the Zernike Institute for Advanced Materials (Experimental) and the Bernoulli Institute (Computational), will study the physics of interface-based memristive devices on semiconducting SrTiO3 substrates and develop phenomenological models to predict the performance of such devices. Such substrates are versatile in that they possess diverse physical properties, thus offering an important platform for testing and applying new computing models. The novel features of these memristive devices are: i) they are exclusively interface-driven rather than bulk, ii) they exploit electric field effects for low power computing, iii) they exhibit a range of analogue outputs whose phase space can be enhanced by tailoring the interfaces, and iv) they use ferromagnetic metals for interfacing with the semiconductor, thus providing additional opportunities to use spin as an operating variable.

This work will benefit from our recent publication on memristive devices that exhibit co-location of memory storage and processing across the device interface and show differences in their temporal behaviour in response to different voltage pulses. The physics of these memristive devices will be investigated for their variability, reliability, plasticity and stochasticity, both for micron-sized and nanosized devices.

Cognitive abilities characteristic of the human brain can be realized by designing new algorithms that include adjustment of the resistance as well as spin voltage as synaptic weights across these nonlinear circuit elements. The output will be used to mimic a range of arbitrary transfer functions through piecewise approximation, using the different slopes and offsets of the device conductance, in close collaboration with AI researchers at the Bernoulli Institute. Using recent insights from deep neural network learning algorithms, optimization methods will be applied, both for the stochastic design of memristive circuits and for finding reinforcement-based perturbation policies for memristive devices.

Project leaders: Tamalika Banerjee and Lambert Schomaker

‘Towards a cognitive computer architecture based on memristive devices: developing short- and long-term memory’ – Awarded in 2019
The goal of this project is to build a pattern-completion memory, which we believe is a critical component in developing novel cognitive computing architectures. We will accomplish this by building a neural network in which we use memristive devices that will act as synapses, and potentially also as soma. One of the two sub-projects focuses on the development of networks, while the other focuses on the materials.

A critical aspect of the project is strong interaction, because the network-building project strongly depends on the underlying materials and is constrained by them, while the materials project is guided by the needs of the network that will be built out of them. As an interface between the two
projects, circuit boards will be built with memristive devices, but also a microcontroller that can take care of functions that have not yet been realized in memristive devices (e.g., initially, memristors will be used as synapses, but the soma will be simulated by the microcontroller). These circuit boards can be connected to form small networks that can be used to test several network designs, and to explore properties of the memristive circuits that cannot be found by pure simulation.

The first goal of the project is to build a short-term pattern recognition memory, then proceed to a short-term pattern completion memory, and finally a long-term pattern completion memory. Suitable demonstrations will be built for each of these to show potential applicability.

Project leaders: Niels Taatgen, Tamalika Banerjee and Jelmer Borst

‘WALLNET: Memristor networks from self-assembled domain walls in oxides’ – Awarded in 2019
This project aims to investigate materials that self-organize in conducting networks that can transmit signals and host memory elements in a similar way to biological neurons and synapses. The project will focus on thin layers of ferroelastic oxides that exhibit domains (crystalline regions of a material with the same structure but different orientation). The domain walls (DWs) separating these domains have reduced symmetry and offer additional functionality at the nanoscale. In particular, enhanced conductivity has been observed at DWs in otherwise insulating materials, giving rise to networks of conductive paths. The crucial property of such domains and DWs is that they can show ‘memristive’ behaviour, i.e., a dependence of the electrical resistance of a material on the history of the applied stimulus. The collective response of a large number of memristive elements in a network is generally believed to be responsible for brain-like functionality.

The lateral conductivity and connectivity of DW networks have not yet been investigated and this project aims to make progress in this direction. To support the development of DW networks with the desired functionality, we propose to model their electrical responses as the terminal behaviour of an electrical circuit with memristive elements. These models will be used to: i) analyse the robustness of terminal behaviour with respect to non-uniformity in the electrical components, ii) synthesize the desired terminal behaviour and iii) study the scalability of such networks. The goal is twofold. First, this will assist in the interpretation of experimental results on DW networks; and, more importantly, this will offer guidelines for the optimization of DW networks to achieve the desired functionality.

Project leaders: Bart Besselink, Beatriz Noheda and Arjan van der Schaft

CogniGron Fellowships: Announcing a CogniGron-IBM Fellowship
Staff can also participate and contribute to the CogniGron research programme through a PhD student who is working in close collaboration with external partners: preferably industry partners with a strong track record or interest in cognitive systems and materials. The goal of these CogniGron Fellowships is to strengthen interaction with industry. Additionally, it will give the PhD
student the opportunity to take an inside view and collaborate with a world-leading industrial partner on cognitive computing. The primary supervisor will hold a position at the Faculty of Science and Engineering and the PhD degree will be awarded by the University of Groningen.

We are very proud to announce that in 2020 a second CogniGron-Industry fellowship has been awarded. CogniGron will partner up with IBM in this project to work on combined volatile/non-volatile memristive ferroelectric arrays.

Running projects awarded in 2020:

*CogniGron IBM Fellowship project: Combined volatile/non-volatile memristive ferroelectric arrays. COFERRAY – Awarded in 2020*

The project aims to develop synaptic devices based on ferroelectric materials. In particular, the goal is to build arrays of ferroelectric memristive devices that can show both short-term and long-term potentiation and depression, which is important for the implementation of neural networks. Si integration of the arrays will also be attempted. Ferroelectrics are becoming increasingly interesting in the memristive devices community.

Ferroelectric (FE) materials are highly sensitive to strain (crystal deformations) and, using current thin film deposition technology, it is possible to engineer the strain state of ferroelectric thin films and modify their energy landscape in order to create accessible metastable states and multiple remanent polarization values. The design of suitable devices, such as ferroelectric tunnel junctions (FETJs), allows mapping those multiple polarization states into resistance values. Unfortunately, FETJs require FE layers of a couple of nanometres, bringing limitations with respect to the robustness of the effect, as well as in the device fabrication. However, ferroelectrics can also be used as gate oxides in field-effect transistors (FETs), with the polarization determining the channel conductance. In FEFETs, the ferroelectric response can be tuned independently from the channel conductance, allowing for additional control.

In this project we plan to make arrays of memristive devices using thin films of ferroelectric BaTiO3 (BTO) grown under a particular strain state, previously investigated by the applicants. Unique to this material is that the behaviour of the films drastically changes depending on the device geometry: lateral input signals induce two well-defined remanent polarization states (non-volatile); while vertical input signals give rise to large switchable polarizations increasing with the applied fields but volatile. The main objective of the PhD project is, therefore, to map out-of-plane and in-plane ferroelectric polarization to short-term and long-term potentiation and construct and array of these devices on Silicon.

*Project leaders: Beatriz Noheda, Bert Offrein (IBM-Research Zurich) and Jean Fompeyrine (Lumiphase AG)*
Running projects awarded before 2020:

*CogniGron IBM Fellowship project: ‘Analogue phase-change memory cells for neuromorphic computing’—Awarded in 2019*

Phase-change memory (PCM) is, to date, arguably the most advanced resistive memory technology. PCM is also being explored for in-memory computing applications, such as performing logical operations as well as realizing hardware substrates for neuromorphic computing. It has been shown that PCM devices can emulate some of the key synaptic and neuronal functionalities, thus facilitating the realization of ultra-low power and dense neuromorphic hardware.

One particularly promising application domain is that of deep learning, where PCM devices organized in a crossbar configuration are used to represent the various synaptic layers in deep neural networks (DNNs). Compared to conventional approaches, PCM-based in-memory computing obviates the need to shuttle around synaptic weights between processing and memory units and this leads to significant gain in energy and throughput. Nevertheless, there is a large gap between current PCM performance and the ideal requirements for non-volatile memory (NVM) as synaptic elements.

In this project, we propose to address this challenge by expanding on a relatively new concept of ‘projected PCM’. We will perform extensive materials and architecture optimization to arrive at an ideal NVM element for deep learning. One of the main initial challenges will be finding PCM materials with high resistivity, low-threshold field and growth-dominant crystallization behaviour. Characteristics associated with nanoscale confinement such as interface resistances and thermoelectric effects will also need to be well understood.

The proposed work will optimally exploit the joint expertise and infrastructure of IBM Zurich and the Zernike Institute for Advanced Materials, with: i) thin-film materials optimization in Groningen, ii) integration and testing of these materials in projected PCM in Zurich, iii) structural characterization of actually switched devices using state-of-the-art electron microscopy in Groningen and, finally, iv) performing in-memory or neuromorphic computing tasks with optimized arrays of projected PCM devices in Zurich.

*Project leaders: Bart Kooi and Abu Sebastian (IBM-Research Zurich)*
Enabling Technology
CogniGron aims to make fundamental advances towards a disruptive technology, and the efforts in this direction require sophisticated research facilities to synthesize and characterize materials and build devices. These facilities are in large part present at the University of Groningen. However, CogniGron has seen the opportunity to excel by supporting new developments in the form of advanced research facilities: the electron microscopy centre and NanoLabNL. Information on these is provided below.

**Electron Microscopy Centre**

The Zernike Institute for Advanced Materials electron microscopy centre was founded in 2019 to maintain and provide a coherent and accessible infrastructure for electron microscopy at the University of Groningen. The microscopy centre is made possible by and will primarily be used by the Zernike Institute for Advanced Materials and CogniGron. Electron microscopy is of key importance for the research of CogniGron as it will help with the understanding of the ultimate origin of memristive behaviour in the materials that will function as artificial (electronic) synapses or neurons. To this end, CogniGron invested (together with the Zernike Institute for Advanced Materials) in the purchase of a new transmission electron microscope (TEM) that allows the study of the structure of materials in unprecedented detail. One of its unique abilities is to produce images of both heavy and very light atoms simultaneously. The purchase also included a second system: a scanning electron microscope, combined with a focused ion beam, which allows scientists to study the general structure of materials (using an electron beam) and extract interesting sections using the ion beam for detailed study in the new TEM. Professor Bart Kooi will be primarily responsible for running the new microscope.
NanoLabNL: Device fabrication facilities

NanoLabNL is a national consortium that was created to build, maintain and provide a coherent and accessible infrastructure for nanotechnology research and innovation in the Netherlands. However, with recent funding developments, maintaining the NanoLabNL facility updates – especially at the level of other countries in our region – is becoming a challenge.

Since the goal of CogniGron is closely related to developing novel electronic devices, for which the nanolithography and fabrication facilities provided by NanoLabNL are crucial, CogniGron has reserved funds to support NanoLabNL in the form of a new electron beam evaporator as well as a technician to support the new PhD students and staff who will be using the NanoLabNL facilities in Groningen. We are aware that more support is needed to maintain the NanoLabNL facilities in Groningen at international standards, and we are constantly working with the NanoLabNL management team to find solutions.
CogniGron Activities
Discussion Sessions
One of the keys to a successful programme is to create sustainable synergy that makes Groningen a unique environment in which everyone – from the materials to the computer science and artificial intelligence scientists to the mathematicians – learn to communicate in the same language and understand each other’s motivations with respect to a common goal. Only then will partnerships arise naturally.

Therefore, we dedicate considerable effort to organizing brainstorming and discussion sessions of half-day duration, to which all the researchers at the Zernike and Bernoulli Institutes with interests close to CogniGron are invited. In these sessions, which have had various formats, the staff learn about each other’s expertise and the first concrete ideas are developed for joint collaborations.

Due to COVID-19, as meetings had to be organised via various online platforms, we noticed that half-day meetings or meetings with larger groups did not have the desired effect. Therefore, we encouraged all the researchers with interest close to CogniGron to organise (online) meetings or discussion sessions with a smaller number of people. These sessions have already given rise to several working teams and proposal submissions, six of which have already received funding (see section: Ongoing Research Projects).

Student Discussion Sessions
Working together with a multidisciplinary team means stepping out of your comfort zone. This is a challenging and time-consuming activity. To facilitate interactions and cross-communication, all newly appointed professors work in more than one field; feel comfortable in two or more different worlds. In this respect, we have high expectations of the PhD students working at CogniGron, where they grow up in an inter- and multi-disciplinary environment. The PhD students will also form the solid foundation upon which the future of CogniGron will be built. CogniGron is, therefore, very happy to see that the students organize themselves weekly meetings with an informal character to discuss their scientific results, scientific challenges they face at the moment and to keep themselves up to date by discussing literature. Occasionally, they also invite researchers to give a presentation in these meetings.

CogniGron@Work Sessions
Being a very new and different initiative, we are aware that we need to make an extra effort to convey our goals and working philosophy to others, including those in our close neighbourhood, as well as to promote the exchange of research progress and ideas. It is with that purpose in mind that CogniGron@Work (CogniGron at work) sessions have initiated. In these sessions, two or more researchers from CogniGron explain their collaborative work, with a focus on the cross-disciplinary character of the research.

After the huge success of the first CogniGron@Work session in September 2019, prof. Tamalika Banerjee (Zernike Institute) and prof. Niels Taatgen (Bernoulli Institute) talked about their research on 'Memristive Interfaces for Bio-inspired Computing', three more CogniGron@Work sessions
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where organised in 2020. CogniGron is also very proud that this year also the first PhD students were able to present their work in the CogniGron@Work series.

**Anouk Goossens and Thomas Tiotto** - “Learning to Approximate Functions Using Nb-doped SrTiO3 Memristors”

Memristors have attracted interest as neuromorphic computation elements because they show promise in enabling efficient hardware implementations of artificial neurons and synapses. We performed measurements on interface-type memristors to validate their use in neuromorphic hardware. Specifically, we utilized Nb-doped SrTiO3 memristors as synapses in a simulated neural network by arranging them into differential synaptic pairs, with the weight of the connection given by the difference in normalized conductance values between the two paired memristors. This network learned to represent functions through a training process based on a novel supervised learning algorithm, during which discrete voltage pulses were applied to one of the two memristors in each pair. To simulate the fact that both the initial state of the physical memristive devices and the impact of each voltage pulse are unknown we injected noise at each time step. Nevertheless, discrete updates based on local knowledge were shown to result in robust learning performance. Using this class of memristive devices as the synaptic weight element in a spiking neural network yields, to our knowledge, one of the first models of this kind, capable of learning to be a universal function approximator, and strongly suggests the suitability of these memristors for usage in future computing platforms.

**Arjan van der Schaft & Dimitri Jeltsema** - “Ideal memcapacitors and meminductors violate the First Law of thermodynamics”

Like memristors (resistors with memory), memcapacitors and meminductors have been proposed as suitable devices for cognitive computing applications. CogniGron researcher Arjan van der Schaft and collaborator Dimitri Jeltsema have mathematically proved that ideal memcapacitors and meminductors share the same properties as the perpetual motion systems of the first kind. Therefore, as those mechanical counterparts, they violate the First Law of thermodynamics. The information that real devices cannot behave as ideal memcapacitors or meminductors, and that, at best, they can only partially emulate their functionality is of great importance for the design of novel devices for neuromorphic applications. The work has just been published in Scientific Reports.

**Lambert Schomaker** - “How to bridge the gap between current deep learning and current neuromorphic computing?”

It has become clear that the researchers in neuromorphic computing focus on training methods for multi-layer perceptrons pointing to a large number of layers in a network as the explanation for the ‘deep’ aspect of neural computing. However, the success of deep learning in current artificial neural networks (CNNs) is due to many factors, the most important of them being the use of 2D convolutions. This means that each layer consists of trainable filters. This requires that a square patch of pixels is dynamically slid over a large 2D field (image) with a stride of 1 pixel in both directions, performing the weight matrix times vector multiplication, at each x, y position. For each hidden unit, there is also a memory field (the feature map), storing and delivering the input
to the filters of the next layer. Such a dynamic functionality heavily relies on Turing/von Neuman controllers outside of the core of the neuromorphic weight-update hardware (e.g., a crossbar with memristors). These complicating facts diminish the poignancy of the ‘low energy’ argument: There are more computations needed than the multiply-add operator. Consequently, there should be a strong need to also address trainable filters, in materials science. As an example, a tedious convolution in x, y can be replaced by an effective one-shot optical filter over a complete 2D plane. For electric variants of neuromorphic computing, a similar wide-field lensing would need to be implemented. Intermediate-representation images at the level of a hidden unit require persistence, at least for the time period that a filter in the next layer is receiving the (usually 2D) pattern. Only when this is addressed can we realize a complete emulation of current deep learning in novel hardware, in CogniGron.

CogniGron Seminars for Invited Speakers
We consider the opportunity to invite experts from around the world to visit Groningen as one of the most important assets of CogniGron. This has been highly advantageous, not only to gain a better understanding of the latest developments in this diverse and emerging field of Cognitive Systems and Materials, but also to create a sense of community and, most importantly, to make CogniGron known to the international and national communities. We are proud of the list of internationally recognized experts who have kindly accepted our invitation and have spent days with us sharing their research ideas and also learning first-hand about the CogniGron vision. In the CogniGron webpages a complete list of speakers is provided, including the title and date of their presentations. Unfortunately, due to COVID-19 the list of speakers in the CogniGron seminar series of 2020 is quite short:

Xavi Marti (IGSresearch and Czech Academy of Sciences)
“Internet of Things and interdisciplinary academic research”
January 13, 2020

Sabina Spiga (CNR-IMM, Agrate Brianza Unit, Italy)
“Resistance switching memories for spiking neural networks”
February 27, 2020
CogniGron Goes Out
Due to COVID-19 most conferences, symposia and workshops that were scheduled for 2020 were cancelled or postponed. However, CogniGron researches did have some opportunities to present their recent work to colleagues around the globe and to be involved on the organization of workshops and conferences.

**Conferences, Symposia and Workshops**

**MANIC-ETN Network Wide Event**  
Conference organized as part the EU’s Horizon 2020 programme under the Marie Skłodowska-Curie grant agreement No. 861153  
October 19-23, 2020

**MELON Workshop: “Materials for Computing”**  
Workshop organized by partner organization as part of the EU Horizon 2020 Research and Innovation Staff Exchange under the grant agreement No. 872631  
October 21-23

**NEUROTECH Education Programme: “What is neuromorphic engineering?”**  
Workshop organized by partner organization as part of the EU Horizon 2020 FETPROACT CSA project on Community Building in Neuromorphic Computing Technologies (NCT) under Grant agreement No. 824103  
November 3, 2020

**NEUROTECH Education Programme: Can neuromorphic go beyond CMOS?”**  
Workshop organized by partner organization as part of the EU Horizon 2020 FETPROACT CSA project on Community Building in Neuromorphic Computing Technologies (NCT) under Grant agreement No. 824103  
December 1, 2020

**Conference Contributions Featuring CogniGron**

**Beatriz Noheda** - “Cognitive Materials, Devices and Systems: Preparing the Future for Energy Efficient Data Analysis” (invited talk)  
Conference on a fair data infrastructure for materials genomics (Fair-ID)  
June 3-5, 2020

**Christian Hirsch** – “Synaptic plasticity and dynamically reinforced random networks”  
2020 ICMNS (International Conference on Mathematical Neuroscience)  
July 6-7, 2020
Herbert Jaeger - “Neuromorphic computing: A productive contradiction in terms” (invited talk)  
SPIE Optics + Photonics 2020 conference  
August 24-28, 2020

Beatriz Noheda – “Why is everyone talking about hafnia-based ferroelectric devices?”  
(Plenary talk)  
Condensed Matter Division Biannual Meeting of the European Physical Society  

Beatriz Noheda – “Memristors and Neuristors in Epitaxy Land—A Deeper Look into the Materials Properties” (Invited Talk)  
Neuromorphic Materials symposium” of the MRS (Materials Research Society) Virtual Spring/Fall Meeting  
November 27 - December 4, 2020

Anouk Goossens & Tamalika Banerjee – “Investigation of Anisotropy and current Control of magnetization in complex oxide heterostructures for spin memristors”  
Joint European Magnetic Symposia, JEMS 2020  
December 7-11, 2020

Elisabetta Chicca – “Exploiting temporal dynamics for sensing” (Invited Talk)  
Phase-Change Switch Workshop on Neuromorphic Computing (IBM)  
December 17, 2020

Beatriz Noheda – “MANIC: Developing materials for neuromorphic devices and circuits” (Invited Talk)  
Phase-Change Switch Workshop on Neuromorphic Computing (IBM)  
December 17, 2020
Industry Relations (IR)
Industrial Partners in CogniGron and Related Projects (A-Z)

aixACCT Systems GmbH
Aachen, Germany

Building Between Bridges
Kortemark, Belgium

CrysTec GmbH
Berlin, Germany

DENSolutions B.V.
Delft, the Netherlands

IBM Research Zurich
Zurich, Switzerland

IMEC - Holst
Eindhoven, the Netherlands

Océ Technologies BV
Venlo, the Netherlands

SmartTip BV
Enschede, the Netherlands

Solmatest BV
Enschede, the Netherlands

Twente Solid State Technology B.V.
Enschede, the Netherlands
Highlighted Publications
After the starting year of CogniGron, and with new staff hired and post-doctoral researches and PhD students started, CogniGron started to obtain more scientific results which were published and well received.

**Peer-Reviewed Publications**


**Honors College paper**

Bhaduri, I (2020) ‘aim of the paper: An investigation of devices and parameters essential for neuromorphic computing

Physics student, University of Groningen
Awards and Recognitions
We are proud to announce that:

Elisabetta Chicca and Beatriz Noheda have been invited to be part of the Editorial board and Advisory board (respectively) of the newly founded Journal “Neuromorphic Computer and Engineering”, with Giacomo Indiveri (member of our Advisory Board) as Editor-in-Chief (http://iopscience.org/nce). This journal offers a much awaited forum for publishing multidisciplinary research exactly matching with the scope of CogniGron.

Boris Koldehofe received the notification that the German Science Foundation continues funding the MAKI - Multi-Mechanisms Adaptation for the Future Internet for the years of 2021-2024. This is very good news as Boris managed the centre, and his subproject will also receive full funding. The research comprises also very nice cooperation towards novel Cognitive Switching Architectures, a research direction he is pursuing within CogniGron.
External Funding
We are aware of the unique position that we have and are committed to obtaining the maximum benefits by developing strategic partnerships by means of national or international consortia and taking advantage of the available matching schemes, as long as the partnerships do not compromise our focus. CogniGron has actively participated in or coordinated seven proposal applications, of which four have already received funding. Details below:

**Proposals Awarded**

**EU Funding**

**BeFerroSynaptic – BEOL technology platform based on ferroelectric synaptic devices for advanced neuromorphic processors**
*Funded by the European Union’s Horizon 2020 research and innovation programme under grant agreement No 871737.*
Coordinators: Stefan Slesazeck (NAMLAB GGMBH, De)
CogniGron Participants: Elisabetta Chicca

**MANIC – Materials for Neuromorphic Circuits**
*This project has received funding from the EU’s Horizon 2020 programme under the Marie Skłodowska-Curie grant agreement No. 861153*
Coordinators: Beatriz Noheda (UG) and Bernd Gotsmann (IBM-Research Zurich)
CogniGron Participants: Beatriz Noheda and Elisabetta Chicca

**MeM-Scales – Memory technologies with multi-scale time constants for neuromorphic architectures**
*This project has received funding from the EU Horizon 2020 Research and Innovation programme under the grant agreement No. 871371*
Coordinator: Elisa Vianello (CEA-Leti, Grenoble, Fr)
CogniGron participants: Herbert Jaeger

**MELON – Memristive and multiferroic materials for emergent logic units in nanoelectronics**
*This project has received funding from the EU Horizon 2020 Research and Innovation Staff Exchange under the grant agreement No. 872631*
Coordinator: Igor Lukyanchuk (University of Picardie Jules Verne, Fr)
CogniGron participants: Beatriz Noheda
NeuroTech – Neuromorphic Technology
This project has received funding from the EU Horizon 2020 FETPROACT CSA project on Community Building in Neuromorphic Computing Technologies (NCT) under Grant agreement No. 824103
Coordinators: Giacomo Indiveri (The University of Zurich and ETH Zurich, CH)
CogniGron Participants: Elisabetta Chicca

NouTouch – Understanding neural coding of touch as enabling technology for prosthetics and robotics
This project has received funding from the European Research Council (ERC) under the European Union’s Horizon 2020 research and innovation No. 813713
Coordinators: Chiara Bartolozzi (Istituto Italiano di Tecnologia, It)
CogniGron Participants: Elisabetta Chicca

National Funding (NL)
Material for neuromorphic devices
This project has received funding from the NWO Visitor’s Travel Grant under the grant agreement No. 9047
Applicant: Beatriz Noheda
CogniGron participant: Travel and stay expenses for the visit of Prof. dr. Diego Rubi (University of Bueno Aires, Argentina)

German Funding (DE)
MemTDE – Memristive Time Difference Encoder
This project has received funding from DFG Individual Research Grant under the grant agreement No. 441959088
Applicant: Elisabetta Chicca
CogniGron participants: Elisabetta Chicca
Outreach Activities
Lectures for a General Audience

Niels Taatgen

**IT Academy colleges: Toekomst van de computer**
IT Academy Noord-Nederland, onderdeel van de Hanzehogeschool Groningen, IT Academy colleges: toekomst van de computer
November 5, 2020

CogniGron in the Media

**Oud-student schenkt 35 miljoen euro aan Rijksuniversiteit Groningen**
NOS – December 14, 2020

**Interview with Beatriz Noheda about large donation from alumnus and CogniGron**
NPO Radio 1 (BV het Nieuws) – December 14, 2020

**Interview with Beatriz Noheda about large donation from alumnus and CogniGron**
Editie NL, RTL4 – December 14, 2020

**Anonieme oud-student schenkt Rijksuniversiteit Groningen 35 miljoen euro**
Dagblad van het Noorden – December 14, 2020

**Ubbo Emmius Fund of the UG receives large donation from alumnus**
University of Groningen news – December 14, 2020

**CogniGron is two years along the path towards ‘human’ computers**
University of Groningen news – December 7, 2020

**We’re one step closer to a brain**
UKrant – July 1, 2020

**Pedestrians in Zuidhorn test the computer of the future**
Pressrelease gemeente Westerkwartier (NL) & CogniGron – February 18, 2020

Career Fairs/Recruitment

Jasper van der Velde

**MIT European Career fair Boston 2020**
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