## Table of Contents

### Foreword
- CogniGron: Born to Make a Difference
- CogniGron Scope
- CogniGron Mission
- Management Team
- Programme Board
- Supervisory Board
- Coordinating Office
- Scientific Advisory Panel

### The Minds of CogniGron
- In-house Expertise
- Materials Expertise
- Artificial Intelligence Expertise
- Computer Science Expertise
- Mathematics Expertise

### The Young Scientists Driving CogniGron
- PhD Students and Postdoctoral Researchers
- Master’s Students
- Bachelor’s Students

### CogniGron Welcomes New Professors
- Introduction of New CogniGron Professors

### Ongoing Research Projects
- Cross-Disciplinary PhD Projects
- CogniGron Fellowships: Announcing a CogniGron-IBM Fellowship

### Enabling Technology
- Electron Microscopy Centre
- NanoLabNL: Device Fabrication Facilities

### CogniGron Activities
- CogniGron Opening Ceremony
- Discussion Sessions
- CogniGron@Work Sessions
- CogniGron Student Symposium
- CogniGron Seminars for Invited Speakers
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>CogniGron Goes Out</td>
<td>59</td>
</tr>
<tr>
<td>Conference Contributions Featuring CogniGron</td>
<td>60</td>
</tr>
<tr>
<td>CogniGron Joins the Broadcom Foundation PhD Workshop on 'Brain-Inspired Computing and Technologies'</td>
<td>63</td>
</tr>
<tr>
<td>Industry Relations (IR)</td>
<td>65</td>
</tr>
<tr>
<td>Industrial Partners in CogniGron and Related Projects (A-Z)</td>
<td>66</td>
</tr>
<tr>
<td>Highlighted Publications</td>
<td>69</td>
</tr>
<tr>
<td>Awards and Honours</td>
<td>73</td>
</tr>
<tr>
<td>External Funding</td>
<td>77</td>
</tr>
<tr>
<td>Proposals Awarded</td>
<td>78</td>
</tr>
<tr>
<td>EU Funding</td>
<td>78</td>
</tr>
<tr>
<td>National Funding (NL)</td>
<td>78</td>
</tr>
<tr>
<td>Outreach Activities</td>
<td>81</td>
</tr>
<tr>
<td>Lectures for a General Audience</td>
<td>82</td>
</tr>
<tr>
<td>CogniGron in the Media</td>
<td>82</td>
</tr>
<tr>
<td>Career Fairs/Recruitment</td>
<td>84</td>
</tr>
<tr>
<td>Contact Information</td>
<td>86</td>
</tr>
</tbody>
</table>
Foreword

We are delighted to present the first annual report of the Groningen Cognitive Systems and Materials Centre (CogniGron). CogniGron was officially founded in February 2018 as a joint venture between the Bernoulli Institute for Mathematics, Computer Science and Artificial Intelligence and the Zernike Institute for Advanced Materials, overseen by the Board of the University of Groningen (UG) and the Board of the Faculty of Science and Engineering, UG.

CogniGron has been made possible thanks to an initial, generous, private donation which the Ubbo Emmius Fund Foundation of the University of Groningen has received for this purpose. This fills us with pride but also with responsibility. Thus, CogniGron is born with the mission of making a difference in the field of Cognitive Computing, such that its future existence is warranted. We are convinced that this will be the case and we are grateful, honored and humbled to take part in this exciting initiative.

About five years ago, we were inspired by the successes of the EU flagship the Human Brain Project (HBP), and similar efforts by strong international industrial players such as IBM and HP, developing brain-inspired (neuromorphic) chips. These chips could help to save power by many orders of magnitude when dealing with large amounts of data in the future, one of the main challenges for the future of computing in our modern societies. However, the scaling of these chips was an issue, and the introduction of new materials and devices was clearly lacking from these developments. We saw that our strengths in Advanced Materials (Zernike Institute) and Computer and Big Data Science (Bernoulli Institute) could offer a great opportunity to help progress in this direction.

Indeed, CogniGron is looking beyond current silicon chips and transistors, developing new materials that will be the basis of new types of devices, which will be part of novel computer architectures with adapted algorithms. The challenge is that all these levels need to be worked out simultaneously, in synergy, with the associated difficulties of communication between experts from very different fields. Thus, we believe that the academic environment, where young researchers can be educated in these values, is the key to success.
Further confirmation that the timing for this ambitious move is just right is that several other similar initiatives have recently started around the world. In the first two years of the Centre we have put a great effort into making contact with others who share our vision and enthusiasm. This intensive development of a network, with the aim of creating a large international family, can be seen from the number, quality and diversity of invited speakers who have participated in the CogniGron Seminars; the formidable international presence on our Advisory Board; as well as the newly hired staff (with nine of the twelve professor positions already filled). The first PhD projects have started and the first scientific results are being produced. In short, CogniGron is up and running!

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 $9 \times 10^{10}$ neurons and $1.5 \times 10^{14}$ 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 TrueNorthTM). 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 in 1996 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 has served as a 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; the control of nano-domains that self-assemble by strain engineering; and the characterization of the distinct properties of domain walls. Her main scientific contributions have been the discovery of low symmetry (monoclinic) phases in high piezoelectric materials (PZT and MPB piezoelectrics) and the observation of domain walls as ‘vertical interfaces’ with a distinct structure and functionalities.
Although her research is fundamental in nature, it 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 neuromorphic computing.

The Programme Board includes the following members:

Prof. dr. Tamalika Banerjee
Professor Spintronics of Functional Materials, 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. Maria Antonietta Loi
Professor Photophysics and Optoelectronics and chair of the board of Zernike Institute for Advanced Materials, University of Groningen.

Prof. dr. Jos Roerdink
Professor Scientific Visualization and Computer Graphics and Director Bernoulli Institute for Mathematics, Computer Science and Artificial Intelligence, University of Groningen.

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.

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

**Drs. Jan de Jeu**  
(from February 2018 till September 2019)  
Member of the Board of the University of Groningen

**Drs. Hans Biemans**  
(from September 2019 onwards)  
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. Dick Veldhuis**  
Managing director of the Faculty of Science and Engineering, University of Groningen.

**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 Center 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 center 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

Material Science

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

Artificial Intelligence

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

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

Computer Science

P10. Computational mathematics
P11. Engineering mathematics
P12. Stochastics

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

Mathematics
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 year, CogniGron has attracted new expertise on the borders of various disciplines, aiming to increase the synergy and collaborative efforts between the different disciplines. This provides a communicative bridge between the existing expertise in materials science, AI, mathematics and computer science.

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

On the left page Figure 1.
Sketch of the existing expertise within the four disciplines involved in CogniGron (expertise is directly linked to each of the individual circles representing a discipline), as well as the new expertise (P1-P12) desired to ensure a fully integrated effort, with efficient interdisciplinary interaction in the Groningen Centre for Cognitive Systems and Materials. 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.
Materials Expertise

The initial guidelines for the Centre 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 replaced with at short timescales and exhibit learning effects over replaced with at 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 material 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-ionics and device physics.

The CogniGron team in 2018-2019 comprises the following members:

Prof. dr. Tamalika Banerjee
Spintronics of Functional Materials

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

Prof. dr. Petra Rudolf
Experimental Solid State Physics
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 the materials of the computing substrate 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 9 x 1010 neurons (1.5 x 1014 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 international connections with researchers at the CWI (Centrum voor Wiskunde en Informatica) in Amsterdam (Sander Bohte) and at the University of Waterloo (Chris Eliasmith) are highly beneficial in this endeavour.

The CogniGron team in 2018-2019 comprises the following members:

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 Modeling

**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 the Centre. 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 already 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.

The CogniGron team in 2018-2019 comprises the following members:

Prof. dr. Michael Biehl
Intelligent Systems

Prof. dr. ir. Georgi Gaydadjiev
Innovative Computer Architecture

Prof. dr. Boris Koldehofe
(per February 1, 2020)
Computer Networks

Prof. dr. Jos Roerdink
Scientific Visualization and Computer Graphics

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 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.

The CogniGron team in 2018-2019 comprises the following members:
Dr. Bart Besselink  
Systems and Control Theory

Prof. dr. Kanat Camlibel  
Systems and Control Theory

Dr. Christian Hirsch  
(per January 1, 2020)  
Topological Data Analysis and Data Science;

Dr. Guanglian Li  
Computational Mathematics

Prof. dr. Arjan van der Schaft  
Applied Analysis

Dr. Alef Sterk  
Dynamical Systems Theory

Prof. dr. ir. Fred Wubs  
Numerical Mathematics

Prof. dr. Holger Waalkens  
Dynamical Systems Theory
The Young Scientists Driving CogniGron

PhD Students and Postdoctoral Researchers

The staff are encouraged to submit joint PhD proposals with PIs from different disciplines. These proposals lead to CogniGron-funded PhD positions. Brainstorming and discussion sessions have been organized to develop the research plans for these positions. Thus far, one postdoc and two PhD students have been funded in this way (see below). 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

Anouk Goossens
(2018-2021)

**Nanoscale memristors for new computing paradigms**
Spintronics of Functional Materials

Anne-Men Huijzer
(2019-2023)

**Memristor Networks**
Systems and Control Theory Research Group

Associated PhD students and Postdocs

Dr. Cynthia Quinteros

**Exploration of ferroic domain walls assemblies in BiFeO3 for neuromorphic implementations**
Nanostructures of Functional Oxides

Dr. Pavan Nukala

**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 Skłodowska-Curie Actions Individual Fellowships (MSCA-IF-2017) grant agreement No. 794954
Nanostructures of Functional Oxides

Mart Salverda

**Neuromorphic phenomena in thin film perovskite oxides**
Nanostructures of Functional Oxides
Wytse Talsma
Neuroplasticity in neural networks utilising semiconducting single-walled carbon nanotube inks
Photophysics and Opto-Electronics

Sanne Berg
Self-assembled networks of functional metal oxides for neuromorphic materials
Nanostructures of Functional Oxides

Silvia Damerio
Thin films of modulated multiferroic oxides as adaptable systems for cognitive computing
Nanostructures of Functional Oxides

Master’s Students
In addition, several Master’s projects have been designed to test CogniGron ideas and their suitability to become PhD projects. The Master’s students involved in CogniGron for the academic years 2018/19 and 2019/20 are listed below:

Sudipta Basu
(supervised by L. Schomaker)
Neuromorphic computing: influencing coupled van der Pol oscillators using memristor-perturbation policies

Swarai Dalmia
(supervised by Lambert Schomaker)
ML-based stochastic circuit design for memristive devices using Generalized Adversarial Networks

Manvi Agarwal
(supervised by Lambert Schomaker)
Recurrent spiking network ensembles

Jie Yan
(supervised by Lambert Schomaker and Yulia Sandamirskaya)
Path Integration and Map Learning Using a Spiking Neural Network for Neuromorphic Computing

Anne-Men Huijzer
(supervised by B. Besselink)
Networks of Memristive Devices as Building Blocks for Neuromorphic Computing
Sanne Berg
(supervised by Beatriz Noheda)
Self-assembled networks of functional metal oxides for neuromorphic materials

Andreas Pentaliotis
(supervised by Jelmer Borst and Niels Taatgen)
Networks of Memristive Devices as Building Blocks for Neuromorphic Computing

Evgenius Stylianidis
(supervised by Beatriz Noheda)
Hafnia-based tunnel junctions as neuromorphic devices

Bachelor’s Students

Ivan Yoychev
(supervised by Lambert Schomaker)
Exploiting connection variation in random meshes for neuromorphic computing

Matthijs Pals
(supervised by Jelmer Borst)
A spiking neuron model of short-term synaptic plasticity in working memory

Arseny Nikonov
(supervised by Jelmer Borst and N. Taatgen)
Simulation of neuromorphic hardware in Nengo
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 synthesis, 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 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 (see page 14) 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 young and middle-career 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. Statistics and Stochastics

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

Significant efforts have been made to advertise the CogniGron positions to 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 and 2019, Nature Careers Expo London 2019 and Faculty of Science and Engineering Career Day 2019).

The first round of advertisements and recruitment led to the appointment of the following excellent researchers.

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.

Curriculum Vitae

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.
**Prof. Herbert Jaeger – Computation in Cognitive Materials**

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.

**Curriculum Vitae**

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. 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.

Curriculum Vitae

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.
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.

**Curriculum Vitae**

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.
Dr Guanglian Li – Computational Mathematics

Guanglian Li has been appointed as an Assistant Professor in Computational Mathematics at the Bernoulli Institute for Mathematics, Computer Science and Artificial Intelligence, within CogniGron. Her position has been designed to bridge the expertise gap between mathematics and computer science. Li’s research interests are in numerical analysis, multiscale modelling and analysis and high-dimensional approximations, with applications in porous media, metamaterials and uncertainty quantification.

As part of the CogniGron research initiative, she will also use her expertise to facilitate the development of new efficient numerical algorithms, treating large numbers of molecules, as well as bridging the multiple scales, which is of great importance in the computational modelling of materials and systems.

Curriculum Vitae

Guanglian Li obtained her PhD from Texas A&M University, College Station, in 2015, under the supervision of Prof. Yalchin Efendiev. During her PhD, she focused on multiscale model reduction for high-contrast flow problems. Subsequently, Guanglian Li was Hausdorff postdoctoral fellow at the Hausdorff Centre for Mathematics, Cluster of Excellence of the University of Bonn, Germany. In 2018, she was awarded a Newton International Fellowship by the Royal Society, based at Imperial College London, where she worked until her move to Groningen in July 2019.
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.

Curriculum Vitae
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.
Ongoing Research Projects
Cross-Disciplinary PhD Projects

Staff can participate and contribute to the CogniGron research programme by having a PhD student or postdoc 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 student or postdoctoral position. 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.

Current projects:

‘Nb-doped SrTiO$_3$ memristive interfaces for bio-inspired computing’

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 SrTiO$_3$ 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:
Prof. Tamalika Banerjee and Prof. Lambert Schomaker
‘Towards a cognitive computer architecture based on memristive devices: developing short- and long-term memory’

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:
Prof. Niels Taatgen, Prof. Tamalika Banerjee and Dr Jelmer Borst
'WALLNET: Memristor networks from self-assembled domain walls in oxides'

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:
Prof. Bart Besselink, Prof. Beatriz Noheda and Prof. 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.

CogniGron is proud to announce that the first CogniGron Fellowship has been awarded to Bart Kooi to facilitate close collaboration with IBM Research Zurich. This first CogniGron IBM Fellowship project is entitled, ‘Analogue phase-change memory cells for neuromorphic computing’.

CogniGron IBM Fellowship project: ‘Analogue phase-change memory cells for neuromorphic computing’

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:
Prof. Bart Kooi and Dr 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**  
(Adapted from press release, 19 September 2019, by René Fransen)

On 19 September, the inauguration of the ZIAM electron microscopy centre took place at the UG Zernike Institute for Advanced Materials, Groningen, with a one-day symposium entitled, ‘The power of aberration-corrected transmission electron microscopy in materials science’. During the inauguration, a new transmission electron microscope (TEM) was introduced 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 new microscope was financed and will primarily be used by the Zernike Institute for Advanced Materials (ZIAM) and the CogniGron research centre. 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, chair of the Nanostructured Materials and Interfaces research group, will be primarily responsible for running the new microscope.

The 4 metre microscope has been installed in a climate-controlled room in the basement of the UG Physics and Chemistry building at the Zernike Campus. The machine itself is hidden behind white panels and remotely operated. After loading the samples into the microscope, the system is left alone for a while. Studying matter at atomic level requires a very controlled environment. Electron microscopes use electromagnetic rather than optical lenses, both to focus the beam and to correct any aberrations. This microscope is the first to be fitted with a double aberration corrector, which increases the resolution.

The microscope allows scientists to see the atoms in thin samples. This microscope is the first to combine several unique capabilities. It is able to produce images of light atoms, such as oxygen or even hydrogen, alongside heavy atoms such as metals. The microscope will primarily be used by the Zernike Institute and CogniGron, and it represents a great asset in the understanding of the ultimate origin of memristive behaviour in the materials that will function as artificial (electronic) synapses or neurons.
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 working with the NanoLabNL management team to find solutions.
CogniGron
Activities
CogniGron Opening Ceremony
The official start of CogniGron was marked with a kick-off meeting on 26 October 2018.

At the official opening, a number of prominent scientists, including various members of the CogniGron Scientific Advisory Panel, gave presentations on the scientific challenges related to the field of CogniGron.

The speakers included Theo Rasing (Radboud University of Nijmegen), Elisabetta Chicca (CITEC – Bielefeld University, Germany), Catherine Schuman (Oak Ridge National Laboratory, USA), Ivan Schuller (University of California San Diego, USA), Heike Riel (IBM Zurich, Switzerland), Regina Dittmann (Forschungszentrum Juelich, Germany), Julie Grollier (CNRS/Thales, France) and Giacomo Indiveri (UZH/ETH Zurich, Switzerland). Three researchers from CogniGron gave presentations: Niels Taatgen (Bernoulli Institute), Davide Grossi (Bernoulli Institute) and Maria Loi (Zernike Institute).

The programme of the day is presented below:

Welcome by Prof. dr. Beatriz Noheda, CogniGron director

Opening words by former President of the Board of the University, Prof. dr. Sibrand Poppema.

Lecture by Prof. dr. Niels Taatgen
(University of Groningen)
From Physical Neurons to Cognitive Programs: How to build a Cognitive Computer Architecture?

Lecture by Prof. dr. Theo Rasing
(Radboud University)
All-optical switching and brain-inspired concepts for low energy information processing

Lecture by Prof. dr. Elisabetta Chicca
(Bielefeld University)
Neuromorphic computing

Lecture by Prof. dr. Catherine Schuman
(Oak Ridge National Lab)
A Co-Design Framework for Neuromorphic Computing Research

Lecture by Prof. dr. Ivan Schuller
(University of California, San Diego)
Quantum Materials for Energy Efficient Quantum Computing
Lecture by Prof. dr. Davide Grossi  
(University of Groningen)  
**A Stroll Through the Theory of Group Decisions**

Lecture by Prof. dr. Maria Antonietta Loi  
(University of Groningen)  
**Carbon Nanotube: from Nano-Transistors to Neuromorphic Devices**

Lecture by Prof. dr. Regina Dittmann  
(Peter Grünberg Institute at Juelich)  
**Redox-based memristive devices: A Current status and challenges for their use in neuromorphic circuits**

Lecture by Prof. dr. Julie Grollier  
(CNRS, Thales)  
**Neuromorphic computing with spin-torque nano-oscillators**

Lecture by Prof. dr. Giacomo Indiveri  
(ETH Zurich & University of Zurich)  
**Neuromorphic Electronic Agents: from sensory processing to autonomous cognitive behavior**

**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 have dedicated 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. Thus far, seven such sessions have been organized, each involving 10 to 25 participants. 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. These sessions have already given rise to several working teams and five proposal submissions, four of which have already received funding (see section: Ongoing Research Projects).
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 been organized. In these sessions, two or more researchers from CogniGron explain their collaborative work, with a focus on the cross-disciplinary character of the research.

The first CogniGron@Work session was held on 25 September 2019. In this session, Tamalika Banerjee (Zernike Institute) and Niels Taatgen (Bernoulli Institute) talked about their research on ‘Memristive Interfaces for Bio-inspired Computing’. They discussed the materials science and artificial intelligence points of view and how their respective areas of expertise strengthened each other. We had a full room with many questions from both staff and students.

CogniGron Student Symposium

We are convinced that another key to success is to foster an environment in which the different disciplines combine their expertise and strengths. We are also aware that it is the young generations that are in the best position to acquire the competences to drive this emerging field. Thus, it is of key importance that we create a young CogniGron community, in which the students can exchange and test novel ideas or start collaborations. Therefore, CogniGron encourages students to interact and discuss the scientific challenges they face with each other. For this purpose, the students at CogniGron have been organizing regular informal meetings.

In addition, annual CogniGron student symposia are also organized. The first took place on 10 May 2019. Here, several students gave an update of their research projects followed by scientific discussions. In addition to students from CogniGron, PhD students from TU Eindhoven (supervised by Yoeri van der Burgt, one of our Advisory Board members) also took part, thus sowing the seed of a national initiative. The programme closed with a plenary talk by an external expert, Prof. Alberto Riminucci.

The programme of the CogniGron student symposium 2109:

**Anouk Goossens**
(group Tamalika Banerjee)

**Nb-doped SrTiO₃ memristors for new computing paradigms**

**Andreas Pentaliotis**
(group Niels Taatgen)

**Simulating memristive neural networks**
Anne-Men Huijzer  
(group Bart Besselink)  
Networks of memristive devices as building blocks for neuromorphic computing

Matthijs Pals  
(group Lambert Schomaker)  
A spiking neuron model of short-term synaptic plasticity in working memory

Sanne Berg  
(group Beatriz Noheda)  
Self-assembled networks of functional metal oxides for neuromorphic materials

Shuyan Shao  
(group Maria Loi)  
Organometal trihalide perovskite based memristors

Setareh Kazemzadeh  
(group Yoeri van de Burgt, TU/e)  
Organic electronic materials in neuromorphic devices for biological applications

Prof. Alberto Riminucci  
(Institute for the Study of Nanostructured Materials, CNR, Italy)  
Charge and spin transport in molecular spin valves and their application in neuromorphic computing

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. Below a complete list of speakers is provided, including the title and date of their presentations.

Carlo Reita – CEA-LETI, France  
Human Brain or Bee Brain? Hardware targets for AI  
December 17, 2019
Marcelo Rozenberg – Laboratoire de Physique des Solides (Orsay) CNRS -Universite Paris-Sud, France
Neuromorphic electronic behavior in transition metal oxide systems; From resistive switching to artificial synapses and neurons
December 4, 2019

Abu Sebastian - IBM Research Zürich, Switzerland
Brain-inspired computing at multiple levels of inspiration: A memory device perspective
November 18, 2019

Eleni Vasilaki –University of Sheffield, United Kingdom
Sparse Reservoir Computing (SpaCe)
November 12, 2019

Paolo Milani – University of Milano, Italy
Fabrication of logic devices based on Au cluster-assembled films for neuromorphic applications
October 11, 2019

Henk Nijmeijer – TU/Eindhoven, the Netherlands
Synchronization in Networks: clocks and brains
September 19, 2019

Alberto Riminucci – CNR Bologna, Italy
Charge and spin transport in molecular spin valves and their application in neuromorphic computing
May 10, 2019

Matt Dale – University of York, United Kingdom
Reservoir computing : substrates, topologies, hierarchies
April 3, 2019

Susan Stepney – University of York, United Kingdom
Unconventional design of unconventional computers
April 3, 2019

Christoph Brabec –Friedrich-Alexander University Nürnberg-Erlangen, Germany and University of Groningen, the Netherlands
“AMANDA” – and highly automated materials’ research platform
March 8, 2019
Miguel Marques – University of Halle, Germany
The second computer revolution in materials science: from density-functional theory to machine learning
January 24, 2019

Giacomo Indiveri – UZH / ETH, Zurich, Switzerland
From biologically plausible neuromorphic circuits to autonomous cognitive systems
October 10, 2018

Nagarajan Valanoor – University of New South Wales, Sydney, Australia
Ferroelastic Domain Wall Mobility in Ferroelectric Multilayers: Stretching the possibilities
October 5, 2018

Bert Kappen – Radboud University Nijmegen, the Netherlands
Future machine learning requires new computing paradigms
July 9, 2018

Scott Keene – Stanford University, USA
Organic resistive memory devices for neuromorphic computing
June 28, 2018

Chris Eliasmith – University of Waterloo, Canada
Key Note lecture Spring School on Cognitive Modeling
April 13, 2018

Terry Stewart – University of Waterloo, Canada
Programming with Neurons: Neural Engineering and Neuromorphic Hardware
April 5, 2018

Isao Inoue – National Institute of Advanced Industrial Science & Technology (AIST) Tokyo
Artificial synapses and neurons based on an insulator-to-2D metal transition of a SrTiO3 surface
March 12, 2018

Christoforos Moutafis – University of Manchester, United Kingdom
Towards Skyrmion-based Electronics
February 12, 2018

Elisabetta Chicca – CITEC, Bielefeld University, Germany
Learning in silico beyond STDP
February 5, 2018
Sergei V. Kalinin – Oak Ridge National Laboratory, USA
Atomic Fabrication via Electron Beams: From Big Data to Atomic Robotics
January 11, 2018

Sander Bohte – CWI Amsterdam, the Netherlands
Efficient Computation in Adaptive Artificial Spiking Neural Networks
December 13, 2017

Jacob Torrejón – CNRS/Thales, France
Neuromorphic computing with nanoscale spintronic oscillators
November 23, 2017

Martin Salinger – I. Physikalisches Institut IA, RWTH Aachen, Germany
How resistively switching materials open up new ways to process information
November 16, 2017

Ivan Schuller – University of California, San Diego
Neuromorphic Computing
November 17, 2017

Ilia Valov – Peter Grünberg Institut, Jülich and IWE2, RWTH Aachen, Germany
Nanoionic systems for the modern nanoelectronics - how memristors can change our future
October 18, 2017

Regina Dittmann – Forschungszentrum Jeulich, Germany
Oxide based memristive devices: current status of understanding and future prospects
September 26, 2017

Manuel Bibes – CNRS/Thales, France
Learning through ferroelectric domain dynamics in solid state synapses
September 12, 2017

Alexander Khajetoorians – RU Nijmegen, the Netherlands
Magnetic LEGO: magnetic design at the single atom level
June 6, 2017

Yoeri van der Burgt – TU/Eindhoven, the Netherlands
An organic artificial synapse for low-energy neuromorphic computing
June 30, 2017
CogniGron Goes Out
Organization of Conferences, Symposia and Workshops

Beatriz Noheda, Christian Wenger, Martin Ziegler and Sabina Spiga
September 16-19, 2019, Warsaw, Poland

CogniGron Student Symposium
Jasper van der Velde
May 10, 2019, Groningen, The Netherlands

Groningen Spring School Cognitive Modeling
Niels Taatgen
March 8-12, 2019, Groningen, The Netherlands

CogniGron Kick-off Meeting
Jasper van der Velde and Beatriz Noheda
October 26, 2018, Groningen, The Netherlands

Conference Contributions Featuring CogniGron
Our staff have also made CogniGron visible at various conferences and meetings:

Herbert Jaeger
Neuromorphic Computing and Data Science
Data Federation Hub Meetup, University of Groningen, the Netherlands
December 12, 2019

Beatriz Noheda
Ferroelectric Materials: from Actuators to Neuromorphic Devices”
Plenary Talk at the M2i Materials Innovation Institute Conference,
Noordwijkerhout, the Netherlands
December 10, 2019

Jasper van der Velde
CogniGron – Brain Inspired Computing
Talk at the Faculty of Science and Engineering Career day 2019, Groningen, the Netherlands
November 28, 2019

Jasper van der Velde
Workshop NWA Materials Consortia
November 26, 2019, AMOLF, Amsterdam, the Netherlands
Herbert Jaeger
“Engineering” Analog Neuromorphic Hardware – A Contradiction in Terms?
Talk at the Nature Conference on Neuromorphic Computing, Beijing, China
October 28-30, 2019

Jasper van der Velde
Brain-Inspired Computing
Talk at EMEA University Student Research Workshop on Brain-Inspired Computing and Technologies
October 13-18, 2019, Delhi, India

Tamalika Banerjee
EMEA University Student Research Workshop on Brain-Inspired Computing and Technologies
October 13-18, 2019, Delhi, India

Marieke van Vugt
EMEA University Student Research Workshop on Brain-Inspired Computing and Technologies
October 13-18, 2019, Delhi, India

Anouk Goossens
EMEA University Student Research Workshop on Brain-Inspired Computing and Technologies
October 13-18, 2019, Delhi, India

Lionel Newman
EMEA University Student Research Workshop on Brain-Inspired Computing and Technologies
October 13-18, 2019, Delhi, India

Herbert Jaeger
An introduction to reservoir computing - A bridge between neuroscience and machine learning
GeLifes
September 5, 2019, Groningen, The Netherlands

Lambert Schomaker
Brain-Inspired Computing
Invited talk at the Odyssey Hackathon 2019: World’s Biggest Blockchain And AI Hackathon
April 11-15, 2019, Groningen, the Netherlands
Jasper van der Velde
Materials for AI
Pitch at NWA matchmaking Route Energy Transition 2019
April 15, 2019, Utrecht, the Netherlands

Niels Taatgen
The World of Brain-inspired Computing
Plenary talk at TechTalks050
April 14, 2019, Groningen, The Netherlands

Maria Loi
Carbon Nanotube: from Nanotransistors to Neuromorphic Devices
Invited talk at the official opening of the Center for Brain-Inspired Nano Systems (BRAINS) at the University of Twente
March 27, 2019, Enschede, The Netherlands

Jasper van der Velde
CogniGron: Materials for AI
Talk at the 2nd Data Workshop Osaka University & University of Groningen
March 12-13, 2019, Osaka, Japan

Niels Taatgen
From physical neurons to cognitive programs: how to build a cognitive computer architecture?
Talk at the Cognitive Computing 2018 Conference – Merging Concepts with Hardware
December 18-20, 2018, Hannover, Germany

Tamalika Banerjee
Cognitive Computing 2018 Conference – Merging Concepts with Hardware
December 18-20, 2018, Hannover, Germany

Jasper van der Velde
CogniGron – Materials for AI
Pitch at Entrepreneurs on Campus Dinner 2018 - Campus Groningen
October 16, 2018, Campus Groningen, The Netherlands
CogniGron Joins the Broadcom Foundation PhD Workshop on ‘Brain-Inspired Computing and Technologies’

From 13-17 October 2019, representatives from CogniGron participated in the annual EMEA University Student Research Workshop on Brain-Inspired Computing and Technologies, funded by the Broadcom Foundation. This year it was hosted by the Indian Institute of Science (IISc) Bangalore, in Delhi, India. The workshop is a joint undertaking of IISc Bangalore, Imperial College London, Tel Aviv University and University College Dublin.

During the workshop, PhD candidates from the different universities collaborate in interdisciplinary teams on designing solutions concerned with brain-related research questions at the interface of engineering, computer science, neuroscience, and beyond. At the end of the workshop, each team presents their project to academics from all of the participating universities, with a winner being selected for best proposal and presentation.

Earlier this year, the Broadcom Foundation kindly invited the Faculty of Science and Engineering (FSE) of the University of Groningen to join this consortium. For this year, it was then decided to send a small delegation to learn more about the setup of this event. The delegation included Professor Tamalika Banerjee, Assistant Professor Marieke van Vugt (who were involved in the evaluation of the group projects), Dr Jasper van der Velde, as scientific coordinator of CogniGron, and the PhD candidates Anouk Goossens and Lionel Newman.

Based on the positive experiences in Delhi, it has been decided that the UG – through FSE and CogniGron – will indeed become a full partner in this exciting annual event. The 2020 and 2021 workshops will be held in Dublin and Groningen, respectively.
Industry Relations (IR)
CogniGron has made an effort to connect with various external partners, to strengthen interaction with industry and gain from its expertise and knowledge.

IBM-Research (Zurich) Our strongest industrial partner is IBM-Research in Zurich. Their research line on Hardware for AI is in excellent synergy with the goals of CogniGron. One of the IBM-Research scientific directors, Dr Heike Riel, is a member our Advisory Board. We have developed the CogniGron-IBM fellowships concept to maintain and strengthen this collaboration. In collaboration with IBM-Research Zurich, we are coordinating the EU H2020 programme on Materials for Neuromorphic Circuits (MANIC), with EUR 4 million in funding. Several industrial partners participate in MANIC (see list below).

Several meetings and workshops have been organized by various participants, with the aim to increase collaboration with industrial partners.


Meet-and-greet with employees of the Ministry of Defence (2019) Organized by the University of Groningen (IR) on topics including cyber safety, big data, artificial intelligence, social innovation, organization models, cultural differences, law and smart industry. Niels Taatgen and Jasper van der Velde represented CogniGron.


UG Meet & Greet XL: Digital Society by the University of Groningen (IR) (2019) Organized by the University of Groningen (IR) on digital society. Niels Taatgen represented CogniGron.
Industrial Partners in CogniGron and Related Projects (A-Z)

aixACCT Systems GmbH
Aachen, Germany

Broadcom Foundation
Newport Beach, California, USA

Building Between Bridges
Kortemark, Belgium

CrysTec GmbH
Berlin, Germany

DENSsolutions B.V.
Delft, the Netherlands

GoogleX
Mountain View, California, USA

IBM Research Zurich
Zurich, Switzerland

IMEC - Holst
Eindhoven, the Netherlands

Océ Technologies BV
Venlo, the Netherlands

Shell BV
The Netherlands

SmartTip BV
Enschede, the Netherlands

Solmates BV
Enschede, the Netherlands

Twente Solid State Technology B.V.
Enschede, the Netherlands
In this starting year of CogniGron also the first publications with a CogniGron affiliation have been published.

**Magneto-ionic control of spin polarization in multiferroic tunnel junctions**
Yingfen Wei, Sylvia Matzen, Cynthia P. Quinteros, Thomas Maroutian, Guillaume Agnus, Philippe Lecoeur & Beatriz Noheda, npj Quantum Materials 4, 62 (2019)
doi: 10.1038/s41535-019-0201-0

**Magnetic Tunnel Junctions Based on Ferroelectric Hf0.5Zr0.5O2 Tunnel Barriers**

**Periodicity-Doubling Cascades: Direct Observation in Ferroelastic Materials**
doi: 10.1103/PhysRevLett.123.087603

**A Spiking Neural Architecture that Learns Tasks**

**Electric field driven memristive behavior at the Schottky interface of Nb-doped SrTiO3**
doi: 10.1063/1.5037965
Awards and Honours
Descartes-Huygens Prize for Manuel Bibes (2017)
Dr Manuel Bibes (CNRS-Thales), expert in ferroelectric memristors and tunnel junction devices, was awarded the Descartes-Huygens prize for his outstanding research. The Descartes-Huygens prize (a grant of EUR 23,000) allowed Bibes to spend three months conducting research in the Netherlands.

Anouk Goossens received the Shell Award (2018)
This prize is awarded annually to three physics students for their Master’s thesis research. Anouk received the prize for her investigation into using the material, Nb-doped SrTiO3, to imitate the functioning of brain synapses.

Beatriz Noheda on the advisory panel of Q-MEEN-C (2019)
The Quantum Materials for Energy Efficient Neuromorphic Computing (Q-MEEN-C), with funding provided by DOE Energy Frontier Research Centers, has as its mission to lay down the quantum-materials-based foundation for the development of an energy-efficient, fault-tolerant computer that is inspired and works like a brain (‘neuromorphic’). The director of the centre is Professor Ivan Schuller.
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 and three are pending. Details below:

**Proposals Awarded**

**EU Funding**

**MANIC – Materials for Neuromorphic Circuits (www.etnmanic.eu)**  
Horizon 2020 - Marie Skłodowska-Curie Innovative Training Networks  
Topic:  
Type of action: MSCA-ITN-2019, November 2019 – November 2023  
Proposal number: 861153  
Coordinators: Beatriz Noheda (UG) and Jean Fompeyrine (IBM-Research Zurich)

**MeM-Scales – Memory technologies with multi-scale time constants for neuromorphic architectures**  
EU-Horizon 2020 project  
Type of action: H2020-ICT-2019, January 2020-December 2022  
Proposal number: 871371  
Coordinators: Elisa Vianello (CEA-Leti, Grenoble, FR)  
CogniGron participants: Herbert Jaeger

**MELON – Memristive and multiferroic materials for emergent logic units in nanoelectronics**  
EU-Horizon 2020  
Applicant: Beatriz Noheda  
Type of Action: H2020-MSCA-RISE-2019  
Proposal number: 872631  
Funding requested: all expenses related to the exchange of students between Argentina’s institutions and Groningen (including materials cost).

**National Funding (NL)**

**Material for neuromorphic devices**  
NWO Visitor’s Travel Grant  
Applicant: Beatriz Noheda  
Funding requested: Travel and stay expenses for the visit of Prof. dr. Diego Rubi (University of Buenos Aires, Argentina)  
Grant no. 9047
Outreach Activities
Lectures for a General Audience

Niels Taatgen
**Future of Artificial Intelligence**
Natuur Wetenschappelijk Genootschap Assen, the Netherlands
November 12, 2018

Niels Taatgen
**Kunstmatige Intelligentie: neurale netwerken in actie**
Presentatie voor De Jonge Onderzoekers (DJO) Groningen
March 22, 2019

Lambert Schomaker
**Brain-Inspired Computing**
Odyssey Hackathon 2019: World’s Biggest Blockchain And Ai Hackathon, Groningen, the Netherlands
April 11-15, 2019

Niels Taatgen
**The World of Brain-inspired Computing**
TechTalks050, Groningen, The Netherlands
April 14, 2019

CogniGron in the Media

NRC Newspaper
**Advertisement 10 CogniGron positions**
May 2018, four weekend editions - half page

Volkskrant Newspaper
**Advertisement 10 CogniGron positions**
May 2018, four weekend editions - half page

Die Zeit (Online)
**Advertisement 10 CogniGron positions**
May – June 2018

NatureJobs
**Advertisement (Banner) 10 CogniGron positions**
May – June 2018
ResearchGate
Advertissement 10 CogniGron positions
May – August 2018

LinkedIn (University of Groningen, CogniGron and Zernike Institute for Advanced Materials)
Advertissement 10 CogniGron positions
May – August 2018

AG Connect
Huidige Computers vreselijk uit de tijd
Interview with Prof. Beatriz Noheda and dr. Jasper van der Velde (Dutch only)
July 25, 2018

Asser Courant
Seminar announcement “NWG Assen: Lezing over Artificial Intelligence” by prof. dr. Niels Taatgen
October 23, 2018

University of Groningen webpage
New generation of smart computers inspired by our brains
October 26, 2018

nu.nl
Groningen krijgt onderzoeksinstituut voor nieuwste generatie computers
October 26, 2018

Campus Groningen
Nieuw RUG onderzoekscentrum CogniGron van start op Campus Groningen/ New UG research center CogniGron set up at Campus Groningen
October 26, 2018

Economie Groningen
RUG heeft wereldprimeur met multidisciplinair onderzoekscentrum voor cognitieve computersystemen
October 26, 2018

RTV Noord
Radio Interview (19.24-23.20min.) with Jasper van der Velde on Opening CogniGron
October 26, 2018
In de Wetenschap - RUG podcast #4
Niels Taatgen, Wim Brons and Nanna Haug Hilton about Artificial Intelligence and CogniGron
(Dutch only)
November 26, 2018

UKrant
*Het brein verslaat de computer/ Brain beats computer*” Interview with dr. Jasper van der Velde
May 1, 2019

University of Groningen webpage
FSE joins the Broadcom foundation PhD workshop in “Brain-Inspired Computing and Technologies
October 30, 2019

**Career Fairs/Recruitment**

Jasper van der Velde
*NatureJobs Career Expo Dusseldorf 2017*

Jasper van der Velde
*MIT European Career fair Boston 2018*

Jasper van der Velde
*NatureJobs Career Expo Dusseldorf 2018*

Jasper van der Velde
*MIT European Career fair Boston 2019*

Jasper van der Velde (Talk)
*Nature Careers Expo London 2019*

Jasper van der Velde (Invited Talk)
*Faculty of Science and Engineering Career Day 2019*
**Contact Information**

<table>
<thead>
<tr>
<th>Role</th>
<th>Name</th>
<th>Room</th>
<th>Tel</th>
<th>Email</th>
</tr>
</thead>
<tbody>
<tr>
<td>Director</td>
<td>Prof. Beatriz Noheda</td>
<td>5117.0016</td>
<td>+31 50 363 4565</td>
<td><a href="mailto:b.noheda@rug.nl">b.noheda@rug.nl</a></td>
</tr>
<tr>
<td>Scientific Coordinator</td>
<td>Dr. Jasper van der Velde</td>
<td>5117.0010</td>
<td>+31 (0)6 48496318</td>
<td><a href="mailto:j.h.m.van.der.velde@rug.nl">j.h.m.van.der.velde@rug.nl</a></td>
</tr>
</tbody>
</table>

**Visiting address**

Office 5117.0016 (Prof. Beatriz Noheda)
Office 5117.0010 (Dr Jasper van der Velde)

University of Groningen
Nijenborgh 4
9747 AG Groningen
The Netherlands
Colophon

Publication
Faculty of Science and Engineering
CogniGon
University of Groningen

Design
StudioTW

Photos
Sylvia Germes:
Cover & page 22-23, 38-39, 44-45, 58-59, 64-65, 67-68, 72-73, 76-77 and 80-81

Gert ten Brink:
Transmission Electron Microscopy (TEM) (Nanostructured Materials and Interfaces, Zernike Institute for Advanced Materials, University of Groningen), page 28

La0.7Ca0.3MnO3:
Scanning Electron Microscopy (SEM)
(Lanthanum Calcium Manganite) “fingerprint” structure used to build synaptic devices,
page 44 and 48


Gerard Kingma:
Page 6-7 and 68-69

© CogniGron
March 2020