COGNIGRON

Towards 10,000x more energy-efficient computer chips

Annual Report CogniGron 2023

university of groningen

UEF Ubbo Emmius Foundation
Moving science forward.

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FOREWORD

I am delighted to present you with the 2023 CogniGron annual report. This year, we have witnessed the thesis defenses of our first three PhD students, including one cum laude (awarded to the top 5% of Dutch students). We have achieved the size that we had planned, with 29 principal investigators involved and more than 50 early career researchers working in different aspects of cognitive systems and materials.

Internationally, we have established our role as a facilitator of interactions and knowledge exchange between scientists, by organising research visits of researchers from all over the world: Australia, United States, United Kingdom, Germany, Belgium and Switzerland. We organised a summer school together with the Neurotronics centre of the University of Kiel (Germany) and a symposium at the Materials Research Society (MRS) Spring Meeting in San Francisco (US). At the same time, we have invested our efforts in creating synergy within Dutch borders, with our participation in the NWA project NL-ECO, that starts in 2024, and the Mission 10-X initiative, next to organising the Neuromorphic Computer Netherlands workshop (NCN 2023) and the first Research Day with the Infomatter department of the AMOLF institute.

These efforts to embrace multidisciplinary exchanges, inside and outside our walls, have given rise to one of the highlights of 2023: the article led by Herbert Jaeger "Toward a formal theory for computing machines made out of whatever physics offers", published in Nature Communications, which has been featured in 11 news outlets and has been accessed 14 thousand times in just a few months. But this was not the only one. You are very welcome to read about more highlights in the following pages.

As the dynamic centre that we are, we have had to say goodbye to some people, of whom we are proud and to whom we are grateful, but we also welcomed new staff. In the second half of 2023, Matthew Cook joined CogniGron as a new full professor of

the AI department at the Bernoulli Institute. He is recognised in the international neuromorphic community as one of the brightest minds working on understanding information processing in the human brain and how to use that knowledge to implement artificial learning systems.

This year, three new EU funded projects have been awarded to CogniGron researchers, among them a prestigious ERC Synergy Grant to Elisabetta Chicca. She has also appeared in the EE|Times podcast by Dr. Sunny Bains. Finally, I would like to highlight the new partnership with Synsense, a Swiss company that commercialises CMOS-based neuromorphic chips. Yes, from educating the next generations to developing actual chips: that is what CogniGron is about.

You may also have noticed that CogniGron has a new look and feel. Reflecting our commitment to innovate and evolve, we have updated our logo and branding to better suit our brain-inspired identity.

As we look ahead, our next step is to create demonstrators. They will represent the convergence of our expertises and pave the way for solutions to societal challenges. In this way, we will show that neuromorphic technology utilising innovative, self-learning materials is not only feasible but essential.

Read further and stay tuned via LinkedIn, X, or our website.

Beatriz Noheda,
scientific director of CogniGron

TIME FOR FUTURE-PROOF COMPUTING

It's hard to imagine a life without the convenience of an online search, working in the cloud, communicating online or consulting ChatGPT. Computing has acquired a central role in our society, and although it has brought global prosperity, it has a downside. Surging data traffic and related energy consumption by data centres, partly due to the rapid increase of AI, cause an unsustainable demand that can't be met by modern computers. For this reason, it's time for a new generation of computers: future-proof computing.

REVOLUTIONISING COMPUTER DESIGN

Despite more than 70 years of continuous innovation within chip and computer design, current events require a new revolutionary approach. To sustain the use of computers, we must combine knowledge and experience from the past 70 years and explore new materials and forms of computer design.

The revolution: neuromorphic computing. This type of computing is up to 10,000 times more energy efficient and thus a game changer for future-proof computing.

THE SOLUTION IS INSIDE OUR HEAD

Can we develop new materials and systems that are far more energy efficient? The proof is literally in our own head: the human brain. Unlike any computer chip, our brain uses an ingenious network to process complex information. It effectively combines processing and storage simultaneously. More so, past experiences make processing information much faster and more energy efficient.

This is why our research at CogniGron is inspired and guided by how our mind works.

WHAT WE DO

Groningen Cognitive Systems and Materials Center (CogniGron) is part of the University of Groningen and a globally recognised and unique multidisciplinary research centre. We conduct fundamental research on self-learning materials and systems for future-proof computing.

Our mission: to design a blueprint for future-proof computers.

Our objective: up to 10,000 times more energy-efficient computer chips.

OUR AMBITION: A FUTURE-PROOF COMPUTING ECOSYSTEM

As CogniGron continues to conduct fundamental research into future-proof computing, translating existing knowledge into specific applications, we aim to connect our scientific knowledge and business skills. We envision an ecosystem where business and knowledge partners collaborate and work on brain-inspired energy-efficient computing solutions.

Within this ecosystem, we will collaborate on:

- Developing new materials as the basis for future-proof computer chips
- Integrating applied engineering research to translate our knowledge into production
- Initiating first applications for the implementation of neuromorphic computing
- Establishing start-ups to bring applications to market

SUPPORTED BY THE UBBO EMMIUS FOUNDATION

In the world of research and academic pursuit, support is the pillar upon which innovation thrives. Within the heart of our research centre, this foundational support has been demonstrated by the invaluable contributions of the Ubbo Emmius Foundation.

As we reflect on another year of discoveries, new connections, and academic achievements, we would like to express our gratitude to the foundation for their commitment to our mission. Through their support, we have been able to advance our research agenda, explore new frontiers of knowledge, and encourage talent within the next generation of scientists. In 2024, our joint mission to shape the future of research and education continues. We look forward to yet another year of working closely together and creating societal impact for a more sustainable future of technology.

UEF Ubbo Emmius Foundation

Moving science forward.

OUR TEAM

In-house expertise

The strength and uniqueness of CogniGron lie in the physical systems that are investigated (with scalability potential beyond current solutions) and in the multidisciplinary character of the approach. We are multidisciplinary by choice and by conviction. Our team of leading experts and next generation talent, unites expertise from physics, materials science, mathematics, computer science and artificial intelligence.

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 years, CogniGron has attracted new expertise on the borders of various disciplines, aiming to increase synergy and collaboration and providing a bridge between existing expertise in materials science, AI, mathematics and computer science.

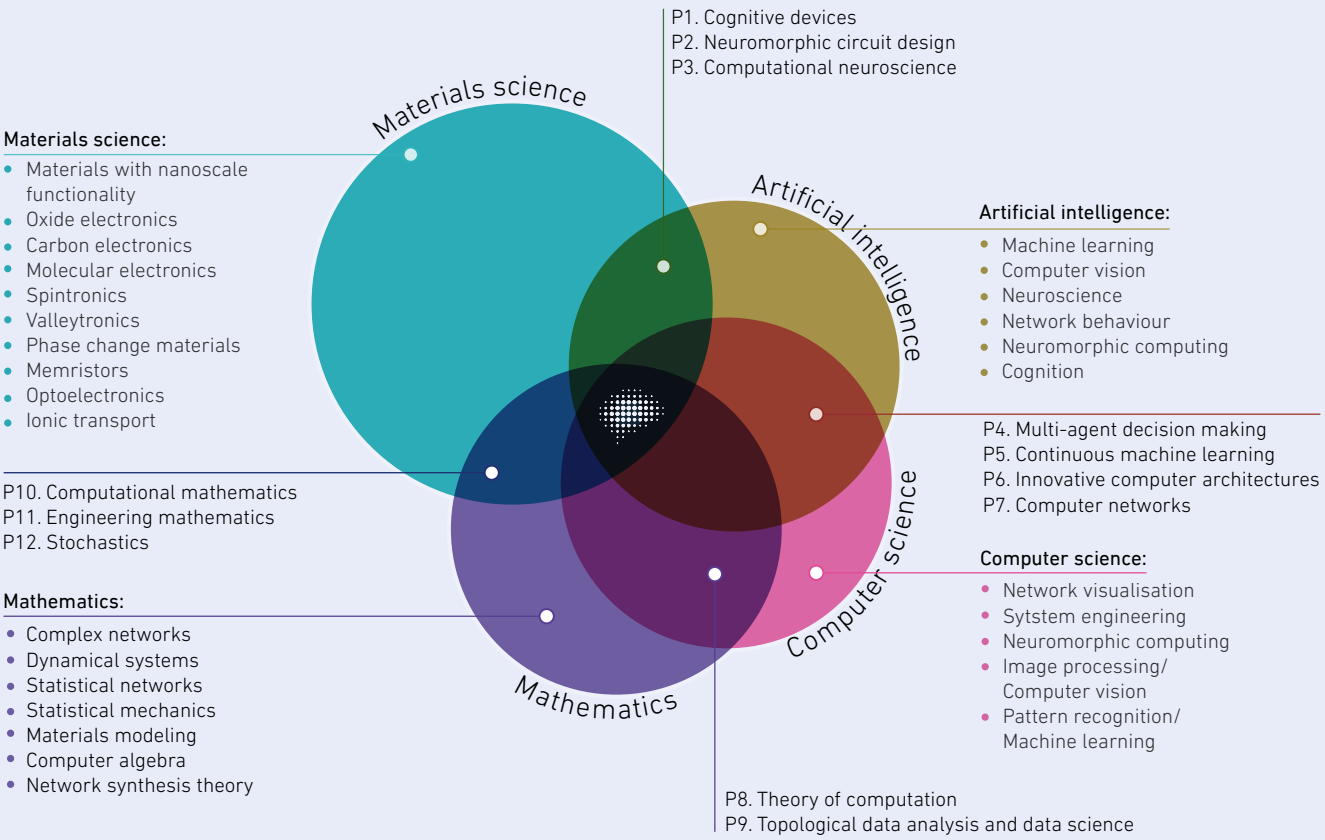


Figure 1. Sketch of the originally existing expertise within the four disciplines involved in CogniGron, as well as of the new interdisciplinary professor positions (P1-P12). The new profiles are located in between the disciplines whose interaction they aim to strengthen (represented by the overlapping areas).

MATERIALS SCIENCE EXPERTISE

The ambition of CogniGron is to develop and build the fundamental building blocks for cognitive computing, also called 'cognitive materials'. The researchers working on these topics are therefore central participants, with leading roles in current research. Materials scientists explore, study and further design electronic materials and devices. The CogniGron research programme encompasses the entire chain of materials research from modelling, synthesis, experiments and theory to device fabrication.

- Prof. Tamalika Banerjee
  Spintronics of Functional Materials
- Prof. Elisabetta Chicca
  Bio-Inspired Circuits and Systems
- Dr. Erika Covi
  Cognitive Devices
- Prof. Bart Kooi
  Nanostructured Materials and Interfaces
- Prof. Maria Loi
  Photophysics and Opto-Electronics
- Prof. Beatriz Noheda
  Nanostructures of Functional Oxides
- Prof. George Palasantzas
  Physics - Surface interactions and Nanostructures
- Prof. Petra Rudolf
  Experimental Solid-State Physics
- Prof. Caspar van der Wal
  Quantum Devices
- Prof. Jianting Ye
  Device Physics of Complex Materials

In the course of 2023, Prof. Caspar van der Wal and Prof. Jianting Ye left CogniGron.


Prof. Maria Loi

ARTIFICIAL INTELLIGENCE EXPERTISE

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. This provides both opportunities and challenges. It should be noted that current neural networking methods are implemented on 'classical computers' called Turing/Von Neumann machines, resulting in a high energy demand, both for computing and communication functions. In close cooperation with materials scientists, artificial intelligence experts develop models and methods facilitating the search for novel materials that form the basis for a new type of computer, that is a neuromorphic or cognitive computer, suitable for neural computing. Thereby, CogniGron covers the full range of theoretical models to find new materials that will enable this new future-proof computer.

- Prof. Sander Bohté
  Neural Computation
- Dr. Jelmer Borst
  Artificial Intelligence
- Prof. Matthew Cook
  Cortex-inspired Computing
- Prof. Davide Grossi
  Cognitive Multiagent Systems
- Prof. Herbert Jaeger
  Computation in Cognitive Materials
- Prof. Lambert Schomaker
  Artificial Intelligence
- Prof. Niels Taatgen
  Artificial Intelligence
- Prof. Bart Verheij
  Computational Argumentation
- Dr. Marieke van Vugt
  Cognitive Modelling

In the course of 2023 Prof. Sander Bohté left CogniGron.

COMPUTER SCIENCE EXPERTISE

Computer science is an essential component in the development of cognitive systems and materials. It addresses fundamental issues to understand basic principles of developing and building novel computer architectures. The computer science expertise within CogniGron is broad.

- Prof. George Azzopardi
  Information Systems
- Prof. Michael Biehl
  Intelligent Systems
- Prof. Georgi Gaydadjiev
  Innovative Computer Architecture
- Prof. Boris Koldehofe
  Computer Networks
- Dr. Revantha Ramanayake
  Theory of Computation
- Prof. Jos Roerdink
  Scientific Visualization and Computer Graphics
- Dr. Fatih Turkmen
  Computer and Network Security
- Dr. Michael Wilkinson
  Digital Image Analysis and Computer Vision

In the course of 2023, Prof. Georgi Gaydadjiev and Prof. Boris Koldehofe left CogniGron. Both are still involved in supervising students and Prof. Georgi Gaydadjiev remains as a member of the programme board.

MATHEMATICS EXPERTISE

A unique feature of CogniGron is the involvement of mathematics. To understand the underlying principles of 'cognitive materials', mathematical principles and modelling are key. In particular, the concepts of networks, control theory and graph theory concepts and tools, as well as the description of dynamics of complex and strongly non-linear phenomena, are of great relevance to design connectivity, adaptivity and plasticity in materials and devices. The mathematics expertise within CogniGron covers a broad spectrum.

- Prof. Bart Besselink
  Systems and Control Theory
- Dr. Gilles Bonnet
  Stochastic Studies and Statistics
- Prof. Kanat Camlibel
  Systems and Control Theory
- Dr. Serte Donderwinkel
  Topological Data Analysis and Data Science (Start in 2024)
- Dr. Julian Koellermeier
  Computational Mathematics
- Prof. Marco Grzegorczyk
  Computational Statistics
- Prof. Arjan van der Schaft
  Applied Analysis
- Dr. Alef Sterk
  Dynamical Systems Theory
- Prof. Holger Waalkens
  Dynamical Systems Theory
- Dr. Alden Waters
  Systems Control and Applied Analysis
- Prof. Fred Wubs
  Numerical Mathematics

In the course of 2023, Prof. Kanat Camlibel, Dr. Alden Waters and Prof. Fred Wubs left CogniGron.

TECHNICAL SUPPORT

CogniGron would not be where it is today without the skills that the technicians bring. The technicians, amongst others, train the students in the various labs and make sure that all the labs run smoothly.

- Dr. Majid Ahmadi
  CogniGron (support Microscopy)
- Ir. Jacob Baas
  Solid State Materials for Electronics
- Henk Bonder
  Nanostructures of Functional Oxides
- Gert ten Brink
  Nanostructured Materials and Interfaces
- Johan Holstein
  Physics of Nanodevices
- Dr. Arjun Joshua
  CogniGron (support clean room)
- Philipp Klein
  Bio-inspired Systems and Circuits

THE NEXT GENERATION

PhD students and postdoctoral researchers

Staff members are encouraged to submit joint PhD proposals with PIs from different disciplines. These proposals lead to CogniGron-funded PhD positions. We organise brainstorming and discussion sessions to develop the research plans for these positions.

- Steven Abreu (2021-2025)
  Computing in non-digital substrates
  Computing in Cognitive Materials group (PI: Herbert Jaeger)

- Jhon Kevin Astoquillca Aquilar (2021-2025)
  Synchronization in random networks
  Stochastics and Statistics group (PI: Holger Waalkens)

- Ishitro Bhaduri (2023-2027)
  Low power probabilistic-bits enabled reckoning
  Spintronics of Functional Materials group (PI: Tamalika Banerjee)

- Sanne Berg (2018-2022, thesis defense in 2023)
  Self-assembled networks of functional metal oxides for neuromorphic materials
  Solid State Materials for Electronics (PI: Beatriz Noheda)

PhD Sanne Berg Graduation

- Remi Brandt (2020-2024)
  Neural networks with observable decisions
  Innovative Computer Architectures (PI: Georgi Gaydadjiev)

- Radu Cimpean (2022-2026)
  The development of ordinary differential equation (ODE) theory and computational models for sense of smell
  Systems Control and Applied Analysis group (PIs: Alden Waters & Stephan Trenn)

- Davide Cipollini (2021-2025)
  Adaptive random non-linear mappings for neural computing in ferroelastic films
  – This project is funded by the EU Horizon 2020 programme MANIC under Marie Skłodowska-Curie grant agreement no. 861153.
  Artificial Intelligence group (PI: Lambert Schomaker)

- Otavio Citton (2023-2027)
  Statistical physics of learning in layered systems of adaptive elements
  Intelligent Systems Group (PI: Michael Biehl)

- Madison Cotteret (2021-2024)
  Neuromorphic memristive VLSI architectures for cognition
  Bio-inspired Circuits and Systems group (PI: Elisabetta Chicca)

- Maxim Fabre (2021-2025)
  On-chip training on analog circuits with memristive devices and bio-plausible learning algorithms
  Bio-inspired Circuits and Systems group (PI: Elisabetta Chicca)

- Anouk Goossens (2018-2023)
  Nanoscale memristors for new computing paradigms
  Spintronics of Functional Materials group (PI: Tamalika Banerjee)

- Guillaume Pourcel (2020-2024)
  Theory of neuromorphic computing
  – This project is funded by the EU Horizon 2020 Research and Innovation programme POSTDIGITAL under the Marie Skłodowska-Curie grant 860360.
  Computing in Cognitive Materials group (PI: Herbert Jaeger)

- Hugh Greatorex (2021-2025)
  Memristive time difference encoder
  Bio-inspired Circuits and Systems group (PI: Elisabetta Chicca)

- Ruben Hamming-Green (2021-2024)
  Combined volatile/non-volatile memristive ferroelectric arrays
  Nanostructures of Functional Oxides group & IBM Research-Zurich (PI: Beatriz Noheda)

- Paul Hansch (2022-2026)
  Smart electronic olfactory system
  Photophysics and Optoelectronics group (PI: Maria Loi)

- Marieke Heidema (2022-2026)
  Learning in memristive electrical circuits
  Systems and Control Theory Research group (PI: Bart Besselink)

- Anne-Men Huijzer (2019-2023)
  Memristor networks
  Systems and Control Theory Research group (PI: Bart Besselink)

- Fabian IJpelaar (2022-2026)
  Qualitative modeling, simulation and exploration of multi-phenomenal materials dynamics
  Computing in Cognitive Materials group: (PI. Herbert Jaeger)

- Azminul Jaman (2020-2024)
  Towards a cognitive computer architecture based on memristive devices: developing short- and long-term memory
  Spintronics of Functional Materials group (PI: Tamalika Banerjee)

- Foelke Janssen (2022-2026)
  Qualitative modeling, simulation and exploration of multi-phenomenal materials dynamics (Q-Mat)
  Solid State Materials for Electronics group (PI: Beatriz Noheda)

- Lyes Khacef (2020-2022)
  Bio-inspired Circuits and Systems group
  (PI: Elisabetta Chicca)

- Philipp Klein (2020-2024)
  Learning in neuromorphic systems
  Bio-inspired Circuits and Systems group (PI: Elisabetta Chicca)

- Alexander Kugele
  Event-based vision for automated driving
  Bio-inspired Circuits and Systems (PI: Elisabetta Chicca)

- Safiere Kuijpers (2023-2027)
  Memristive models for faster material design cycles towards applications
  Computational & Numerical Mathematics group (PI: Julian Koellermeier)

- Dr. Celestine Lawrence (2020-2023)
  Theory of neuromorphic computing
  – This project has received funding from the EU Horizon 2020 Research and Innovation programme MEMSCALES under grant agreement no. 871371.
  Computing in Cognitive Materials group (PI: Herbert Jaeger)

- Mian Li (2020-2024)
  Morphological image analysis of conduction maps
  – This project has received funding from the EU's Horizon 2020 programme MANIC under the Marie Skłodowska-Curie grant agreement 861153.
  Scientific Visualization and Computer Graphics (PIs: Michael Wilkinson & Jos Roerdink)

- Jesse Luchtenveld (2021-2025)
  Analogue phase-change memory cells for neuromorphic computing
  Nanostructured Materials and Interfaces group & IBM Research-Zurich (PIs: Bart Kooi and Abu Sebastian)

- Michele Mastella (2020-2024)
  Neuromorphic embedded processing for touch
  – This project is funded by the EU Horizon 2020 Research and Innovation project NEUTOUCH, under grant agreement no. 813713.
  Bio-inspired Circuits and Systems group (PI: Elisabetta Chicca)

- Ton Juny Pina (2022-2026)
  Neuromorphic odor classification
  Bio-inspired systems and circuits group (PI: Elisabetta Chicca)

- Jan Rieck (2019-2024)
  Memristor networks from self-assembled domain walls in oxides
  – This project has received funding from the EU's Horizon 2020 programme MANIC, under the Marie Skłodowska-Curie grant agreement.
  Solid State Materials for Electronics (PI: Beatiz Noheda)

- Julien van der Ree (2021-2024)
  Nanoparticle based percolating networks towards neuromorphic computing
  Physics - Surface interactions and Nanostructures group (PI: George Palasantzas)

- Ole Richter (2020-2024)
  Neuromorphic integrated systems for network stability and homeostasis
  Bio-inspired Circuits and Systems group (PI: Elisabetta Chicca)

- Dr. Nicoletta Risi (2022-2024)
  Bio-inspired Circuits and Systems group
  (PI: Elisabetta Chicca)

- Saad Saleh (2020-2024)
  New switching architectures with memristors for neuromorphic computing
  Computer Networks group (PI. Boris Koldehofe)

- Mart Salverda (2018-2023)
  Neuromorphic phenomena in thin film perovskite oxides
  Solid State Materials for Electronics (PI: Beatiz Noheda)

- Jordi Timmermans (2022-2026)
  Nb-doped SrTiO3 memristive interfaces for bio inspired computing
  Artificial Intelligence group (PI: Lambert Schomaker)

- Thomas Tiotto (2020-2024)
  Towards a cognitive computer architecture based on memristive devices: developing short- and long-term memory
  Artificial Intelligence group (PI: Niels Taatgen)

- Karoline Tran (2020-2024)
  Carbon nanotube-based neuromorphic electronics
  Photophysics and Optoelectronics group (PI: Maria A. Loi)

- Willian Soares Girão (2020-2023)
  Neuromorphic circuits for novel devices
  – This project has received funding from the EU's Horizon 2020 programme MANIC under the Marie Skłodowska-Curie grant agreement 861153.
  Bio-inspired Circuits and Systems (PI: Elisabetta Chicca)

- Dr. Gaurav Vats (2023- 2025)
  SMART: Synchronised neuro-Memristive Architecture for Reinforced learning Technology
  – This project has received funding from the EU's Horizon 2020 programme SMART under the Marie Skłodowska-Curie grant agreement (Grant agreement No 892669.
  Solid State Materials for Electronics (PI: Beatiz Noheda)

- Peter van der Wal (2023-2027)
  Robust learning of sparse representations: brain-inspired inhibition and statistical physics analysis
  Information Systems group (PI: George Azzopardi)

- Daniel Willhalm (2020-2024)
  Large deviations in stochastic geometry
  Topological Data Analysis and Data Science group (PI: Tobias Muller)

- Jingtian Zhao (2023- 2027)
  Ferroelectric memristive devices
  – This project has received funding from the Chinese Scholarship Council (CSC)
  Solid State Materials for Electronics (PI: Beatiz Noheda)

- Dr. Alejandro Pequeño Zurro (2023-2027)
  Tactile Internet: remote sensing with neuromorphic technology
  – This project has received funding from the Dutch NWA Project NL-ECO.
  Bio-inspired Circuits and Systems (PI: Elisabetta Chicca)

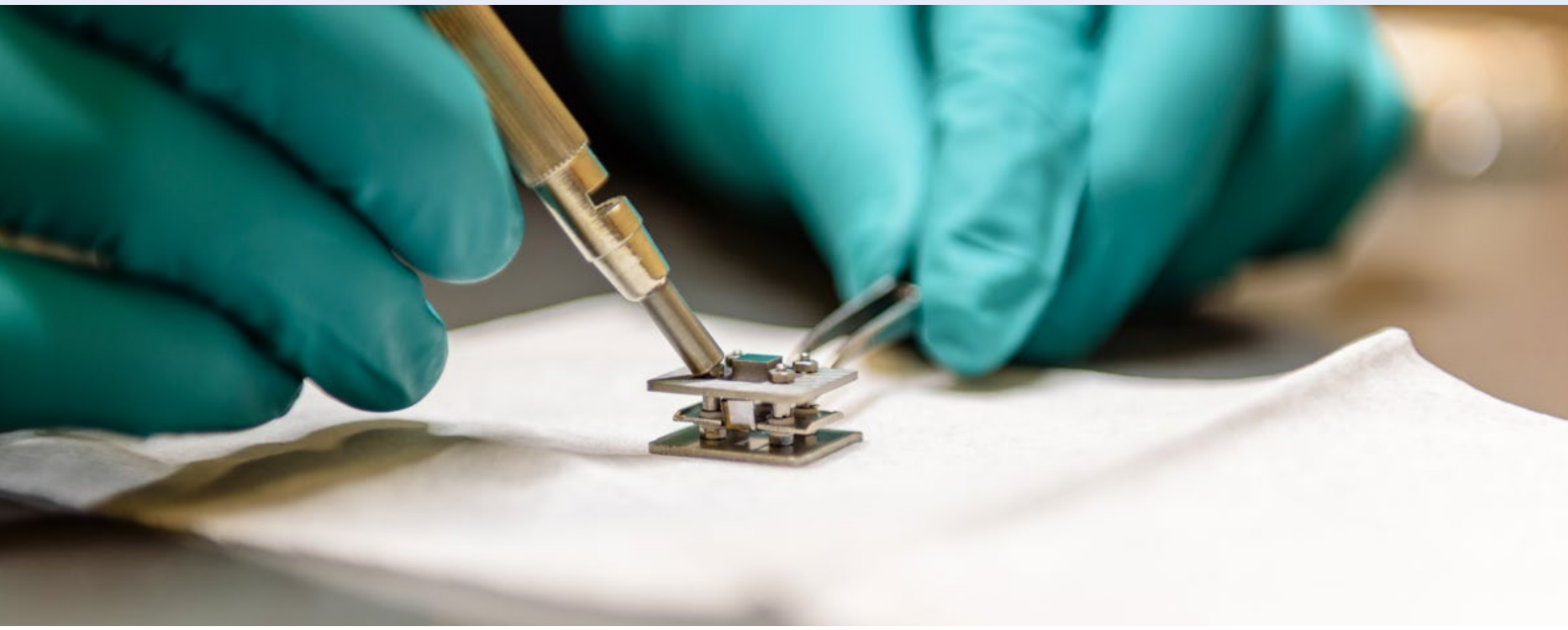
NEW STAFF

CogniGron is excited to share that Matthew Cook became a part of our team in 2023. With his extensive knowledge and enthusiasm for neural architectures and information processing, he brings valuable expertise to our team. We look forward to the insights and ideas that he will bring.

PROF. MATTHEW COOK

With a background spanning both industry and academia — among which Wolfram Research, Caltech and ETH Zurich — Matthew Cook brings a depth of experience to CogniGron. Throughout his career, he has established himself as a leader in the field of neural architectures for neural information processing, building a track record of success in neuromorphic engineering and connectomics. His work on the link between the deep-network algorithms used in machine learning, as well as the spiking neural networks used to implement neuromorphic computing systems, have had a major impact in the field. Furthermore his groundbreaking work on relational networks provides a framework for linking detailed low-level biologically plausible neural network architectures to high-level cognitive and behavioural models.

In his new role at CogniGron, Matthew Cook will establish a new research direction in Groningen and will work closely with our teams in materials science, artificial intelligence, mathematics and computer science. His expertise will be invaluable to our organisation as we continue to do fundamental research into self-learning materials and systems for cognitive computing – computing that has the ability to learn and to handle complex challenges in a highly efficient way, inspired by how the brain works.



OUTLOOK TO 2024

New team members for 2024 include Erika Covi and Serte Donderwinkel.

DR. ERIKA COVI

CogniGron welcomes Erika Covi as a marvellous new addition to our research team. Erika has held positions at the National Research Council of Italy (CNR) and NaMLab GmbH, Dresden (Germany), where she worked as a ERC Group Leader. Her research interests lie at the intersection of circuit design, emerging devices, and brain-inspired computing.

Erika has a track record and experience in areas that have become very strategic in the last few years, such as emerging memories, memristive devices, circuit design, and neuromorphic/in-memory computing. In 2022, she was awarded a ERC personal grant on Memristive Neurons and Synapses for Neuromorphic Edge Computing (MEMRINESS).

In her new role at CogniGron, she will set up a new research direction in Cognitive Devices, working closely with the Bio-inspired Circuit and Systems team, and strengthening the bridge between the material science and physics groups and the artificial intelligence and computer science groups. Her expertise is in great demand and we are very much looking forward to welcoming her and joining our goal to develop a one-of-a-kind neuromorphic chip.

DR. SERTE DONDERWINKEL

We also welcome Serte Donderwinkel as a wonderful new addition to the team as an assistant professor in Probability Theory. Serte obtained her BSc in Mathematics at the University of Groningen, after which she moved to the UK, where she completed a master's degree at the University of Cambridge and a PhD at the University of Oxford. She then did a postdoctoral stay at McGill University (Canada), before returning to Groningen.

Her research focuses on the study of random trees and graphs. The common denominator of her projects is that they involve creative sampling procedures that, combined with tools from (stochastic) analysis, allow her to study the large-scale structure of the random object. At CogniGron, she aims to put her theoretical background to use to improve the understanding of phenomena observed in real-world networks, such as phase transitions and self-organised criticality.

UNLOCKING THE FUTURE

MIMICKING THE HUMAN BRAIN FOR INFORMATION PROCESSING

Meet Matthew: a trailblazer in the realm of neural networks and artificial intelligence, whose journey from Zurich to Groningen in 2023 has embodied a quest for innovation and collaboration. His story is one of embracing change in the pursuit of unlocking the secrets of how the human brain processes information, combining insights from different disciplines.

By Clelia Richters-Teodoro

Matthew's fascination with understanding the human mind began in childhood. "Since I was a child, I have always wanted to understand how I think, to understand how the thinking process works, how one thought leads to another. When I grew up, I was disappointed to find out that even the experts and the book authors didn't know the answer. So this is what I try to understand," he recalls. This early curiosity set the stage for a lifelong journey into the complexities of neural networks and artificial intelligence.

After a decade of working at a software company, he decided to return to academia, pursuing a PhD at Caltech in Southern California, to follow his dream of understanding the human mind.
His academic odyssey then led him to the Institute of Neuroinformatics in Zurich, a joint institute of the University of Zurich and ETH Zurich, where he led an interdisciplinary research group for 17 years, working in computational neuroscience, unconventional computing, and connectomics. Matthew's path then came to Groningen, drawn by CogniGron's energised community and its supportive structures for encouraging interdisciplinary collaboration. Transitioning to Groningen brought its own set of challenges, from the logistics of frequent travel to adapting to a new landscape. Yet, amidst the bustling streets and vibrant culture, Matthew found a sense of belonging and renewal.

Comparing Zurich and Groningen, Matthew is captivated by Groningen's relaxed and welcoming atmosphere. Conversations with fellow academics echoed his sentiments, affirming Groningen as a hub of creativity and contentment.

Looking to the future, Matthew envisions CogniGron as a nexus of collaboration, where diverse minds converge to unlock the deep potential of human-inspired information processing. He champions spontaneous interactions between researchers as the most important catalyst for innovation and progress, envisioning a future where academic boundaries dissolve and interdisciplinary visions bring groups together.

When asked about his contribution to CogniGron, Matthew explains: "Within the Cognitive Circuits and Systems theme, in our group we make conjectures about how the human cortex processes information. Based on these ideas, we build functioning systems that reproduce cortical capabilities such as visual processing, sensor fusion, abstract inference, and coordinated motor control. Through this process of conjecture and construction, we distill fundamental principles that enable neuromorphic algorithms to self-organise into systems exhibiting basic elements of intelligent behaviour."

He further explains his dual approach: "On the one hand, I study how very simple components (less capable than a transistor) can form functioning systems with high-level computational behaviours. On the other hand, I study how neural networks can self-organise into systems exhibiting some sort of intelligent behaviour. As these neural systems show us what they can easily do, we learn to reimagine what computation is." This dual focus underscores his commitment to merging the best aspects of engineered and naturally inspired systems. Matthew also looks forward to working directly with the Materials Science groups in CogniGron. As he says, "The Cognigron environment is ideal for connecting us with researchers developing new materials, allowing us to analyse the computational potential of these materials."

As we celebrate another year of advancement and discovery, Matthew's journey is a perfect representation of the unwavering spirit of CogniGron—a place where the future is unlocked, one breakthrough at a time.

GOVERNANCE

At the heart of our research centre lies a dynamic framework of leadership and oversight, designed to drive innovation, foster collaboration, and ensure the highest standards of performance. From the timely guidance of our supervisory board to the tireless efforts of our programme board, each facet of our management team is crafted to create an environment of efficiency and continuous improvement to realise the ambitions and goals of CogniGron.

SCIENTIFIC DIRECTOR

The success of CogniGron is rooted in the dedication and vision of its founding scientific director, **Prof. Beatriz Noheda.** The scientific director is responsible for the scientific programme and chairs the programme board. The director functions as the official representative of the centre and shapes the cutting-edge scientific programme.

Beatriz Noheda received her PhD in Physics from the Universidad Autónoma de Madrid, Spain. In 2003, after holding various positions at Saarland University, the Clarendon Laboratory in Oxford, Brookhaven National Lab in New York and the Vrije Universiteit in Amsterdam, she was awarded a Rosalind Franklin Fellowship by the University of Groningen, where she is now Full Professor. Noheda is a Fellow of the American Physical Society and recipient of the IEEE Robert E. Newnham Ferroelectrics Award. She has served as a member of numerous national and international committees and several editorial boards. She is the author of more than 150 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 and multiferroic materials, often used as memory elements. Her research, although fundamental in nature, is inspired by two main application areas that, together, she believes will enable the next technological revolution: piezoelectric energy harvesting for low-power electronics and the development of novel materials for adaptable electronics and neuromorphic computing.

PROGRAMME BOARD

The programme board steers us toward groundbreaking discoveries. The programme board, chaired by the scientific director, is the driving force behind CogniGron's scientific strategy and daily operations. This team allocates the budget, determines the scientific strategy, and is responsible for the daily running of the scientific programme, as well as the recruitment of new staff. Chaired by the director, the programme board is composed of the following members:

- Prof. Tamalika Banerjee
  Professor Physics of Nanodevices
- Prof. Maria Loi
  Photophysics and Optoelectronics
- Prof. Elisabetta Chicca
  Bio-Inspired Circuits and Systems
- Prof. Georgi Gaydadjiev
  Professor Innovative Computer Architectures
- Prof. Lambert Schomaker
  Professor Artificial Intelligence
- Dr. Alef Sterk
  Assistant Professor Mathematics
- Prof. Niels Taatgen
  Professor Artificial Intelligence and Chair of the Board of the Bernoulli Institute for Mathematics, Computer Science and Artificial Intelligence

- Prof. Moniek Tromp
  Professor Materials Chemistry
  Director Zernike Institute for Advanced Materials

- Prof. Ton Engbersen - Advisor to the Programme Board
  Professor Data Science Engineering

Changes to the CogniGron Programme Board
In 2023, Prof. Elisabetta Chicca replaced Prof. Maria Loi as a member of the programme board. Prof. Maria Loi has been a key contributor for the realisation of CogniGron from the start and she is co-responsible for the successes obtained thus far. We would like to thank Maria for her dedication, which has been instrumental in positioning CogniGron where it stands today.

SUPERVISORY BOARD

The Supervisory Board oversees the long term strategy of the research centre, and advises the scientific director on significant changes in focus and implementation of the programme. It is composed of the following persons:

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

- Prof. Joost Frenken
  Dean of the Faculty of Science and Engineering, University of Groningen

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

COORDINATING OFFICE

The coordinating office assists the scientific director and the programme board in all aspects of management, outreach and communication activities. **Dr. Jasper van der Velde,** scientific coordinator for CogniGron, left CogniGron in the course of 2023. As Beatriz Noheda mentioned in her speech during his farewell, Jasper has been the soul of CogniGron, working closely with the director from the start, drafting every new position, organising hiring committees, double doctorates and MoU documents, scientific visits, coordinating EU proposals, organising events and developing communication reports. We are indebted to Jasper for all he has done in these 6 years.

Clelia Richters-Teodoro MA started in 2023 as an event manager and management assistant. From 2024 onward, **Dr. Hilde de Gier** assumes the role of scientific coordinator.

SCIENTIFIC ADVISORY PANEL

CogniGron is proud to have an elite team of researchers to form the international scientific advisory panel. Their expertise and vision on brain-inspired concepts and technologies are of great value and guidance in delineating new scientific directions.

- Prof. Giacomo Indiveri
  Professor Neuromorphic Cognitive Systems and Director of the Institute of Neuroinformatics
  UZH / ETH Zurich, Switzerland

- Prof. 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. Ivan Schuller
  Professor Nanoscience and Director of QMEENC (Quantum Materials for Energy Efficient Neuromorphic Computing)
  Department of Physics and Centre for Advanced Nanoscience, University of California, San Diego, USA

- Prof. Rainer Waser
  Professor of Electrical Engineering and Information Technology at RWTH Aachen University, Germany, and Director of the Peter Grünberg Institute, Julich, Germany

- Prof. Yoeri van de Burgt
  Assistant Professor in Microsystems group
  Institute of Complex Molecular Studies (ICMS), TU Eindhoven, Netherlands

- Prof. Wilfred van der Wiel
  Professor of Nano Electronics and Director of the Centre for Brain-Inspired Electronics (BRAINS)
  University of Twente, Netherlands

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

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

- Prof. Tony Kenyon
  Professor of Nanoelectronic & Nanophotonic Materials
  University College London, United Kingdom

RESEARCH PROJECTS

Cross-disciplinary PhD projects

In this first phase of CogniGron, staff can participate and contribute to CogniGron by having a PhD student funded via the programme. A requirement is that staff and team members fully commit to the scientific goals and work plan of CogniGron. In addition, projects that are submitted jointly by two PIs and strengthen the collaboration between different disciplines are prioritised. A four-page proposal is submitted for each project. 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 and institutes. The proposals are reviewed by the CogniGron programme board and, if needed, by the external scientific advisory panel.

PROJECTS AWARDED IN 2023

Low power probabilistic bits enabled reckoning

The collaborative goal of this project is to achieve a proof of concept of an in-memory random number generator using probabilistic bits as well as probabilistic hardware for solving optimisation problems efficiently.

Project leaders: Tamalika Banerjee (Physics) and Georgi Gaydadjiev (Computer Science)

PhD student: Ishitro Bhaduri

Aligning learning and modeling in a small computational brain

The understanding and control of existing cognitively relevant hardware is still limited. We will build on existing research on innovative materials, such as HfO2 based memristors, to develop new statistical techniques and analysis pipelines to investigate their behaviour. In parallel we will address the problem of aligning, learning and reasoning in cognitive hardware design. For the design of new cognitive devices we will develop new artificial intelligence methods that are meaningful in the target domain and make sense of the data. The two projects are connected by a shared mathematical modelling technique, namely Bayesian networks. Bayesian networks are a flexible and easy-to-interpret tool for modelling the dependencies in complex data.

Project leaders: Marco Grzegorczyk (Mathematics), Bart Verheij (AI), Beatriz Noheda (Physics)

PhD students to be hired in 2024.

Robust learning of sparse representations: brain-inspired inhibition and statistical physics analysis

(awarded in 2022)

Sparsity is among the key factors that contribute to high energy-efficient processing in the brain. Neuroscientists believe that inhibition is a crucial property that results in sparse and thus highly energy efficient representations. Sparsity and inhibition are the focus of this project, consisting of two key objectives: the investigation of push-pull inhibition embedded in convolutional and spiking neural networks, and the systematic study of learning processes in model situations.

Project leaders: George Azzopardi (AI) and Michael Biehl (Computer Science)

PhD students: Otavio Citton and Peter van der Wal

Memristive models for faster material design cycles towards applications

(awarded in 2022)

Long development cycles for memristive devices and materials are inhibiting innovation due to large parameter spaces, complex manufacturing processes, and necessary measurement series. This limits physical insight, performance, and applications of memristors. The project tackles this challenge by a close interaction of mathematical modelling and material science, in which newly acquired experimental data and models from material scientists are used in a closed design loop together with state-of-the-art mathematical techniques. The goal of this project is to combine mathematical and material models to improve understanding of memristive materials, speedup memristor design and extend memristors' application areas.

Project leaders: Tamalika Banerjee (Physics) and Julian Koellermeier (Mathematics)

PhD student: Safiere Kuijpers

Smart electronic olfactory system

(awarded in 2021)

The use of so-called electronic noses has spread widely in many industrial sectors thanks to their ability to detect chemicals in very small concentrations. In the healthcare sector, this technology is starting to play a key role as a rapid and low-cost diagnostic tool for many diseases. In this project we are specifically interested in the development of electronic noses for lung cancer detection.

Project leaders: Elisabetta Chicca (Electronics), Maria Loi (Physics) and Alden Waters/Stephan Trenn (Mathematics)

PhD students: Radu Cimpean, Paul Hansch and Juny Pina

Qualitative modelling, simulation and exploration of multi-phenomenal materials dynamics

(awarded in 2021)

Current approaches to computing based on digital hardware have limitations and call for novel alternatives. The aim of this project is to pioneer a new qualitative physics formalism, together with a qualitative physics engine that is able to simulate a wide range of phenomena while being fast to run, replacing numerical accuracy by qualitative validity.

Project leaders: Herbert Jaeger (AI) and Beatriz Noheda (Physics)

PhD students: Foelke Jansen and Fabian IJperlaar

Nanoparticle based percolating networks towards neuromorphic computing

(awarded in 2020)

Nanoparticle percolating networks exhibit interesting switching behaviour and potentiation, which are characteristics of the brain with neurons and synapses. In this project, phase change material nanoparticles are designed, synthesised and mathematically modelled. These materials are expected to have a richer network activity and therefore excellent materials used for neuromorphic computing.

Project leaders: George Palasantzas & Bart Kooi (Physics), Holger Waalkens & Daniel Valesin (Mathematics)

PhD students: Julien van der Ree and Jhon Kevin Astoquillca Aguilar

Nb-doped SrTiO3 memristive interfaces for bio-inspired computing

(awarded in 2019)

This project studies the physics of interface-based memristive devices on semiconducting SrTiO3 substrates and develops phenomenological models to predict the performance of such devices.

Project leaders: Tamalika Banerjee (Physics) and Lambert Schomaker (AI)

PhD students: Azminul Jaman and Jordi Timmermans

Towards a cognitive computer architecture based on memristive devices: developing short- and long-term memory

(awarded in 2019)

The goal of this project is to build a pattern-completion memory, which we believe is a critical component in developing novel cognitive computing architectures. We will accomplish this by building a neural network in which memristive devices 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.

Project leaders: Niels Taatgen and Jelmer Borst (AI), Tamalika Banerjee (Physics)

PhD students: Anouk Goossens and Thomas Tiotto

WALLNET: Memristor networks from self-assembled domain walls in oxides

(awarded in 2019)

This project investigates materials that self-organise in conducting networks that can transmit signals and host memory elements in a similar way to biological neurons and synapses.

Project leaders: Bart Besselink and Arjan van der Schaft (Mathematics), Beatriz Noheda (Physics)

PhD students: Jan Rieck and Anne-Men Huijzer

COGNIGRON FELLOWSHIPS

Staff can also participate and contribute to the CogniGron research programme through a PhD student who works 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-IBM FELLOWSHIPS

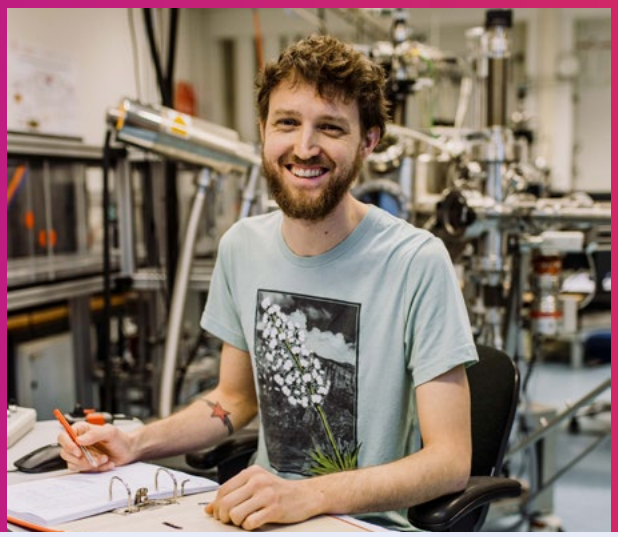
Two CogniGron-IBM fellowships were awarded. CogniGron has partnered with IBM in these projects to work on novel materials for neuromorphic computing.

Combined volatile/non-volatile memristive ferroelectric arrays

The project aims to develop synaptic devices, similar to those in the brain, based on ferroelectric materials. In particular, the goal is to build arrays of these (memristive) devices that can show both short-term and long-term potentiation and depression, which is important for the implementation of neural networks.

Project leaders: Beatriz Noheda (CogniGron), Sigi Karg and Bert Jan Offrein (IBM-Research Zurich)

PhD student: Ruben Hamming-Green



Analogue phase-change memory cells for neuromorphic computing

Phase-change memories are, to date, arguably the most advanced resistive memory technologies. Phase-change memories are also being explored for in-memory computing applications, such as performing logical operations as well as realising hardware substrates for neuromorphic computing. It has been shown that phase-change memory devices can emulate some of the key synaptic and neuronal functionalities, thus facilitating the realisation of ultra-low power and dense neuromorphic hardware. In this project, we propose a relatively new concept of phase-change memory.

Project leaders: Bart Kooi (CogniGron) and Abu Sebastian (IBM-Research Zurich)

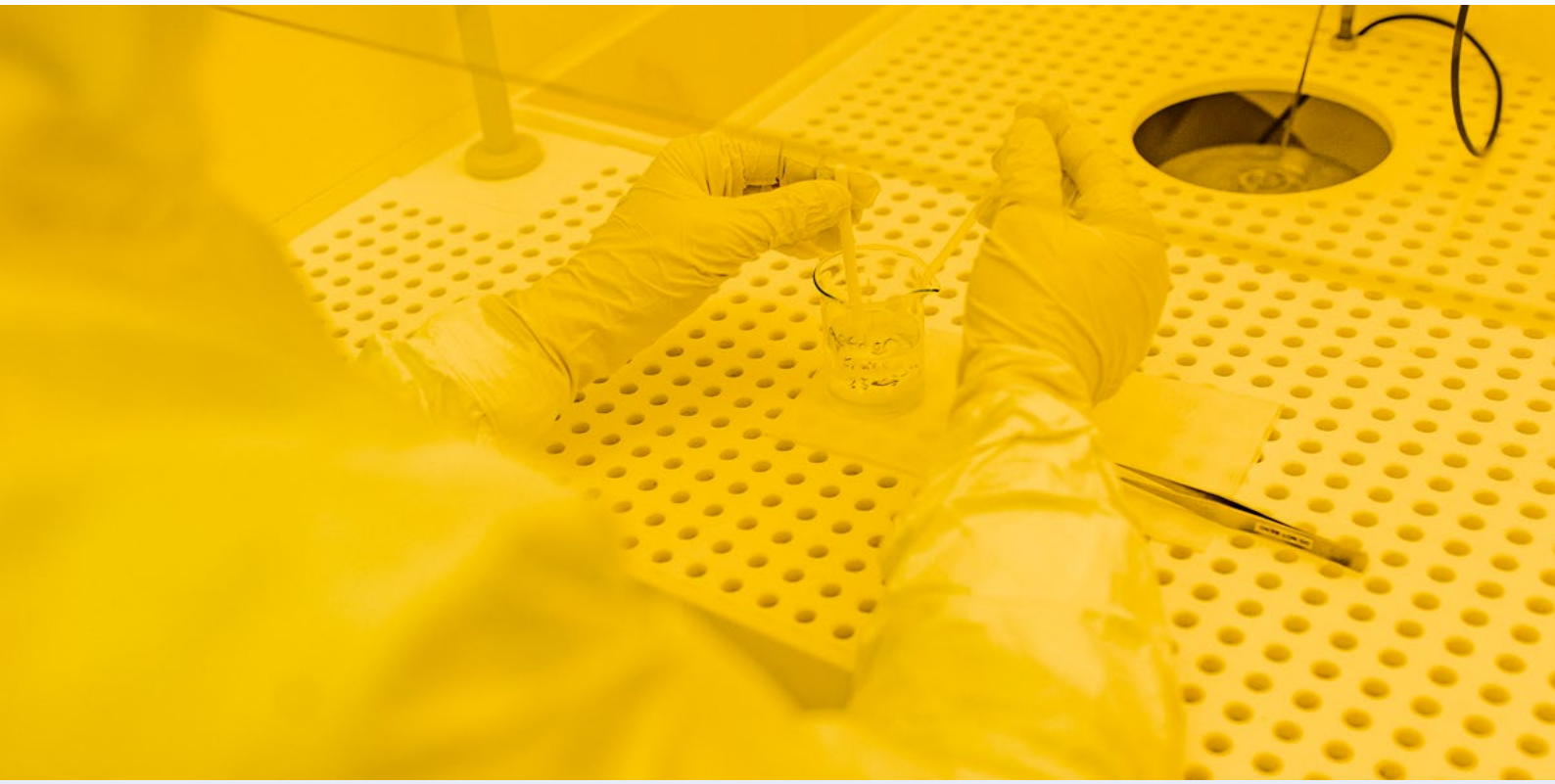
PhD student: Jesse Luchtenveld

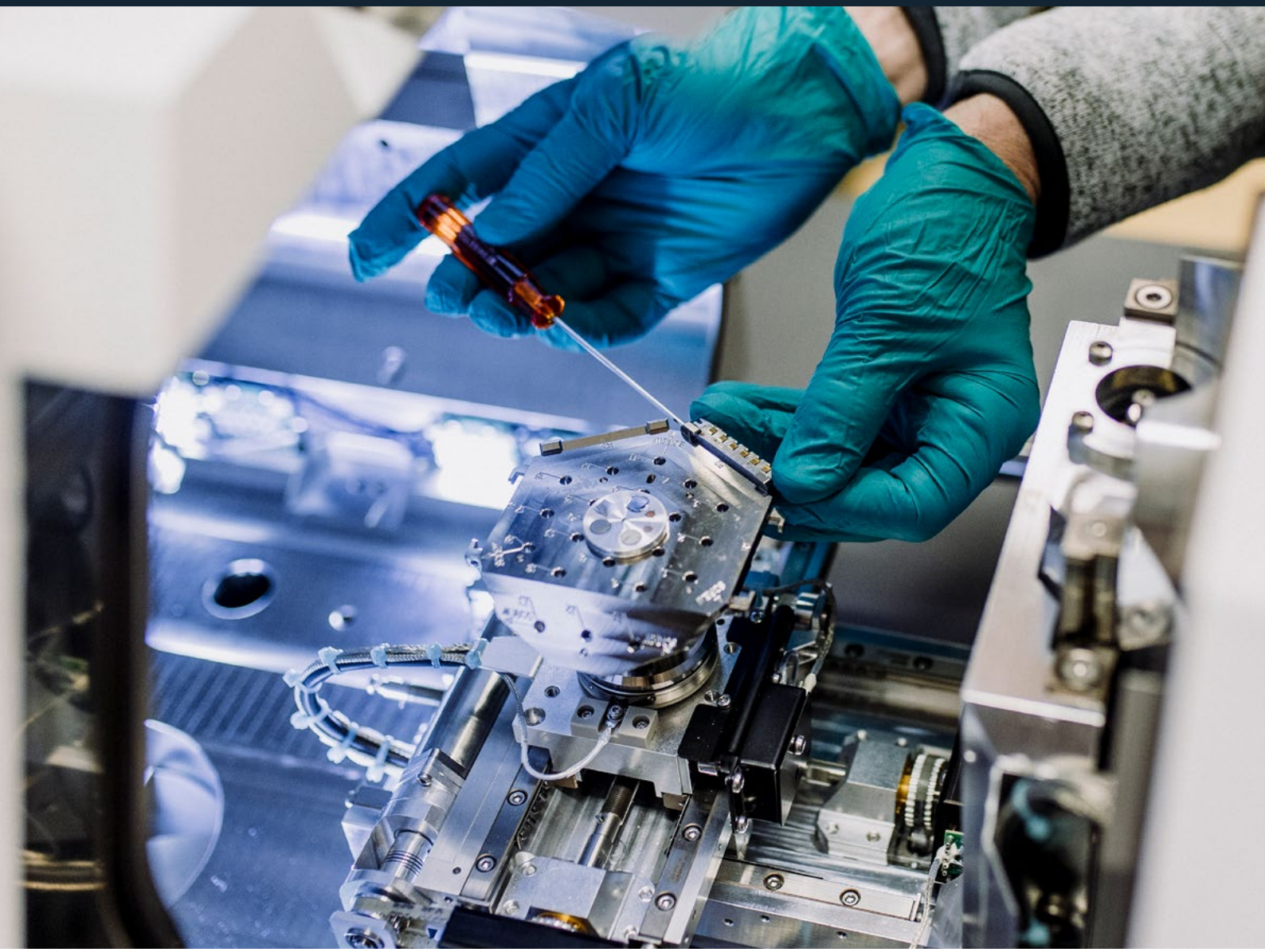
ENABLING TECHNOLOGIES

CogniGron aims to make fundamental advances towards a disruptive technology, and the efforts in this direction require sophisticated research facilities to synthesise and characterise 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 two advanced research facilities: the electron microscopy centre and NanoLabNL.

ELECTRON MICROSCOPY CENTRE

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





NANOLABNL: NANOFABRICATION 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 through necessary updates — especially to keep up with developments in other countries in our region — is becoming a challenge.

The long-term stability of NanoLabNL is vital for CogniGron and we believe there is a need for CogniGron and NanolabNL to work together and make sure the facilities are up-to-date with the newest technological advances. Since the goal of CogniGron is closely related to developing novel electronic devices, for which the nanolithography and fabrication facilities provided by NanoLabNL are crucial, CogniGron has reserved funds to support NanoLabNL in the form of a new electron beam evaporator as well as a technician to support the new PhD students and staff who will be using the NanoLabNL facilities in Groningen. We are aware that more support is needed to maintain the NanoLabNL facilities in Groningen at international standards, and we are constantly working with the NanoLabNL management team to find solutions. Therefore, CogniGron has reserved a yearly budget for the running costs of NanoLabNL Groningen from 2021 until 2025 and CogniGron researchers can make use of the cleanroom facilities at no cost. CogniGron counts with Arjun Joshua to support the NanoLab activities of CogniGron staff.

COGNIGRON ACTIVITIES

DISCUSSION SESSIONS

One of the keys to a successful research programme is to create sustainable synergy in a unique environment where everyone — from materials scientists to the computer scientists and from artificial intelligence scientists to mathematicians — understands each other's motivations with respect to the common goal. Only then will partnerships arise naturally. This requires investing in cross-disciplinary education aiming to understand each other's language and concepts.

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

STUDENT DISCUSSION SESSIONS

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

EDUCATIONAL PROGRAMME

The increasing interest of our new and existing staff towards neuromorphic materials, devices and computers is reflected in the educational programme. Two new courses on core CogniGron subjects have been developed and incorporated in the Applied Physics master curriculum as elective courses: 'Neuromorphic circuit design' (given by Elisabetta Chicca) and 'Memristive devices' (given by Beatriz Noheda). These have become very popular and are followed not only by regular Applied Physics and Nanoscience master students, but also as elective courses and graduate courses for AI and Computer Science master and PhD students, respectively.

A list of basic courses is available to all CogniGron students to facilitate their immersion in other relevant disciplines.

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 close by, as well as to promote the exchange of research progress and ideas. In the CogniGron@work sessions every Monday, researchers from CogniGron explain their work, with a focus on the cross-disciplinary character of the research.

COGNIGRON SEMINARS FOR INVITED SPEAKERS

We cherish the opportunity to invite experts from around the world to visit Groningen and consider it 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, as well as to make CogniGron known to the international and national communities. We are proud of the list of internationally recognised experts who have kindly accepted our invitation and have spent days with us sharing their research ideas and also learning first-hand about the CogniGron vision. In the CogniGron webpages a complete list of speakers is provided, including the titles and dates of their presentations. In 2023, we had the following speakers:

- Simon Brown (University of Canterbury, UK)
  "Brain-like computation with percolating networks of nanoparticles"
- Horatio Cox (University College London)
  "Measuring the ionic diffusion in silicon oxide memristors and harnessing their frequency response"
- Barbara Webb (University of Edinburgh, Scotland)
  "Vector manipulation in the brain of an insect"
- Alessio Franci (University of Liège)
  "Excitable decision-making"
- Tobias Meuser (TU Darmstadt, DE)
  "Adaptive monitoring for resilient future computer networks"
- Jennifer Hasler (Georgia Tech, USA)
  "Programmable analog integrated circuits"
- Pieter Roelfsema (Netherlands Institute for Neuroscience, Amsterdam & Institut de la Vision, Paris)
  "How neurons create conscious perceptions – a new route for restoring vision in blind individuals"
- Bert Jan Offrein (IBM-Research Zurich, CH)
  "Analog signal processing for power-efficient neuromorphic computing"

OUTREACH

Podcast with Elisabetta Chicca: On-Chip Learning is Missing Neuromorphic Building Block

In this podcast, Sunny Bains talks to Elisabetta Chicca about building neural chips with memristors, adding electronic brains to neural robots, and some of the current difficulties with learning algorithms for spiking systems.

OTHER (CO-)ORGANISED EVENTS

Symposium at the MRS 2023 Spring Meeting & Exhibit

San Francisco (United States), 10-14 April 2023

As part of the segment Quantum Materials and Systems, Beatriz Noheda co-organised a session titled "Functional Ferroic Materials for Unconventional Computing".

Innovation Day

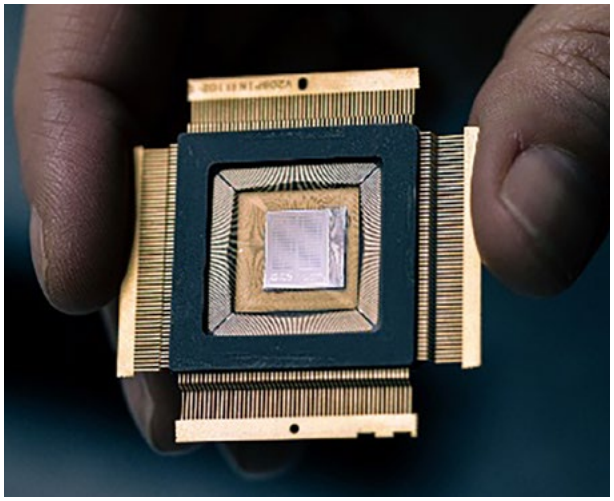
House of Connections, Groningen (The Netherlands), 14 June 2023

Successful innovation requires breakthrough technologies that can solve significant problems. These technologies often emerge from academic research labs that receive high recognition, typically through valorisation, ensuring societal impact and value capture. This Innovation Day, co-organised by CogniGron, offered a unique platform for RUG and UMCG innovators to showcase their work and for investors to flourish. This year's event focused on Deep Technologies.

CogniGron/Neurotronics (CAU, Kiel University) Summer School Neuromorphic Computing

Groningen (The Netherlands), 14-17 June 2023

CogniGron and the Neurotronics centre at CAU Kiel University organised a joint summer school on Neuromorphic Computing for their PhD students.



Neuromorphic Computing in the Netherlands Workshop (NCN 2023), 3rd edition

House of Connections, Groningen (The Netherlands), 2 October 2023

Neuromorphic Computing drives inspiration from biological computational principles to design novel, more efficient computing solutions. Its highly heterogeneous community calls for more scientific interactions to foster cross-fertilisation of ideas, promote collaborations, and train a new generation of future leading 'neuromorphs'. The NCN2023 meeting, organised by Nicoletta Risi and Elisabetta Chicca, was aimed at gathering leading experts and junior researchers in one place to discuss current trends and open challenges in the field, from algorithmic, architectural, and application domains. Complementing previous years' topics, this edition will focus on Bio-inspired computing paradigms and emerging technologies.

AMOLF-CogniGron Knowledge Exchange Day

House of Connections, Groningen (The Netherlands), 24 November 2023

At this first AMOLF-CogniGron Knowledge Exchange Day, we welcomed our colleagues from the Information in Matter department at AMOLF for a day filled with lectures and inspiration sessions on neuromorphic computing. Many of our experts were present to share their latest research results and new computer chips in the making. PhD students got to present their research during the poster session. Apart from lectures and discussions, there was ample opportunity to get to know each other better, socialise and build connections. The Knowledge Exchange Day was a great success and will be an annual event between AMOLF and CogniGron.

PARTNERSHIPS

Strategic partnerships play a crucial role in advancing scientific research and technological innovation. CogniGron believes in the power of working together, between different disciplines, but also between different institutions.

University College London and Western Sydney University

Two such significant collaborations in the field of neuromorphic computing are with Western Sydney University (WSU) and University College London (UCL). After setting up a formal agreement between the International Centre for Neuromorphic Systems, led by Prof. André van Schaik at WSU in 2021, CogniGron has set up an agreement with UCL in 2022 with Prof. Tony Kenyon's team.

The partnership with UCL and WSU brings together experts fostering a multidisciplinary approach to address the challenges and potential of neuromorphic computing. These strategic partnerships create a unique opportunity to push the boundaries of neuromorphic computing. Through joint research projects, knowledge sharing and collaborative initiatives with UCL and WSU, we can accelerate the education of a new generation of researchers and the development of innovative algorithms, hardware architectures, and applications that leverage the power of neuromorphic computing.

Neurotronics Centre at Kiel University

In 2022 we started organising joint workshops and conferences with the CRC 1461 – Neurotronics Research Centre at Kiel University, led by Prof. Dr. Hermann Kohlstedt. The CRC 'Neurotronics: Bio-inspired Information Pathways' will explore and propel the research of novel hardware technologies as a cornerstone for novel bio-inspired computing architectures paving the way towards an unconventional information processing. They envision impacts in various research fields in science and technology, such as robotics and brain implants.

The first joint event we organised was Color Line Workshop on Bio-Inspired Information Pathways. The workshop took place on the ferry between Kiel-Oslo-Kiel.

In 2023 a second joint event was organised, namely a PhD Summerschool on neuromorphic computing. The summer school took place in Groningen.

SynSense located in Zurich

In 2023, SynSense and CogniGron started a collaboration to evaluate the low-power neuromorphic sensory processors from SynSense. The CogniGron research groups will use the Speck™ low-power vision system to develop visually guided closed-loop systems. They will also evaluate the Xylo™ microWatt Audio processing platform to explore auditory scene analysis applications.

SynSense is a world-leading neuromorphic engineering company. It provides custom-tailored, ultra-low-power silicon design solutions for industrial and consumer machine-learning inference applications. As a "full-stack" neuromorphic engineering company, SynSense delivers complete solutions, including custom IP, hardware, and software configurations to meet specific application needs. SynSense was founded in March 2017 in Zürich Switzerland, based on groundbreaking advances in neuromorphic computing hardware developed at the Institute of Neuroinformatics of the University of Zurich and the ETH Zurich.

INDUSTRY RELATIONS

These are the industrial partners who worked with CogniGron or collaborated via projects involving our researchers.

- aixACCT Systems GmbH
  Aachen, Germany
- Building Between Bridges
  Kortemark, Belgium
- CrysTec GmbH
  Berlin, Germany
- DENSsolutions BV
  Delft, the Netherlands
- IBM Research Zurich
  Zurich, Switzerland
- IMEC - Holst
  Eindhoven, the Netherlands
- Océ Technologies BV
  Venlo, the Netherlands
- SmartTip BV
  Enschede, the Netherlands
- Solmates BV
  Enschede, the Netherlands
- SynSense
  Zürich, Switzerland
- Demcon TSST
  Enschede, the Netherlands

PRIZES AND AWARDS

Yingfen Wei, Gaurav Vats and Beatriz Noheda's article chosen as Neuromorphic Computing and Engineering highlight of 2022

The Neuromorphic Computing and Engineering journal selected CogniGron's work on Synaptic behaviour in ferroelectric materials as a highlight of 2022. According to Neuromorphic Computing and Engineering the article — 'Synaptic behaviour in ferroelectric epitaxial rhombohedral Hf0.5Zr0.5O2 thin films' — provides an example of the high quality, innovative and interesting work that was published in the journal. The highlighted papers were chosen based on reviewers' reports, and represent our best-regarded articles across a number of topics.

Anouk Goossens, Miina Leiviska and Tamalika Banerjee selected for the Outstanding Article, Impact Award for Original Research 2022

The article 'Anisotropy and Current Control of Magnetization in SrRuO3/SrTiO3 Heterostructures for Spin-Memristors' was selected for the Outstanding Article, Impact Award for Original Research, for the year 2022 by Frontiers in Nanotechnology (Frontiers).

Millions for research on heritage and stress in young children awarded to Lambert Schomaker and Menno Reijneveld

CogniGron programme board member Lambert Schomaker is the coordinator of an awarded NWA grant of €103 million for the HAICu project. This project brings together AI and Digital Humanities researchers, heritage professionals, and interested citizens who work together to achieve scientific breakthroughs in order to open up, link, and analyse large-scale digital heritage collections.

Saad Saleh's startup 'Quetta' ranked Top-5 in the 'Patent Innovation Award' category at the European Innovation Academy for pioneering memristor-based network switches

Saad Saleh's research focuses on the study of novel hardware technologies, especially Memristors, for supporting energy-efficient and cognitive computational models in current network devices.

QUETTA

Saad Saleh awarded 4TU.NIRICT funding for participation in the European Innovation Academy 2023

Saad Saleh was among the five recipients of 4TU.NIRICT funding for entrepreneurship and innovation. The funding was meant for participation in the European Innovation Academy 2023 in Porto, Portugal, where students had the opportunity to participate in a 3-week study abroad programme about entrepreneurship and innovation to develop an entrepreneurial mindset, build their business skill set and stand out in a competitive world.

ERC Synergy Grant for Elisabetta Chicca

Professor Elisabetta Chicca's project SWIMS (Stochastic Spiking Wireless Multimodal Sensory Systems) was awarded with an ERC Research Grant from the European Research Council. The project received 13.5M euros under the Synergy programme. SWIMS is revolutionising the landscape of smart wireless multimodal sensory systems. By embracing bio-inspired design principles, SWIMS is reshaping hardware to achieve exceptional energy efficiency, particularly in event detection and communication.

PUBLICATIONS

Highlighted Publications

From the publications submitted in 2023, we highlight the following:

Research paper of Saad Saleh has been accepted at the 43rd IEEE International Conference on Computer Communications (INFOCOM 2024): "Analog In-Network Computing through Memristor-based Match-Compute Processing"

By Saad Saleh (CogniGron, Groningen), Anouk Goossens (CogniGron, Groningen), Sunny Shu (University of Groningen), Tamalika Banerjee (CogniGron, Groningen), Boris Koldehofe (CogniGron, Groningen, and Technische Universität Ilmenau, Germany).

Abstract

Current network functions consume a significant amount of energy and lack the capacity to support more expressive learning models like neuromorphic functions. The major reason is the underlying transistor-based components that require continuous energy-intensive data movements between the storage and computational units. In this research, we propose the use of a novel component, called Memristor, which can colocalise computation and storage, and provide computational capabilities. Building on memristors, we propose the concept of match-compute processing for supporting energy efficient network functions. Considering the analog processing of memristors, we propose a Probabilistic Content Addressable Memory (pCAM) abstraction which can provide analog match functions. pCAM provides deterministic and probabilistic outputs depending upon the closeness of match of an incoming query with the specified network policy. pCAM uses a crossbar array for line rate matrix multiplications on the match outputs. We proposed a match-compute packet processing architecture and developed the programming abstractions for a baseline network function, i.e., Active Queue Management, which drops packets based upon the higher-order derivatives of sojourn times and buffer sizes. The analysis of match-compute processing over a physically fabricated memristor chip showed only 0.01 fJ/bit/cell of energy consumption, which is 50 times less than the traditional match-action processing.

Preliminary findings of this research were published at the prestigious ACM Workshop on Hot Topics in Networks (HotNets 2023).

Nature Communications Article: "Toward a formal theory for computing machines made out of whatever physics offers"

By Herbert Jaeger (CogniGron, Groningen), Beatriz Noheda (CogniGron, Groningen) and Wilfred G. van der Wiel (BRAINS, University of Twente, Enschede, and Westfälische Wilhelms-Universität Münster, Germany).

Abstract

Approaching limitations of digital computing technologies have spurred research in neuromorphic and other unconventional approaches to computing. Here we argue that if we want to engineer unconventional computing systems in a systematic way, we need guidance from a formal theory that is different from the classical symbolic-algorithmic Turing machine theory. We propose a general strategy for developing such a theory, and within that general view, a specific approach that we call fluent computing. In contrast to Turing, who modelled computing processes from a top-down perspective as symbolic reasoning, we adopt the scientific paradigm of physics and model physical computing systems bottom-up by formal-

ising what can ultimately be measured in a physical computing system. This leads to an understanding of computing as the structuring of processes, while classical models of computing systems describe the processing of structures.

Neuromorphic Computing and Engineering Article: "Conduction and entropy analysis of a mixed memristor-resistor model for neuromorphic networks"

By Davide Cipollini (CogniGron, Groningen) and Lambert R. B. Schomaker (CogniGron, Groningen).

Abstract

To build neuromorphic hardware with self-assembled memristive networks, it is necessary to determine how the functional connectivity between electrodes can be adjusted, under the application of external signals. In this work, we analyse a model of a disordered memristor-resistor network, within the framework of graph theory. Such a model is well suited for the simulation of physical self-assembled neuromorphic materials where impurities are likely to be present. Two primary mechanisms that modulate the collective dynamics are investigated: the strength of interaction, i.e. the ratio of the two limiting conductance states of the memristive components, and the role of disorder in the form of density of Ohmic conductors (OCs) diluting the network. We consider the case where a fraction of the network edges has memristive properties, while the remaining part shows pure Ohmic behaviour. We consider both the case of poor and good OCs. Both the role of the interaction strength and the presence of OCs are investigated in relation to the trace formation between electrodes at the fixed point of the dynamics. The latter is analysed through an ideal observer approach. Thus, network entropy is used to understand the self-reinforcing and cooperative inhibition of other memristive elements resulting in the formation of a winner-take-all path. Both the low interaction strength and the dilution of the memristive fraction in a network provide a reduction of the steep non-linearity in the network conductance under the application of a steady input voltage. Entropy analysis shows enhanced robustness in selective trace formation to the applied voltage for heterogeneous networks of memristors diluted by poor OCs in the vicinity of the percolation threshold. The input voltage controls the diversity in trace formation.

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Other Publications 2023

Badillo-Ávila, M. Á., Taleb, S., Carreno-Jiménez, B., Mokabber, T., Castanedo-Pérez, R., Torres-Delgado, G., ... & Acuautla, M. (2023). (001)-oriented Sr: HfO2 ferroelectric films deposited by a flexible chemical solution method. ChemRxiv. 2023; doi:10.26434/chemrxiv-2023-8cxnf

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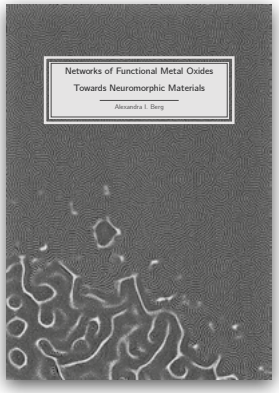
PhD theses 2023

Networks of functional metal oxides towards neuromorphic materials

PhD candidate: A.I. (Sanne) Berg
When: 29 August 2023
Promotores: Prof. Beatriz Noheda, Prof. Giuseppe Portale



Abstract:
Artificial Intelligence (AI) has seen a massive increase in importance over the past years, and with it comes the high power consumption required for operation of deep learning networks. One way to reduce the power consumption of these systems is to move away from computing on central processing units (CPU), accelerated by graphics processing units (GPU) and look into brain-inspired (neuromorphic) hardware. Current neuromorphic chips outperform conventional computers when considering power consumption for tasks such as pattern recognition. But the large number of transistors required for these chips to emulate one neuron, limits their functionality. To lower the power consumption further, research is looking into new materials and novel device structures, with a special focus on memristors. A memristor (or memory resistor) is a device with a variable resistance that can be programmed and which depends on the history of the voltage that was applied to the device. Interestingly, these devices remember their resistance state even when the power is turned off, they are non-volatile.
In this work, Sanne Berg investigates the creation of self-assembled nanoscale networks of oxide materials with the intention of developing richer, more complex, and more tunable materials, including memristors. She achieves this by combining polymer imprinting and -templating to form highly ordered and interconnected networks of different functional metal oxides. Berg shows that many materials are within reach for the combined templating and imprinting method and that these materials show promise for future applications in adaptable electronics.

Complex oxides for computing beyond von Neumann

PhD candidate: A.S. (Anouk) Goossens
When: 3 October 2023
Promotores: Prof. Tamalika Banerjee, Prof. Lambert Schomaker

Abstract:

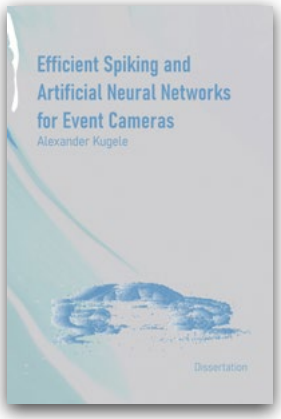
Reducing transistor dimensions cannot sustain the growing demand for better technology. To reduce the power consumption while increasing the technological performance we can take inspiration from the brain – a naturally energy-efficient system and focus on integrating more intelligent components on chips. The brain's efficiency largely stems from the co-location of memory and processing units, which we can emulate using smart materials and devices that perform the functionalities of neurons and synapses. Leading candidates for this are devices that can switch between multiple resistive states through an external stimulus. Anouk Goossens' thesis focuses on building such devices using complex oxides - a class of materials that is highly tunable due to a strong coupling between different degrees of freedom.

Goossens explores resistive switching in interfacial memristors based on metal contacts on the unconventional semiconductor Nb-doped SrTiO3. These devices are tunable from both sides of the interface. By reducing the metal electrode area the resistance ratio is enhanced, which is an unconventional but desirable effect – downscaling tends to negatively impact device performance, but Goossens found the opposite to be the case. Altering the doping concentration allowed her to control a range of parameters including the stochasticity, memory window and switching speed.

Goossens also worked on spintronic devices using ferromagnetic SrRuO3 layers. Goossens: "we show the ability to control the magnetic anisotropy and influence the magnetisation using current – two key parameters for device scalability. By integrating these layers into magnetic tunnel junctions we demonstrate relatively large changes in resistance and multiple non-volatile resistance states."

Efficient spiking and artificial neural networks for event cameras

PhD candidate: A.P. (Alexander) Kugele
When: 19 December 2023
Promotor: Prof. Elisabetta Chicca



Abstract:

From smartphones over cars to robots: Cameras are built into almost every modern technological device. Albeit being such a versatile sensor, they have inherent limitations, for example when using them at night, or when trying to capture a fast-moving object. Recently, event cameras have become attractive alternatives to regular cameras in these scenarios. By measuring brightness changes instead of absolute brightness, event cameras are faster, more energy-efficient and less susceptible to global illumination. Efficient algorithms to process event camera data (event streams) are imperial to make use of these advantages.

This thesis presents multiple approaches to obtain or improve neural networks to detect and classify objects by learning from event streams. A specific focus is put on spiking neural networks (SNNs), which is a class of algorithms that work similar to a biological brain, in that each neuron carries an internal state and communicates via binary signals (spikes). We present a method to obtain a spiking neural network for event stream classification from an ANN, and subsequently show that the spiking networks are more efficient than their ANN counterpart, while reaching the same performance in multiple benchmarks. To improve energy-efficiency further, we develop a mixed SNN-ANN network, that directly learns from data and is able to detect fast-moving objects. We also introduce an object memory, that enables training networks on shorter sequences. Overall, the methods developed in this thesis improve the object detection capabilities of event camera systems, enabling a future use in applications like automated driving or domestic robots.

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 is actively participating in or coordinating externally funded projects. Details are provided below:

EU FUNDING

Crystalline Oxides for Next Generation Computing and Emerging Photonic Technologies (CONCEPT)

This project has received funding from HORIZON Research and Innovation Actions / HORIZON-RIA under grant agreement no. 101135946

- Coordinator: Henrik Hovde Sønsteby (University of Oslo, Norway)
- CogniGron participant: Beatriz Noheda
- Amount: € 423,110.00

Topological Solitons in Ferroics for Unconventional Computing (TOPOCOM)

This project has received funding from the EU Horizon 2020 programme under the Marie Skłodowska-Curie grant agreement no. 101119608

- Coordinators: Dennis Meier and Marianne Lenes (Norwegian University of Science and Technology, Norway)
- CogniGron participant: Beatriz Noheda
- Amount: € 274,370.40

Transforming IoT Sensory Systems for a Sustainable Future (SWIMS)

This project has received funding from the European Research Council under grant agreement no. 101119062

- Coordinator: Gerhard Fettweis (TU Dresden, Germany)
- CogniGron participant: Elisabetta Chicca
- Amount: € 2,714,222.50

BeFerroSynaptic – BEOL technology platform based on ferroelectric synaptic devices for advanced neuromorphic processors

This project has received funding from the EU Horizon 2020 research and innovation programme under grant agreement no, 871737

- Coordinator: Stefan Slesazeck (NaMLab gGmbH, Germany)
- CogniGron participant: Elisabetta Chicca
- Amount: € 387,625.00

Insectneuronano – Insect-Brain Inspired Neuromorphic Nanophotonics

This project has received funding from the EU Horizon 2020 European Innovation Council programme under grant agreement no. 101046790

- Coordinator: Anders Mikkelsen (Lund University, SE)
- CogniGron participant: Elisabetta Chicca
- Amount: € 272,990.00

MANIC – Materials for Neuromorphic Circuits

This project has received funding from the EU Horizon 2020 programme under Marie Skłodowska-Curie grant agreement no. 861153

- Coordinators: Beatriz Noheda (Groningen) and Bernd Gotsmann (IBM-Research Zurich, Switzerland)
- CogniGron participants: Beatriz Noheda, Elisabetta Chicca, Lambert Schomaker, Michael Wilkinson, Jos Roerdink
- Amount: € 1,091,836.00

MeM-Scales – Memory technologies with multi-scale time constants for neuromorphic architectures

This project has received funding from the EU Horizon 2020 programme under grant agreement no. 871371

- Coordinator: Elisa Vianello (CEA-Leti, Grenoble, France)
- CogniGron participant: Herbert Jaeger
- Amount: € 304,379.00

MELON – Memristive and multiferroic materials for emergent logic units in nanoelectronics

This project has received funding from the EU Horizon 2020 Research and Innovation Staff Exchange programme under grant agreement no. 872631

- Coordinator: Igor Lukyanchuk (University of Picardie Jules Verne, France)
- CogniGron participant: Beatriz Noheda
- Amount: € 308,200.00

NeuroTech – Neuromorphic Technology

This project has received funding from the EU Horizon 2020 FETPROACT CSA project on Community Building in Neuromorphic Computing Technologies (NCT) under grant agreement no. 824103

- Coordinator: Giacomo Indiveri (The University of Zurich and ETH Zurich, Switzerland)
- CogniGron participant: Elisabetta Chicca
- Amount: € 65,867.30

NouTouch – Understanding neural coding of touch as enabling technology for prosthetics and robotics

This project has received funding from the European Research Council (ERC) under grant agreement no. 813713

- Coordinator: Chiara Bartolozzi (Istituto Italiano di Tecnologia, Italy)
- CogniGron participant: Elisabetta Chicca
- Amount: € 177,079.92

Post-Digital – Post-Digital Computing

This project has received funding from the EU Horizon 2020 programme under Marie Skłodowska-Curie grant agreement no. 860360

- Coordinator: Sergei Turitsyn (Aston University, UK)
- CogniGron participant: Herbert Jaeger
- Amount: € 531,239.76

Respite – Reconfigurable Superconducting And Photonic Technologies Of The Future

This project has received funding from the EU Horizon 2020 Pathfinder programme under grant agreement no. 101098717

- Coordinator: Delft University
- CogniGron participant: Bart Kooi
- Amount: € 395,198.75

NATIONAL FUNDING

NL-ECO

This project has received funding from within the Dutch NWA-ORC scheme under grant agreement no. NWA.1389.20.140

- Coordinator: Hans Hilgenkamp (University of Twente, NL)
- CogniGron participants: Beatriz Noheda, Tamalika Banerjee, Georgi Gaydadjev, Niels Taatgen and Elisabetta Chicca.
- Amount: € 971,211.00

Materials for neuromorphic devices

This project has received funding from an NWO Visitor's Travel Grant under grant agreement no. 9047

- Applicant: Beatriz Noheda
- Visitor: Prof. Diego Rubi (University of Buenos Aires, Argentina)
- Amount: € 7,500.00

OTHER INTERNATIONAL FUNDING

MemTDE – Memristive Time Difference Encoder

This project has received funding from the German Science Foundation (DFG) under individual research grant agreement no. 441959088

- Applicant: Elisabetta Chicca
- CogniGron participant: Elisabetta Chicca
- Amount: € 278,750.00

MAKI - Multi-Mechanisms Adaptation

This project has received funding from the German Science Foundation (DFG) via the Collaborative Research Centre 1053

- Applicant: Boris Koldehofe
- CogniGron participant: Boris Koldehofe
- Funding via the University of Darmstadt

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