CogniGron Kick-off Meeting

26 October 2018

To break new scientific ground!
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CogniGron

The University of Groningen has created the Groningen Cognitive Systems and Materials Center (CogniGron) in order to join efforts from different disciplines with the goal of developing novel architectures for cognitive computing. 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 develop learning at the materials level. Within CogniGron research groups from the Bernoulli Institute for Mathematics, Computer Science and Artificial Intelligence, as well as the Zernike Institute for Advanced Materials will work together towards this goal. CogniGron is honoured to be supported by an extraordinary Advisory Board of world-recognized leaders working in this new exciting research direction.

Beatriz Noheda
Scientific Director Groningen Cognitive Systems and Materials
CogniGron
Programme

9: 00hrs Opening words by Sibrand Poppema (former president of the board of the University of Groningen)

9:15hrs Niels Taatgen (University of Groningen)
9:45hrs Theo Rasing (Radboud University of Nijmegen)

10:15hrs coffee break

10:45hrs Elisabetta Chicca (CITEC - Bielefeld University, Germany)
11:15hrs Catherine Schuman (Oak Ridge National Laboratory, USA)
11:45hrs Ivan Schuller (University of California San Diego, USA)

12:15hrs Lunch break

13:45hrs Davide Grossi (University of Groningen)
14:15hrs Heike Riel (IBM Zurich, Switzerland)
14:45hrs Maria Loi (University of Groningen)

15:15hrs coffee Break

15:45hrs Regina Dittmann (Forschungszentrum Juelich, Germany)
16:15hrs Julie Grollier (CNRS/Thales, France)
16:45hrs Giacomo Indiveri (UZH / ETH Zurich, Switzerland)

17:15hrs closing remarks By Jasper Knoester (Dean of the Faculty of Science and Engineering, University of Groningen) and drinks

The day will be chaired by Beatriz Noheda (Scientific Director Cogni-Gron)
A Cognitive Computer based on neuromorphic hardware requires more than building neural networks out of new materials. Just like conventional computer architectures, multiple levels of abstraction are needed to support flexible computation, each with its own representation that can be reduced to the underlying level. A critical difference between computer and cognitive architectures is that the latter is based on learning. Here, I present a possible framework based on several existing theories, and show some examples of models that bridge different levels.
All-optical switching and brain-inspired concepts for low energy information processing

Theo Rasing

Institute of Molecules and Materials
Radboud University Nijmegen

While data has become an indispensable part of modern society, the sheer amount of data being generated every second is breathtaking, both in its scale and in its growth, while the number of devices generating these data is rapidly expanding. This not only pushes current technologies to their limits, but also that of our energy production: our ICT and data centres already consume around 7% of the world’s electricity production and with the growth rate of ICT-technologies, this energy consumption is rapidly becoming unsustainable.

We try to develop materials and concepts that mimic the efficiency of the brain by combining local processing and storage, using adaptable physical interactions that can implement learning algorithms. We demonstrate, by modelling, that a reconfigurable and self-learning structure can be achieved, which implements the prototype perceptron model of a neural network based on magneto-optical interactions. Importantly, we show that optimization of synaptic weights is achieved by a global feedback mechanism, such that learning does not rely on external storage or additional optimization schemes. For the experimental realization of adaptive synaptic structures, we choose to use optically controllable magnetization in a thin Co/Pt film, using circularly polarized picosecond pulse trains. The combined stochastic/deterministic nature of all-optical switching in this material offers the possibility to continuously vary the magneto-optical Faraday rotation with the number of pulses, yielding the necessary ingredient to realize a perceptron-like structure. First results of this model structure will be demonstrated.

Neuromorphic computing

Elisabetta Chicca
CITEC
Bielefeld University, Germany

Man made computing architectures are based on principles fundamentally different from those of biological systems. Their elementary blocks operate in a serial manner and encode information in digital variables. Memory and computation rely on different components with distinct locations. In contrast, biological systems are fully parallel and transmit information in the form of all-or-none events which can be considered digital but encode information in analog variables (e.g. spike timing, mean firing rate). Memory and computation rely on the same physical substrate and are therefore co-localized.

These differences hinder a close mimicking of biological computation by conventional computing systems. Alternatively, physical models based on analog circuits and memristive devices can be constructed following the principles observed in nervous systems. In my talk I discuss this approach, its advantages and drawbacks, challenges and promises.
A Co-Design Framework for Neuromorphic Computing Research

Catherine Schuman

Oak Ridge National Laboratory
USA

Neuromorphic research spans a wide variety of research topics, including materials science, devices, architectures, systems software, models, algorithms, and applications. To enable major advances in neuromorphic computing, these research efforts need to be linked through co-design and collaboration. In this talk, a co-design framework for neuromorphic computing research will be presented. This co-design framework includes both system software and training algorithms that can support a variety of architectures/devices as well as a variety of applications. Preliminary results will be presented from both the hardware perspective and the application perspective.
Quantum Materials for Energy Efficient Neuromorphic Computing

Ivan Schuller

Condensed Matter Physics Group
University of California, San Diego, USA

Prof. Ivan K. Schuller, of the Physics Department, the California Institute for Telecommunications and Information Technology (Calit2) and the Center for Advanced Nanoscience (CAN) at the University of California-San Diego, is a Solid State Physicist. A Fellow of the American Physical Society and a member of the Chilean, Spanish and Belgian Academies of Sciences, he has won many awards such as the American Physical Society’s Wheatley (1999) and Adler Awards (2003), the German von Humbold prize (2002), the Materials Research Society Medal (2004), the Lawrence Award from the US Department of Energy (2005), a Honoris Causa Doctorate (2005) from the Spanish Universidad Complutense, the largest European University, the Somiya Award from the International Union of Materials Research Societies (2008) and the UCSD Academic Senate Research Lectureship in Science, Engineering and Medicine (2008). He has published more than 480 technical papers and 20 patents, has given more than 350 invited lectures at international conferences and is one of the 100 most cited physicists (out of 500,000) in the last 15 years. Prof. Schuller’s work was mentioned in the justification for the 2007 Nobel Prize as a precursor to the discovery of Giant Magnetoresistance.

Prof. Schuller has extensive expertise in the high technology area. He is the head of a group of more than 10 researchers (technicians, students and postdocs), focusing their attention on the basic research of Nanostructured, Organic, Magnetic and Superconducting materials. As the Director of the AFOSR funded Multidisciplinary Research Initiative (MURI) on Integrated Nanosensors he lead a group of more than 40 physicists, chemists, bio-chemists and engineers focusing on the development of multiple nanosensors on a chip, with integrated power, limited computation and wireless communications. He has been a consultant to a variety of governmental commissions and national laboratories in the US, Latin America and Europe and to many commercial enterprises in the high technology area. He is the president of the IMDEA-Nanociencia Foundation which supports Nanoscience and Nanotechnology in Spain.

In addition to his scientific activities, Prof. Schuller has extensive science related outreach and artistic activities. He has given numerous public lectures world wide in museums and TV about science to young and old, in several of the 7 languages he speaks. His movie “When Things Get Small” centered on Nanoscience has been translated to Spanish and Portuguese, has won 5 regional EMMYs, 2 TELLYs, a 1st Place Gold Camera Award and a 2nd place at the MRS professional film festival. His play “W=S” centered on the life of William Shockley is in the process of production. He is currently writing the script for his second full-length feature movie “When Things Get Big”.

A Stroll Through the Theory of Group Decisions

Davide Grossi

Bernoulli Institute for Mathematics, Computer Science and Artificial Intelligence
University of Groningen, The Netherlands

In this talk I will give a brief overview of important results on the theory of collective decision-making: how systems consisting of distinct individual components can take 'good' decisions as a whole. The focus will not be on my own results, but rather on giving an overview of the field (which spans across different disciplines, from AI and CS to Economics and Biology), and its possible interfaces with cognitive systems and materials research.
Carbon Nanotube: from nano-transistors to neuromorphic devices

Maria Antonietta Loi
Zernike Institute for Advanced Materials
University of Groningen, The Netherlands

Carbon nanotubes have been considered for many years one of the few materials that can eventually substitute silicon, when the physical limit of the miniaturization of the silicon transistor channel length will be reached. In my presentation I will first discuss as we have solved one of the main problems inherent with the manipulation of carbon nanotubes, fabricating field effect transistors in a highly reproducible fashion by chemically self-assembly semiconducting carbon nanotubes. Then I will discuss if this nanomaterial can have a role in the fabrication of artificial neurons and in the future development of neuromorphic electronics.
Transitional metal oxides exhibit a reversible, non-volatile change in electrical resistance upon electrical stimulus, a phenomenon known as resistive switching. In the simplest case resistive switching memory cells, or so called memristive devices, can be switched between a low resistance state (LRS) and a high resistance states (HRS) which can be interpreted as the logical “1” and “0”, respectively. However, it is important to note that resistive switching cells often show multiple resistive states rather than only two logical states and can therefore be used for multibit memory or implemented as synapses in neuromorphic circuits.

Based on the current knowledge, resistive switching in memristive elements based on transition metal oxides can be ascribed to electrically induced redox-processes at the oxide/electrode interface, which occur either in a spatially confined switching filament, multiple filaments or in a spatially homogeneous, area-dependent manner.

In this talk, we will present the recent status of understanding of switching and failure mechanisms of redox-based memristive devices. Based on this, we will discuss challenges and strategies to gain control over the performance and reliability of the devices which will be crucial for their use in future neuromorphic circuits.
Neuromorphic computing with spin-torque nano-oscillators

Julie Grollier
CNRS/Thales
France

The brain displays many features typical of non-linear dynamical networks, such as synchronization or complex transient behaviour. These observations have inspired a whole class of models that harness the power of complex non-linear dynamical networks for computing. In this framework, neurons are modeled as non-linear oscillators, and synapses as the coupling between oscillators. These abstract models are very good at processing waveforms for pattern recognition. However there are very few hardware implementations of these systems, because large numbers of interacting non-linear oscillators are indeed. Magnetic nano-devices, and in particular spin-torque oscillators are interesting in this context because of their tunability combined with their small size, CMOS compatibility, endurance and speed. In this talk, I will show different ways of leveraging the non-linear dynamics of spin-torque nano-oscillators for neuromorphic computing, and present our first experimental results of speech recognition.

Neuromorphic Electronic Agents: from sensory processing to autonomous cognitive behavior

Giacomo Indiveri

UZH / ETH Zurich
Switzerland

For many practical tasks that involve real-time interactions with the environment, conventional computing systems cannot match the performance of biological systems. One of the reasons is that the architecture of nervous systems, in which billions of neurons communicate with spikes in parallel, is very different from that of today’s computers. Recently developed brain-inspired hardware architectures that emulate the biophysics of neurons and synapses in silicon represent a promising technology for implementing alternative low-power and compact computing paradigms.

In this presentation I will describe recently developed neuromorphic processors and show how they can be interfaced to robotic platforms to implement autonomous cognitive agents.
About CogniGron
About Groningen Cognitive Systems and Materials

Our mission is 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.

Groningen Cognitive systems and Materials Center is a research initiative that started beginning of 2018 and aims to address fundamental questions of relevance for developing materials and systems for cognitive computing. The center is embedded in the Faculty of Science and Engineering (FSE) and is created to provide structure, coherence and visibility to a joint research program that comprises researchers from materials science, physics, chemistry, mathematics, computer science and artificial intelligence. The research program aims to generate focus and critical mass to address the challenge of including new functional materials in the design of the new generation of cognitive computers, focussing on the fundamental research aspects. Tens of PhD students from different disciplines will work for seven years towards this goal.
Our Goals

The main goal of CogniGron is to create self-learning materials that will perform the tasks that are now assigned to thousands of transistors and complex algorithms in a more efficient and straightforward manner, hence, 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, this is the first initiative of such kind that unites expertise from the disciplines of physics, materials science, mathematics, computer science and artificial intelligence.

Our program on 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. neuromorphic chip TrueNorthTM). We will also investigate and design the optimal implementation of such new material structures at the system level. Hereby we keep a close connection to possible applications from the start, as the optimal characteristics of the materials and architectures will vary for different applications. Further, we aim to realize cognitive functionality on established computer platforms. To this end, the program will build on collaborations between researchers from materials science (physics and chemistry), computer science, artificial intelligence and mathematics.

For the first seven years (2018-2025), the research program has two well-defined goals:

- To demonstrate cognitive functionality using physical networks in materials. Specifically, the goal is to implement this cognitive functionality in a material system where the signal transfer paths and adaptive inter-connections are present at the nanoscale within the material itself;

- To build complex systems (capable of more complex learning functions) from the simpler, above mentioned, cognitive units. General challenges concern computer architecture and networking (complexity of hardware and software design, multilayered architecture), development of new program languages and algorithms, network synthesis, systems engineering (systems of systems), robustness to noise and variability, as well as scalability.
*P1-P12: Vacant positions
Programme Board

Prof. dr. Tamalika Banerjee
Associate Professor Physics of Nanodevices

e-mail: t.banerjee@rug.nl

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

e-mail: m.k.camlibel@rug.nl

Prof. dr. Maria Antonietta Loi
Professor Photophysics and Optoelectronics and board member of Zernike Institute for Advanced Materials

e-mail: m.a.loi@rug.nl

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

e-mail: j.b.t.m.roerdink@rug.nl

Prof. dr. Lambert Schomaker
Professor Artificial Intelligence

e-mail: l.r.b.schomaker@rug.nl

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

e-mail: n.a.taatgen@rug.nl

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

e-mail: c.h.van.der.wal@rug.nl

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

e-mail: a.p.j.engbersen@rug.nl