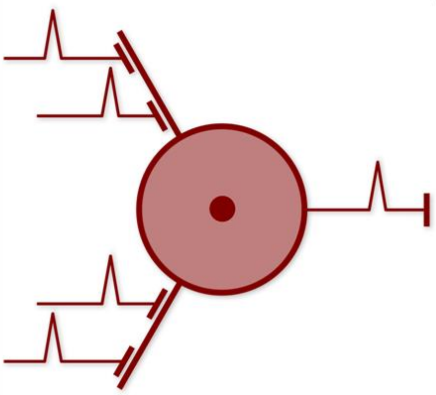
2nd International Workshop

Neurotronics: Bio-inspired information pathways

Christian-Albrechts-Universität zu Kiel

Technische Fakultät



2nd September – 5th September 2019

Venue:
Christian-Albrechts University Kiel
and
Color Line Ferry Kiel – Oslo - Kiel

CAU Kiel:	https://www.uni-kiel.de/index-e.shtml
Nanoelectronics :	http://www.tf.uni-kiel.de/etit/NANO/en?set_language=en
Ferry:	https://www.colorline.com/kiel-oslo/cruise-kiel-oslo

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Feel free to contact me in case of questions during travel or during the workshop:

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Ferry information:

- Be at the terminal at the latest 1 hour prior to departure.
- Entry regulations for Norway, remember to bring a valid ID. Norway is introducing border controls on all ferries from Sweden, Denmark and Germany. We encourage all guests to bring their passports when checking in.
- Passport, Valid ID is required. Passport is highly recommended.
- Time to be back on the ship in Oslo, returning guests needs to be present at the ship min. 30 minutes prior to departure

2nd International Workshop
Neurotronics: Bio-inspired information pathways

2nd September – 5th September 2019

The research on memristive devices and their application in neuromorphic systems has become one of the most exciting areas in solid state physics and electronic systems. The possibility to engineer interfaces on the atomic scale accompanied with a tremendous progress in the electronic and structural analytics has led to a gradually better matching of experimental results with theoretical predictions and thus, to the hope of discovering new and/or improved functional memory devices. Memristive devices exhibit a wealth of phenomena and attracted a considerable interest from both the fundamental and device relevant point of research. The scope of this 2nd International Workshop on Memristive devices for neuronal Systems is to provide a forum for fruitful and interdisciplinary discussions between experimentalists and theorist from solid state devices to neurobiology and most to bring students close to the forefront of this research area in science.

Renowned experts are invited to introduce fundamental topics from the broad area of functional memory devices for a wide audience to facilitate the transfer of concepts from different fields and stimulate new research activities across the traditional borders of research areas from devices physics to neuronal systems. A poster session will allow participants to present and discuss their newest results to deepen and broaden their knowledge on the topics covered by this seminar, which will be:

- **Memristive Devices: Concepts and practical implantations**
- **Electrical and structural characterization**
- **Coding and encoding in neuronal systems**
- **Neuromorphic systems comprising memristive devices**

The workshop is supported by the German Research Society (DFG) via the Research Unit 2093 entitled “Memristive Devices for neuronal Systems”.

More details about our Research Unit 2093:
http://www.for2093.uni-kiel.de/en?set_language=en

The Research Unit 2093 focuses on the transfer the principles of neuronal, synaptic plasticity as well as biological storage to a mixed-signal circuitry comprising memristive devices. Basic cellular types of learning as known on the cellular level form neurons and synapses will be implemented in technical systems. Both implicit and explicit types of learning should be realized in networks. The memristive devices are studied in detail with respect to static and dynamic properties. In particular the research is orientated on the trisynaptic circuit of the hippocampus, as an essential part of basal learning processes in vertebrates and a few invertebrates. The hippocampus is crucial for pattern recognition and is the transfer region between short term and long term memory. Finally, central neurobiological concepts as cognitive cards and place cells should be mimicked by analogue circuits using memristive devices.

Welcome and Overview DFG Research Unit 2093

Hermann Kohlstedt
Nanoelectronics – Christian-Albrechts University Kiel, Germany

Abstract: The main focus of the research unit is the transfer of the neuronal, synaptic plasticity and information storage into an analogue circuit technology with the help of nanoelectronic, memristive devices. The challenge will be to transfer synaptic plasticity mechanisms as a basis of learning- and memory processes in biological systems to memristive technological circuits. This includes the simulation of neurobiological cellular mechanisms as they occur in neurons and synapses via memristive devices. The aim is the structural and technological reconstruction of cellular learning- and memory forms that enable the simulation of implicit and explicit learning processes. A detailed characterization of static and dynamic characteristics of memristive devices and a simulation of cellular learning mechanisms by using memristive systems enables the emulation of learning- and memory processes in neurobiologically inspired network circuits. Furthermore, we aim to adapt neurobiological circuit processes based on the special structure of the mammalian hippocampal trisynaptic circuit. The research group aims to reach this ambitious goal through a network of scientists with complementary expert knowledge.

Scientific Biography

Hermann Kohlstedt is Professor of Nanoelectronics at the Engineering Department of the Christian-Albrechts University (CAU) Kiel, Germany. Prior to this appointment at CAU, he was leading a research group from 1991 to 2009 at the Research Center Jülich, Germany that focused on advanced electronic device concepts and associated materials- processing issues. From 1986 to 1989 he worked at the Institute for Millimeterwave Radiostronomy (IRAM) in Grenoble, France and received his PhD in Physics from the Kassel University in 1989 on superconducting tunnel junctions for heterodyne receivers. From 1990 to 1991 he held a one year appointment at the Advantest Corporation in Sapporo, Japan. His representative work includes metallic and complex oxide superconducting - magnetic - and ferroelectric tunnel junctions in the frame work of transport properties and thin film analysis. In 2005/06 he was on sabbatical at the Materials Science Department of the UC Berkeley and the Advanced Light Source (ALS) at the Lawrence Berkeley National Laboratory, USA. Since 2009 he is working in the field of memristive device for neuromorphic circuits and he is spokesperson of the DFG (German Research Society) Research Unit RU 2093 entitled: "*Memristive Devices for neuronal Systems*". He authored and co-authored more than 190 papers in peer- review journals. Since July 2018 he is Dean of the Faculty of Engineering at Kiel University.

International Workshop:

"Neurotronics: Bio-inspired information pathways"

2nd September 2019 (Monday) - 5th September 2019 (Thursday)

Agenda

Venue:	**Faculty of Engineering, Kiel University, Germany** **Kaiserstr.2, 24143 Kiel, Germany** **Bldg. D, Aquarium**		**(2nd September 2019)**
and	**Color Line Ferry**	**Kiel – Oslo – Kiel**	**(3rd to 5th September 2019)**

1st Day: 2nd September 2019, Monday - Aquarium and Faculty of Engineering @ CAU Kiel

09:30 - 10:00	Hermann Kohlstedt:	*Welcome and overview DFG Research Unit 2093*
10:00 - 11:00	André Fiala:	*Deciphering a neuronal circuit underlying learning and memory: The Drosophila mushroom body as a study case*
11:00 - 12:00	Mark Shein-Idelson	*Sliders & Dragons: explorations of population dynamics in ancestral cortices*
12:00 - 13.00	Lunch	
13:00 - 14:00	Simon Rumpel	*The dynamics of neocortical circuits*
14:00 - 16:00	Lab-Tours	Faculty of Engineering and Institute of Psychology, CAU Kiel
16:00 - 16:30	Break	
16:30 - 17:00	Joint discussion and ferry info (Aquarium)	
17:00 - 19:00	Poster session (RU 2093)/draft beer and snacks (accompanying persons are welcome!)	
	Transfer to Hotels	

2nd Day: 3rd September 2019, Tuesday - Color Line - Kiel

10:30	**Transfer Hotel - Pier**	
12:00	**Arrival at Color Line Ferry in Kiel, Norwegian Pier and CHECK-IN**	
13:00	**Boarding**	
14.15	Begin of workshop	
14:30 - 15:30	Philipp Hoevel	*(De)Synchronization in networks of delay-coupled neuronal oscillators*
15:30 - 16:30	Claus C. Hilgetag	*How can characteristic brain networks be formed?*
16:30 - 16:45	Break	

16:45 - 17:45 B. Linares-Barranco *Memristive Neuromorphic Systems*

17:45 - 18:45 Paolo Milani *Neuronal-like electrical spiking activity in nanostructured Au two-terminal devices*

18:45 - 19:45 Joint discussion

Dinner

3rd Day: 4th September 2019, Wednesday - Color Line - Oslo

08:15 Begin of workshop

08:30 - 09:30 Beatriz Noheda *The matter of future computers: complex oxides for synaptic devices*

10:15 - 13:30 Sightseeing in Oslo, Norway, all passengers should be back on the ferry at 13:30

14:15 Begin of workshop

14:30 - 15:00 Christoph Schlüter *Hard X-Rays for in operando device characterization*

15:00 – 15:30 Yury Matveyev *Gauging an electric potential profile across ferroelectric HfO2 capacitors*

15:30 - 16:45 Break

16:45 - 17:45 Bruno Barazani *Blending Sensing and Computing in MEMS*

17:45 - 19:00 Joint Discussion and Conclusion

Dinner

4th Day: 5th September 2019, Thursday - Color Line - Kiel

10:00 Arrival of Color Line in Kiel (Norwegian Pier)
11:00 End of Workshop

Lab-Tour during the workshop:

„Neurotronics: Bio-inspired information pathways“

Monday: 2nd September 2019
2 pm to 4 pm

Faculty of Engineering: **East Coast**
(Group leader: Tom Birkoben)

Experiment/Demonstrator	**Bldg./Phone**	**Responsible**
Memristive Devices	C-043/6097	Finn Zahari
Impedance Spectroscopy	C-047/6089	Richard Marquardt
Electron Microscopy	E-011/6350	Ole Gronenberg
Cleanroom	E/6089	Tom Birkoben
Robotic and automatic control	F-120/6121	Manuel Amersdorfer
3D printed (Mem-)sensors	A-224/6187	Leonard Siebert

Institute of Psychology: **West Coast**
(Group leader: Henning Winterfeld)

Experiment	**Room/Phone**	**Responsible**
Psychology of Memory and Emotions[1]	OS 62 R307/4871	Christian Kaernbach
Cognitive Psychology of Reptiles[2]	Hermann-Rodewald-Str. 8 / +49 1520 4973736	Jannes Freiberg

! Bus transfer to the west coast tour will be available !

[1] The Emotion Lab at Kiel University (Olshausenstraße 62, 3rd floor) is mainly concerned with peripheral physiological recordings such as skin conductance, heart beats and BVP, breathing, in response to emotional stimuli or decision situations. A speciality is the optical recording of goose bumps as a sign of deep emotional involvement. We study also sexual arousal and reaction to appetitive food stimuli. Other topics include music psychology and auditory and visual sensory memory.

[2] Our Reptile Lab is under construction. We show the housing where we plan to keep the animals as well as the provisional experimental setup and discuss potential experiments.

Poster session during the workshop:

„Neurotronics: Bio-inspired information pathways“

Monday: 2nd September 2019
5 pm – 7 pm, Faculty of Engineering

1. Large-scale technology platform for memristive devices
S. Park, T. Ivanov, S. Klett and M. Ziegler
Micro- and Nanoelectronic Systems, Technische Universität Ilmenau, Germany

2. Active, artificial hair cells: damped nonlinear oscillator model
C. Lenk[1], L. Seeber[1], S. Gutschmidt[2], M. Ziegler[1] and P. Hövel[3]
[1] Micro- and Nanoelectronic Systems, Technische Universität Ilmenau, Germany
[2] University of Canterbury, Christchurch, New Zealand
[3] School of Mathematical Sciences, University College Cork, Cork, Ireland

3. Analog resistive switching with HfOx-based double-barrier memristive devices
F. Zahari[1], M. Ziegler[2] and H. Kohlstedt[1]
[1] Nanoelectronics, Faculty of Engineering, Kiel University, 24143 Kiel, Germany
[2] Department of Micro- and Nanoelectronic Systems, TU Ilmenau, 98693 Ilmenau, Germany

4. Reliability of CMOS integrated memristive HfO2 arrays with respect to neuromorphic computing
M. K. Mahadevaiah[1], E. Perez[1], Ch. Wenger[1,2], A. Grossi[3], C. Zambelli[3], P. Olivo[3], F. Zahari[4], H. Kohlstedt[4] and M. Ziegler[5]
[1] IHP-Leibniz-Institut fuer innovative Mikroelektronik, Frankfurt (Oder) 15236, Germany
[2] Brandenburg Medical School, Neuruppin 16816, Germany
[3] Dip. di Ingegneria Università degli Studi di Ferrara
[4] Nanoelektronik, Technische Fakultät Christian-Albrechts-Universität zu Kiel
[5] Dept. of Microelectronic and Nanoelectronic Systems TU Ilmenau

5. Diffusive Memristive Switching on the Nanoscale: From individual Nanoparticles towards Scalable Nanocomposite Devices
A. Vahl[1], A. Hassanien[2], N. Carstens[1], T. Strunskus[1] and F. Faupel[1]
[1] Chair for Multicomponent Materials, Kiel University, Kaiser Str. 2, 24143 Kiel, Germany
[2] Department of Condensed Matter Physics, J. Stefan Institute, Jamova 39, 1000 Ljubljana, Slovenia

6. Modelling and design concepts for memsensors as devices with enhanced capabilities in neuromorphic engineering
A. Vahl[1], N. Carstens[1], J. Carstensen[2], M.-I. Terasa[2], S. Kaps[2], T. Strunskus[1], R. Adelung[2] and F. Faupel[1]
[1] Institute for Materials Science – Chair for Multicomponent Materials, Faculty of Engineering, Christian-Albrechts-University of Kiel, Kaiserstr. 2, 24143 Kiel (Germany)
[2] Institute for Materials Science – Chair for Functional Nanomaterials, Faculty of Engineering, Christian-Albrechts-University of Kiel, Kaiserstr. 2, 24143 Kiel (Germany)

7. Modeling and Simulation of Memristive Devices
S. Dirkmann, T. Gergs, F. Jalled, J. Trieschmann and T. Mussenbrock
Chair of Electrodynamics and Physical Electronics, Brandenburg University of Technology Cottbus-Senftenberg, Germany

8. Pattern Recognition for COPD Diagnostics Using an Artificial Neural Network and Its Potential Integration on Hardware-based Neuromorphic Platforms
P. S. Zarrin and Ch. Wenger*,
IHP–Leibniz-Institut fuer innovative Mikroelektronik, Frankfurt (Oder) 15236, Germany
*Brandenburg Medical School, Neuruppin 16816, Germany

9. Ex situ experiments on memristive prototype devices by TEM
O. Gronenberg[1], J. Strobel[1], L. Kienle[1], N. Carstens[2], A. Vahl[2] and F. Faupel[2]
[1] Synthesis and Real Structure, Faculty of Engineering, Kiel University, Germany
[2] Nanocomposite Materials, Faculty of Engineering, Kiel University, Germany

10. Photocatalytic gold layer growth on thin and structured TiO2 substrates"
J. Bläsi[1], L. Senne[1], A. Vahl[2], S. Veziroglu[2], N. Carstens[2], F. Faupel[2], C. Aktas[2] and M. Gerken[1]
[1] Chair for Integrated Systems and Photonics, Faculty of Engineering, Kiel University, Germany
[2] Chair for Multicomponent Materials, Faculty of Engineering, Kiel University, Germany

11. DirectInk Writing of sensoric components towards integration into memsensitive networks
M.-I. Terasa[1], L. Seibert[1], A. Vahl[2], N. Carstens[2], F. Faupel[2] and R. Adelung[1]
[1] Chair Functional Nanomaterials, Faculty of Engineering, Kiel University,
[2] Chair for Multicomponent Materials, Faculty of Engineering, Kiel University,

12. Multi-cluster formations in adaptive networks of Kuramoto oscillators
P. Feketa, A. Schaum and T. Meurer
Chair of Automatic Control, Faculty of Engineering, Kiel University, Germany

13. Bifurcation without parameters in a chaotic system with a memristive element
Tom Birkoben[1], Moritz Drangmeister[2], Finn Zahari[1], Serhiy Yanchuk[3], Philipp Hövel[4,2] and Hermann Kohlstedt[1]
[1] Nanoelektronik, Technische Fakultät, Christian-Albrechts-Universität zu Kiel, 24143 Kiel, Germany
[2] Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany
[3] Institut für Mathematik, Technische Universität Berlin, Straße des 17. Juni 136, 10623 Berlin, Germany
[4] School of Mathematical Science, University College Cork, Western Road, Cork T12 XF64, Ireland

14. Wave Digital Emulation of Synapses and Neuronal Oscillators
D. Michaelis and K. Ochs
Chair of Digital Communication Systems, RU Bochum, Germany

15. Synchrony in Memristive Circuits and Related Applications
D. Michaelis and K. Ochs
Chair of Digital Communication Systems, RU Bochum, Germany

16. Hippocampal pattern separation and completion performance in a novel visual discrimination task: insights from a combined behavioural and neurocomputational approach

Nick Diederich[1,2], Christian Kaernbach[3], Thorsten Bartsch[4] and Martin Ziegler[2]
[1] Chair of Nanoelectronics, Faculty of Engineering, Kiel University, Germany
[2] Microelectronic and Nanoelectronic Systems Group, Ilmenau University
[3] Institute of Psychology, Kiel University, Germany
[4] Department of Neurology, University Hospital Schleswig-Holstein, Kiel University, Germany

17. How similar is similar? A novel sensory memory task based on visual pink noise

C. Kaernbach[1], T. Bartsch[2], A. Schubert[1], J. Kanczok[1], A. M. Ulrich[1] and M. Brütt[1]
[1] Institute of Psychology, Kiel University, Germany
[2] Department of Neurology, University Hospital Schleswig-Holstein, Kiel University, Germany

18. A maximum likelihood approach to fit Gaussian signal detection models to multi-response tasks

M. Brütt and C. Kaernbach,
Institute of Psychology, Kiel University, Germany

19. The visual sensory memory task in different populations

I. Schneider[1,2], C. Kaernbach[2] and T. Bartsch[1]
[1] Department of Neurology, University Hospital Schleswig-Holstein, Kiel University, Germany
[2] Institute of Psychology, Kiel University, Germany

20. Reptile cognition: Decision under risk

J. Freiberg[1], C. Kaernbach[1] and P. Wulff[2]
[1] Institute of Psychology, Kiel University, Germany
[2] Institute of Physiology, Kiel University, Germany

Deciphering a neuronal circuit underlying learning and memory: The *Drosophila* mushroom body as a study case

André Fiala

Department of Molecular Neurobiology of Behavior, Georg-August-University of Göttingen

Abstract: Deciphering how neuronal circuits encode sensory stimuli, control behavior, learn and store memories represents a key task in modern neuroscience. For such an endeavor, the fruit fly *Drosophila melanogaster* is particularly suitable. It combines relative brain simplicity, behavioral richness, and, due to many genetic tools, unique experimental accessibility. Associative odor learning provides a means to analyze how sensory representations are encoded across widely distributed neurons and synapses, and how the synaptic stimulus representation is modified through learning. Our research focuses on the mushroom body of the *Drosophila* central brain. The mushroom body is an evolutionary ancient, higher-order brain structure, comprising but ~2200 intrinsic neurons. It integrates input from multiple sensory modalities as well as information about internal states with positive or negative experience. Its output then is integrated with innate behavioral tendencies to bring about learned behavior. The mushroom body features structural, functional, and cellular similarity with several distinct mammalian brain structures. Our recent research on how sparsely activated, distributed synapses de-synchronize as a result of associative learning will be presented and discussed as a paradigmatic case of how a neuronal circuit operates to encode learned information. The circuitry of the mushroom body and its function might also inspire the design of information-storing technical devices. Conversely, the invention of hardware for adaptive systems might potentially be of help for formulating hypotheses on the function of brain circuits.

Scientific Biography

André Fiala received his Diploma in 1996 and a doctoral degree on molecular mechanisms underlying learning and memory formation in honeybees in June 1999, both from the Free University Berlin. After a position as a postdoctoral research fellow at the Memorial Sloan-Kettering Institute in New York from 2000 until 2001 he worked until 2008 as a postdoctoral researcher at the Department of Genetics and Neurobiology of the Julius-Maximilians-University of Würzburg and received his Habilitation degree there. Since 2008 he is Professor for Molecular Neurobiology of Behavior at the Georg-August-University of Göttingen.

His laboratory uses the model organism *Drosophila melanogaster* to dissect neuronal circuits underlying adaptive behavior, learning and memory formation. His lab has pioneered *in vivo* optical calcium imaging of neuronal activity using genetically encoded fluorescence sensors and *in vivo* manipulation of neuronal activity using microbial opsins (optogenetics) in *Drosophila*. His research group focuses on determining principles of olfactory coding, on neuronal circuits controlling motivational behavior, and on localizing synaptic plasticity underlying associative olfactory learning.

Sliders & Dragons: explorations of population dynamics in ancestral cortices

Mark Shein-Idelson

Department of neurobiology and the Sagol School for Neuroscience, Tel-Aviv University, Israel

Abstract: Throughout the history of neuroscience, a large set of model systems has been used for studying a large variety of neuro-physiological questions. These model systems were frequently chosen for their unique experimental advantages, but studying them also provided a wider perspective on basic questions: By examining the manifestation of a given biological phenomenon across different species, one could separate the salient or fundamental from the transient or variable and identify principles of neuronal processing. In my talk I will focus on how studying reptilian forebrains can shed light on cortical computations and on the evolution of these computations. In particular, I will show how can use turtles to study the structure-function relations in neural circuits [1] and what can lizard studies tell us about the organization of collective neuronal dynamics during sleep and across brain states [2].

[1] Shein-Idelson M, Pammer L, Hemberger M and Laurent G (2017). Large-scale mapping of cortical synaptic projections with extracellular electrode arrays. Nat. Meth. 14(9):882-890.
[2] Shein-Idelson M*, Ondracek J M*, Liaw H, Reiter S, Laurent G (2016). Slow Waves, Sharp-waves, Ripples and REM in Sleeping Dragons. Science. 352 (6285), 590-595.

Scientific Biography

Mark Shein-Idelson received his BA from the department of physics, the Israeli Institute of Technology (Technion). For my MSc studies he moved to the physics department at Tel-Aviv University, focusing on physics of complex systems. He joined the lab of Prof. Eshel Ben-Jacob and was engaged in theoretic and experimental work aimed at understanding the regulation of network dynamics during development. His interest in neuronal population dynamics brought me to the lab of Prof. Yael Hanein in electrical engineering at the center for nano-technology in Tel-Aviv University. During his time there he developed methods for controlling the structure and connectivity patterns of neuronal networks in-vitro. Utilizing these techniques he studied how the topology of neuronal networks affects population dynamics. For his post-doctoral he moved to Frankfurt am Main to work with Prof. Gilles Laurent at the Max Planck Institute for Brain Research. During this period he became interested in reptile neurophysiology and worked on the evolution of sleep and on developing ex-vivo model systems for studying population dynamics in the three layered cortex of turtles. In march 2018 he started his own lab at the neurobiology department in Tel-Aviv University. In his lab he studies the evolution of neuronal computation and sensory processing in reptilian model systems.

The dynamics of neocortical circuits

Simon Rumpel

Institute of Physiology, Focus Program Translational Neurosciences, University Medical Center, Johannes Gutenberg University Mainz

Abstract: A traditional view of the healthy, adult brain is that it has -- after a period of developmental plasticity -- reached a mature and highly stable state. This stable state safeguards stable brain function and therefore plastic adaptations in brain circuits are only transiently observed in response to external events, such as learning-related memory formation. However, recent findings challenge this view and indicate that neuronal circuits in the adult brain display a surprisingly high level of intrinsic dynamics even under basal conditions. I will share recent data from chronic *in vivo* imaging studies in the auditory cortex of mice. At the connectivity level following individual synaptic connections and at the activity level monitoring functional cell assemblies over the course of multiple days, we observe substantial remodeling of the individual elements, while global parameters such as synapse density or fraction of sound responsive cells are stably maintained. This indicates that neuronal networks operate in a dynamic equilibrium during basal conditions.

Learning transiently disrupts the equilibrium and biases synaptic and cell assembly dynamics. This indicates that writing a memory into a neuronal network implicates the weaving in of information into ongoing dynamics rather than resembling the printing into a static wax slate, as Plato's famous analogy suggests. Taken together, continuous, intrinsic dynamics appear to be a fundamental property of neural circuits compatible with macroscopically stable behaviors. In addition, they could provide living neural circuits with computational abilities a fixed structure cannot offer.

Scientific Biography

Simon Rumpel studied Biology and received his PhD degree in Neuroscience (2001) at the Ruhr-University Bochum, Germany. From 2001 to 2006 he was a Post-Doctoral Fellow at the Cold Spring Harbor Laboratory, NY, USA and pursued research on the neurobiological mechanisms underlying the formation of memories. He became independent group leader at the Institute of Molecular Pathology (IMP) in Vienna, Austria from 2006 to 2014 and is since 2014 Associate Professor at the Institute of Physiology. He combines tools from molecular biology to monitor or manipulate neurons in the auditory cortex of mice in the context of behavior. His research is focused on the questions how auditory representations in neocortical circuits mediate percepts of sound and how these representations are transformed into long-term memories.

(De)Synchronization in networks of delay-coupled neuronal oscillators

Philipp Hoevel

School of Mathematical Sciences, University College Cork, Ireland

Abstract: The aim for a better understanding of the dynamics on complex networks has sparked many research efforts within the interdisciplinary field of nonlinear dynamical systems. I will focus on the synchronization/desynchronization transitions in networks of delay-coupled excitable systems [1]. The local dynamics are described by generic models for type-I excitability (SNIC or SNIPER bifurcation) and for type-II excitability (Hopf bifurcation). For large delay times both type-I and type-II systems behave in a similar way. This is different for small delay times, where the case of type-I excitability shows multiple transitions between synchronization and desynchronization, when the fraction of inhibitory links is increased.
One important implication of these results is that there exist complex networks for which the adding of inhibitory links in a small-world fashion may not only lead to a loss of stable synchronisation, but may also restabilize synchronisation or introduce multiple transitions between synchronization and desynchronization [2].

[1] E. Schöll, J. Lehnert, A. Keane, T. Dahms, and P. Hövel: *Control of desynchronization transitions in delay-coupled networks of type-I and type-II excitable systems*, Selforganization in Complex Systems: The Past, Present, and Future of Synergetics, Springer, (2016), pp. 25–42.
[2] A. Keane, T. Dahms, J. Lehnert, S. A. Suryanarayana, P. Hövel, and E. Schöll: *Synchronisation in networks of delay-coupled type-I excitable systems*, Eur. Phys. J. B **85**, 407 (2012).

Scientific Biography

Philipp Hövel is a trained mathematician and physicist, who currently works as a permanent lecturer in the Department of Applied Mathematics at University College Cork, Ireland. He received his graduate degrees in physics and mathematics from Technische Universität Berlin in 2004 and 2006, respectively, his PhD with distinction on Control of complex nonlinear systems with delay in 2009, and completed his habilitation in Theoretical Physics in 2017.

His research mission is to lift the boundaries between data-oriented science, theoretical approaches, and numerical simulations addressing interdisciplinary questions based on an overlap of nonlinear dynamics, network science, and control theory. His areas of mathematical expertise include complex systems, bifurcation theory, delay, differential equations, and complex networks. Besides mathematical modelling and analytical investigations, he has always looked for experimental validation of his theoretical findings and a combination of the models with empirical data. His interdisciplinary research concept has led to better insight and fundamental understanding of synchronization processes and other dynamical phenomena.

How can characteristic brain networks be formed?

Claus C Hilgetag

Institute of Computational Neuroscience, University Medical Ctr Eppendorf, Hamburg University

Abstract: Brain networks show a highly specific, architecture- and distance-dependent connectivity and characteristic large-scale features such as modules and hubs. The formation of such characteristic connectivity features may be viewed from three perspectives. First, in the evolutionary perspective, desirable aspects of connectivity, such as minimal wiring or short processing paths, are optimized by random variations [1-3]. This perspective has the drawback of teleological guessing and does not illuminate the actual biological mechanisms of network formation. Second, the ontogenetic perspective considers how concrete growth mechanisms may act within spatial and temporal developmental gradients to produce characteristic network features, without the need for activity-dependent wiring [4-6]. Third, activity-dependent plasticity mechanisms may further rewire the connectivity based on the network activity [7]. I will discuss findings from all three perspectives, based on computational simulations.

[1] Kaiser M, Hilgetag CC (2006) Nonoptimal component placement, but short processing paths, due to long-distance projections in neural systems. PLoS Comput Biol. 2: e95

[2] Kaiser M, Hilgetag CC (2010) Optimal hierarchical modular topologies for producing limited sustained activation of neural networks. Front Neuroinform 4:8

[3] Chen Y, Wang S, Hilgetag CC, Zhou C (2017) Features of spatial and functional segregation and integration of the primate connectome revealed by trade-off between wiring cost and efficiency. PLoS Comput Biol 13: e1005776

[4] Kaiser M, Hilgetag CC (2004) Spatial growth of real-world networks. Phys Rev E Stat Nonlin Soft Matter Phys. 69: 036103

[5] Beul SF, Goulas A, Hilgetag CC (2018) Comprehensive computational modelling of the development of mammalian cortical connectivity underlying an architectonic type principle. PLoS Comput Biol 14: e1006550

[6] Goulas A, Betzel RF, Hilgetag CC (2019) Spatiotemporal ontogeny of brain wiring. Sci Adv 5: eaav9694

[7] Damicelli F, Hilgetag CC, Hütt MT, Messé A (2019) Topological reinforcement as a principle of modularity emergence in brain networks. Netw Neurosci 3: 589

Scientific Biography

Claus C Hilgetag trained in Biophysics in Berlin and in Neuroscience in Edinburgh, Oxford, Newcastle upon Tyne and Boston. In 2001 he became part of the founding faculty of International University Bremen and in 2011 he moved to the University Medical Center Eppendorf of Hamburg University, where he directs the Institute of Computational Neuroscience. Hilgetag is interested in all aspects of brain connectivity, and in particular investigates the formation of characteristic brain network features, the relationship of brain connectivity with other aspects of brain architecture, the grounding of brain dynamics in structural connectivity as well as the experimental and pathological perturbation of brain network function.

Memristive Neuromorphic Systems

Bernabé Linares-Barranco

Instituto de Microelectrónica de Sevilla (IMSE-CNM), CSIC and Universidad de Sevilla

Abstract: Nanoscale memristors promise to be fabricated over CMOS substrates with densities of over 4x10^12 elements per cm^2 (which corresponds to a 50nm pitch). This would provide an overwhelming memory density very tightly coupled to CMOS computing elements. There are many fields where this disruptive advantage can be exploited. One of them is neuromorphic computing and learning systems. In this talk we present some ideas on how to exploit this technological possibility for implementing hybrid memristive-CMOS systems, as well as on-going work. We will start by introducing event-driven spiking neural systems, with special emphasis on bio-inspired vision, how they can learn through Spike-Timing-Dependent-Plasticity (STDP), and how this can be exploited with combined memristor-CMOS chips. Recent state-of-the-art results will be shown.

Scientific Biography

Bernabé Linares-Barranco received the B. S. degree in electronic physics in June 1986 and the M. S. degree in microelectronics in September 1987, both from the University of Seville , Sevilla , Spain . He received a first Ph.D. degree in high-frequency OTA-C oscillator design in June 1990 from the University of Seville, Spain, and a second Ph.D deegree in analog neural network design in December 1991 from Texas A&M University , College-Station, USA.

Since June 1991, he has been a Tenured Scientist at the "Instituto de Microelectrónica de Sevilla" , Spain , a Mixed Center between the University of Sevilla and the Spanish Research Council (CSIC). He has been on sabbaticals at The Johns Hopkins University (USA), Texas A&M University (USA), The Manchester University (UK), and Lincoln University (UK). He is presently Full Professor and Director of the "Insitituto de Microelectrónica de Sevilla".

He has been involved with circuit design for telecommunication circuits, VLSI emulators of biological neurons, VLSI neural based pattern recognition systems, hearing aids, precision circuit design for instrumentation equipment, VLSI transistor mismatch parameters characterization, and over the past 20 years has been deeply involved with neuromorphic spiking circuits and systems, with strong emphasis on vision and exploiting nanoscale memristive devices for learning. He is co-founder of two start-ups, Prophesee SA and GrAI-Matter-Labs SAS, both on neuromorphic hardware. He is an IEEE Fellow since January 2010.

Neuronal-like electrical spiking activity in nanostructured Au two-terminal devices

Paolo Milani

CIMAINA and Department of Physics, University of Milano, Italy

Abstract: Networks based on nanoscale resistive switching junctions are considered promising for the fabrication of neuromorphic computing architectures. Here I report that metallic nanostructured Au films fabricated by bare gold nanoparticles produced in the gas phase and with thickness well beyond the electrical percolation threshold, show a non-ohmic electrical behavior and complex and reproducible resistive switching.

We analyzed and compared the electrical activity of cluster-assembled Au nanostructured films with the spontaneous electrical activity of neuron networks, showing that despite their differences in origin and function, the electrical activity of both networks has similar statistical properties. The presence of recurrent features in the switching behavior such as a threshold voltage for the appearance of the switching activity, recurrently and discrete explored resistance values and their dependence from the structural features of the cluster-assembled film (average thickness, resistance value reached on the percolation curve), offers the possibility to exploit such class of systems for the fabrication of complex networks suitable for reservoir computing, using a straightforward bottom-up approach.

Scientific Biography

Paolo Milani is Full Professor at the Department of Physics of the University of Milano. He graduated in Physics from the University of Pavia (Italy) in 1984 and he received his Docteur es Sciences (PhD) in 1991 from the Ecole Polytechnique Federale of Lausanne. He founded in 1992 the Molecular Beams and Nanocrystalline Materials Laboratory at the University of Milano. His research focuses on cluster-assembled nanostructured materials for neuromorphic systems, stretchable electronics, biomedicine, soft robotics. He has published more than 250 papers on refereed journals, several review papers and a monograph on supersonic cluster beam deposition for the synthesis of nanostructured thin films. Currently, Milani serves as Director of the Interdisciplinary Center for Nanostructured Materials and Interfaces of the University of Milano.

He is co-editor of the Springer book series Carbon Materials Chemistry and Physics, regional editor for Europe of the Journal of Nanoparticle Research, member of the editorial boards of Advances in Physics X, KONA Powder and Particle Journal, and Journal of Aerosol Science.He holds twenty patents in the field of nanotechnology and he is co-founder of three companies: TETHIS spa active in the field of nanostructured devices for cancer diagnostics, WISE srl producing implantable electrodes for neuromodulation, EOS srl producing optical diagnostic systems for nanoparticles in complex biological fluids.

The matter of future computers: complex oxides for synaptic devices

Beatriz Noheda

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University of Groningen, The Netherlands

Abstract: Although neuromorphic computing concepts have been put forward half a century ago, the urgency for low power solutions that can handle big data efficiently, is a recent development. Also recent is the realization that transistors and standard circuit elements will not allow sufficient progress in this direction. It is now clear that the quest for low-power cognitive computing needs a holistic approach that starts with the use of materials with intrinsic plasticity. Here I will highlight how the latest progress in materials science can offer promising alternatives for future cognitive devices. The focus will be on complex oxides, as they often display multiple nearly-degenerate states among which the system can transition with very small changes of external stimuli, therefore, offering excellent basis to achieve large responses with low driving voltages. In addition, their sensitivity to composition or strain, allows engineering of a very diverse set of functionalities by purposeful synthesis of thin layers or heterostructures, which nowadays is possible down to the atomic control. Emphasis will be made on new materials developments, such as the novel nanoscale ferroelectrics based on HfO_2, as well as on materials that self-assemble in organized networks forming nanoscale conduction paths, such as thin films with ferroelastic, nanometer-size domains or polymer-assisted templating of complex oxides.

Scientific Biography

Beatriz Noheda received her PhD in Physics in 1996 from the Autonomous University of Madrid. After various stays and positions at the University of Saarlandes, Clarendon Laboratory in Oxford, Brookhaven National Lab in New York and the Vrije Universiteit in Amsterdam, in 2003 she was awarded a Rosalind Franklin Fellowship by the University of Groningen, where she is now Full Professor. Noheda is a Fellow of the American Physical Society for her research on ferroelectric and multiferroic materials and has served as member of numerous committees and several editorial boards. She is author of more than 100 publications, receives more than 10 invitations per year to speak in international conferences and has given 6 plenary and keynote talks. Currently Noheda serves as director of the newly founded *Groningen Center for Cognitive Systems and Materials* (*CogniGron*). Noheda has recently started a research initiative towards adaptable electronic phases for based on thin films that present ordering phenomena and modulated phases that can be controlled and manipulated under electric fields.

Hard X-Rays for *in operando* device characterization

Christoph Schlueter

Photon Science, Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany

Abstract: Electrons emitted at high kinetic energies (HAXPES) cover probing depths of several tens of nanometers. Hence, the established strengths of conventional photoelectron spectroscopy for electronic and chemical structure investigations can be applied to real functional materials. In September 2018, the new X-ray undulator beamline (P22), fully dedicated to HAXPES techniques, opened to users. P22 hosts four specialized experimental end stations for high-resolution studies of the electronic and chemical structure of complex materials, realistic device-like structures and catalytic interfaces. The main instrument for conventional HAXPES techniques offers sample cooling and in situ electrical characterization for operando studies.

The potential of HAXPES investigations is showcased by two examples of novel non-volatile memory concepts: i) TiO_2 -based resistive random access memory (RRAM) and ii) HfO_2 based ferroelectric random access memory (FeRAM).

TiO_2-based RRAM devices reveal clear spectroscopic changes upon switching the resistive state. The most dramatic change is found in the bottom region of the device indicating movement and redistribution of Oxygen ions within the film. The results emphasize the importance of thin film quality with regard to the oxygen content and provide evidence that a fine control of post-deposition annealing offers a strong way to tune the resistive switching behavior.

HfO_2 based FeRAM is one of the most competitive concepts for 'ideal' non-volatile memory. The switchable polarization of ferroelectrics controls functional properties of these devices through the electric potential distribution across a capacitor device however, the experimental characterization of the local electric potential at the nanoscale has so far not been possible. Here, we showcase a new methodology which allows us, for the first time, to experimentally quantify the polarization-dependent potential profile across few-nanometer-thick ferroelectric $Hf_{0.5}Zr_{0.5}O_2$ thin films.

Scientific Biography

Christoph Schlueter received his diploma in applied mineralogy and crystallography from the Ludwig-Maximillian University, Munich, Germany in 2009. He earned his PhD in Physics from University of Hamburg, Germany in 2013 for his work on 'Electronic and atomic structure of metal-oxide heterostructures' while being placed at the HAXPES beamline ID32 at the ESRF, Grenoble, France. He continued his work on spectroscopic investigations of metal oxide surfaces and interfaces during his stay at beamline I09 at Diamond Light Source Ltd., Didcot, UK. Since 2017 he is beamline manager of the new Hard X-Ray Photoelectron Spectroscopy beamline P22 at DESY.

Gauging an electric potential profile across ferroelectric HfO_2 capacitors

Yury Matveyev

Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany

Abstract: Among various novel non-volatile memory concepts, the one based on the remnant polarization in ferroelectric (FE) films (FeRAM) is advantageous due to very low power consumption and theoretically unlimited endurance. In addition, such architectures as FE-MOSFET and ferroelectric tunnel junction (FTJ) can offer a non-destructive readout. The recent discovery of FE properties in doped and alloyed HfO_2 films has opened an opportunity to develop a fully CMOS-compatible FERAM. However, the realization of both FE-MOSFET and FTJ based on HfO_2 films require careful optimization of electronic properties in functional stack. Therefore, the determination of true potential distribution across the FE stack including electronic band line-up at interfaces is critically important.

In this work, we present the results of the standing-wave hard X-ray photoemission spectroscopy in operando study of functional FE $Hf_{0.5}Zr_{0.5}O_2$ based capacitors modelling memory devices. In order to switch polarization and monitor the actual polarization values in the device, we used parallel electrical characterization. By analyzing the set of spectroscopic data obtained at different exciting x-ray incident angles, we reconstruct full potential profile in the device and its changes following the polarization reversal.

Scientific Biography

Yury Matveyev received the M. S. degree in solid state physics in 2008 at the Laser Department of Moscow Engineering Physics Institute, Russia (MEPhI). In 2011 he defended his Ph.D. at the at Solid State Physics department, MEPhI. In 2011-2014 he was a postdoctoral research associate at the laboratory “Functional materials for nanoelectronics”, MEPhI. During this period, he became a member of the group performing experiments at hard X-ray photoelectron spectroscopy (HAXPES) stations at DESY (Hamburg, Germany). In 2014-2018 he was a research associate in laboratory “Functional materials and devices for nanoelectronics“, Moscow Institute of Physics and Technology. Since 2018 he is a postdoctoral researcher at HAXPES P22 beamline, DESY, Hamburg.

His main scientific interest has been investigation of oxide-based memristors, in particular HfO_2-based redox resistive switching memory devices and novel memory devices, based on ferroelectric-HfO_2. He was working on the integration of memristor in pre-fabricated wafers with CMOS logic and their functionalization as neuromorphic devices. His recent work was related to the development of the such unique techniques as *operando* HAXPES, and its implementation to the investigation of electric and chemical properties of nanoscale multilayered structures in order to get insight into memristors` switching mechanisms.

Blending Sensing and Computing in MEMS

Bruno Barazani

Interdisciplinary Institute for Technological Innovation - 3IT, University of Sherbrooke, Quebec, Canada

Abstract: This study concerns the design, fabrication, and test of a micro electro-mechanical system (MEMS) comprising an accelerometer coupled to an oscillating beam able to blend sensing and neuromorphic computing functions. The MEMS device uses the accelerometer response to modulate an electrical signal, which drives the computing beam in its resonance frequency. Piezoresistive measurements of the beam oscillations feed the virtual nodes of a reservoir computer, which exploit the beam non-linear behavior. As a proof of concept, the Parity benchmark was tested in order to demonstrate the computing capabilities of the device.

Scientific Biography

Bruno Barazani is a research scientist currently working as a Postdoctoral fellow at Université de Sherbrooke (3IT) in the design, microfabrication, and validation of neuromorphic MEMS sensors. PhD and MSc in Mechanical Engineering and BEng in Mechatronics Engineering. Possess expertise in MEMS, bioMEMS, sensors, actuators, design, simulation, microfabrication, and characterization. PhD from Dalhousie University, NS, Canada (2017) concerning MEMS actuators to measure the mechanical properties of single cells - publication selected as one the Highlights of 2017 (Journal of Micromechanics and Microengineering). MSc from University of Sao Paulo, SP, Brazil (2012) focused on materials manufacturing and characterization. Passionate about micro/nanotechnology and interdisciplinary subjects, speaks fluent English and Portuguese and intermediate French and Spanish.

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