MAX PLANCK INSTITUTE
OF MICROSTRUCTURE PHYSICS

International Symposium:

Beyond von-Neumann Computing: Computing meets Nanophysics

to be held at the

Nationale Akademie der Wissenschaften Leopoldina
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Jointly organized by the Max Planck Institute of Microstructure Physics and the German National Academy of Sciences, Leopoldina

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Public evening lecture (Simultaneous English translation will be provided during the talk)

Wednesday, September 6, 18:00

Karten des Denkens: die Vermessung neuronaler Netzwerke

Prof. Dr. Moritz Helmstaedter
Max-Planck-Institut für Hirnforschung, Frankfurt(Main), Deutschland

Unser Gehirn ist eine beeindruckende Errungenschaft: Es ermöglicht uns Freunde selbst unter schlechten Sichtverhältnissen wiederzuerkennen, unser Auto zu finden, auch abstrakte Muster zu unterscheiden. Das Ziel unserer Forschung ist zu verstehen, wie unser Gehirn zu solchen Aufgaben in der Lage ist. Strukturell ist eines der beeindruckendsten Phänomene unseres Nervensystems die enorm komplexe Kommunikation zwischen Milliarden von Nervenzellen. Jedes Neuron kommuniziert direkt mit mehr als eintausend anderen Neuronen – das sind mehr Kommunikationspartner als die meisten Menschen haben!

Die Kommunikations-Struktur von Nervenzellnetzwerken zu kartieren und also die Kabel im Gehirn zu entwirren, ist das Ziel des neuen Forschungsfeldes ‚Connectomics'. In diesem Vortrag wird Moritz Helmstaedter die neuesten Durchbrüche der Connectomics präsentieren, beginnend bei leistungsfähigen Elektronenmikroskopen bis hin zur Datenanalyse durch Mensch und Computer. Um die Datenanalyse für große Datensätze überhaupt zu ermöglichen, entwickelt Helmstaedters Forschungsabteilung wissenschaftliche Computerspiele mit dem Ziel, die Öffentlichkeit für die Forschung zu begeistern und zur Mithilfe zu motivieren. Die Neurowissenschaften wollen so einem Verständnis des erstaunlichen Computers näherkommen, der in unseren Köpfen operiert.

Thursday, September 7, 09:00

What is "Computing"?

[Herbert Jäger]
Jacobs Universität Bremen, Deutschland

At first sight, the answer to the title question seems easy: computing is what computers do, and computers we all know. However, the modern digital programmable computer is not the only thing that "computes". The brain arguably also does it. And what does your radio receiver? or Grandma's clock on the wall? or an amoeba that finds its way to food more robustly than a self-driving car finds the right highway exit? In fact, "computing" has been conceived in numerous different ways in the past and the present time. The scintillating aspects of "computing" have led to a variety of formal models which each capture only some part of the phenomenon. This talk gives a quick survey and highlights the relevance of theories of computing for current research in non-digital computational micro- and nanodevices.

Thursday, September 7, 10:00

Machine learning and AI for the sciences -- towards understanding

Klaus-Robert Müller
Technische Universität Berlin, Deutschland
Korea University, Seoul, South Korea
Max-Planck-Institut für Informatik, Saarbrücken, Deutschland

In recent years machine learning (ML) and Artificial Intelligence (AI) methods have begun to play a more and more enabling role in the sciences and in industry. In particular the advent of large and/or complex data corpora has given rise to new technological challenges and possibilities.

The talk will touch upon the topic of ML applications in sciences, here, in Neuroscience, Medicine and Physics and discuss possibilities for extracting information from machine learning models for furthering our understanding by explaining nonlinear ML models.

Finally briefly perspectives and limits will be outlined.

Thursday, September 7, 11:30

von Neumann's Other Architecture

Rodney Douglas
Institute of Neuroinformatics, ETHZ and UZH, Zurich, Switzerland

von Neumann's classical computer architecture was designed to implement an approximation to the abstract Universal Turing Machine, a processor only of symbols. However, von Neumann quickly realized that the deeper challenge concerns physical processors able to process physical instances of themselves rather than symbols. Unfortunately, his untimely death permitted only a first step in this profoundly novel direction -- his theory of self-replicating automata. But, beyond replication of individuals lies the even more challenging process of their co-ordinated differentiation and assembly into functional aggregates - into stable organisms able to interact intelligently and economically with their environment. I will describe our attempts to understand these principles of self-construction in the context of the embryological development of neurons and their circuits in the cerebral cortex, the region of the mammalian brain that is crucial to intelligent behavior.

Thursday, September 7, 12:30

Can we reverse-engineer the brain?

Michael Roukes
California Institute of Technology, USA

Although our understanding of the properties of individual neurons and their role in brain computations has advanced significantly over the past several decades, we are still far from elucidating how complex assemblies of neurons – that is, brain circuits – interact to process information. The U.S. BRAIN Initiative (Brain Research through Advancing Innovative Neurotechnologies), which we helped to launch in 2013, seeks to change the status quo by nurturing the development next-gen instrumentation. But this Initiative has brought overarching and crucial questions to the forefront. Among these are: *What constitutes a brain circuit? What is the correct "basis set" of physical measurements that will give clear insight into brain activity? Are there, as yet, "hidden variables" in brain computations?* I will review this landscape, and describe our collaborative, multi-institutional effort to advance this field through nano-enabled neurotechnology.

Thursday, September 7, 14:30

Neurocomputing principles

Bert Kappen
Donders Institute for Neuroscience, Radboud University, Nijmegen, The Netherlands
Gatsby Computational Neuroscience Unit, UCL London, UK

The functionality and architecture of the animal brain is very different from modern computers. Computer architectures are based on the ideas of Turing and von Neumann, that physically separates processing and memory on the chip. Instead, the brain performs distributed local computing, where memory and processing are integrated at the neural level. The brain has amazing capability for pattern recognition and learning, functionalities at which computers are very poor. In addition, the brain seems to make effective use of stochasticity that is inherent in synapses and neurons to facilitate robustness and energy efficiency. In this talk, I review some of the main neural network architectures and learning mechanisms. A key issue is that learning require global error signals to adapt individual connections. I discuss several mechanisms how such computations can be implemented in principle on a chip using local computation only.

Thursday, September 7, 15:30

Parcellation of Human Cerebral Cortex

David C. Van Essen
Alumni Endowed Professor
Department of Neuroscience, Washington University in St. Louis, USA

The cerebral cortex plays critical but diverse roles in cognition, perception, emotion, and motor control. Obtaining an accurate map of functionally relevant cortical areas is a long-standing challenge. This lecture will review recent progress in parcellating human cerebral cortex in individuals as well as group averages. Major challenges include the complexity and variability of cortical convolutions, variability in size of individual cortical areas and their relationship to cortical folds, and the subtle distinctions between some neighboring areas. We generated a novel parcellation of human cortex using high-quality multimodal data from the Human Connectome Project (HCP). This parcellation contains 180 areas in each hemisphere, with notably high bilateral symmetry. Accurate cortical parcellation in individual subjects enables systematic analyses of individual variability in relation to many neurobiological features as well as behavioral measures available in the freely shared HCP data. This approach should also be applicable to other projects and populations.

Thursday, September 7, 17:00

Computing for Biology – Biology for Computing

Thomas Lengauer
Max-Planck-Institut für Informatik, Saarbrücken, Deutschland

About 25 years ago, two interactions between the scientific disciplines of biology and informatics were emerging.

One field uses traditional computing technology to help analyzing biological data and model biological systems. This field has been firmly established today under the terms bioinformatics and computational biology. The field has experienced tremendous growth due to the dramatic progress in experimental technology for generating biomolecular data and the resulting demand for their analysis.

The other field, reversely, aims at using biomolecular technology for computing and has received the names Molecular Computing or, more focused, DNA computing. Whereas there appears to be an active research community in this field, the field is still in its emergent stage, due to the difficulties of implementing reliable molecular computing technology and the difficulty of identifying a “killer application” that cannot be suitably addressed by any competing technology.

The talk will give an overview of the state of both fields and make an attempt to put them into relation.

Thursday, September 7, 18:00

Bits and Brains

Theo Rasing
Radboud University, Nijmegen, The Netherlands

Data is the fuel of the new digital economy that has stimulated a whole new class of innovative technologies and businesses. While data has become an indispensable part of modern society, the rate at which data is generated is exploding. This is not only pushing our current technologies to their limits, but also that of our energy production: our ICT and data centers already consume around 5 % of the world electricity production and with an annual increase of 7 %, this is rapidly becoming unsustainable. We have created a consortium of condensed matter, material and neuro scientists with the aim 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.

Friday, September 8, 09:00

Building better brains – key innovations in the evolution of a fluid computing machine

Fred Wolf
Max-Planck-Institut für Dynamik und Selbstorganisation und
Bernstein Center for Computational Neuroscience, Göttingen, Deutschland

Since Zuse, Turing, and von Neumann developed the first man-made computing devices, these machines have perhaps seen about 100 generations of iterative improvement in the hands of smart engineers. Animal nervous systems, while subject to the blind tinkering of biological evolution, have seen millions of cycles of random modification and ruthless testing. In this process, brain architecture in large mammals including humans emerged through a sequence of key innovations: the invention of neocortex about 200 million years ago, its extraordinary expansion and the generation of deep processing hierarchies with the rise of modern mammals. I will first give an overview of these fundamental transformations and then discuss recent work combining mathematical theory, precision measurement of neocortical architecture and synthetic biology approaches to uncover the forces that drove brain architecture to an apparently unique and perhaps optimal design.

Friday, September 8, 10:00

Learning pattern classification with coupled spintronic nano-oscillators

P. Talatchian[1], M. Romera[1], F. Abreu Araujo[1], S. Tsunegi[2], H. Kubota[2], H. Yakushiji[2], A. Fukushima[2], S. Yuasa[2], P. Bortolotti[1], V. Cros[1], D. Vodenicarevic[3], N. Locatelli[3], D. Querlioz[3], J. Grollier[1]
[1] Unité Mixte de Physique CNRS/Thales, Palaiseau, et Université Paris-Sud, Orsay, France
[2] Spintronics Research Center, AIST, Tsukuba, Japan
[3] Centre de Nanosciences et de Nanotechnologies, CNRS, Université Paris-Sud, Orsay, France

presented by:

Julie Grollier

Biological neurons emit periodic electrical spikes and can synchronize their rhythmic activity. Inspired from these features, many neural network models exploit synchronization to compute with assemblies of non-linear oscillators. It would be attractive to implement them in hardware, with industry-compatible nanoscale oscillators capable of synchronization. However, despite numerous proposals, there is today no demonstration of pattern recognition with coupled nano-oscillators. One difficulty is that training these networks requires tuning the coupling between oscillators. Here we show experimentally that thanks to their high frequency tunability, spintronic nano-oscillators can learn to perform pattern recognition through synchronization. We train a network of four weakly-coupled spin-torque nano-oscillators to recognize spoken vowels by tuning their frequencies according to an automatic learning rule. Through simulations we show that the high experimental recognition rates (up to 91 %) stem from the weak-coupling regime and the high tunability of spin-torque nano-oscillators. These results open new paths towards highly energy efficient bio-inspired computing on-chip based on non-linear nano-devices.

This work was supported by the ERC grant bio*SPIN*spired n°682955

Friday, September 8, 11:30

Integrated photonics for neuromorphic computing

[Joyce Poon](#)
University of Toronto
Department of Electrical and Computer Engineering

Recent advances in silicon photonics and hybrid integration have led to the realization of photonic integrated circuits with unprecedented complexity. While most of these photonic integrated circuits are meant for telecommunication applications, the opportunity emerges for silicon photonics to be an enabling technology for neuromorphic computing. In this talk, I will discuss the potential roles of silicon integrated photonics in brain-inspired computing. I will review the progress in silicon integrated photonics and emerging efforts in the research community to implement photonic artificial neural networks. I will also present ongoing efforts in my group, done in cooperation with an international team of collaborators, on using silicon integrated photonics to realize new neurotechnology tools for brain activity mapping.

Friday, September 8, 12:30

Removing the Golden Handcuffs

R. Stanley Williams
Hewlett Packard Enterprise Senior Fellow
Hewlett Packard Labs, Palo Alto, USA

For five decades, computing has been driven by Moore's Law and the exponential advances that were enabled by semiconductor scaling. However, to turn those advances into products as quickly as possible, computers were trapped by the von Neumann architecture and all of its limitations. We face the end of traditional transistor scaling, but also understand from basic physics and the example of the brain that our present computing machines are still orders of magnitude away from any fundamental limits. Many creative ideas have not yet been fully explored because of resource limitations, and new proposals for re-inventing computing are appearing at a rapid pace. New exponential advances in computing capability will likely arise from the combination of different computational paradigms, architectures, structures, materials and physics. I will provide specific examples that implement new approaches, including memory-driven computing (https://www.labs.hpe.com/next-next/mdc), photonic fabrics for transporting data (http://genzconsortium.org/faq/gen-z-technology/) and biologically inspired accelerators (http://svivek.com/research/publications/isca16.pdf) to dramatically accelerate specific applications. This may in fact be the most exciting time since the days of Turing and Shannon to be working in the field of computing.