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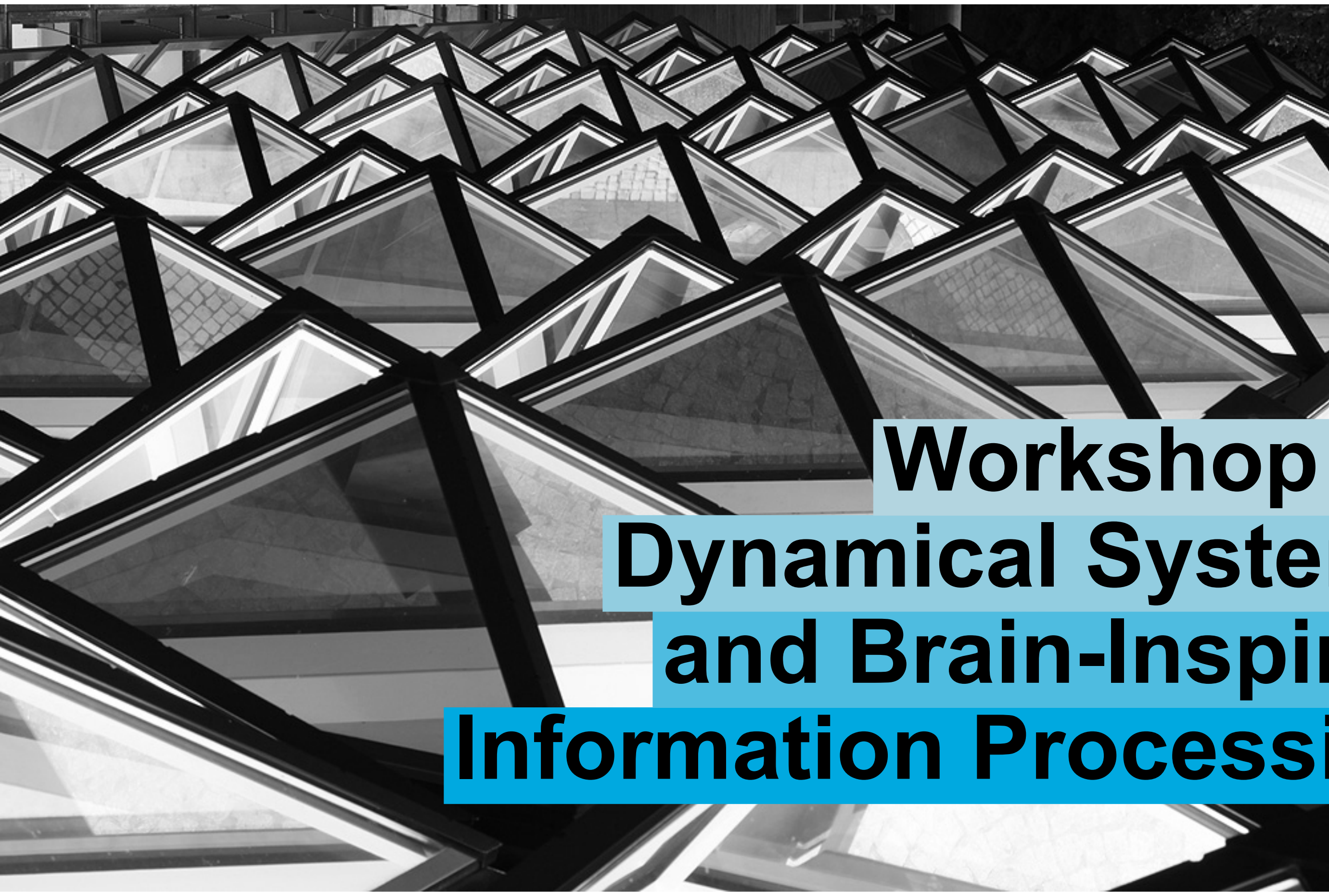

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Abstracts of Oral and Poster Presentations

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Multi-level optical weights for integrated optical neural networks

Reservoir computing in various physical implementations have been demonstrated using optical, electrical, and mechanical systems. Using bulk optical and electro-optical components for delayed-feedback systems are a popular approach to realize reservoirs with several hundreds of nodes. More compact approaches based on integrated photonics with reduced number of nodes have recently been shown. The silicon photonic chips show good results in various computational tasks, but are limited in size due to optical losses. In addition, the synaptic weights are stored in software, which limits the scalability of such systems. To increase the neural network size, to decrease the power consumption, and to facilitate system designs of such networks, the output of the reservoirs needs to be processed directly in hardware. To enable such processing, a novel set of integrated building blocks such as optical amplifiers and non-volatile optical synapses must be developed.

In our work, we show multi-level optical weights embedded in a silicon photonic platform and discuss concepts of how to co-integrate such devices with embedded optical amplifiers in the next generation of silicon photonic reservoir chips. The weights rely on the stabilization of different ferroelectric domain patterns in barium titanate thin films, which can be controlled by applying short voltage pulses of 100 ns. Our results are the first experimental demonstration of an electrically driven, multi-level optical weight in integrated photonic circuits, which could serve as key synaptic building block in future networks used for reservoir computing.

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Spectral Analysis on Echo State Networks

As one of the most important paradigms of recurrent neural networks, the echo state network (ESN) has been applied to a wide range of fields, from robotics to medicine, and language processing. A key feature of the ESN paradigm is its reservoir a directed and weighted networkthat represents the connections between neurons. Despite extensive research efforts, the impact of the reservoir topology on the ESN performance remains unclear. Here we explore the impact of cycles in the reservoir and show how to alter their number and weights to adapt ESN to different tasks. Using signal processing and control theoretical tools, we analytically derive rules to improve ESN performance and we validate our results in various benchmark problems. Our approach provides a new way of designing more efficient recurrent neural networks and sheds light into the information processing properties of complex systems.

Piotr Antonik[1], Michiel Hermans[1], Marc Haelterman[2], and Serge Massar[1]

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Chaotic time series prediction using a photonic reservoir computer with output feedback

Reservoir computing is a bio-inspired computing paradigm for processing time-dependent signals. Its hardware implementations have received much attention because of their simplicity and remarkable performance on a series of benchmark tasks. In previous experiments the output was uncoupled from the system and in most cases simply computed offline on a post-processing computer. However, numerical investigations have shown that feeding the output back into the reservoir would open the possibility of long-horizon time series forecasting. Here we present a photonic reservoir computer with output feedback, and demonstrate its capacity to generate periodic time series and to emulate chaotic systems. We study in detail the effect of experimental noise on system performance. In the case of chaotic systems, this leads us to introduce several metrics, based on standard signal processing techniques, to evaluate the quality of the emulation. Our work significantly enlarges the range of tasks that can be solved by hardware reservoir computers, and therefore the range of applications they could potentially tackle. It also raises novel questions in nonlinear dynamics and chaos theory.

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Improving performance of analog readout layers for photonic reservoir computers with online learning

Reservoir computing is a bio-inspired computing paradigm for processing time-dependent signals. The performance of its hardware implementation is comparable to state-of-the-art digital algorithms on a series of benchmark tasks. The major bottleneck of its implementations is the readout layer, based on slow offline post-processing. Few analogue solutions have been proposed, but all suffered from noticeable decrease in performance due to added complexity of the setup. Here, we propose the use of online training to solve these issues. We study the applicability of this method using numerical simulations of an experimentally feasible reservoir computer with an analogue readout layer. We also consider a nonlinear output layer, which

would be very difficult to train with traditional methods. We show numerically that online learning allows to circumvent the added complexity of the analogue layer and obtain the same level of performance as with a digital layer. This work paves the way to high-performance fully analogue reservoir computers through the use of online training of the output layers.

Apostolos Argyris

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Signal restoration in optical communications using photonic information processing

We show the potential of photonic information processing to improve the incoherent detection of critically degraded optical communication signals after fiber transmission. A photonic reservoir approach based on semiconductor lasers with time-delayed feedback is considered. Experimental results show at least two orders of magnitude improvement in bit error rate of the recovered data, when compared to the performance of linear classification algorithms that exclude the reservoir operation.

Stéphane Barland

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Regenerative optical memory in a delayed excitable system

A neuron-like excitable optical system can store information in patterns of spikes when it is submitted to a long delayed retroaction term. Although the spike-timing pattern may be blurred by noise and interactions between excitable spikes, an appropriate parameter modulation can overcome this process. It can also lead to the formation defects in a soliton lattice, which we call “meta-solitons”.

Andrej Berg, Oleksandra Kukharenko, and Christine Peter

Universität Konstanz, Germany

Dimensionality reduction for characterization of protein conformations from MD simulations

Molecular dynamics (MD) simulations have applications in a broad scientific field to sample the conformational space of atoms and molecules. Investigation of system, such as proteins, can yield insight in molecular processes on the atomistic scale. Such a high resolution means also that the underlying space is highly complex. One way of analyzing trajectories produced with MD simulations is the calculation of time series of a few selected descriptors, also called collective variables (CVs). Although, interpretation of this low dimensional data is easy and can be often compared directly with experimental results, there are some drawbacks, as well. One has to know which are the most important descriptors for the investigated problem. By selection of inadequate CVs crucial states and processes might be neglected. Increasing the number of CVs is therefore important to improve the characterization of complex molecular systems. However, interpretation of this data is not trivial.

Here we analyze the conformational space of eight differently connected Ubiquitin dimers (diUb), which differ in their signaling functions in the eukaryotic cell. The conformations of diUb are described by a set of distances [Hu 16]. We applied a dimensionality reduction algorithm to reduce the 144 dimensional distance space to 2D. The projected data can be used for comparison of conformations of different diUb types and simulation models [Trib 12]. To gain insight into the recognition mechanism of the Ub signaling system conformational states can be defined and analyzed on their relative stability.

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Floris Laporte[1], Alessio Lugnan[1], Joni Dambre[2], and **Peter Bienstman**[1]

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Novel photonic reservoir computing architectures

We will discuss two alternative reservoir computing architectures.

A first one a new design for a passive photonic reservoir computer on a silicon photonics chip in the context of optical communication applications. The design consists of a photonic crystal cavity with a quarter stadium shape, which is known to foster interesting mixing dynamics. These mixing properties turn out to be very useful for successful time-dependent optical signal processing tasks for telecommunication, such as for example header recognition.

A second architecture relates to a set of scattering pillars in the context of the sorting of biological cells, which can be used to reduce error rates. The computational power required to classify cell holograms is a major limit to the throughput of label-free cell sorting based on digital holographic microscopy. We propose a simple integrated photonic stage comprising a collection of silica pillar scatterers as an effective nonlinear mixing interface between the light scattered by a cell and an image sensor. The light processing operated by the photonic stage allows for the use of a simple linear classifier implemented in the electric domain and applied on a limited number of pixels. The use of scatterers allows for an error rate reduction up to 50% concerning the classification of cells with 2 different average nucleus sizes.

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Spike-patterns in relaxation-type oscillators comprising finite time delay

Mutual phase synchronization of coupled nonlinear oscillators encompasses a broad range of phenomena in science and engineering [Piko 01]. Most of the theoretical and experimental work assumes instantaneous coupling schemes, where the signal propagation speed between individual oscillators is considered as infinitely fast. Nonetheless, over the last decades it became clear that signal time delay can play a significant role in complex systems such as gene-regulator networks or coupled neuronal oscillator networks. Interestingly, it turned out that time delay can lead to counterintuitive results. For example, delay can induce or suppress instabilities in otherwise stable and non-stable complex dynamical systems, respectively [Erns 95]. Here we present our results on relaxation-type oscillators comprising a finite time delay during pulse coupling. The oscillators are based on programmable unijunction transistor circuits, which offer a simple read out of the pulse trains (spike patterns) as well as the realization of excitatory and inhibitory coupling schemes. A Field Programmable Gate Array (FPGA, Cyclon V) was applied to generate adjustable signal time-delays. For both, the oscillator period and the time delay, biological relevant times in the order of several tenths of milliseconds were used. The spikes of a relaxation oscillator were delayed and feed back to the excitatory and inhibitory input of the same oscillator [Klin 15]. This self-projected system led to different patterns and can be considered as the simplest system to study reentry mechanisms [Foss 00, Edel 93].

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Large scale spatio-temporal networks of nonlinear oscillators for neuromorphic computing

We show the potential of photonic information processing to improve the incoherent detection of critically degraded optical communication signals after fiber transmission. A photonic reservoir approach based on semiconductor lasers with time-delayed feedback is considered. Experimental results show at least two orders of magnitude improvement in bit error rate of the recovered data, when compared to the performance of linear classification algorithms that exclude the reservoir operation.

Sen Cheng

Institut für Neuroinformatik, Ruhr-Universität Bochum, Germany

Dynamics of sequence memory storage in the hippocampus

We previously suggested that temporal sequences of neural activation play an important role in the function of the hippocampal circuit in episodic memory, the memory of personally experienced events. In our framework, called CRISP, area CA3 was suggested to produces temporal sequential activities intrinsically through its recurrent connectivity. These sequences are then hetero-associated with sequences that are driven by sensory inputs to store episodic memories. We recently studied the feasibility of CRISP in a computational model. The accuracy of sequential memory can be high, but it critically depends on both the dynamics of CA3 and hetero-association through the hippocampal circuit. Specifically, the CA3 dynamics has to be robust to noise, which requires temporally uncorrelated patterns in CA3 and plasticity in CA3. Our results offer preliminary evidence that CRISP is a viable theory for episodic memory storage in the hippocampus, although some aspect might need to be amended.

Stéphane Chrétien

National Physics Laboratory, UK

Adaptive online model selection for linear and non-linear AR

Model selection is an important task which may have a tremendous impact on time series forecasting. Unfortunately, model selection can be computationaly expensive, especially in the case of non-linear models such as models governed by complex deep networks. We present a new approach to model selection using the Hedge algorithm. We will analyse the theoretical performance of the method in the linear case and in some non-linear cases. We will show computational experiments that demonstrate the effectiveness of the proposed approach in various settings. In particular, experimental results using a recent approach by Binkowski, Marti and Donnat will be presented.

Joni Dambre

IDLab, Ghent University - imec, Belgium

Reservoir computing with limited state observability: Perspectives on learning

Physical reservoir computing (PRC) is a general-purpose technique that uses the principles of reservoir computing to optimally exploit the intrinsic dynamics of physical systems for performing computation. It uses a physical nonlinear dynamical system as a spatio-temporal kernel, to project the input data into a higher dimensional space. A simple machine learning technique, usually linear regression, is then used to combine the observed state space signals into a good approximation of the desired output.

It is often advocated as an analog alternative for general-purpose computation in niches where digital computation breaks down due to bandwidth limitations or due to the increasing variability induced by extreme scaling. It typically deals with technologies in which not all hardware parameters are well known or even constant across all hardware instantiations. This implies that a direct transfer between simulation and physical hardware is not possible, and at least part of the learning has to be done on the actual hardware. As this learning happens in a supervised way, using digital computers, the concept of physical reservoir computing heavily relies on being able to digitize as much as possible of the reservoirs state space.

When internal states are not available for the learning algorithm, or only to a limited extent, alternative approaches have to be explored. After summarizing our experience with this problem with integrated photonic reservoirs in the H2020 PHRESCO project, this talk will highlight some machine learning approaches that are possible candidates for addressing the learning problem under limited observability.

Laurent Daudet

LightOn

Université Paris Diderot, France

Wave propagation in strongly scattering materials: A playground for physics, signal processing, and machine learning

It has long been considered that the multiple diffusion resulting from the propagation of waves in extremely disordered environments, such as light through biological tissues or a fine layer of paint, destroyed all the information carried by these waves. In recent years, particularly in optics with wavefront control techniques, it has been shown that wave propagation is extremely complex but remains linear. In fact, by discretizing the inputs (spatial light modulators) and outputs (digital cameras), the propagation performs the equivalent of a random projection, i.e. the multiplication of the input vector by a random matrix. It is now possible to use such random media as ”lenses” focusing light at a given point, but with an enormous number of degrees of freedom. In this context, we have shown that these environments act precisely as the ”compressed sensing” model systems, allowing the acquisition of signals with a number of measurements closest to the actual quantity of information. Conversely, one can see this physical system as an optimal mixer of information, realizing instantaneously in an analogue way an elementary computation brick integrating in many Machine Learning schemes. We will present a method of classification of images based on random features obtained optically.

Lyudmila Grigoryeva[1], Juan-Pablo Ortega[2,3]

[1]Universität Konstanz, Germany
[2]Universität Sankt Gallen, Switzerland
[3]Centre National de la Recherche Scientifique (CNRS), France

Universal discrete-time reservoir computers with stochastic inputs and linear readouts using non-homogeneous state-affine systems

A new class of non-homogeneous state-affine systems is introduced. Sufficient conditions are identified that guarantee first, that the associated reservoir computers with linear readouts are causal, time-invariant, and satisfy the fading memory property and second, that a subset of this class is universal in the category of fading memory filters with stochastic bounded inputs. This means that any discrete-time filter that satisfies the fading memory property with random inputs of that type can be uniformly approximated by elements in the non-homogeneous state-affine family.

Claudius Gros, Laura Martin, Michael Nowak, Tim Koglin, and Bulcsú Sándor

Institute for Theoretical Physics, Goethe University Frankfurt, Germany

Regular and chaotic attractors in the sensorimotor loop: Simulated and real-world robots on the move

We examine simulated and real-world self-organized robots characterized by a controller containing only a single neuron per actuator. This neuron has access only to the state of the actuator it controls (propriocetion), e.g. of the current angle of a wheel. We show that locomotion occurs in these biologically inspired animats when limit cycles and/or chaotic attractors form in the combined phase space of neural activity, robot-body and environmental variables (the sensorimotor loop). We find in particular that short-term synaptic plasticity (STSP) tends to destabilize fixpoint attractors. STSP, which is characterized by timescales of several hundreds of milliseconds, may hence be relevant for the generation of motor signals.

Xu He, Herbert Jaeger

Jacobs University Bremen, Germany

Overcoming catastrophic forgetting by conceptors

Catastrophic interference has been a major roadblock in the research of continual learning. Here we propose a variant of the back-propagation algorithm, “conceptor-aided back-prop” (CAB), in which gradients are shielded by conceptors against degradation of previously learned tasks. Conceptors have their origin in reservoir computing, where they have been previously shown to overcome catastrophic forgetting. CAB extends these results to deep feedforward networks. On the disjoint MNIST task CAB outperforms two other methods for coping with catastrophic interference that have recently been proposed in the deep learning field.

Herbert Jaeger

Jacobs University Bremen, Germany

Brain-inspired information processing: Beyond the Turing machine

Some aspects of human brain-based information processing can be approximately captured by the Turing model of computation. But many aspects cannot. These non-Turing, non-digital aspects arise from the unwieldy physics of physiological neural substrates: stochasticity, irreproducibility, inhomogeneity, aging, timescale mixes, and more. Such obnoxious characteristics are shared with many unconventional physical substrates that are currently being considered for novel microchip technologies. This talk attempts to identify key coordinates of a future theory for brain-inspired information processing, setting such a theory apart from the Turing paradigm of computation in an as concrete as possible manner.

Coralie Joucla[1], Damien Gabriel[1,2], Lyudmila Grigoryeva[3], Juan-Pablo Ortega[4,5], and Emmanuel Haffen[1,2]

[1]Univ. Bourgogne Franche-Comté, France
[2]CHRU Besançon, France
[3]Universität Konstanz, Germany
[4]Universität Sankt Gallen, Switzerland
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A subject personalized frequency domain features selection approach using genetic algorithm to improve SVM classification in EEG N400 paradigm

In recent years, progress in medicine allowed to keep alive an increasing number of patients with disorders of consciousness. However, differential diagnosis between patients who have a residual level of consciousness and those who do not using electroencephalography (EEG) as a brain-imagery method can be challenging.

Thus, a variety of machine learning methods have been developed to extract the relevant information from EEG recordings and to identify different categories of EEG data. From the literature, in most of the cases, said methods reported very different results, because of the high inter-individual variability from one subject to another.

In this study, we used a genetic algorithm to optimize features selection with Fourier transform for each of the 29 healthy subjects before a Support Vector Machine (SVM) classification. The optimized parameters were: start and end of the period of interest (in ms) in the EEG data, the size of the sliding window and overlap for the Fourier transform. Results showed a significant improvement of classification accuracy and p-value, compared to results obtained using the same literature reference parameters for all the participants.

Wosen E. Kassa[2], Evangelia Dimitriadou[2], Marc Haelterman[2], Serge Massar[1]

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[2]OPERA-Photonique, Université libre de Bruxelles, Belgium

All-optical computing based of frequency parallelism integrated on InP

Photonic reservoir computing based on sequential processing using periodic input mask has already achieved state-of-the-art performance. However, the processing speed is limited by the electronics used to implement the input layer. By introducing a parallel processing architecture where the nonlinear nodes are processed simultaneously, the fiber cavity can be shorter, hence higher processing speed. This also allows the possibility of integrating the system on a photonic chip. Frequency based reservoir computing is one such technique where frequency neuron states are multiplexed in the frequency domain allowing parallel information processing. Previous implementation of this architecture using monochromatic laser as an optical source and phase modulator in the fiber cavity suggested that the performance of the system is dependent on the number frequency combs. This can be achieved using a comb generator such as mode lock lasers. In this paper, we present the works done so far towards the realization of integrated reservoir computer based on frequency parallel architecture shown in Figure 1 (Frequency reservoir computer) on a generic InP platform.

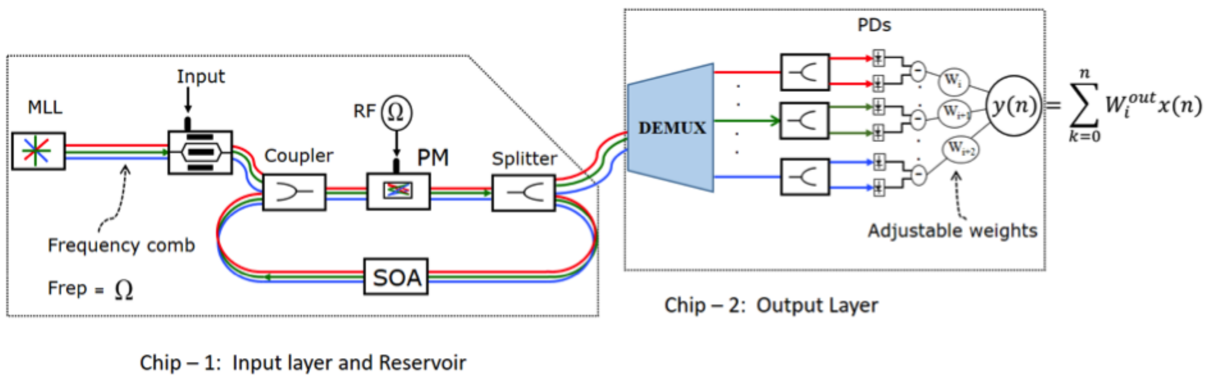

Figure 1: Frequency reservoir computer

Oleksandra Kukharenko
Universität Konstanz, Germany

Quantitative analysis of protein dynamics

Atomistic molecular dynamics (MD) simulations allow direct observation of the dynamics of a folding/unfolding event in relatively small biomolecules (few thousands of atoms). A common approach in this field consists of considering molecular structures as dynamical systems by modeling them using classical mechanical principles. As a result a high dimensional description of the energetically accessible regions of the phase space is obtained. This space usually has a highly complex, non-linear and possibly fractal structure.

In this talk we will focus on important computational issues that arise when assessing the high-dimensional output obtained from atomistic MD simulations of proteins. More specifically, at the time of modeling their dynamical behavior, and when identifying their states and features and obtaining kinetic and thermodynamical estimates. We expect that some of the proposed problems can be addressed by reservoir computing approach.

L. Larger, A. Baylon-Fuentes, D. Brunner, Y. K. Chembo, M. Jacquot, B. Marquez, and B. Penkovskyi

FEMTO-ST, University Bourgogne Franche-Comté, France

Delay dynamics emulating a spatio-temporal network: from the model to photonic Reservoir Computing

Delay dynamical systems are purely temporal dynamics, nevertheless being capable for developing high dimensional and complex chaotic motions in an infinite dimensional phase space. Such particular class of dynamics have also the great advantage to be physically tractable in various engineering applications, demonstrating efficient optoelectronic signal generation or processing capabilities with attractive performances: High-bit rate optical chaos encryption, ultra-fast random number generation, high-spectral purity microwave radar sources, and more recently photonic Reservoir Computing. We will develop the latter framework, showing how a delay dynamical system can formally, and also experimentally, emulate the equivalent of a neural network, which can be further used to demonstrate ultra-fast photonic hardware neuromorphic computing on a classification task.

Tobias Lemke, Christine Peter

Universität Konstanz, Germany

Neural network based prediction of conformational free energies - new route towards coarse grained simulation models

Coarse grained models rely on an accurate description of the underlying potential of mean force / free energy surface. We present a neural network based method how to obtain high dimensional free energy surfaces from atomistic molecular dynamics simulation trajectories. We apply this method to create coarse grained models of homo-oligomers relevant as mineralization modifiers. Monte Carlo simulations on the coarse grained level based on the free energy surface predicted by the neural network are in good agreement with atomistic molecular dynamics data. Furthermore, the neural network is not only able to describe the free energy surface of oligomer lengths that it was trained on but is also able to make predictions for longer chains.

Serge Massar

Université libre de Bruxelles, Belgium

Photonic Reservoir Computing

Reservoir computing is a brain inspired artificial intelligence algorithm with excellent performance on tasks such as speech recognition or time series prediction. We present this algorithm

and its connection with neuroscience. The reservoir computing algorithm can be easily implemented in hardware. We present several photonic implementations based on a simple architecture consisting of a single non linear node and a delay line. These analog implementations have performance comparable to digital implementations. We discuss the future of photonic reservoir computing and more generally of analog brain inspired computing.

Fábio Schittler Neves[1], Marc Timme[1,2]

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[2]Technical University of Dresden, Germany

Heteroclinic Networks in state space supporting universal bio-inspired computing

Heteroclinic networks naturally emerge as objects underlying the nonlinear dynamics of networked systems, in particular coupled oscillators. They are abstract networks in states space – a collection of saddle states linked via heteroclinic connections – and form the skeleton supporting collective dynamics across a range of systems. Here we propose heteroclinic computing, a framework to exploit the driven, self-organized dynamics near heteroclinic networks for solving computational tasks in a bio-inspired way. We show that such systems naturally serve as analog-digital converters, can execute arbitrary (multi-bit) n-ary computations in parallel and enable almost exponential scaling of the number of solvable tasks with system size. Moreover, the new computing framework is independent of specific implementations and may include systems of phase-coupled, pulse-coupled oscillators or competitive Lotka-Volterra-like systems. We explain the features of the mechanisms underlying heteroclinic computing and discuss open questions regarding encoding-decoding interplay, memory integrated with information processing in such systems and options for implementing a heteroclinic computer in hardware.

Jaël Pauwels, Guy Van der Sande, Arno Bouwens, Marc Haelterman, Serge Massar

Université libre de Bruxelles, Belgium

Parallel optical reservoir computing: Towards a high-performance scalable implementation

Our research targets efficient (high speed and low power) analogue photonic computing systems based on the concept of reservoir computing (RC). This computing paradigm offers a framework to exploit the transient dynamics of a nonlinear dynamical system for performing useful computations. Our approach uses the massive parallelism and high bandwidth offered by optics, while the system architecture remains simple and is easily scalable. This research

will thus allow us to overcome the limited scalability and parallelism of state of the art photonic integrated reservoir computers.

Our spatially parallel photonic reservoir consists of a free-space Fabry-Pérot cavity where the back-end coupler is replaced by a reflective diffractive optical element (DOE). The neurons are encoded as spots on the input coupler, arranged in a rectangular grid. A single lens inside the cavity, with its Fourier planes on the cavity mirrors, transforms each spot on the input coupler (the neuron) into a corresponding plane wave component at the back-end of the cavity. At this end all plane wave components are incident on the DOE with different angles. As such, the DOE couples the neurons by diffracting each incident plane wave at angles corresponding with other neurons. Because the DOE is implemented using a programmable spatial light modulator, we can change the coupling between the neurons. The reservoir itself is linear, and a nonlinearity is found in the readout layer: the output photodiodes measure the optical power, which scales with the square of the optical field strength. A 9 by 9 grid of neurons can be implemented at GHz rate, limited by the numerical aperture and size of the photodiodes in the readout layer.

The presented work focuses on the numerical investigation of the role of the diffractive coupling between the neurons. We discuss the effect of the diffractive coupling on the simulated RC performance on a standard benchmark test. Although the system has not yet been verified experimentally, the simulations yield promising results, thereby validating the proposed RC scheme.

Simon Morando[1,2], Marie-Cécile Pera[1,2], Nadia Y. Steiner[1,2,3], Samir Jemei[1,2], Daniel Hissel[1,2], and Laurent Larger[1]

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Reservoir computing applied to the diagnostic of fuel cells

Fuel cells are electrochemical devices that can convert hydrogen and oxygen from air into electricity and heat with water as a byproduct. Their operation depends on the supplied gas flows, their humidity and the temperature. In case of fault in the control of these variables, the state of health of the stack can be suboptimal : drying, flooding, low hydrogen and oxygen flows. These situations have to be detected as early as possible to allow the recovering of normal state of health and no additional sensors to avoid an increase of the cost and the decrease of the reliability. To achieve this, the voltage is monitored and analyzed though reservoir computing. Faulty conditions are detected in more than 80% of the cases.

This study has been realized thanks to the ANR-OH Risque BIPHOPROC and the Labex Action (contract ANR-11-LABX-001).

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Delay-based reservoir computing: Tackling information processing capacity degradation due to system response time

Reservoir Computing (RC) can be efficiently implemented using a single nonlinear neuron subject to delayed feedback. In this delay-based RC the spatial multiplexing of the input in the standard RC systems with N neurons is replaced by time-multiplexing. The reservoir is composed of N outputs of the system distributed along the delay line. Connections between these N virtual nodes are established through the delayed feedback. Delay-based RC has allowed hardware implementation in photonic systems that have the potential to develop high- speed information processing. However, the information processing rate is limited by the bandwidth of the photonic system. The information processing time is given by $T_p = N\theta$, where θ is the time interval between two virtual nodes. Tp can be reduced by decreasing the node distance. However, when θ is smaller than the response time of the system T, the systems inertia couples consecutive virtual nodes. These redundant network connections reduce the number of linearly independent reservoir states, and the information processing capacity is degraded.

In this work we show using numerical simulations that performance degradation due to system response time can be reduced when the delay time τ is much greater than the information processing time T_p. We consider a semiconductor laser with Ikeda type nonlinearity subject to optoelectronic feedback. The linear and nonlinear information processing capacities are obtained for different values of θ/T. It is found that information processing capacity is boosted for small values of θ/T if τ is much greater than T_p. A similar performance is obtained for different tasks for small and large values of θ/T if these values of the delay time are used.

Gordon Pipa

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Multi Delay coupled reservoirs

Neuromorphic computing provides a promising platform for processing high-dimensional noisy signals on dedicated hardware. Using design elements inspired by neurobiological findings and advances in machine learning methodology, delay-coupled systems have recently been developed in the field of neuromorphic computing. Delayed feedback connections enable such systems to generate a complex representation of injected input in the internal state of single nodes, which in our context refer to hardware components with nonlinear behavior and without any memory. In contrast to classical combinatorial circuits or feed-forward networks, this state is not distributed in space but in time. Hardware implementations with low hardware component counts are therefore particularly easy to design for delay-coupled systems. In this talk, we present an argument for using delay-coupled reservoirs using multiple feedback terms with different delays. We present a theoretical analysis of the resulting system, discuss surprising effects pertaining to the precise choice of delays, and provide a guideline for the optimal design of such systems.

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Photonic reservoir computing using a small network of micro-ring resonators

In this talk, we describe a photonic architecture based on a small network of nonlinear micro-resonators integrated on a Silicon chip. We demonstrate based on extensive numerical simulations that this photonic integrated circuit can be used as a reservoir computer to perform nonlinear binary-type tasks, such as the XOR task, at bitrate exceeding tens of Gb/s. Then, we make a comparative performance analysis between our new architecture and the previous one based on purely passive elements (i.e. delay lines, combiner, and splitter). We show that the level of performance can exceed that of this previous chip under specific operational conditions. Finally, we provide a detail analysis of tunable parameters (i.e. optical detuning and the injected optical power) on the level of performance of our architecture. This work provides evidence this type of architecture is suitable for high-speed neuromorphic information processing in the field of optical telecommunications.

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Machine learning in finance

We show several interesting applications of machine learning in banking industry ranging from calibration problems to high-dimensional risk management. Empirical findings are accompagnied by a theoretical framework on sparse representations of the involved functions.

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Attractor metadynamics in a small autonomous RNN

In neural networks differences in time scales, spanning the range from milliseconds (membrane potential) to hours (plasticity), play an important role in cognitive processing tasks. Modeling such networks by dynamical systems with distinct time scales one finds that the fixpoints of the fast subsystem are destroyed by the additional time evolution of the slow subsystem. The remnants of the destroyed fix points are present in the full system as *transiently attracting states* [Gros 07] forming the slow manifold. These relics can guide the flow across the manifold and thus strongly influence the behavior of the overall system. Especially in high dimensional systems it is not trivial to compute the entire slow manifold, neither to determine its effect on the overall dynamics.

As a resolution, in this contribution we elaborate the concept of stable/unstable *adiabatic fixpoints (AFP)*, which are the stable/unstable fixpoints of the fast subsystem in the adiabatic limit, i. e. when the slow subsystem is infinitely slow, only acting as parametric variable [Wern 16]. We then can map each state of the overall dynamics onto exactly one *target point*, i.e. the stable AFP that the system would converge to in the adiabatic limit. Even in a high dimensional system we thus find for any given trajectory a lower dimensional manifold of effective transiently attracting states. We analyze the evolution of the transiently attracting states termed *attractor metadynamics* using it as a key to understand the dynamics of complex dynamical systems. Further, we investigate the average distance between a trajectory and its target manifold and the distribution of distances. Thereby we are able to quantify the effect of the transiently attracting states on the overall dynamics.

We present and illustrate our results for an autonomous three-neuron system that consists of continuous-time point neurons [LiGr 13] with an intrinsic adaption being substantially slower than the primary neural activity. Depending on the symmetry of the system we find attractors that are dominated by the target points and symmetry protected cases that do not settle close to any transiently attracting state. We show how these states can be classified in terms of their attractor metadynamics. For completeness we also present a chaotic attractor of the same system and its transiently attracting states, gaining further insight on the origin of chaos.

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Synchronization of memristively coupled van der Pol oscillators

Conscious and perception are without doubt one of the most fascinating functionalities of the human brain and results from massive parallel computing in a huge self-organizing dynamical neural network. Neural synchrony is an elegant concept which tries to explain the underlying computing scheme by using dynamical network behaviours. In this talk I show that memristive devices allow a new degree of freedom to the concept of neural synchrony: a local memory which supports a transient connectivity. By using a 4-inch full device technology electrochemical metallization (ECM) cells with the layer sequence Al/TiO2-x/Au are fabricated. Those devices are used to couple self-sustained van der Pol oscillators in an electronic circuit. As a result an autonomous frequency adaptation and phase locking is observed. The underlying circuit and device requirements and their impact to neuromorphic computing are discussed in this talk.

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