### **WORKSHOP**

# ADAPTIVITY IN NONLINEAR DYNAMICAL SYSTEMS

Tuesday 20 Sep – Friday 23 Sep | 2022 | POTSDAM/ HYBRID









#### **ORGANISERS**

- Rico Berner (Humboldt-Universität zu Berlin)
- Sarah Loos (University of Cambridge)
- Jakub Sawicki (Potsdam-Institute for Climate Impact Research)

#### **CONTACT PERSON**

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#### COVID REGULATIONS

- \* If possible, please **test yourself** before arrival at the workshop
- \* Please bring a face mask with you that has to be worn in case
  - a distance of 2m cannot be guaranteed
  - the ventilation of the rooms with fresh air is not possible
- \* Hand sanitizer will be available.
- \* In case you have symptoms, of a cold, please do not attend the workshop.
- \* Please refrain from physical contact such as hugging and shaking hands.

#### WELCOME NOTE FROM ORGANIZERS

A widespread feature of natural and artificial complex systems is their adaptivity. Dynamical networks with adaptive couplings appear in various real-world systems such as power grid, social, and neural networks, and they form the backbone of many control strategies and machine learning algorithms. There is lively interest in modelling real-world adaptive systems as well as pushing forward the boundaries of feedback control and artificial learning. In spite of the exhilarating innovation drive in each of the related scientific fields, little attempts have been undertaken, so far, to facilitate the cross-pollination between the different disciplines.

This workshop aims to make the first step in breaking the barriers between different scientific communities and bring together researchers from a wide range of backgrounds including physics, biology, engineering, mathematics, social science, and musicology. The workshop serves as a platform for young and senior researchers to embark on partnerships for interdisciplinary research. The workshop is organized as a hybrid event with a mixture of virtual and in-person talks.

Thanks for coming and welcome to the workshop. Approach us, if you have any questions and enjoy the programme!

Rico Berner, Sarah Loos, and Jakub Sawicki

#### FINANCIAL SUPPORT

The workshop is financially supported by the Joachim Herz Stiftung: Workshop on 'Adaptivity in nonlinear dynamical systems'.



#### NOTE

The workshop will adhere to the rules of good scientific and ethical practice. This means that it is not allowed to copy presentations from the presentation computer or to record presentations during video conference sessions. It is also forbidden to take photographs of oral presentations without explicitly given permission of the presenter.

#### **BREAKS AND LUNCH**

Beverages and coffee break snacks will be provided in front of the meeting room. Please follow the rules of conduct in regards the hygiene and safety during the breaks, as well.

Lunch is included in the workshop, too and is available in the canteen (and only there) of the science campus. Vouchers (as the payment method in the canteen) will be distributed to the participants before the lunch break at the registration desk.

## PRACTICAL INFORMATION

## PROGRAMME

	Tuesday, September 20	Wednesday, September 21 Thursday, September 22	Thursday, September 22	Friday, September 23
8:00 - 09:30		Registration	ration	
08:30	Welcome note	Otofoo Kooloob*	Oorbin Vondon	*040/\(\)\(\)
10:00	Keynote talk:	Otelal roesoll	Odilily Lallorluh	GIOVAIIIII VOIDA
10:30	Eckehard Schöll	Coffee break	Coffee break	Coffee break
11:00	Coffee break	100 G	:0V CC	Obility   Orong O
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12:00		Aida Hajizadeh*	Wolfram Barfuss*	Jobst Heitzig
12:30 - 14:30		Lunch and Discussion time	cussion time	
14:30	Simic cocmis	Cmor Korin*	*roid: 19 Joine C	Mobras Associ
15:00			Dalliel Gautille	Wellindz Alivaii
15:30	Coffee break	Arioto Adiobi	Coffee break	*: aclo \
16:00	Matthias Wolfrum		+Good acitachoo	
16:30	**************************************	Coffee break	Oebastiali Goldi	Summary and Farewell
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17:30		Poster Session &	Allie2a Jell	
18:00		Get-together		
18:30				
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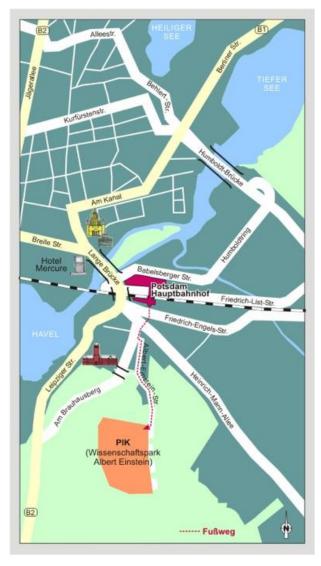
\*online talk

talk + discussion 45 + 15 min or 23 + 7 min

Adaptivity in neuronal and biological systems
Adaptive mechanisms in music perception
Mathematical models of adaptive systems
Reservoir computing and artificial learning
Adaptation in socio-economic systems

#### **LOCATION**

# Navigate from Potsdam Main Station to PIK Telegraphenberg



By Bus: a minibus (No. 691) leaves Potsdam main station (platform 7) heading towards "Einstein-Wissenschaftspark" in the mornings and in the evenings

Walk: ~20 minutes

#### Navigate to the Conference Hall/Canteen





https://pik-potsdam.zoom.us/my/adaptive.workshop

Meeting-ID: 358 991 4988

Passcode: 548565



#### PIK-WIFI

Wi-Fi: PIK-Visitors

Visitor password: aRC\$90!JS7Pi?

ACCESSING EDUROAM AT PIK

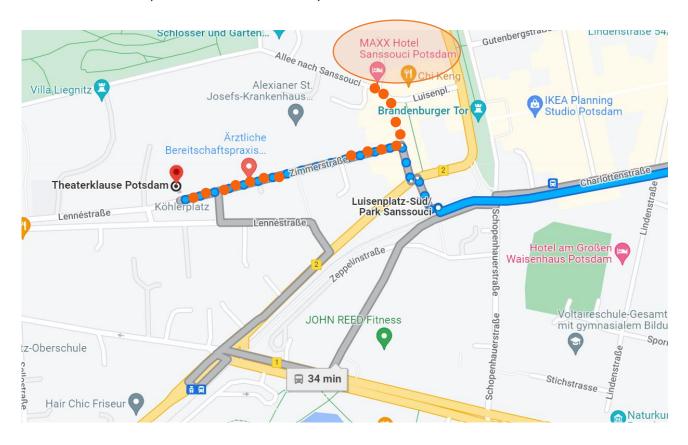
For Log-In to the "eduroam" network please use the method and credentials provided by your institute.



For the invited speakers we are planning a **conference dinner** on Thursday at **19.00 h**. evening where you are cordially invited.

The restaurant is:

THEATERKLAUSE, Zimmerstraße 10–11, 14471 Potsdam



It takes about half an hour to get there from the conference venue:

From station 'Potsdam Hbf' (~20 min walk from conference venue):

- Bus line 605 (direction Potsdam, Science Park West) until station 'Luisenplatz-Süd/Park Sanssouci' and then 5 min walk
- Bus line 631 (direction Werder Bahnhof) from station until station 'Feuerbachstr.'

For those who stay in the **Hotel (MAXX Hotel)**, it is only a 4 minute walk (marked with orange dots) to the restaurant

#### TITLES AND ABSTRACTS

TUESDAY, SEPTEMBER 20

09:30 - 10:00

**Welcome Note** 

10:00 - 11:00

## Partial Synchronization Patterns in Adaptive Networks Eckehard Schöll (PIK, GER)

We review partial synchronization patterns emerging in networks of adaptively coupled nonlinear oscillators. Power grids, as well as neuronal networks with synaptic plasticity, and physiological networks of the immune system and the parenchyma coupled adaptively by cytokines, describe real-world systems of tremendous importance for our daily life. This contribution provides a new perspective by demonstrating that power grids can be viewed as a special class of adaptive networks, where the coupling weights are continuously adapted by feedback of the dynamics, and both the local dynamics and the coupling weights evolve in time as co-evolutionary processes. Such adaptive networks are very common in neural networks with synaptic plasticity. In terms of power grids, the power flow into the network nodes from other nodes represent pseudo coupling weights. This modelling approach allows one to transfer methods and results from neural networks, in particular the emergence of solitary states and multifrequency clusters, which may form in a hierarchical way and destabilize the desirable completely synchronized operating state of the power grid. In this work, the relation between these two types of networks, in particular the model of Kuramoto-Sakaguchi phase oscillators with inertia (swing equation for power grids) and the model of phase oscillators with adaptivity, is used to gain insights into the dynamical properties of solitary states and multifrequency clusters in power grid networks. Furthermore, with adaptively coupled phase oscillators in a 2-layer physiological network we present functional modeling of tumor disease and sepsis.



11:30 – 12:30

#### **Complex Climate Networks under Changing Conditions** Jürgen Kurths (PIK, GER)

The Earth system is a very complex and dynamical one basing on various feedbacks. This makes predictions and risk analysis even of very strong (sometime extreme) events as floods, landslides, heatwaves, or earthquakes a challenging task. I will introduce a recently developed approach via complex networks mainly to describe the climate system and to analyze strong climate events. First, an inverse problem has to be treated: Is there a backbone-like structure underlying the climate system? For this, we have proposed a method to reconstruct and analyze a complex network from spatio-temporal data. This approach enables us to uncover relations to global and regional circulation patterns in oceans and atmosphere, which leads to construct substantially better predictions, in particular for the onset of the Indian Summer Monsoon, extreme rainfall in South America, the Indian Ocean Dipole and tropical cyclones. An important characteristic of system Eartis its transient nature at various time scales, from quaternary till ms; system Earth is hence very adaptive in response to outer and inner perturbations. Its description requires more refined data analysis techniques. Here an evolving network analysis is presented to detect short-living tropical cyclones.



14:30 - 15:30



#### Spontaneous symmetry breaking in identically coupled inhibitory neural masses with adaptation

Simona Olmi (CNR, IT)

Whisking is the rhythmic cyclic vibrissae sweeping action, consisting of repetitive forward protraction) and backward (retraction) movements at an average frequency of about 8 Hz. At the basis of whisking generation is the vIRt nucleus in the medulla, composed of inhibitory neurons which innervate motoneurons of the vibrissa muscles. Starting from the microscopic dynamics of quadratic integrate-and-fire (QIF) neurons, we construct and analyze an exact neural mass model of the vIRt circuit composed of two inhibitory coupled neuronal populations with adaptation and exponentially decaying synapses, with the purpose of finding a model able to explain the generation of a rhythm driving the whisking activity in rodents. An exact derivation is possible for networks of QIF neurons, representing the normal form of Hodgkin's class I excitable membranes, thanks to the analytic techniques

developed for coupled phase oscillators. This exact neural mass model has been successfully employed to reveal the mechanisms at the basis of theta-nested gamma oscillations, the coexistence of slow and fast gamma oscillations and to model working memory. In this work, we show the role played by the adaptation in guiding the emergent dynamics. Various dynamical regimes can be observed: periodic collective oscillations (in phase and in antiphase), asymmetric collective oscillations, asymmetric fixed points and various bistability regions in the parameter space. In addition to that, it is found that adaptation is a mechanism by which Cross-Frequency Coupling between theta and gamma frequencies can occur. We also introduce the effects of the pre-Bötzinger complex through an external inhibitory oscillating forcing and we study the phase locking between the two populations, in order to evaluate the forcing influence on both populations. It turns out that phase locked states are possible and there are cases in which the forced populations are not fully entrained with the external input.



16:00 - 16:30

## Dynamics of a stochastic excitable system with slowly adapting feedback Matthias Wolfrum (WIAS-Berlin, GER)

We study an excitable active rotator with slowly adapting nonlinear feedback and noise. Depending on the adaptation and the noise level, this system may display noise-induced spiking, noise-perturbed oscillations, or stochastic bursting. We show how the system exhibits transitions between these dynamical regimes, as well as how one can enhance or suppress the coherence resonance or effectively control the features of the stochastic bursting. The setup can be considered a paradigmatic model for a neuron with a slow recovery variable or, more generally, as an excitable system under the influence of a nonlinear control mechanism. We employ a multiple timescale approach that combines the classical adiabatic elimination with averaging of rapid oscillations and stochastic averaging of noise-induced fluctuations by a corresponding stationary Fokker—Planck equation. This allows us to perform a numerical bifurcation analysis of a reduced slow system and to determine the parameter regions associated with different types of dynamics. In particular, we demonstrate the existence of a region of bistability, where the noise-induced switching between a stationary and an oscillatory regime gives rise to stochastic bursting.

16:30 - 17:30

## Using Nonlinear Maths and Physics to Treat Parkinson's With a Vibrating Glove

#### Peter Tass (Stanford Medicine, USA)

Abnormally strong neuronal synchronization is a hallmark of Parkinson's disease (PD). In medically refractory PD patients, standard deep brain stimulation (DBS) reduces specific symptoms during stimulus delivery. Coordinated Reset (CR)-DBS is a computationally developed technique which uses dedicated patterns of electrical stimuli to specifically counteract abnormal neuronal synchronization by desynchronization. The very goal of CR stimulation is to make neuronal populations unlearn abnormal synaptic connectivity patterns, in this way inducing long-lasting relief. Long-lasting therapeutic and desynchronizing CR-DBS effects were demonstrated in Parkinsonian (MPTP) monkeys and externalized PD patients. To provide a non- invasive alternative to DBS, we developed vibrotactile Coordinated Reset (vCR) fingertip stimulation. To this end, instead of administering electrical bursts through depth electrodes, we non-invasively deliver weak vibratory bursts in a CR mode to patients' fingertips. In a first-in-human study, vCR fingertip stimulation was administered to 5 idiopathic PD patients for in total 4 h per day on 3 consecutive days. Off-medication kinematic assessments revealed improved gait and bradykinesia during stimulation days and after 1 month after cessation of stimulation. In a pilot study, six idiopathic PD patients were treated with vCR stimulation delivered for in total 4 hours per day for 3 months. Patients' conditions were evaluated after medication withdrawal (off medication) by means of MDS-UPDRS III scores and EEG recordings before and after 3 months of vCR. vCR therapy caused a statistically and clinically significant reduction of PD symptoms off medication together with a significant reduction of high beta (21-30 Hz) power in the sensorimotor cortex

(https://www.youtube.com/watch?v=dSjv6m4xLH0). Additionally, in a case series in 3 idiopathic PD patients, 6+ months of vCR therapy caused a significant motor improvement, where off-medication MDS-UPDRS III scores decreased linearly. The ultimate goal of vCR is to induce sustained symptom relief by non-invasively delivering weak vibratory stimulation patterns only regularly or occasionally.

#### WEDNESDAY, SEPTEMBER 21

09:30 - 10:30



#### Predictive processes and the peculiar case of music Stefan Koelsch (University of Bergen, NOR)

I suggest that music perception is an active act of listening, providing an irresistible epistemic offering. When listening to music we constantly generate plausible hypotheses about what could happen next, while actively attending to music resolves the ensuing uncertainty. Within the predictive coding framework, I present a novel formulation of precision filtering and attentional selection, which explains why some lower-level auditory, and even higherlevel music-syntactic processes elicited by irregular events are relatively exempt from topdown predictive processes. I will review findings providing unique evidence for the attentional selection of salient auditory features, and present fMRI data on emotional effects of predictive processes during music listening. My formulations suggests that 'listening' is a more active process than traditionally conceived in models of perception.



11:00 - 12:00

#### Physical Culture Theory: Adaptive physical, conscious, and cultural processes forming music

Rolf Bader (University of Hamburg, GER)

Music, in terms of musical instrument acoustics, brain dynamics of music perception, as well as the interplay of musicians, audiences, and musical culture is an adaptive, self-organizing process. Musical instruments consist of subsystems, tubes, reeds, strings, or soundboards, where traveling acoustic impulses make subsystems adapt one to another, resulting in harmonic, but also bifurcating, or chaotic transient sounds. Only this adaptation leads to the emergence of sounds with harmonic ratios of 1:2:3:... i.e. musical pitches, and therefore make melodies or musical scores possible at all.

Thereby, subsystems less damped and of lower dimensionality force other subsystems to adapt to their eigenfrequencies. These acoustic and therefore basically electric impulses get blurred by room acoustics and are reconstructed in the human cochlear in terms of phase

alliance, as well as coincidence detection of neurons in the nucleus cochlearis or the trapezoid body of the auditory nervous system. The synchronization of these impulses into neural bursts are the basis for pitch perception as a spatio-temporal electrical field, as consciousness or conscious content. On higher levels, neocortical synchronizations do represent musical tension and form. This again leads to new musical performance as adaptation to external input and the circle closes as a synchronization process. Larger cultural entities do show such adaptations as historical, ethical, or semantic music and culture formation, as a set of many brains and cultural artifacts like musical instruments, performance venues, and all sorts of musical artifacts and activities. Therefore, a physical culture theory is able to represent this global adaptation process on the level of spatio-temporal electrical patterns of interacting electrical energy bursts.

12:00 - 12:30



#### Adaptation of responses in auditory cortex

Aida Hajizadeh (Leibniz Institute for Neurobiology, GER)

Auditory stimuli are characterized by their temporal and spectral pattern. In dealing with this information, auditory cortex (AC) shows context sensitive responses. This sensitivity is reflected, for example, in adaptation, the reduction of the response magnitude of auditory neurons to repetitive stimulation, which is, for example, revealed by event-related fields (ERFs) of the magnetoencephalogram. Despite decades of research, the underlying mechanisms of context sensitive responses in AC are still under debate, with short-term synaptic depression (STSD) being one physiologically plausible candidate. We examined this hypothesis by using a mechanistic model based on AC anatomy. The computational units of the model are simplified cortical columns consisting of a mean-field excitatory and a meanfield inhibitory cell population. These columns are represented by their own state variables in coupled first-order differential equations. Both cell populations are characterised by nonlinear firing rates, and their dynamics are coupled to the dynamics of STSD, which is governed by its own first-order differential equation. The cortical columns are organised based on the serial core-belt-parabelt network structure of AC, a feature which is central to the mammalian AC. In this work, instead of solving the state equations by numerical solvers, the model dynamics are analysed. This was achieved by linearising the state equations and solving the STSD equation by time-scale separation. In so doing, it could be shown that ERF waveforms emerge from the interference pattern of superimposed normal modes whose properties depend on the entire AC network structure as well as the input. Also, we could show that ERF adaptation is a result of the modulation of normal modes due to the STSD where the reduction of ERF magnitude is only a by-product.



14:30 - 15:30

Design features of a long-term memory circuit

Omer Karin (University of Cambridge, UK)

Biological systems can maintain memories over long timescales, with examples including memories in the brain and immune system. It is currently unknown how functional properties of memory systems, such as memory persistence, can be established by biological circuits. To address this question, we focus on transgenerational epigenetic inheritance in C. elegans. In response to a trigger, worms silence a target gene for multiple generations, resisting strong dilution due to growth and reproduction. Silencing may also be maintained indefinitely upon selection according to silencing levels. We show that these properties imply fine-tuning of biochemical rates in which the silencing system is positioned near the transition to bistability. We demonstrate that this behavior emerges from a generic mechanism based on competition for synthesis resources, which leads to self-organization around a critical state with broad silencing timescales. The theory makes distinct predictions and offers insights into the design principles of long-term memory systems.

15:30 - 16:30

#### The role of adaptation in neuronal coding

Christoph Miehl (Max Planck Institute for Brain Research, GER)

In an ever-changing environment, animals and humans must rapidly extract useful information from sensory stimuli. While potentially harmful novel or unexpected stimuli need to trigger fast and reliable responses to ensure survival, repeated or predictable stimuli provide less meaningful information. In the brain, multiple mechanisms operate at different timescales to appropriately adapt neuronal responses and ensure efficient coding of expected and unexpected stimuli. In my talk, I will outline some of the strategies by which neurons in the brain can adapt to different types of sensory stimuli. I will present how, in a computational model of biologically-plausible neuronal networks, the change in the coupling strength from inhibitory to excitatory neurons (known as inhibitory plasticity) is a key player in allowing adaptation to expected versus unexpected sensory stimuli, providing a mechanistic understanding of how the brain might solve the problem of adaptivity.

16:30 – 17:00

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**COFFEE BREAK** 



#### Network data analysis of sepsis patients

Moritz Alkofer (TU Berlin, GER), Fenja Drauschke (TU Berlin, GER)

Within a dynamical systems perspective on the modeling of sepsis and its organdamaging consequences, we present a statistical analysis of medical data of sepsis patients from hospital intense care units. We process the data and group them according to several features. To do so we apply vector autoregression to time series patient data and establish granger causalities. The results are compared with computer simulations within a functional two-layer network model for sepsis based upon the interaction of parenchymal cells and immune cells via cytokines, and the coevolutionary dynamics of parenchymal, immune cells, and cytokines. By means of the simple paradigmatic model of phase oscillators with adaptive coupling weights in a two-layer system, we analyze the emergence of organ threatening interactions between the dysregulated immune system and the parenchyma. We demonstrate that the complex cellular cooperation between parenchyma and stroma (immune layer) either in the physiological or in the pathological case can be related to dynamical patterns of the network. In this way we explain sepsis by the dysregulation of the healthy homeostatic state (frequency synchronized) leading to a pathological state (desynchronized or multifrequency cluster) in the parenchyma. We provide insight into the complex stabilizing and destabilizing interplay of parenchyma and stroma by determining critical parameters of the model from the real patients' data.

## Collective Activity Bursting in a Population of Excitable Units Adaptively Coupled to a Pool of Resources

Richard Sebastian Eydam (RIKEN – Center for Brain Science, JPN)

We explore how a population of globally coupled active rotators interacts with a slowly adapting pool of resources. To investigate, we use the separation of timescales and apply singular perturbation theory to separate the (fast) layer dynamics from the (slow) reduced system dynamics. The layer dynamics is treated in the framework of Ott-Antonsen which allows uncovering the underlying structure of the dynamics by applying numerical bifurcation theory. Our framework explains collective activity bursting which originates from the interplay of population mean-field and resource dynamics. Due to a change in the base level of available resources, the system can develop multistability. Furthermore, close criticality the system may transition from an inactive state to collective activity bursting.

## Self-Organized Multifrequency Clusters in an Oscillating Electrochemical System with Adaptive Coupling

Yukiteru Murakami (TU Munich, GER)

Network adaptation is believed to be crucial in various contexts such as neural information processing, ecology, and communication networks. Until now, however, the realization of adaptive networks has been limited mainly to mathematical models. We present an experimental system, the oscillatory photo-electrodissolution of n-type silicon, in which different locations are coupled due to nonlinear, global, and non-local contributions that together form an adaptive coupling. The rate of the dissolution mediated by photoexcited holes is governed by two parameters, the applied illumination intensity, and the external electrical control. The diffusion and migration of valence band holes parallel to the electrode surface result in a spatial nonlocal coupling. In addition, an external resistance in series with the electrode acts as global negative feedback which promotes synchronization. When reducing the illumination intensity, we observed the emergence of self-organized multifrequency clusters from a uniform oscillatory state, pointing to an adaptive coupling structure. Furthermore, by using a spatial light modulator, which allows a position- dependent control of the illumination, different dynamical states can be established on an electrode simultaneously. Under heterogeneous illumination condition, we have generated prototypical individual oscillating spots on the silicon surface, which serve as coupled discrete oscillators and will allow us to study the adaptive response of networks to different stimuli in the future.

## Resonant velocity tuning of solitary states in networks of coupled phase oscillators

Jakob Niehues (PIK, GER)

The operational stability of electrical power grids is of utmost importance to ensure a reliable supply of energy and prevent damages and blackouts. Conventional control schemes and grid architecture are challenged by the transition to sustainable energy generation as few, large generators with massive rotating turbines in a highly centralized grid are replaced by many distributed, fluctuating sources of varying size, such as solar and wind power. Therefore, identifying robust and cost-efficient grid architecture, as well as weak points to avoid when planning and building power grids, is an ongoing research area. The voltage and frequency dynamics of AC power grids can be modeled as coupled non-linear oscillators on sparse complex networks. In addition

to the desired operating state, in which all nodes are synchronized at network frequency, e.g., 50 Hz, there exists a variety of partially synchronized attractor states. Solitary states consist of a large, synchronized cluster and a single oscillator that rotates with a different velocity, i.e., AC frequency. They pose a threat to power grid stability, as they would cause overload damages and can be easily reached through single-node perturbations. Especially vulnerable to such perturbations are dense sprouts, which are degree-1 nodes with distinct topological properties and a well-connected neighbor. Novel solitary states in which the velocity of the dense sprout differs from its natural velocity have recently been discovered in numerical simulations. In this work, we propose a toy model with which we can theoretically explain the presence of the novel solitary states. It can be used to adjust network architecture to prevent their occurrence. In this model, the rest of the synchronized complex network is reduced to its key factor, i.e. the degree of the neighbor. Applying a linearization approach, we obtain an approximate analytical solution close to the full non-linear dynamics. We then derive a self-consistency equation for the velocity of the solitary node. We demonstrate that the toy model resembles highly localized network modes in the linear stability regime around the operating state. The velocity of the dense sprout arises from resonance with this network mode under the constraint of matching the network's power flow. We investigate the stability regime of the novel solitary states and its dependence on initial conditions, system parameters, i.e., characteristics of grid components, and topology.

#### THURSDAY, SEPTEMBER 22

09:30 - 10:30

## Adaptive dynamical networks: from multiclusters to recurrent synchronization

Serhiy Yanchuk (HU Berlin, GER)

The talk introduces adaptive dynamical networks and presents examples of emergent phenomena in such networks. We will focus on two phenomena: Multiclusters and Recurrent Synchronization. For multiclusters, the network reorganizes in such a way that strongly connected sub-networks emerge that are relatively weakly connected to each other. Recurrent synchronization occurs when the topology of the network dynamically changes such that the network recurrently synchronizes and then desynchronizes.



11:00 – 12:00

## The influence of a transport process on the epidemic threshold Jan Mölter (Technical University of Munich, GER)

In today's interconnected world, it is of paramount importance to take transport processes induced by human mobility into account when considering the spreading of an epidemic. The global airline or the local public transport network alike provide room for people to meet in oftentimes small and poorly ventilated spaces, facilitating the spreading of a contagion. Importantly, these transient encounters are not restricted to each individual's immediate social environment. In this talk, we will introduce a network model of epidemic dynamics in a population in the presence of a transport process. We will discuss the derivation of the corresponding mean-field equations and quantify the influence of the transport process on the epidemic threshold.

12:00 - 12:30



#### Non-linear dynamics of collective multi-agent reinforcement learning in changing and uncertain environments

#### Wolfram Barfuss (University of Tübingen, GER)

Complex adaptive systems occur in all domains across all scales, from cells to societies. The question, however, of how the various forms of collective and cooperative behavior can emerge from individual behavior and feedback to influence those individuals remains open. Complex systems theory focuses on emerging patterns from deliberately simple individuals. Fields such as machine learning and cognitive neuroscience emphasize individual capabilities without considering the collective level much. To date, however, little work went into modeling the effects of changing and uncertain environments on emergent collective behavior from individually self-learning agents.

To this end, I present how to efficiently describe the emergent behavior of biologically plausible and parsimonious learning agents via dynamical systems theory. The resulting learning dynamics apply to a wide range of scenarios highlighting when agents can learn better outcomes faster, in a more stable way, and even overcome social dilemmas. They also allow the application of dynamical systems theory to multi-agent learning, as demonstrated by the emergence of limit cycles and chaos, critical transitions with a slowing down of the learning processes at the tipping point, and the separation of the learning dynamics into fast and slow directions.

The presented approach has the potential to become a practical, lightweight, and robust tool for mathematical researchers working in the fields of biology, social sciences, and machine learning to create insights into collective learning in uncertain and changing environments.



## 12:30 – 14:30 LUNCH AND DISCUSSION TIME

14:30 - 15:30



#### Controlling dynamical systems using next-generation reservoir computina

#### Daniel Gauthier (Ohio State University, USA)

Controlling complex dynamical systems that display chaos was demonstrated over thirty years ago. These methods typically make measurements on a surface-of-section in phase space and the control perturbations are designed based on a learned linearized model of the dynamics. When controlling to an unstable periodic orbit of the system, only small control perturbations are required as long as the system's trajectory approaches a neighborhood of the unstable periodic orbit. Here, I describe an approach for realizing a fully nonlinear controller for dynamical systems that uses a state-of-the-art machine learning approach, known as next-generation reservoir computing, that learns the system's dynamics and uses this this model for control. No physical model of the controlled system is required, the model can be updated quickly to improve its accuracy or adjust for changes in the dynamical system, and it can be deployed on low-computation-power embedded controllers. I give examples of controlling a chaotic double-scroll electronic circuit and a small unmanned aerial system.



16:00 - 17:00

## What do neural networks learn? Adapting representations to data structure Sebastian Goldt (SISSA, IT)

Neural networks are powerful feature extractors - but how do they dynamically adapt to the structure of their training data during learning? We investigate this question by introducing several synthetic data models, each of which accounts for a salient feature of modern data sets: low intrinsic dimension of images, symmetries and non-Gaussian statistics, and finally sequence memory. Using tochrisols from statistics and statistical physics, we will show how the learning dynamics and the representations are shaped by the statistical properties of the training data.

17:00 - 18:00



#### Alireza Seif (IBM, USA)

Machine learning methods have emerged as exciting tools to study problems in statistical and condensed matter physics, such as classifying phases of matter, detecting order parameters and generating configurations of a system from observed data. In the first part of this talk, we discuss how a machine learning algorithm that is trained to infer the direction of time's arrow identifies entropy production as the relevant physical quantity in its

#### THURSDAY, SEPTEMBER 22

decision-making process. We will then present a simple model for learning sequence-to-sequence (seq2seq) tasks. Specifically, we will present a simple model for a seq2seq task that gives us explicit control over the degree of memory, or non-Markovianity. We then show how changing the non-Markovianity of the process and the memory of the learning model interact and affect the performance of the algorithm in the seq2seq task.

#### FRIDAY, SEPTEMBER 23

09:30 - 10:30



#### Feedback between active matter and its environment

Giovanni Volpe (University of Gothenburg, SWE)

I will present some examples of how feedback cycles can occur between active matter and its environment. In particular, I'll show the formation of active molecules and active droploids from passive colloidal building blocks; the emergence of non-Boltzmann statistics and active-depletion forces between plates in an active bath; and the environment topography alters the way to multicellularity in the bacterium Myxococcus xanthus.



11:00 - 12:00

## Modelling the co-evolution of opinions and social networks Philipp Lorenz-Spreen (Max Planck Institute for Human Development, GER)

Do we change our opinions according to our friends or do we change our friends according to our opinions? This question is usually difficult to answer, but for the specific case of online social networks it can be approximated. By combining models of opinion dynamics by social influence with data from social media we can come closer to a causal understanding of this co-evolution. We propose a model that couples both via homophilious interactions and the opinion dynamics as a reinforcing mechanism, which is driving the evolution to extreme opinions from moderate initial conditions. We show that the transition between a global consensus and emerging radicalized states is mostly governed by social influence and by the controversialness of the topic discussed. With a simple extension of this model towards multiple dimensions, we can reproduce another empirically observed phenomena: issue alignment, which describes the growing correlation of opinions towards rather unrelated topics.

12:00 - 12:30

#### TriCl, a generic model of social dynamics Jobst Heitzig (PIK, GER)

TriCl is a generic model of complex social dynamics including social tipping. It models the changing relationships and actions between entities of any number of different entity types as a continuous-time stochastic process of discrete events (more precisely: a Markov jump process). All modelled processes are represented by the same type of basic dynamics: the formation and breaking of bilateral and triangular relationships of different types. A reference implementation is available at https://github.com/mensch72/tricl. TriCl might be useful as a universal social dynamics approximator, in a similar way as artificial neural networks are universal function approximators.



14:30 - 15:30

## Spatio-temporal correlated fluctuations in complex networks Mehrnaz Anvari (PIK, GER)

Complex networks consist of many units or agents that interact in nonlinear ways. Their dynamics thus self-organizes into new, collective forms of behaviors that are not obvious from analyzing their individual units and are therefore hard to understand, predict, mitigate or control. Complex networks of immediate socio-economic relevance can be dynamically driven by multiple external influences, perturbations and fluctuations on various time scales. These fluctuations can have time-spatial correlation and cause - sometimes rapid, sometimes persistent - changes of system states over time. In this talk, I discuss firstly about the necessity of data analysis and data-driven models to get the better insight regarding the characteristics of fluctuations that complex networks are subject to them. Then I will demonstrate the response of complex networks with different topology when they are exposed to different spatio-temporal correlated fluctuations.

15:30 - 16:30

#### (n) The uses of memory in olfactory search

#### Antonio Celani (International Centre for Theoretical Physics (ICTP), IT)

Many organisms, from insects to mammals, have developed exquisite skills in searching for sources of odor from huge distances in turbulent atmospheric conditions. How are these sequences of very sparse detections translated into effective strategies to reach the source in the shortest time? Here we present a Reinforcement Learning algorithm that discovers such strategies with minimal memory requirements.

16:30 - 17.00

**Summary and Farewell** 



Questions to think about during the workshop:

- 1. What role do adaptive mechanisms play in your field, and in which way does adaptivity factor into the models and approaches you use?
- 2. Which challenges could be solved by using adaptive mechanisms? In your opinion, what are open research questions and what are the future perspectives of adaptivity?

THANKS FOR YOUR PARTICIPATION