10th SICC INTERNATIONAL TUTORIAL WORKSHOP
"TOPICS IN NONLINEAR DYNAMICS"

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SALONE D'ONORE, CASTELLO DEL VALENTINO

NONLINEAR DYNAMICS IN COMPUTATIONAL NEUROSCIENCE: FROM PHYSICS AND BIOLOGY TO ICT

organized by
F. CORINTO (POLITECNICO DI TORINO, ITALY) AND A. TORCINI (MARSEILLE UNIVERSITY, FRANCE)

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Investissements d'Avenir
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Italian Society for Chaos and Complexity
Ministero degli Affari Esteri e della Cooperazione Internazionale
FONDAZIONE CRT
POLITECNICO DI TORINO
CAS IEEE Circuits and Systems Society
NETT Neural Engineering Transformative Technologies

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NONLINEAR DYNAMICS IN COMPUTATIONAL NEUROSCIENCE: FROM PHYSICS AND BIOLOGY TO ICT

Neuroscience aims to address how the human brain works and how it gives rise to the human behavior, these represent some of the most ambitious challenges of the next centuries. Their relevance is testified from the enourmous economical investments performed by several nations in this research field. In this context Computational Neuroscience is a new emerging discipline devoted to the study of brain functions in terms of the information processing properties of the structures forming the nervous system. Computational Neuroscience is inherently interdisciplinary since it bridges different fields ranging from Neuroscience to Physics, from Psychology to Neural Engineering, from Cognitive Science to Applied Mathematics.

The workshop "Nonlinear Dynamics in Computational Neuroscience: from Physics and Biology to ICT" offers an unique opportunity to meet researchers working across (and between) disciplines linked to Computational Neuroscience. In particular, computational neuroscients, neurophysiologists and neural engineers will have the opportunity to present their most recent results to a young audience, constituted mainly by PhD students, and to interact directly among them. The program ranges from nonlinear dynamical approaches to the understanding of neural computation to physiology, from the simulations of brain circuits to the development of engineering devices and platforms for neuromorphic computation. The speakers will be specifically advised to perform didactic presentations of their results in order to allow the active participation to the discussion of young PhD students from different disciplines as well as to researchers interested in the field of Computational Neuroscience. Specific poster sessions will be organized with the purpose on one side to allow the young participants to present their latest results and on the other side to increase the opportunity of networking among the participants and renowed experts of the discipline.

This workshop represents the 10th of a series of tutorial workshops annually organized by the Italian Society of Chaos and Complexity (SICC) to explore the emergence of new research fields, where nonlinear dynamics and control theory can play a relevant role. These workshops have been traditionally devoted to an audience mainly constituted by PhD students or young researchers working in complex systems.The workshop is kindly supported by the:

- SICC - Italian Society for Chaos and Complexity
- IEEE Circuits and Systems Society - IEEE CASS Outreach 2015 Initiative
- Politecnico di Torino
- MemoCIS - Memristors-Devices, Models, Circuits, Systems and Applications, COST Action IC 1401
- NETT - Neural Engineering Transformative Technologies, Marie Curie Initial Training project
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ORGANIZING COMMITTEE

This workshop "Nonlinear Dynamics in Computational Neuroscience: from Physics and Biology to ICT" is organized by Fernando Corinto (Politecnico di Torino, Italy) and Alessandro Torcini (Marseille University, France) in collaboration with the SICC.

CONFIRMED KEYNOTE SPEAKERS

- Cristina Becchio (University of Turin, Italy)
- Ruben Moreno Bote (CIBERSAM - Barcelona, Spain)
- Emilio Carbone (University of Turin, Italy)
- Stephen Coombes (University of Nottingham, UK)
- Angelo Di Garbo (Istituto di Biofisica CNR - Pisa, Italy)
- Steve Furber (The University of Manchester, UK)
- Julius Georgiou (University of Cyprus, Cyprus)
- Viktor Jirsa (INSERM - Marseille, France)
- Stefano Luccioli (ISC CNR - Florence, Italy)
- Maurizio Mattia (ISS - Roma, Italy)
- Rosaria Rinaldi (Institute of Nanoscience CNR - Lecce, Italy)
- Benedetto Sacchetti (University of Turin, Italy)
- Maria Sanchez-Vives (IDIBAPS - Barcelona, Spain)
- Ronald Tetzlaff (TU Dresden, Germany)
- Alessandro Torcini (Marseille University, France)
- Santo Banerjee (University Putra Malaysia, Malaysia)
- Kyeong-Sik Min (Kookmin Univ, Korea)

PROGRAM

Monday, September 07

8.00 – 8.50 Registration

8.50 – 9.10 Welcome address and Opening of the School:
Marco Gilli (Rector of the Politecnico di Torino) and Mario di Bernardo (President SICC)
9.10 – 10.00 Stephen Coombes "Mathematical neuroscience: from neurons to networks"
10.00 – 10.50 Steve Furber "The SpiNNaker Project"

10.50 – 11.20 Coffee Break

11.20 – 12.10 Emilio Carbone "Monitoring neuronal complexity and channelopathies using classical and newly designed neurobiosensors"
12.10 – 13.00 Viktor Jirsa "Translational Neuroscience: How does bifurcation theory aid improving epileptic surgery?"

13.00 - 14.20 Lunch

14.20 – 15.10 Marco Cambiaghi and Benedetto Sacchetti "Neural circuitry of long-term fear memories"
15:10 – 16.00 Ronald Tetzlaff "Fading memory of non-volatile memristors?"
16.00 – 17.30 Plenary meeting SICC
18.00 - 22.00 Visit and welcome reception to "Museo Nazionale del Cinema" (Torino - Mole Antonelliana)

Tuesday, September 08

9.10 – 10.00 Stefano Luccioli "Cliques of a few functional hub neurons control the whole network activity"
10.00 – 10.50 Maurizio Mattia "The metastable dynamics of cortical modules: from slow oscillations towards wakefulness"

10.50 – 11.20 Coffee Break

11.20 – 11.45 Alessandro Torcini "Cell assembly dynamics of sparsely-connected inhibitory networks"
11.45 – 12.10 Angelo Di Garbo "Inferring the interdependence between time series and its directionality"
12.10 – 13.00 Julius Georgiou "Implementing the Hodgkin-Huxley Nerve Axon Model with Sub- threshold CMOS Transistors and Capacitors"

13.00 -14.20 Lunch

14.20 – 15.10 Rubén Moreno Bote "Causal Inference and Dynamic Explaining Away by Spiking Networks"
15.10 - 16.00 Rosaria Rinaldi "Nanotechnologies for Neurosciences"

16.00 - 16.30 Coffee Break

16.00 - 18.00 Poster Session

Wednesday, September 09

9.10 – 10.00 Santo Banerjee "Complexity and Nonlinear Dynamics in Biomedical Signals"
10.00 – 10.50 Mavi Sanchez-Vives "Impact of network excitability on cortical emergent patterns and wave propagation"

10.50 – 11.20 Coffee Break

11.20 – 12.10 Cristina Becchio "How do we understand other minds? Kinematic specification of intention and beyond"
12.10 – 13.00 Kyeong-Sik Min and Fernando Corinto "Memristor Crossbar Circuits"
13.00 – 13.15 Closing of the meeting

13.15 – 14.30 Lunch

HOW DO WE UNDERSTAND OTHER MINDS? KINEMATIC SPECIFICATION OF INTENTION AND BEYOND

Cristina Becchio[1,2]
[1] **Department of Robotics, Brain and Cognitive Sciences, Italian Institute of Technology, Genova, Italy**
[2] **Department of Psychology, University of Torino, Torino, Italy** **cristina.becchio@unito.it**

A generally unexpressed assumption behind much current social cognition research is the so-called "Unobservability Principle" (UP). According to the UP, minds are composed of exclusively intracranial phenomena, perceptually inaccessible and thus unobservable to everyone but their owner. Mental states, such as beliefs and intentions, are private, internal and not observable in others. Contrary to the UP, I will argue that intentions are (to some extent) visible in others' movements. First, I will present evidence that intentions influence response properties and shape movement kinematics during movement execution. Next, I will show that observers are especially attuned to kinematic information and can use early differences in visual kinematics to anticipate another person's goal. I shall conclude by summarizing these findings into an 'Observability Principle': Intentions are observable to the extent that i) they are specified at a tangible and quantifiable level in the movement kinematics; II) observers are perceptually attuned to intention information conveyed by movement kinematics.

CAUSAL INFERENCE AND DYNAMIC EXPLAINING AWAY BY SPIKING NETWORKS

Rubén Moreno Bote
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While the brain uses spiking neurons for communication, theoretical research on brain computations has in most parts focused on non-spiking networks. The nature of spike-based algorithms that achieve complex computations, such as object probabilistic inference, are largely unknown. In this talk I will show that a family of non-linear, high-dimensional quadratic optimization problems, which correspond to causal inference problems, can be solved exactly and efficiently by networks of spiking neurons. The network naturally implements the non-negativity of causal contributions that is fundamental to causal inference, and uses simple operations, such as linear synapses with realistic time constants, and the neuron spiking generating and reset non-linearities. The network infers the set of most likely causes from an observation using 'dynamic explaining away', which is implemented by tuned inhibition. The algorithm performs remarkably well even when the network intrinsically generates variable spike trains, the timing of spikes is scrambled by external sources of noise, or the network is mistuned. This type of networks might underlie tasks such as odor identification and classification.

MONITORING NEURONAL COMPLEXITY AND CHANNELOPATHIES USING CLASSICAL AND NEWLY DESIGNED NEUROBIOSENSORS

Emilio Carbone
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Neuronal signals timely regulate the dynamics of complex neuronal networks that form the human brain. They are generated by molecular events that derive from rapid conformational changes of integral membrane proteins (ion channels, receptors

and transporters). Membrane ion channels and receptors thus generate electrical signals (action potentials), regulate neurotransmitter release (synaptic transmission) and control the rapid exchange of information between sensory and central neurons and computational activity within specific brain areas.
Monitoring the signals generated by single neurons or neuronal networks in vitro and in vivo is a central task to understand the molecular basis of the central nervous system physiology and to identify the molecular targets for the treatment of channelopathies that are at the origin of neurodegenerative diseases (Alzheimer, Parkinson, depression, sleep disorders, chronic stress, …).
To date exist a large number of multi-electrode arrays (MEAs) made of different material (TiN, ITO, CMOS, MOSFET, carbon-based, conductive polymers, ….) able to detect the electrical activity of neuronal networks, but exist few examples of "lab-on-chips" capable of detecting the quantal release of neurotransmitters from neurons or neuroendocrine cells with high-time resolution and signal-to-noise ratio.
Most recently, new generations of diamond-based microchips of high- and low-density have been shown capable of detecting neurotransmitter release, either from groups of cells or within single-cell microdomains (Piccolo et al. Adv. Mat., 2013; Gosso et al. J. Physiol., 2014; Conte et al. Phys. Stat. Sol. A, 2015; Picollo et al., Sensors, 2015). The potentiality of using these newly developed devices in combination with classical recording techniques to investigate neuronal complexity in physiological and pathological conditions will be discussed.

MATHEMATICAL NEUROSCIENCE: FROM NEURONS TO NETWORKS

Stephen Coombes
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The tools of dynamical systems theory are having an increasing impact on our understanding of patterns of neural activity. In this talk I will describe how to build tractable tissue level models that maintain a strong link with biophysical reality. These models typically take the form of nonlinear integro-differential equations. Their non-local nature has led to the development of a set of analytical and numerical tools for the study of waves, bumps and patterns, based around natural extensions of those used for local differential equation models. Here I will present an overview of these techniques. Time permitting I will also present recent results on next generation neural field models obtained via a mean field reduction from networks of nonlinear integrate-and-fire neurons.

INFERRING THE INTERDEPENDENCE BETWEEN TIME SERIES AND ITS DIRECTIONALITY

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A method to detect linear and nonlinear correlations between a pair of time series is introduced and described. This method, called the Boolean Slope Coherence (BSC), was tested using bivariate time series generated with different models and the corresponding results were compared with those obtained with other known coupling measures. The results show that the BSC method works well and therefore can be employed to quantify the coupling level between a pair of signals. Moreover, the BSC algorithm also works for signals contaminated by noise. In addition, the BSC method can be used to establish the prevalence of the coupling directionality. Examples of its application to neurophysiological recordings, from visual and motor cortices, will be presented too.

THE SPINNAKER PROJECT

Steve Furber
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The SpiNNaker (Spiking Neural Network Architecture) project aims to produce a massively-parallel computer capable of modelling large-scale neural networks in biological real time. The machine has been 15 years in conception and ten years in construction, and has far delivered a 100,000-core machine in a single 19-inch rack, which is now being expanded towards the million-core full system. Even with a million processor cores the machine will be capable of modelling only perhaps 1% of the network complexity of the human brain, underlining the scale of the challenge of developing technologies capable of supporting full brain models.

IMPLEMENTING THE HODGKIN-HUXLEY NERVE AXON MODEL WITH SUB-THRESHOLD CMOS TRANSISTORS AND CAPACITORS

Julius Georgiou
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Hodgkin and Huxley's Nerve Axon model remains a cornerstone neural model, despite being over 60 years old. Nevertheless its complexity is such that simulating large populations of neural models is impractical, even with today's powerful computers. A methodology to build this model using only transistors operating in the sub-threshold regime and capacitors is presented, opening the way for hardware based emulation of neural circuits using this cornerstone model. Developments in creating Memristors at the nano-scale promises to replace the "state-holding" capacitors with memristive elements, thus enabling significant size reduction.

TRANSLATIONAL NEUROSCIENCE: HOW DOES BIFURCATION THEORY AID IMPROVING EPILEPTIC SURGERY?

Viktor Jirsa
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Seizures can occur spontaneously and in a recurrent manner, which defines epilepsy; or they can be induced in a normal brain under a variety of conditions in most neuronal networks and species from flies to humans. Such universality raises the possibility that invariant properties exist that characterize seizures under different physiological and pathological conditions. Starting from first principles of the theory of slow-fast systems in nonlinear dynamics, we conceptualize seizure dynamics mathematically and establish a taxonomy of seizures based on seizure onset and offset bifurcations. We demonstrate that only five state variables linked by integral-differential equations are sufficient to describe the onset, time course and offset of ictal-like discharges as well as their recurrence. These state variables define the model system called the Epileptor, where two state variables are responsible for generating rapid discharges (fast time scale), two for spike and wave events (intermediate time scale) and one permittivity variable (slow time scale). The permittivity variable captures effects evolving on slow timescales, including extracellular ionic concentrations and energy metabolism, with time delays of up to seconds as observed clinically. We propose that normal and ictal activities coexist: a separatrix acts as a barrier (or seizure threshold) between these states. Seizure onset is reached upon the collision of normal brain trajectories with the separatrix. We show theoretically and experimentally how a system can be pushed toward seizure under a wide variety of conditions. Within our experimental model, the onset and offset of ictal-like discharges are well-defined mathematical events: a saddle-node and homoclinic bifurcation, respectively. These bifurcations necessitate a baseline shift at onset and a logarithmic scaling of interspike intervals at offset. These predictions were not only confirmed in our in vitro experiments, but also for focal seizures recorded in different syndromes, brain regions and species (humans and zebrafish). Extending this generic approach rooted in nonlinear dynamics towards human brain networks, we reconstruct personalized connectivity matrices of human epileptic patients using Diffusion Tensor weighted Imaging (DTI). Subsets of brain regions generating seizures in patients with refractory partial epilepsy are referred to as the epileptogenic zone (EZ). During a seizure, paroxysmal activity is not restricted to the EZ, but may recruit other brain regions and propagate activity through large brain networks, which comprise brain regions that are not necessarily epileptogenic. The identification of the EZ is crucial for candidates for neurosurgery and requires unambiguous criteria that evaluate the degree of epileptogenicity of brain regions. Stability analyses of propagating waves provide a set of indices quantifying the degree of epileptogenicity and predict conditions, under which seizures propagate to nonepileptogenic brain regions, explaining the responses to intracerebral electric stimulation in epileptogenic and nonepileptogenic areas. We demonstrate the predictive value of our seizure propagation model by validating it against empirical patient data. In conjunction, our results provide guidance in the presurgical evaluation of epileptogenicity based on electrographic signatures in intracerebral electroencephalograms.

CLIQUES OF A FEW FUNCTIONAL HUB NEURONS CONTROL THE WHOLE NETWORK ACTIVITY

Stefano Luccioli

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Recent experiments have shown that single neuron stimulation can impact network dynamics in immature and adult neuronal circuits. Here we show a novel mechanism which can explain the peculiar role played by a few specific neurons in promoting/arresting the activity of the whole population. For this purpose, we consider a standard neuronal network model, with short-term synaptic plasticity, whose population activity is characterized by peaks of synchronous activity (population bursts). We analyse networks with different architectures, mimicking also different stages of maturation, and we report the conditions that lead to the emergence of a self-organized pool of a few neurons, responsible for the build-up of the population bursts. In particular the collective events of synchronous activity are driven by the sequential and coordinated activation of these peculiar critical neurons arranged in a clique. These neurons are hubs in a functional sense, as the played role is not related to the intrinsic degree of connectivity but to the order of firing before the ignition of the PB. The existence of this peculiar pool of neurons has the consequence that perturbations of even one single neuron of the clique, through the deletion from the network or the injection of a current, strongly impact the collective dynamics and bring even to the arrest of the bursting activity.

THE METASTABLE DYNAMICS OF CORTICAL MODULES: FROM SLOW OSCILLATIONS TOWARDS WAKEFULNESS

Maurizio Mattia

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Slow oscillations (SO) are a stereotyped activity pattern pervasively expressed during slow-wave sleep and deep anaesthesia by the cerebral cortex of many species. SO in sensorial cortices are known to mirror early neuronal processing of environmental stimuli, and occur simultaneously in cell assemblies at different cortical depths and positions as a concerted multiscale activity. Here, I will present some recent advances in the understanding of the mechanistic organization of such

multiscale phenomenon, by following the chain of activations and inactivations of the different layers of the rat visual cortex under different levels of anaesthesia. I will show that Up states under deep anaesthesia initiate in layer 6 spreading upward towards the cortical surface, and that layer 5 assemblies give rise to hysteresis loops like in flip-flop computational units. Such bistability together with short-term adaptation mechanisms result in a relaxation oscillator dynamics which underlies cyclic Up/Down transitions. Finally, I will show how the features of this limit cycle change as the anaesthesia fades out approaching the waking brain state.

NANOTECHNOLOGIES FOR NEUROSCIENCES

Rosaria Rinaldi
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Eleonore Trefftz Professor (WZ) Technical University Dresden, Germany

The applications of nanotechnology in the field of neuroscience can be divided into two main strands: i) applications in the field of basic research and ii) applications in the clinical field. In the first area we deal with: a) developing and applying nano-engineered materials to promote adhesion, growth and neuronal differentiation and to understand the neurobiological mechanisms underlying these processes; b) fabricating nano-systems (for example, "nano-electrodes" implantable) for direct iteration, recording and stimulation of the neurons at the molecular level; c) applying nano-structures and nanoscale resolution microscocpy for advanced and better resolution imaging and diagnostics . In the clinical context, however, the primary goal is to limit or reverse the disease process in neurodegenerative diseases.

In this talk I will present three different approaches at the crossing between basic research and application in clinical field. First of all I will talk about the study of the effect of dipeptides in neurodegenerative diseases. Carnosine is an endogenous dipeptide abundant in the central nervous system and it seems to counteract proteotoxicity and protein accumulation in neurodegenerative conditions, such as Alzheimer's Disease (AD). However, its direct impact on the dynamics of AD-related fibril formation remains uninvestigated. We considered the effects of Carnosine on the formation of fibrils/aggregates of the amyloidogenic peptide fragment Ab1-42, a major hallmark of AD injury. Atomic force microscopy and Thioflavin T assays showed inhibition of Ab1-42 fibrillogenesis in vitro and differences in the aggregation state of Ab1-42 small pre-fibrillar structures (monomers and small oligomers) in the presence of carnosine. In silico molecular docking supported the experimental data, calculating possible conformational carnosine/Ab1-42 interactions.

The development of ("scaffolds") nano-engineered biocompatible materials that might facilitate and accelerate neuronal growth are one of the fundamental objectives of modern tissue engineering. It has been shown that these approaches are capable of promoting neuronal differentiation in the sites damaged by reducing the inflammatory and neuro-pathological effects. Also, applications of nano- and micro-scale polymeric capsules, embedding growth factors or neuro-protective molecules, severely limit the damaging effects of free radicals that are generated as a result of trauma in the damaged areas and trigger processes of trauma and ischemia in the central nervous system and neuro-degenerative disorders. Some recent advances in these field will be presented and discussed.

Another clinically very relevant field concerns the construction and the application of nano-particles of materials of different type (inorganic, organic, polymeric, biological) that can be administered systemically and transport in a targeted and effective way drugs, small molecules and/or stem cells through the blood brain barrier. This is a primary goal in clinical research for the treatment of a wide family of neurological disorders, as well as brain tumors. In this respect we are focusing onto a novel method for cell-encapsulation within ALG micro capsules (μCs) and/or nanovesicles (NVs). Smaller capsules have the advantage of a higher surface to volume ratio allowing good transport of necessary nutrients while presenting also higher stability. With this respect, a fine control of bead size and shape is crucial and should be carefully considered. A suitable methodology for production of μCs and NVs under controlled conditions, for single or more cells and molecule encapsulation, can be obtained by hydrodynamic focusing in appositely fabricated disposable microfluidic devices, in an aseptic environment.

NEURAL CIRCUITRY OF LONG-TERM FEAR MEMORIES

Marco Cambiaghi and Benedetto Sacchetti
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Memories of emotional experiences are studied using classical Pavlovian conditioning, a procedure in which the subject is exposed to a conditioned stimulus (CS), such as a tone, in association with an unconditioned stimulus (US), typically a footshock. Following pairing, the CS takes on the affective qualities of the US and it will later, in absence of the US, evoke conditioned emotional responses. However, despite a large number of studies, how and where in the brain do we store the affective/motivational significance of sensory stimuli acquired through life experiences? Scientists have long investigated how "limbic" structures, such as the basolateral amygdala (BLA), process affective stimuli. By analyzing electrophysiological activity (LFP and spikes), we showed that the association between an auditory cue and an emotional experience is stored in the connections between the auditory cortex – namely the Te2 region – and the amygdala, within the theta frequency range. This functional connectivity stems from memory consolidation processes, since it is present during remote, but not recent, memory retrieval. Moreover, the observed increase in synchrony is cue and region specific. A preponderant Te2-to-BLA directionality characterizes this dialogue, and the percentage of time the Te2 leads the BLA predicts the latency to display defensive behavior. In the absence of Te2-to-BLA information transfer, the BLA did not display any recall-evoked activity and animals were unable to retrieve remote memories. We conclude that memories stored in higher order sensory cortices lead BLA activity to distinguish between learned threatening and neutral stimuli.

IMPACT OF NETWORK EXCITABILITY ON CORTICAL EMERGENT PATTERNS AND WAVE PROPAGATION

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Collective phenomena emerging from activity reverberation in cortical circuits at different spatio-temporal scales results in a rich variety of dynamical states. Slow (around or below 1 Hz) and fast (15-100 Hz) rhythms are spontaneously generated by the cortical network, propagating or synchonizing populations across the cortex. There are different factors that modulate the emergent activity, the excitability of the network being one of them. Different excitability levels not only determine the temporal aspects such as the oscillatory patterns and their temporal regularity. They also determine the spatial structure, place of wave initiation and the propagation spatial patterns. In this presentation I will discuss the spatiotemporal properties of the emergent cortical activity following experimental manipulations to control excitability such as varying temperature, potassium levels, anesthesia levels or electric fields. Network modelling based on these experimental results helps us to better understand network dynamics and to predict the outcome of perturbing the network.

FADING MEMORY OF NON-VOLATILE MEMRISTORS?

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Recently, memristors are considered in several investigations for the development of high-density memory devices and as neuron and synapse models in the realization of new types of neuromorphic systems. Especially, it can be expected that the rich dynamical behavior of memristors will lead to the development of new far more efficient circuits in future information technology. While, a lot of efforts will be spend to the fabrication of devices based on different materials, the determination of their circuit theoretic properties is still restricted to a few investigations. Leon Chua has given important contributions [1,2] e.g. by providing a classification scheme of memristors and methods allowing the determination of their DC V-I curves. Especially, volatility of memristors is characterized in these publications in the sense that the effect of the past input signals a device has been subjected to has been forgotten.
In this contribution an introduction to the theory of memristors will be given in detail. Especially, the question of memory volatility will be addressed by assuming the mathematical model of a Tantalum oxide (TaO) device recently fabricated from Hewlett-Packard. New results will be given in the presentation.

[1] L. O. Chua, "If it's pinched, it's a memristor," Semicond. Sci. Technol., Special Issue on Memristive Devices, vol. 29, no. 10, Sep. 2014.
[2] L. O. Chua, "Everything you wish to know about memristors but are afraid to ask", Radioengineering, vol. 24, no. 2, June 2015

CELL ASSEMBLY DYNAMICS OF SPARSELY-CONNECTED INHIBITORY NETWORKS: A SIMPLE MODEL FOR THE COLLECTIVE ACTIVITY OF STRIATAL PROJECTION NEURONS

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T he striatum is a brain structure involved in many functional roles, from action selection to learning and motor control. Some noticeable experiments demonstrated that the striatum encodes information received from sensory areas by the alternating activation of small assemblies of Medium Spiny Neurons firing synchronously. We propose a simple mathematical model of inhibitory neurons which is able to capture some of the most relevant features of the striatal dynamics. The simplicity of the model allows to identify the minimal ingredients required by a neural network to display the rich behavior observed in the striatum. The derivation of an easily tractable model can allow a deeper understanding
of the fundamental mechanisms at the basis of the striatal dynamics and eventually to elucidate in a near future how neural diseases, like Parkinson and Huntigthon disease, alter the normal behaviour of Medium Spiny Neurons. Striatal projection neurons form a sparsely-connected inhibitory network, and this arrangement may be essential for the appropriate temporal organization of behavior. Here we show that a sparse inhibitory network of artificial Leaky-Integrate-and-Fire neurons can reproduce key features of striatal population activity, as observed in brain slices [Carrillo-Reid et al., J. Neurophysiology 99 (2008) 1435--1450]. In particular we develop a new metric to determine the conditions under which sparse inhibitory networks form anti-correlated cell assemblies with variable firing rates of individual cells. We find that in this parameter range, the network displays an input-specific sequence of cell assembly switching, and can optimally discriminate between similar inputs. Our results support the proposal [Ponzi and Wickens, PLoS Comp Biol 9 (2013) e1002954] that striatal network topology is set up to allow stimulus-selective, temporally-extended sequential activation of cell assemblies.

COMPLEXITY AND NONLINEAR DYNAMICS IN BIOMEDICAL SIGNALS

Santo Banerjee
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The complexity of a signal can be measured by the Recurrence period density entropy (RPDE) from the reconstructed phase space. A window based RPDE method is an effective method for the classification of signals, as RPDE is an average entropic measure of the whole phase space dynamics. Phase space analysis is one of the most useful methods for explanation of long term behavior. It is an abstract Euclidean space that reflects asymptotic nature of the interconnected variables which are responsible for the original dynamics of the state of a signal.

Phase space reconstruction is a very effective tool to investigate the nonlinear dynamics and chaos in any signal. We propose that for a well formed trajectory, phase space reconstruction in time domain is not sufficient in case of continuous biomedical signals with slowly varying gradients. It can be observed that in case of biomedical signals, time domain information is not sufficient to characterize the continuous dynamics of the signal. Thus need to incorporate frequency domain information along with time domain through wavelet analysis, which produces more information on the dynamics and also a well-formed attractor. The nonlinear phenomenon can be investigated well form the time-frequency domain results.

The changes in complexity in nonlinear biomedical signals quantify some interesting outputs. It can be observed that in case of Heart Rate Variability (HRV) the complexity is higher than the same for a cardiac patient. That is, a healthy heart is more complex in nature.

These methods can be effective and well implemented in clinical settings for more information in biomedical analysis.

MEMRISTOR CROSSBAR CIRCUITS

Kyeong-Sik Min and Fernando Corinto
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Human brain is full of mysterious things that have not been understood so far. Among many mysterious things in brain, neocortex takes the largest portion and plays the most important role in the entire brain. The neocortex has an appearance of thin organic sheet of neural tissue which is approximately 1,000-cm2 in area and 2-mm thick with columnar structure and 6 different layers. In spite of this biological appearance, the neocortex can be thought as a kind of memory circuit, where its functions are related to most of human cognitive activities such as vision, hearing, sensory perception, understanding languages, etc. Hence, to mimic the human brain functions electronically, we need to realize an electronic neocortex circuit that can be based on the recent nanotechnology.

As one possible approach of realizing the electronic neocortex using nanoscale technology, we discuss memristor-based crossbar circuits in this presentation. Memristors are known non-volatile, low-power, CMOS-process compatible, and can be stacked layer by layer. Due to these aspects, memristor-based crossbar circuits can be used in mimicking human brain functions such as image and speech recognition which can be regarded a basic starting step toward future electronic neocortex. In this presentation, the memristor-based crossbar circuits would be introduced and compared in this presentation for possible neuromorphic applications. Also, we discuss not only the problems of memristor crossbars in training and recalling processes for neuromorphic applications, but also the future possibility of memristor-based electronic neocortex.

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MATHEMATICAL ANALYSIS OF A MODEL OF FORWARD LOCOMOTION OF C. ELEGANS

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DERIVING LOW-DIMENSIONAL MODELS FOR THE SPIKE RATE DYNAMICS OF ADAPTIVE INTEGRATE-AND-FIRE NEURONS

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BIFURCATIONS AND INFLUENCE OF THE COUPLING ON A NETWORK OF HINDMARSH-ROSE NEURONS

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STOCHASTIC MEAN-FIELD FORMULATION OF DILUTED NEURAL NETWORKS DISPLAYING COLLECTIVE DYNAMICS

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PATTERN LEARNING AND RECOGNITION WITH SPIN TORQUE OSCILLATORY NETWORK

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DIGITAL CELLULAR NONLINEAR NETWORK (CNN) FOR VIDEO PROCESSING

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STUDY OF NON LINEAR OSCILLATORS BY HARMONIC BALANCE METHOD

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ROLES FOR PACEMAKER PROPERTIES AND SYNAPTIC DEPRESSION IN ROBUSTNESS OF A CENTRAL PATTERN GENERATOR

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SOME APPLICATIONS OF MAP-BASED NEURON MODELS IN COMPUTATIONAL NEUROSCIENCE

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VORTEX-BASED SPIN TRANSFER NON-LINEAR OSCILLATOR MODEL FOR NEURO-INSPIRED ARCHITECTURE DESIGN

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DOUBLING PERIOD AND CHAOS IN A DIFFEOMORPHISM OF HENON TYPE

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EXPERIMENTAL EMERGENT BEHAVIOR IN NETWORKS OF CHAOTIC OSCILLATORS

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TOP-DOWN PROFILING METHODOLOGY AND NEW PARTITION AND PLACEMENT TOOL TO IMPROVE SPIKING NEURAL NETWORK SIMULATIONS ON A MASSIVELY MANY-CORE NEUROMORPHIC PLATFORM

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