Multistability in Neurodynamics

A workshop held at the 18th annual CNS*2009 meeting in Berlin, July 23 2009

Organizer: Gennady Cymbalyuk, Georgia State University

This workshop is focused on the co-existence of regimes of activity of neurons. Such multistability enhances potential flexibility to the nervous system and has many implications for motor control, dynamical memory, information processing, perception and decision making. The goal of this workshop is to identify the scenarios leading to multistability in the neuronal dynamics and discuss its potential roles in the operation of the central nervous system under normal and pathological conditions. Multistability has been studied combining theoretical and experimental approaches since the pioneering works by Rinzel, 1978 and Guttman et al**.**, 1980. It is intensively studied on different levels. On the cellular level, multistability is co-existence of basic regimes like bursting, spiking, sub-threshold oscillations and silence. On the network level, examples of multistability include co-existence of different synchronization modes, and polyrhythmic bursting patterns.

Visit the workshop web-site for the updated schedule:
http://www.phy-astr.gsu.edu/cymbalyuk/MultistabilityWorkshop.htm
Key-note speakers:
Kristan, William, University of California San Diego, - Division of Biology
Leech swimming and crawling: Alternative states of the same CPG?

Shilnikov, Andrey, Georgia State University, - Neuroscience Institute
Polyrhythms in Central Pattern Generator motifs

Invited speakers:
Bazhenov, Maxim, University of California Riverside, CA,- Dept. of Cell Biology and Neuroscience,
Extracellular Potassium Dynamics and Epileptogenesis
Canavier, Carmen, Louisiana State University,- School of Medicine in New Orleans
Predicting Multistability using Phase Resetting

Compte, Albert, - University Miguel Hernandez, Spain
A bistable cortical network in slow oscillations

Cymbalyuk , Gennady, Georgia State University, - Dept. of Physics and Astronomy
Single neurons with multiple activities

Moreno-Bote, Ruben, University of Rochester, NY- *Dept of Brain and Cognitive Sciences*
Balanced noise and adaptation in neuronal competition models of perceptual bistability

Pikovsky, Arkady Universität Potsdam, - Dept. of Physics, Potsdam University, Germany
(by M. Rosenblum and A. Pikovsky)
Multistability in ensembles of nonlinearly coupled oscillators

Popovych, Oleksandr and Peter Tass

Long-Lasting Therapeutic Effects of Coordinated Reset Deep Brain Stimulation
Institute of Neurosciences and Medicine - Neuromodulation (INM-7), Research Center Juelich, D-52425 Juelich, Germany

Schedule
Multistability in Neurodynamics

July 23, 2009
9:05-9:10 **Gennady Cymbalyuk** *Introductory notes*

Chair of the session: Gennady Cymbalyuk
9:10-10:00 **William Kristan** University of California San Diego
Leech swimming and crawling: Alternative states of the same CPG?
10:00-10:50 **Andrey Shilnikov** Georgia State University
Polyrhythms in Central Pattern Generator motifs

10:50-11:00 Break

Chair of the session: Arkady Pikovsky
11:00-11:35 **Ruben Moreno-Bote** University of Rochester
Balanced noise and adaptation in neuronal competition models of perceptual bistability
11:35-12:10 **Carmen Canavier** Louisiana State University
Predicting Multistability using Phase Resetting

12:10 - 13:30 Lunch Break

Chair of the session: Carmen Canavier
13:30-14:05 **Maxim Bazhenov** University of California Riverside
Extracellular Potassium Dynamics and Epileptogenesis
14:05-14:40 **Arkady Pikovsky** Potsdam University
Multistability in ensembles of nonlinearly coupled oscillators
14:40-15:15 **Oleksandr Popovych** Research Center Juelich, Germany
Long-Lasting Therapeutic Effects of Coordinated Reset Deep Brain Stimulation

15:15- 15:25 Break

Chair of the session: Andrey Shilnikov
15:25-16:00 **Albert Compte** University Miguel Hernandez, Spain
A bistable cortical network in slow oscillations
16:00-16:35 **Gennady Cymbalyuk** Georgia State University
Single neurons with multiple activities
16:35-17:00 Discussion and closing remarks

Abstracts

Extracellular Potassium Dynamics and Epileptogenesis
Maxim Bazhenov
Dept. of Cell Biology and Neuroscience, University of California Riverside, CA

Extracellular ion concentrations change as a function of neuronal activity and also represent important factors influencing the dynamic state of a population of neurons. In particular, relatively small changes in extracellular potassium concentration mediate substantial changes in neuronal excitability and intrinsic firing patterns. While experimental approaches are limited in their ability to shed light on the dynamic feedback interaction between ion concentration and neural activity, computational models and dynamic system theory provide powerful tools to study activity-dependent modulation of intrinsic excitability mediated by extracellular ion concentration dynamics. Drawing on results obtained with biophysical network models of the thalamocortical system, I will discuss the potential role of extracellular potassium concentration dynamics in the generation of epileptoform activity in neocortical networks.

Predicting Multistability using Phase Resetting
Carmen Canavier
School of Medicine in New Orleans, Louisiana State University

Nonlinear dynamical systems such as networks of oscillatory Hodgkin-Huxley type model neurons frequently exhibit multistability. We have observed that in model networks of N neurons, the fully synchronous state can coexist with states in which there are synchronous clusters, or with an asynchronous state. In two neuron networks, N:1 locking (including 1:1) can be bistable with an aperiodic or complex asynchronous state. We assume pulsatile coupling and examine only networks in which the effect of one perturbation dies out before the next one is received. The phase resetting curve is generated with an input that closely resembles the input a given neuron will receive in the closed circuit. Then the periodic lockings exhibited by such a circuit can be predicted based on the phase resetting curve (PRC) using existence and stability criteria that assume a firing order. The aperiodic and complex periodic modes exhibited by such a circuit can be predicted using a map that does not assume a firing order but simply updates the phases on each cycle based on the PRC. Furthermore, phase resetting theory can be used to identify perturbations to the network that would facilitate transitions between synchrony and other firing patterns. These perturbations could induce synchrony or terminate it depending upon the temporal and spatial patterning, thus enabling transient periods of synchronization.

A bistable cortical network in slow oscillations

Albert Compte
University Miguel Hernandez, Spain

Bistability between network attractors have been hypothesized to constitute a fundamental computational element in cortical circuits. I will discuss here how data and modeling of up and down states in vitro suggests that the cortical network resides in a regime of bistability between network states, and how this helps specify regimes of operation of cortical circuits in the broader context of theoretical research on network state bistability.

Single neurons with multiple activities

Gennady Cymbalyuk
Neuroscience Institute and Dept. of Physics and Astronomy, Georgia State University

Bursting, tonic spiking, sub-threshold oscillations and silence are basic robust regimes of activity of a single neuron. A neuronal model demonstrates three different types of co-existence: (1) silence and bursting, (2) silence and tonic spiking, and (3) silence and sub-threshold oscillations. We show that these types of co-existence can be explicated by the Rinzel scenario with the unstable sub-threshold oscillations (USTO) separating silence and an oscillatory regime and setting the threshold between them. The range of parameters, where the co-existence is observed, is determined by the critical values at which the USTO appear and disappear. More precisely, the USTO occur through the sub-critical Andronov-Hopf bifurcation, where the rest state loses stability. Then, the USTO disappear on the homoclinic bifurcation near which the oscillatory regime disappears as a regime. The bifurcation values are calculated and shown to match the empirical transition values found in Cymbalyuk et al., 2002. Also, we investigate how modulations of different ionic currents affect the range of co-existence.

Leech swimming and crawling: Alternative states of the same CPG?

William B. Kristan
Sect. of Neurobiology, Div. of Biological Sciences, University of California, San Diego, CA

Many animal behaviors are based on rhythmic central pattern generators (CPGs), which are typically groups of interacting neurons that produce complex, oscillatory motor output without need of sensory feedback. The assumption is that each rhythmic behavior is produced by a distinct CPG, although they may interact with one other for coordination (e.g., so we can chew and breath without choking). An alternative possibility is that stably rhythmic neuronal circuits are rare and that, once invented, they get used for other purposes. My colleagues and I have several observations that suggest the latter possibility: we think that swimming and crawling--two very distinct behaviors in the medicinal leech—are produced by the same neuronal circuit. This was a surprise because the behaviors operate at very different time scales—1 to 2 Hz for swimming, 0.05 to 0.1 Hz for crawling—and activate very different sets of muscles. How two such different behaviors use the same neuronal circuitry raises interesting evolutionary questions, and also difficult functional questions: how can the same neuronal network produce very different motor output? I will present our evidence that these two behaviors use the same neurons, then discuss what we know about the underlying neuronal circuits.

Balanced noise and adaptation in neuronal competition models of perceptual bistability

Ruben Moreno-Bote
Dept. of Brain and Cognitive Sciences, University of Rochester, NY

When an observer views a stimulus that allows two distinct interpretations, only one interpretation is perceived at any given time, and perception switches between the two in a stochastic manner. The neuronal mechanisms responsible for these stochastic alternations are still unknown. Two important candidates for the generation of the perceptual alternations are neuronal adaptation (e.g., firing rate adaptation or synaptic depression) and neuronal noise (e.g., spiking variability). Previous models have emphasized each mechanism, but without systematically studying them together. Using neuronal competition models I show that, in order to reproduce the statistical features of distributions of dominance times typically observed in experiments, the noise level and the adaptation strength have to be finely balanced. This balance needs to be such that the system lies close to the bifurcation point separating its attractor and oscillatory regimes [1-2]. This working regime can have important functional consequences, since it might allow a fast switching between behaviors through small modifications of the network or inputs' parameters. Novel experiments that suggest that perceptual bistability is a form of active sampling from probability distributions over the underlying causes will also be discussed, highlighting the role of noise as an active mechanism for perceptual exploration.

Long-Lasting Therapeutic Effects of Coordinated Reset Deep Brain Stimulation

Oleksandr Popovych, and Peter Tass
Institute of Neurosciences and Medicine - Neuromodulation (INM-7), Research Center Juelich, D-52425 Juelich, Germany

We present a multisite coordinated reset stimulation, a method for effective desynchronization of neuronal population. This stimulation technique has been developed with methods from statistical physics and nonlinear dynamics in oscillator networks and models of neuronal populations. It exploits dynamical self-organization principles and establishes a mild, but effective control and is designed for deep brain stimulation. Taking into account the synaptic plasticity, which could lead to bi- or multistability of the neuronal dynamics, the desynchronizing coordinated reset stimulation is shown to shift a neuronal population from a stable synchronized (pathological) state characteristic e.g., for Parkinson's disease to a stable desynchronized (healthy) state. In a first clinical proof of principle study we show that - in accordance with theoretical predictions - the method is effective and has long-lasting therapeutic effects from the electrophysiological and clinical standpoint.

Multistability in ensembles of nonlinearly coupled oscillators

Michael Rosenblum, and Arkady Pikovsky
Dept. of Physics, Potsdam University, Germany

In a usual approach to the dynamics of large populations of coupled oscillatory systems the coupling is assumed to be linear -- in the sense that its properties do not depend on the strength of interaction. We introduce a notion of nonlinear coupling, where the interaction may have different properties for small and large acting forces. Such a dependence one observes, e.g., in experiments with real neurons. We demonstrate some novel effects which the nonlinear coupling imposes in large ensembles -- transition to partial synchronization, multistability, etc.

Polyrhythms in Central Pattern Generator motifs

Andrey Shilnikov
Neuroscience Institute, Georgia State University

A Central Pattern Generator is a small neural network controlling various vital repetitive locomotive functions including respiration and walking of humans, swimming and crawling of leeches etc. This talk is focused on the onset of polyrhythmic dynamics in a multi-functional CPG, where every oscillatory attractor corresponds to a specific rhythm and is conjectured to be associated with a particular type of locomotive activity. By elaborating on various configurations of mutually inhibitory and mixed motifs, network building blocks, we intend to describe some universal synergetic mechanisms of emergent synchronous behaviors in CPGs.