Conference on Mathematical Neuroscience

An activity of the project ***Shaping new Directions in Mathematics for Science and Society***

Scientific Committee

Acknowledgements. The Conference on Mathematical Neuroscience is supported by the Ministerio de Educación y Ciencia (ref. MTM2005-24568-E), by the European Comission through the project *Shaping new Directions in Mathematics for Science and Society* (ref. 015661) and by the Universitat Politècnica de Catalunya.

Contents

1 Programme

	THU 31	**FRI 1**	**SAT 2**	**SUN 3**	**MON 4**
9:00-9:30		**J.Rinzel**	**N.Kopell**	**Ermentrout**	
9:30-10:00		*Dynamics of perceptual bistability*	*Multiple interacting rhythms in the nervous system*	*What makes a neuron spike? Reliability and dynamics*	**G.Medvedev** (9:45-10:15) *Multimodal oscillations: from dopamine neurons to solid fuel combustion*
10:00-10:45		**J.Smith** *Models of respiratory neurons and networks in the central nervous system*	**Sánchez-Vives** *Bistability and rhythmicity in the cortical network: mechanisms of generation and control*	**B.Smith** *Spatiotemporal codes and plasticity: How the olfactory system may detect, identify and interpret odors*	**J.L.van Hemmen** (10:15-10:45) *How lateral line hydrodynamics allows fish to localize both predator and prey*
10:45-11:15		Coffee Break			

11:15-11:45		**S.Coombes** *On the dynamics of dendritic trees: morphology, resonant membrane and active spines*	**J.Hertz** *Cross-Correlations in Cortical Networks*	**A.Borisyuk** *The dynamic range of bursting in a network of respiratory pacemaker cells*	**M.Rudolph** *Neuronal dynamics in the active brain: Some insights from intracellular and theoretical studies*
11:45-12:15		**J.Rubin** *Giant squid, hidden canard: the 3D geometry of the Hodgkin-Huxley model*	**K.Josic** *Co-variation of output rate and correlation*	**T.Lewis** *Firing dynamics of electrically coupled pairs of inhibitory interneurons in the neocortex*	**N.Brunel** *Statistical properties of excitatory synaptic connectivity optimizing information storage*
12:15-12:45		**A.Bose** *Multistability and reduction to one-dimensional maps*	**G.Deco** *The role of statistical fluctuations in probabilistic decision-making*	**Françoise** *Attractive periodic orbits of weakly coupled oscillators*	**J.Best** *A mathematical model for the development of sleep regulation*
12:45-13:15		Reception lunch	Lunchtime	**B.Gutkin** *GABA Reversal Pontetials Control Synchronization of Neuronal Oscillators*	Lunchtime
13:15-15:00				Lunchtime	

15:00-15:30		**M.Teicher** Synchronization		**P.Latham** *Requiem for the spike*	**A.Aersten** *Cortical Network Dynamics-Precision in a noisy environment?*
15:30-16:00		**D.Hansel** *The ring model of cortical dynamics: delayed insights*	Cultural Activities	**L.Tao** *Reverse correlation and network architecture*	**W.Senn** *Perceptual learning through top-down gain modulation*
16:00-16:30		**Poster Session**		**Poster Session**	**E.Shea-Brown** *Network architecture and spiking dynamics of coupled phase oscillators*
16:30-18:00					
18:00-19:15	Arrivals and registration			Social dinner	

2 General Information

Lecture Room: The conference will take place in "Auditori Rocafort" of the Centre Cultural i de Congressos Lauredià, next to the Universitat d'Andorra.

Secretariat: The CRM Secretariat will be available to the participants with the following timetable:
1 and 3 September: from 9.00 to 13.15
2 September: from 9.00 to 13.00
4 September: from 9.30 to 16.30

Computer facilities: The participants will have a computer room at the Universitat d'Andorra with the following timetable: 9:00 to 18:00. To access the computer use:
username: neuromath
password: neuromath
domini: UA
There is also wireless internet connection at the Universitat d'Andorra.

Additional working spaces: We have arranged two extra rooms (Seminari 2 and Seminari 3) for the participants to work in. They are located at the Centre Cultural i de Congressos Lauredià.

Cultural Activity and dinner: We are organising 2 cultural activities for Saturday, September 2, and a social dinner for Sunday, September 3, at the "Hotel Roc de Caldes" Restaurant. More information will be provided upon arrival. Everyone interested in participating will be required to sign up before September 2 (at noon) at the Secretariat. A non-refundable 5 euros fee will have to be paid to register to one or both activities.

Breaks: Coffee and pastries will be served during the morning to all participants at the Centre Cultural i de Congressos Lauredià.

Lunch: The CRM provides all participants with free lunch tickets to be used at a number of Restaurants. The tickets and the list of restaurants on campus will be provided upon arrival together with the rest of the documents.

Picture: A group picture will be taken during the conference. We will inform you of the day, time and place to meet.

Local emergency numbers:

Medical emergency number	Tel 116
Universitat d'Andorra number	Tel. 743 000
Police number	Tel. 110
Firefighters, ambulances	Tel. 118

3 Abstracts of Main Speakers

Cortical Network Dynamics - Precision In A Noisy Environment?

Ad Aertsen (University Freiburg, Germany)

Studies of cortical network function on the basis of multiple single-neuron recordings have revealed neuronal interactions which depend on stimulus and behavioral context. These interactions exhibit dynamics on several different time scales, with time constants down to the millisecond range. Mechanisms underlying such dynamic network organization are investigated by experimental and theoretical approaches. Our current research focuses on two interrelated aspects: variability1 and precision2 of cortical network activity. Extending previous model work3 in which we investigated conditions for the occurrence of precise joint-spiking events in cortical network activity, I will present recent findings from ongoing experimental and theoretical work in our laboratory4-10, undertaken to test and expand some of the model predictions. Specifically, I will discuss new findings regarding the feasibility and constraints of precise synchronization dynamics in cortical networks, resulting from a critical evaluation of biological constraints from cortical connectivity and in vivo physiology, and dynamical constraints from large-scale cortical network simulations.

Supported by GIF, DFG-GraKo, EU-FACETS, and BMBF (Grant 01GQ0420 to BCCN-Freiburg). Further information at www.brainworks.uni-freiburg.de and www.bccn.uni-freiburg.de

References:

1. Arieli A, Sterkin A, Grinvald A, Aertsen A (1996) Dynamics of ongoing activity: explanation of the large variability in evoked cortical responses. *Science* 273:1868-1871

2. Riehle A, Grün S, Diesmann M, Aertsen A (1997) Spike synchronization and rate modulation differentially involved in motor cortical function. *Science* 278:1950-1953

3. Diesmann M, Gewaltig MO, Aertsen A 1999 Stable propagation of synchronous spiking in cortical neural networks. *Nature* 402:529-533

4. Kuhn A, Rotter S, Aertsen A (2003) Higher-order statistics of input ensembles and the response of simple model neurons. *Neural Computation* 15: 67-101

5. Mehring C, Hehl U, Kubo M, Diesmann M, Aertsen A (2003) Activity dynamics and propagation of synchronous spiking in locally connected

random networks. *Biol Cybern* 88: 395-408
6. Kuhn A, Aertsen A, Rotter S (2004) Neuronal integration of synaptic input in the fluctuation-driven regime. *J Neurosci* 24: 2345-2356
7. Léger J-F, Stern EA, Aertsen A, Heck D (2005) Synaptic integration in rat frontal cortex shaped by network activity. *J Neurophysiol* 93: 281-293
8. Morrison A, Mehring C, Geisel T, Aertsen A, Diesmann M (2005) Advancing the boundaries of high connectivity network simulation with distributed computing. *Neural Computation* 17: 1776-1801
9. Boucsein C, Nawrot MP, Rotter S, Aertsen A, Heck D (2005) Controlling synaptic input patterns in vitro by dynamic photo stimulation. J Neurophysiol 94: 2948-2958 10. Kumar A, Rotter S, Aertsen A (2006) Propagation of synfire activity in locally connected networks with conductance-based synapses. *Cosyne* 2006 *Abstr* 72

Email address: aertsen@biologie.uni-freiburg.de

A Mathematical Model for the Development of Sleep Regulation.

Janet Best (Ohio State University at Columbus, USA)

Sleep is a complex process in which many brain circuits participate. Recent experiments suggest that the newborn rat may serve as a simplified experimental model, with a basic sleep-switch circuit that cycles rapidly between wake and sleep states. The adult pattern of consolidated bouts of sleep and wakefulness develops during the first three weeks of life as other neuronal circuits develop and provide modulation. The nature of both the basic sleep-switch circuit and the modulatory circuits remain poorly understood. In this talk I will discuss a mathematical model for sleep in the maturing rat that combines probabilistic and geometric dynamical systems theory approaches to address questions concerning how these circuits generate and maintain sleep states.

Email address: jbest@mbi.osu.edu

The dynamic range of bursting in a network of respiratory pacemaker cells.

Alla Borisyuk (University of Utah, USA)

A network of excitatory neurons within the pre-Botzinger complex of the mammalian brainstem has been found experimentally to generate robust, synchronzied population bursts of activity. We consider a two-cell reduction of an earlier experimentally-calibrated model to demonstrate that, over a broad range of synaptic coupling strengths, the network can support two qualitatively distinct forms of bursting, as well as two distinct forms of tonic spiking. Understanding the dynamical mechanisms responsible for these different activity modes, allows us to uncover the importance of spike asynchrony, to explain the changes in burst duration and interburst intervals and an enhancement in the parameter range over which bursting occurs.

Email address: borisyuk@math.utah.edu

Multistability and reduction to one-dimensional maps.

Amithaba Bose (New Jersey Institute of Technology, USA)

Multistability of rhythmic patterns is a useful property for a neuronal network to possess. For example, it may allow hippocampal networks to store different patterns each of which represents a distinct memory. In central pattern generating networks, multistability allows the network to switch between different rhythmic activities which correspond to different behavioral states of the animal. A question that is common to these networks is how to prove the existence and stability of the periodic solutions that represent the rhythmic activity. Typically the set of governing equations for these systems consists of large numbers of ODEs and a primary challenge is to develop techniques to locate periodic solutions in high-dimensional phase spaces. In this talk, I will discuss reduction techniques that allow us to define relevant one-dimensional maps whose fixed points correspond to periodic solutions of the larger set of equations. I will focus on a two-cell inhibitory network in which each of the cells possesses a low-threshold T-like current. This simple network possesses a wide variety of dynamic behavior, and, in particular, exhibits multistability of burst solutions. Each multistable burst consists of different numbers of spikes. I will show how to define and use a one-dimensional map that is based on the interval between successive spikes. The primary mathematical tool involves the use of geometric singular perturbation theory. Time permitting, I will also discuss reduction to one-dimensional maps in the context of a globally inhibitory network.

Email address: bose@njit.edu

Network architecture and spiking dynamics of coupled phase oscillators.

Eric Shea-Brown (New York University, USA)

We seek basic principles that describe how architecture constrains dynamics in networks of coupled limit cycle oscillators, and as time permits present results of this type drawn from two different categories. First, architecture alone can force subsets to have the same frequencies for periodic solutions and the same winding numbers for general solutions. Our analysis here follows the theory of coupled systems of ODEs in $\mathbb{R}^N$ developed by Stewart, Golubitsky, Pivato, and Torok, and we concentrate on applications in neural modelling, where "spike" events are driven by cells crossing specified phases are of primary interest. We show that, when individual cells in a network are described by phase or certain or integrate-and-fire dynamics, the network architecture plays a surprisingly strong role in restricting what spiking patterns can be produced and what features of these patterns are preserved over time. Second, we study driven phase oscillator networks, and consider another effect of architecture: the role of feedback connections in determining regular vs. chaotic responses to external forcing. These observations are discussed in the the context of the "reliability" of neural spiking. This is joint work with Kresimir Josic, Marty Golubitsky, Kevin Lin, and Lai-Sang Young.

Email address: ebrown@math.nyu.edu

Statistical properties of excitatory synaptic connectivity optimizing information storage.

Nicolas Brunel (Université Paris V, France)

It is widely believed that synaptic modifications underlie learning and memory. If this hypothesis is true, measurements of statistical properties of synaptic connections between neurons should allow us to test theories of learning. In the first part of the talk, I will consider the perceptron, the simplest feed-forward network model. I will show how one can compute the distribution of synaptic weights for a perceptron with purely excitatory weights that optimizes storage capacity. This distribution has two striking features: (i) it contains a large number (at least 50) of exactly zero weights (‘silent’ or ‘potential’ synapses); (ii) positive weights are distributed according to a monotonically decreasing function. Since classical theories of the cerebellum consider Purkinje cells as being neurobiological implementations of perceptrons, it is then natural to investigate how this theoretical distribution fits with the one that was recently obtained experimentally using paired recordings in adult cerebellar rat slices. We find that the theoretical distribution fits closely the experimental distribution, suggesting Purkinje cells function close to their optimal capacity in adult rats, which we estimate to be about 5Kb per cell. In the second part of the talk, I will consider a network with a recurrent architecture, and show that in the hypothesis that the network functions as an auto-associative memory, the distribution of synaptic weights is exactly the same as the one for a perceptron, and hence contains a large fraction of ‘silent’, or ‘potential’ synapses. Finally, I will consider correlations between synaptic weights sharing pre or postsynaptic neurons, and compare the theoretical results with recently published data on synaptic connectivity in cortical slices.

Email address: nicolas.brunel@univ-paris5.fr

On the dynamics of dendritic trees: morphology, resonant membrane and active spines.

Stephen Coombes (University of Nottingham, United Kingdom)

Dendrites form the major components of neurons. They are complex, branching structures that receive and process thousands of synaptic inputs from other neurons. It is well known that dendritic morphology plays an important role in neuronal function. By extending the ‘sum-over-paths’ approach of Abbott et.al. (Biol. Cybern., 1991, Vol. 66, pp. 49 – 60) I will describe a mathematical technique that allows one to determine the role of quasi-active membrane in determining somatic response to injected current. To illustrate the power of this formalism I use it in conjunction with dual recording and cell reconstruction data to reveal the combined role of architecture and resonance in determining neuronal output. Although interesting in its own right the study of quasi-active membrane is really only a first (linear) step in describing the dynamics of the nonlinear membrane now known to be present in the dendrites of many types of neuron. Interestingly excitable channels may be found in the dendritic spines that stud cortical neurons. In the latter part of my talk I will discuss recent work on the Spike-Diffuse-Spike model of a branched dendritic tree with active spines. Although the model is truly nonlinear, the use of threshold (integrate-and-fire) dynamics in the spine-head leads to a computationally cheap model, which in certain instances (such as for the study of saltatory travelling waves) is also analytically tractable.

Email address: stephen.coombes@nottingham.ac.uk

The Role of Statistical Fluctuations in Probabilistic Decision- Making.

Gustavo Deco (Universitat Pompeu Fabra, Spain)

Decision-making has become the paradigm of choice for many neuroscientists aiming to understand the neural basis of intelligent behavior, seen as the link between perception and action. Behavioral, neurophysiological, and theoretical studies are converging to a common theory that assumes an underlying diffusion process which integrates both the accumulation of perceptual and cognitive evidence for making the decision and motor choice in one unifying neural network. Biologically realistic neural circuits have been designed in computational and theoretical neuroscience to implement stochastic noise driven decision-making. Such models generally involve two populations of excitatory neurons engaged in competitive interactions mediated by inhibition. Sensory input may bias the competition in favor of one of the populations, potentially resulting in a gradually developing decision in which neurons in the chosen population exhibit increased activity while activity in the other population is inhibited. In this scenario both the spontaneous state, in which both populations of excitatory neurons exhibit low-level activity, and the decision-state are stable for the same set of parameter values, i.e. they are bistable. Decision-making is then understood as the fluctuation-driven, probabilistic transition from the spontaneous to the decision state. In this talk, we will analyse and discuss the role of statistical fluctuations due to finite size noise in the decision-making process.

Email address: gustavo.deco@upf.edu

What makes a neuron spike? Reliability and dynamics.

Bard Ermentrout (University of Pittsburgh, USA)

I will describe behavior of nearly regularly firing neurons in the presence of noisy stimuli. I first describe the phase resetting curve and then turn to an important computational concept - the spike-triggered average. The STA is the optimal linear filter for reconstructing firing rates from stimuli. I show that the STA and the PRC are closely related. I then show that the reliability and the STA are related and use this to show that neurons are tuned to noise which has the spectral characteristics of excitatory synapses. This work is joint with Nathan Urban and Roberto Fernandez-Galan

Email address: bard@math.pitt.edu

Attractive periodic orbits of weakly coupled oscillators.

Jean-Pierre François (Université de Paris VI, France)

Recent results have been obtained on the existence of periodic orbits of nonlinear periodic differential systems with a small parameter (joint work with A. Buica and J. Llibre). In this talk, we consider the application of these techniques to the study of weakly coupled oscillators and its relation to some models in neurosciences.

Email address: jpf@ccr.jussieu.fr

GABA Reversal Pontetials Control Synchronization of Neuronal Oscillators.

Boris Gutkin (Institut Pasteur, France)

GABA-A synapse reversal potential is controlled by the concentration of chloride. This concentration can change significantly during development and as a function of neuronal activity. Thus GABA inhibition can be hyperpolarizing, shunting or partially depolarizing. Previous results pint-pointed the conditions under which hyperpolarizing inhibition (or depolarizing excitation) can lead to synchrony of neural oscillators. Here we examine the role of the GABAergic reversal potential in generation of synchronous oscillations in circuits of neural oscillators. Using weakly coupled oscillator analysis we show when shunting and partially depolarizing inhibition can produce synchrony, asynchrony and co-existence of the two. In particular, we show that this depends critically on such factors as the firing rate, the speed of the synapse, spike frequency adaptation and most importantly on the dynamics of spike generation (type I vs. type II). We back up our analysis with directly simulations of small circuits of conductance based neurons as well as large-scale networks of neural oscillators. The simulation results are compatible with the analysis: e.g. when bistability is predicted analytically the large scale-network shows clustered states. This is joint work with Ho Young Jeong.

Email address: bgutkin@pasteur.fr

The ring model of cortical dynamics: delayed insights.

David Hansel (Université Paris V, France)

Electrophysiological and anatomical data indicate that many regions of the cerebral cortex are functionally organized. For instance, in primary visual cortex (V1), where neurons display selective responses to the orientation of elongated stimuli, cells with similar preferred orientations tend to interact more than those with different preferred orientations. These patterns of connectivity can influence the intrinsic dynamics of cortical circuits as has been shown theoretically in the framework of the classical "ring model" that has been used in modeling local cortical circuits for more than ten years. Several biophysical processes induce delays on the order of milliseconds in neuronal interactions. These include spike generation, finite-velocity propagation of action potentials, synaptic dynamics and dendritic integration. My talk focuses on the dynamics of networks consisting of an excitatory and an inhibitory population of neurons with a "ring architecture". I will briefly review the spatio-temporal patterns that arise when interactions are instantaneous, as in the classical ring model. Then I will show that the presence of delays gives rise to a wealth of new bifurcations leading to a very rich phase diagram. In particular I will show that the network can display synchronous chaotic activity when the interactions are dominated by inhibition at short range and excitation at long range. I will conclude by briefly discussing the possible physiological significance of these varieties of states for sensory processing and memory storage.

Email address: David.Hansel@biomedicale.univ-paris5.fr

Cross-Correlations in Cortical Networks.

John Hertz (NORDITA, Denmark)

Theoretical considerations, network simulations, and experimental findings all suggest that correlated neuronal activity is present in cortical networks.

What network properties underlie such correlations, and what parameters control their magnitude? I will describe two approaches to these questions, one analytic and the other numerical, in the framework of model networks of the sort introduced by Amit and Brunel (AB) and by van Vreewsijk and Sompolinsky (vVS), which can be thought of describing generic cortical columns. They consist of two populations of neurons, an excitatory and an inhibitory one, both driven by external excitatory input. The neurons are randomly interconnected, with on average $K >> 1$ inputs per neuron and any two neurons sharing a fraction $\sim K/N$ of their inputs, where N is the network size. I study cross correlations in them in states of irregular firing.

In the analytic approach, applied to a slightly-modified vVS model, I try to make a self-consistent calculation of the average cross-correlations, based on the following idea: Relative to the autocorrelations, cross-correlations contribute with an extra factor K to the fluctuations in the neuronal input. Therefore, if one is to avoid near-total firing synchrony, the average cross-correlation between neurons can be at most of order $1/K$ relative to the autocorrelation. In order for this to be true, the correlation between *inputs* to different neurons must also be of order $1/K$. This simple argument then leads directly to the prediction that the average cross-correlation between neurons is *negative*, with its magnitude a factor smaller by exactly a factor N than the autocorrelation. Furthermore, the mean square fluctuations of the input are just reduced by a factor $(1 - K/N)$ relative to the values they would have in the dilute-connection limit treated by vVS. Simulations of this model seem to agree with this theory.

However, simulations of more realistic networks (the AB model, with conductance-based synapses and, in some cases, neurons with Hodgkin-Huxley currents instead of integrate-and-fire ones) do not show the same behaviour. The average cross-correlation/autocorrelation ratio is generally positive and proportional to K/N, rather than $1/N$, though with a coefficient ($\sim 10^{-2}$) small enough that the ratio is always of order $1/K$ or less in all the cases where irregular asynchronous firing states were achieved.

Email address: hertz@nordita.dk

Co-variation of output rate and correlation.

Kresimir Josic (University of Houston, USA)

There is strong evidence that the spike responses of distinct cortical neurons are correlated during sensory processing. We study the way neurons transform correlated input currents into correlations between their spike trains. We present experimental and numerical evidence that strongly suggests that the susceptibility to a synchronizing input increases with firing rate. A simple analytical expression that relates the correlations of the input currents, the firing rate, and the output correlation accurately matches simulations with leaky integrate and fire (LIF) neurons. To unravel the mechanism underlying this covariation we replace the pair of neurons with two correlated random variables, lacking any dynamics yet undergoing a threshold transformation. For certain distributions we find behavior that matches that observed in the neurons.

We also explore the computational consequences of this observation to the processing of static stimuli by a population of identically tuned and correlated neurons. We present a mean field theory, which includes both fluctuations and co-fluctuations, for a two layer feedforward network, and show that the inclusion of a "synchrony tuning" compatible with a classic rate tuning helps to increase information transfer in layered networks. These results show how a fundamental relation between output rate and correlation can enhance population selectivity. This is joint work with Jaime de la Rocha (NYU), Brent Doiron (NYU) and Eric Shea-Brown (NYU).

Email address: josic@math.uh.edu

Multiple Interacting Rhythms in the Nervous System.

Nancy Kopell (Boston University, USA)

The nervous system produces electrical activity whose spectral content is related to cognitive state and behavior. This talk focuses on the gamma (30-90 Hz) and theta (4-8 Hz) spectral bands. Such rhythms have been found concurrently in the hippocampus, the part of the brain associated with the formation of new memories. In vitro experiments have produced both gamma and theta rhythms under different modulatory circumstances. In recent work, Gloveli et al. have shown that the CA3 part of the hippocampus produces gamma rhythms in transverse slices, theta rhythms in longitudinal slices and nested gamma/theta in coronal slices (whose slice angle is between that of transverse and longitudinal). This talk discusses how this may come about, starting with models of the gamma and theta rhythms, using two different kinds of interneurons, basket cells and oriens lacunosum-moleculare (O-LM) cells. Low dimensional maps are used to explain the interaction of the two interneuron types to get a coherent theta rhythm. The difference in spectral content associated with the different kinds of slices is shown to be a consequence of the difference in preserved connectivity in the different slices, with the gamma rhythm predominating when the basket cell interneurons have more connections, and the theta when the processess of the O-LM cells are more preserved. Modeling shows that the spectral content of the full model depends on the outcome of the competition of the (excitatory) pyramidal cells and the O-LM cells for control of the basket cells. The talk also discusses the relationship between the dynamics of gamma/theta nesting and bursting in single cells.

Email address: nk@bu.edu

Requiem for the spike.

Peter Latham (Gatsby Computational Neuroscience Unit, United Kingdom)

A major open question in neuroscience is: "what's the neural code?". The standard approach to answering this, pioneered by Richmond and Optican almost two decades ago [1], is to record spike trains and compute information under different coding models. Unfortunately, this approach requires huge amounts of data and thus, despite considerable efforts and some success, it is still not clear to what extent the neural code, in mammalian cortex, relies on precise spike timing, and in particular on spike patterns.

An alternative approach follows from the observation that if spike patterns are to carry information, they must be precisely repeatable. We may thus ask the question: does the massively recurrent connectivity that is a salient feature of cortical networks place intrinsic limits on precise repeatability, and thus on the extent to which spike patterns can carry information?

We show here that one can answer this question by measuring the mean increase in the firing rate of an average neuron in response to a single synaptic input. If the mean increase is sufficiently large, then the network must be chaotic at the microscopic level, which in turn precludes precisely repeatable spike trains. To address this experimentally, we use in-vivo patch-clamp recordings from cortical pyramidal neurons in barrel cortex of anesthetized rats, and we find that these networks are highly chaotic. We then perform single neuron simulations with models of biophysically realistic neurons and large network simulations with conductance-based neurons. Consistent with our experiments and with previous studies [2,3], we find the same result: highly chaotic dynamics. Finally, we connect quantitatively the mean increase in firing rate with a lower bound on the precision at which spike timing can carry information.

References:
1. B.J. Richmond and L.M. Optican, J. Neurophysiol. 57:132-46; 57:147-61 (1987).
2. C. van Vreeswijk and H. Sompolinsky, Neural Comput. 10:1321-1371 (1998).
3. A. Banerjee, Neural Comput. 13:161-193; 13:195-225 (2001); J. Comput. Neurosci. 20:321-48 (2006).

Email address: pel@gatsby.ucl.ac.uk

Firing Dynamics of Electrically Coupled Pairs of Inhibitory Interneurons in the Neocortex.

Tim Lewis (University of California, Davis, USA)

Electrical coupling between neurons has recently been described in many vertebrate brain areas. Experimental studies have shown that electrical coupling promotes synchrony wherever it is sufficiently strong, but these studies have been limited in their analysis of the conditions leading to synchrony. Theoretical studies, on the other hand, have systematically examined the synchronizing ability of electrical coupling. They predict that under most conditions electrical synapses promote synchronous activity, but they can also support anti-phase activity between coupled neurons. However, these theoretical results have not been tested in real cells.

We performed a systematic analysis of phase-locking in real pairs of somatosensory cortical fast-spiking (FS) and low threshold- spiking (LTS) interneurons and in a conductance-based model of a pair of FS cells. Phase-response curves (PRCs) were obtained for both real interneurons and for the FS cell model. We then used PRCs and the theory of weakly coupled oscillators to make predictions about the phase-locking characteristics of cell pairs. Phase-locking was directly examined by driving interneuron pairs through a wide range of firing frequencies. The strength of electrical coupling varied naturally among cell pairs and was varied artificially in some cell pairs using dynamic clamp. The robustness of phase-locked states to differences in intrinsic frequencies of cells was also examined.

Our results show that electrical coupling between cortical interneurons of the same type gives them the ability to robustly synchronize their firing over a wide range of conditions. This work was done in collaboration with: Jaime G. Mancilla, David J. Pinto, John Rinzel and Barry W. Connors.

Email address: tlewis@math.ucdavis.edu

Multimodal oscillations: from dopamine neurons to solid fuel combustion.

Georgi S. Medvedev (Drexel University, USA)

Systems of differential equations close to an Andronov-Hopf bifurcation (AHB) have been subject to intense research in both finite- and infinite-dimensional settings due to their dynamical complexity and importance in applications. The latter range from models in fluid dynamics to those in the life sciences. In particular, many differential equation models in computational neuroscience feature proximity to AHB.

In this work, we study one- and two-parameter families of flows in R^3 near an AHB. We identify conditions on the global vector field, which yield a rich family of multimodal orbits passing close to a weakly unstable saddle-focus. We perform a detailed asymptotic analysis of the trajectories in the vicinity of the saddle-focus. Our analysis covers both cases of sub- and supercritical AHB. For the supercritical case, we find that the periodic orbits born from the AHB are bimodal when viewed in the frame of coordinates generated by the linearization about the bifurcating equilibrium. If the AHB is subcritical it is accompanied with appearance of multimodal orbits, which consist of long series of nearly harmonic oscillations separated by large amplitude spikes. We analyze the dependence of the interspike intervals (which can be extremely long) on the control parameters. In particular, we show that the interspike intervals grow logarithmically as the boundary between regions of sub- and supercritical AHB is approached in the parameter space. We also identify a window of complex and possibly chaotic oscillations near the boundary between the regions of sub- and supercritical AHB and explain the mechanism generating these oscillations. Finally, we discuss the applications of our results to models of Hodgkin-Huxley type and to a problem in solid fuel combustion. This is a joint work with Yun Yoo.

Email address: medvedev@drexel.edu

Dynamics of perceptual bistability.

John Rinzel (New York University, USA)

In binocular rivalry, a widely studied paradigm for visual perceptual bistabilty, each eye views different images but perception alternates randomly between them on the time scale of seconds. We will view some demonstrations and I will describe results for various models that have been proposed to account for some of the observed phenomena. Many models implement neuronal competition via reciprocally inhibitory populations. Each population corresponds to one percept and during rivaling alternations only one population is active at a time. At one level of idealization, firing rate (mean field) models are formulated without stochastic features and the alternations are periodic. Switching between percepts is due to a slow negative feedback process (say, adaptation or synaptic depression). In several models of this class dominance duration decreases monotonically with increasing strength of stimulus, in accord with experiments (e.g., "Proposition IV" of Levelt, 1968) – but only within a certain range of stimulus strength. We find additionally, by simulation and numerical bifurcation analysis, that they also predict in other stimulus regimes different behaviors: non-rivaling steady dominance, and rivalry with dominance durations increasing with increasing stimulus strength. We conclude that because of such discrepancies (non-monotonic vs monotonic dependence of duration vs stimulus strength) additional experimental tests of Levelt's Proposition IV are needed.

We have further developed a new, attractor-based framework for binocular rivalry in which alternations are induced by noise, and are absent without it. Our framework is instantiated at different levels of description – with bistable potential-well models, with rate-based and with spiking network models. In order to produce experimental-like distributions of dominance periods (lognormal or gamma-like) we find that two mechanistic features are important: noise mediated by NMDA synapses and weak adaptation. In our architecture the competing units are pairs of excitatory and inhibitory sub-populations. Inhibition is not through direct reciprocal connections, but rather is driven by a global excitatory pool. This architecture leads to behavior consistent with Levelt's Proposition IV. Furthermore, the architecture readily generalizes to several competing populations, providing a model and novel predictions for multi-stability phenomena.

Email address: rinzel@cns.nyu.edu

Giant squid, hidden canard: the 3D geometry of the Hodgkin-Huxley model.

Jonathan Rubin (University of Pittsburgh, USA)

The classical Hodgkin-Huxley (HH) model for the action potential of a space-clamped squid giant axon represents a rich source of interesting dynamics. It has been demonstrated that changes in the timescales associated with the gating variables in the HH model can lead to a significant slowing of the firing rate, in some cases including chaotic dynamics. In this joint work with M. Wechselberger, we explain these phenomena via a thorough geometric analysis, including application of recently developed theory on canards, and associated mixed-mode oscillations, in 3D systems with two slow variables.

Email address: rubin@math.pitt.edu

Neuronal dynamics in the active brain: Some insights from intracellular and theoretical studies.

Michelle Rudolph (CNRS, France)

The intense and sustained activity seen in the living brain crucially shapes intracellular dynamics, in particular the integration of synaptic inputs and superthreshold cellular responses. A characterisation of this intracellular dynamics, in combination with theoretical and mathematical models of cellular and synaptic dynamics, can be used to infer statistical properties of synaptic inputs and, thus, to characterize activity in the surrounding neuronal network. The talk will summarise some aspects of neuronal behaviour in the active brain from an intracellular point of view, and suggest some insights into the mutual link between single cell and network dynamics. Particular focus will be put on cortical neurons in the awake state, which is characterised by a desynchronized EEG. Here, intracellular recordings display a depolarized state, sustained firing as well as a fluctuating subthreshold membrane dynamics caused by the intense barrage with synaptic inputs. However, it is not known how neurons process information in such states. By combining intracellular recordings from cortical neurons during natural states of vigilance with computational models, the question of how conductance dynamics determines activity in such states can be addressed. The main message emerging from these studies indicates that not only inhibition determines the conductance state of the membrane in awake animals, but also that inhibitory inputs have a determinant influence on spiking. This suggests that activated states are mostly defined by inhibitory conductances and their dynamics, pleading for a powerful role for interneurons in information processing.

Email address: Rudolph@iaf.cnrs-gif.fr

Bistability and rhythmicity in the cortical network: mechanisms of generation and control.

Maria V. Sanchez-Vives (Universidad Miguel Hernández)

Neocortical neurons -both excitatory and inhibitory- exhibit spontaneous plateau depolarizations (up states) even in the absence of stimuli. This is an emergent property of the cortical network that occurs in the various states of vigilance. During slow wave sleep up states alternate with periods of silence or down states with a frequency of ¡1Hz (Steriade et al., J Neurosci 13: 32521993). This same rhythm is also generated by the cortical network maintained in vitro if the slices are bathed in an artificial cerebrospinal fluid of ionic composition similar to the one in vivo , given that it provides the right level of network excitability (Sanchez-Vives and McCormick, Nat Neurosci 3:1027, 2000). Recurrent connections between cortical neurons, a correct excitatory / inhibitory balance and the presence of certain ionic currents seem to be sufficient to maintain such switching between activated and silent cortical states, and this has been as well demonstrated in a computer model of the cortical network (Compte et al., J Neurophys 89:2707, 2003). Bistability between up and down states occurring during sleep is displaced towards a permanent up state during the awake (Steriade and Timofeev, Neuron 37:563, 2003). This suggests that the understanding of the mechanisms that generate up states can provide insight into the functioning of the cortex during alert states. A distinct activity of the alert states that has been described in association with sensory and cognitive processing is fast (beta and gamma), synchronized rhythmicity. During the epoch of network activation (up states) local cortical ensembles synchronize and generate a network rhythm in the beta and gamma range, and our data shows that the cortical microcircuitry alone can generate and synchronize fast oscillatory activity even in the in vitro, isolated cortical network. In this presentation intrinsic mechanisms that generate persistent activity in cortical neurons will also be discussed, along with their possible implications for the maintenance of activated states and memory processes.

Email address: mavi.sanchez@umh.es

Perceptual learning through top-down gain modulation.

Walter Senn (University of Bern, Switzerland)

The primary visual cortex (V1) intrinsically modulates the feedforward input to enable object recognition at later stages of the visual pathway. Collinear edge detectors in V1, for instance, mutually enhance their activity to improve the perception of lines in a noisy background. As a consequence, subjects judge a segment within a line brighter than it actually is. Unsupervised perceptual learning may suppress this perceptional bias by repetitive discrimination training, without impairing the general line extraction capabilities. Is it possible to achieve perceptual improvements without changing the hard-wiring of V1? We suggest that (1) a top-down recruitment of recurrent inhibition and (2) a top-down gain increase are universal neuronal footprints of perceptual learning within V1. The top-down recruitment of recurrent inhibition suppresses the intrinsic neuronal dynamics and removes perceptual biases, but does not induce further synaptic long-term changes within V1. The top-down gain increase enhances the perceptual sensitivity, without need of changing the feedforward drive to V1. We show that these two features explain perceptual learning for such different tasks as brightness discrimination and interval bisection. The selection of the required top-down input can be achieved through Hebbian synaptic plasticity.

Email address: wsenn@cns.unibe.ch

Spatiotemporal codes and plasticity: How the olfactory system may detect, identify and interpret odors.

Brian Smith (Ohio State University, USA)

Considerable debate exists regarding the mechanisms that underlie temporally dynamic responses in early processing of olfactory sensory information. In both insects and mammals, a highly interconnected neural network transforms a distributed, high dimensional sensory input. Several studies have now shown that the transformed response is not stationary. Within a few hundred milliseconds after onset of stimulation, the response evolves through a sequence of activation patterns (the transient phase) to a final state that may be a repeating pattern (attractor). Recent behavioral date indicate that increased sampling time improves detectability, and possibly discriminability, of odorants. Furthermore, learning the association of an odorant with reward may change the dynamics of the neural network. I will present a computational model of AL circuitry that suggests mechanisms for generating both transient and attractor-based dynamic responses. This minimal model is capable of decorrelating of sensory inputs through time. It produces a large number of transient or attractor patterns, which depends on connectivity and threshold parameters.

Email address: brian.h.smith@asu.edu

Models Of Respiratory Neurons And Networks In The Central Nervous System.

Jeffrey C. Smith (National Institute of Health, USA)

Cellular and Systems Neurobiology Section, National Institute of Neurological Disorders and Stroke (NINDS), National Institutes of Health (NIH), Bethesda, MD, USA

Neural networks in the mammalian central nervous system (CNS) that generate respiratory movements provide an ideal, experimentally accessible model system for analyses of mechanisms by which the CNS generates neural rhythms and spatiotemporal patterns of activity. Over the past decade, extensive experimental data has been obtained on cellular and circuit properties of respiratory neurons and incorporated into quasi-realistic biophysical models that explain mechanisms of rhythm generation and spatiotemporal pattern formation. In this talk I will focus on our data-inspired modeling analyses of cellular and network mechanisms of rhythm generation. A heterogeneous network of excitatory neurons in the brainstem pre-Bötzinger complex (pBC) is an essential component of the rhythm generator, and I will emphasize our current work on rhythm-generation mechanisms in this network. The pBC network exhibits autorhythmic properties arising from dynamic interactions of excitatory synaptic currents and intrinsic cellular currents, which endow intrinsic rhythmic bursting properties to a subset of neurons when isolated from synaptic inputs. Our analyses of intrinsic cellular mechanisms indicate that two subthreshold neuronal conductances in particular contribute to cellular- and network-level oscillatory bursting: a persistent sodium conductance (NaP) and a potassium-dominated Leak conductance. NaP has voltage-dependent activation/inactivation properties with very slow inactivation kinetics at subthreshold voltages. This kinetics gives rise to the slow recovery process that underlies regenerative, synchronized bursting at cellular and network levels. Leak is voltage-independent and due in part to TASK channels- a subclass of two-pore potassium channels that are modulated by a variety of neurotransmitters and physiological regulatory signals. NaP is also modulated for regulation of rhythm generation by physiological signals such as low oxygen. Our analyses indicate that rhythm generation in the pBC network can be understood to an important extent by modeling the contributions of NaP and Leak operating in the context of an excitatory network of coupled cells. In general I will also consider a number of issues related to the dynamic integration of these cellular and circuit-level properties, including mechanisms of rhythmic cell synchronization and emergent oscillatory properties of the pre-Bötzinger complex network. Dynamical systems analyses that have been applied to explain mechanisms of rhythm generation at the cellular and network levels will also be discussed. Supported by the Intramural Research Program of NINDS, NIH.

References: Butera, R.J., J. Rubin, D. Terman and J.C. Smith. Oscillatory bursting mechanisms in respiratory pacemaker neurons and networks. In: Bursting. The Genesis of Rhythm in the Nervous System, edited by S. Coombes & P.C. Bressloff, World Scientific Press, pp. 303-347, 2005.

Email address: jsmith@helix.nih.gov

Reverse Correlation and Network Architecture.

Louis Tao (New Jersey Institute of Technology, USA)

Reverse-time Correlation (RTC) measurements gives the average response dynamics of individual neurons within a recurrent neuronal network. The resulting RTC function provides specific information about the nature of the recurrent network connections, and in particular, the strength of network inhibition. We present a set of models that uncover and explain the relation between RTC functions and network architecture.

Email address: tao@njit.edu

Synchronization.

Teicher Mina (Emmy Noether Research Institute for Mathematics, Israel)

We will present a new analysis showing synchronization of neural activity in behaving animals - unlike the previous common assumtion that the code depends on the firing rate.

Email address: teicher@macs.biu.ac.il

How Lateral Line Hydrodynamics Allows Fish to Localize both Predator and Prey.

J. Leo van Hemmen (Technische Universität München, Germany)

About half of the vertebrates are fish. They use their lateral-line system to analyze water motion around their body and in so doing localize predator, prey, and conspecifics. The functional unit of the fish lateral line is a mechanoreceptive neuromast, which is in essence a cupula, a gelatinous protuberance sticking into the water and detecting local water flow. The detection stimulates sensory hair cells at the basis of the cupula. Neuromasts are either free standing on the skin (superficial neuromasts, SN) or in a system of canals directly under the skin and communicating with the outside through pores (canal neuromasts, CN). It has been shown that CN are insensitive to constant flow (e.g., while the fish is swimming) whereas SN are not. Nobody, however, has ever proposed a mathematical model to relate the water perturbation in the fish environment to the water motion in the canal, the neuromasts displacement, and the ensuing neuronal information processing. That it what we are going to do here.

For the modelng of stimuli hydrodynamics is essential. Because of the character of most stimuli a linear approximation of the Navier-Stokes equations due to Stokes is justified. Starting with a multipole expansion we present an analysis of the input to the CN and show how and why the fish eigenmotion does not influence their observing pressure differences through the pores. Furthermore, we indicate the range of the lateral-line system, viz., a fish length, and show how CN and SN give rise to an input of exactly the same character so that it is immaterial to the nervous system underlying the neuromasts where the input comes from. For example for schooling CNs are essential to locate the direct neighbors. Finally, we indicate how map formation might occur, a map being a neuronal representation of the outside world.

In particular, a key question is now how fish may get the appropriate neuronal "hard"ware. In so doing, catching time differences arising from the input on the skin is expected to be important. Spike-timing-dependent synaptic plasticity (STDP) [1], which has been experimentally demonstrated, seems to be the natural tool. The development of synaptic software could, though need not, be "supervised" by the visual system during daytime. Here we show how supervised STDP allows learning what is where in the dark. In addition, the learning procedure is derived from a minimization principle and can be generalized to perform similar tasks elsewhere.

References:
[1] W. Gerstner, R. Kempter, J.L. van Hemmen, and H. Wagner, A neuronal learning rule for sub-millisecond temporal coding, Nature **383** (1996) 76-78.

Email address: LvH@tum.de

4 Abstracts of Posters

Action potential propagation in dendrites with non-uniform morphology and voltage-gated channel properties: predictions of local traveling wave attractors.

Corey Acker (University of Connecticut, USA)

Dendrites of many classes of neurons express voltage-gated sodium channels and are able to actively propagate action potentials generated in the axon. These backpropagating action potentials play an important role in synaptic plasticity and synaptic integration. Action potential propagation in dendrites is complicated by non-uniform morphology and voltage-gated channel distributions and properties, and as a result, action potential amplitude can vary with distance from the axon. In some cases, amplitude can suddenly begin to decline rapidly, a phenomenon called backpropagation failure. We show that local traveling wave attractors can be used to understand and predict changes in action potential amplitude due to the non-uniformities found along these dendrites. Attractor disappearance (bifurcation) can lead to rapid amplitude decline and may explain experimentally observed propagation failures. By computing these underlying attractors, and combining predictions with multicompartmental simulations, one is able to dissect effects on propagation due to morphology from those due to channel properties. Propagation failures are commonly due to changes in channel properties, but can also occur due to severe branch points, but only when channel properties leave the dendrite susceptible to this. This is joint work with John White (Boston University, Boston MA).

Email address: acker@uchc.edu, jwhite@bu.edu

The stochastic integrator: a network model to approximate integrals.

Rita Almeida (Universitat Pompeu Fabra, Spain)

The ability to approximate the integral of a time varying signal is likely to be important for many parts of the nervous system. For example, keeping track of the current position and direction of motion may require integration of velocity and acceleration signals provided by peripheral sensors. In this work we suggest a mechanism for integral approximation and demonstrate how this mechanism can be implemented in a network of neurons. The approach relies on a set of interconnected identical units receiving the same inputs. The units undergo stochastic transitions between two semi-stable states; they are either in a low activity "down" state or in a high activity "up" state. The probability of one unit going from the down to the up state during a short time interval is small and is modulated by the input it receives. An approximation of the integral of positive inputs to the units can be read out from the activities of all the units given that the following conditions are fulfilled: (i) For an input of a fixed magnitude the expected number of units that undergoes a transition from the down to the up state is a linear function of the time that the input is on; (ii) For a fixed time interval the expected number of units that undergoes a transition from the down to the up state is a linear function of the magnitude of the input. For these two conditions to hold we show that the transition probabilities must satisfy a simple relationship with the input to be integrated and the relative number of units in each state. The bistable units used consist of a set of interconnected neurons and can be described by the average firing rate of a population of excitatory neurons or by the spiking activities of two populations, one of excitatory neurons and one of inhibitory neurons. Koulakov et al. introduced the idea of using a network of bistable units to approximate integrals of certain input functions. Their implementation relies on that each unit has slightly different sensitivity to the input stimuli and it will always undergo a transition provided it receives the appropriate input. One potential advantage of the present approach, which uses stochastic transitions is that one does not need to assume a precise range of variability of the sensitivity of the units. This is joint work with Anders Ledberg and Gustavo (Universitat Pompeu Fabra, Spain).

References:

1. Koulakov et al.2002 *Nature Neuroscience* **5(8)**:775-782.

Email address: ritap.almeida@upf.edu

Observation Of Chaos In Networks With Strong Delayed Self-Inhibition And Weak Excitatory Feedback.

Demian Battaglia (University René Descartes - Paris V, Paris, France)

It has recently been shown that the introduction of explicit delays generates a very rich repertoire of different dynamical states (uniform oscillations, standing waves, chaos, etc.) in large networks which are analogue to the classical "ring model" for feature selectivity in local cortical circuits. It can be shown that the complexity of the phase diagram is substantially preserved when the size of the system is reduced to a very small number of neurons. In this poster, we focus in particular on the mechanisms underlying the transition to chaos in the smallest possible N=2 ring model. We show that chaotic oscillations are always found in presence of a strong delayed self-inhibition if the strength of the bidirectional excitatory connections exceeds a small critical value. This chaotic phase is very robust and it exists in a wide range of the ratio between the internal and the reciprocal delays. The onset of chaos (via a Feigenbaum period-doubling scenario) is preceded by a characteristic transition (at the point of perfect decoupling among the two units) toward a periodic phase exhibiting phase-locking at an intermediate phase-shift between 0 and π. The asymmetry among the two units is preserved in the early chaotic phase, where the respective fluctuations in the amplitude of the oscillations differs up to two order of magnitude: the neuronal unit whose phase is in advance with respect to the the other oscillates indeed much more regularly and it deviates from perfect periodicity only because of the very small excitatory feedback. We analyse as well in parallel an explicitly asymmetric N=2 "cutted-ring" model in which one of the two excitatory connections of the original N=2 ring has been removed. We show in this case that the driven unit develops chaotic oscillations following exactly the same bifurcation sequence. This observation supports the hypothesis that in the original ring model one of the units might actually play (because of the spontaneous symmetry breaking) the role of a driver inducing chaos in the second neuron which receives from it an oscillating excitatory input current. This is joint work with Nicolas Brunel and Davis Hansel.

Email address: emian.battaglia@univ-paris5.fr

A biophysical model to explore the efects of network activity on short-term synaptic depression.

José Manuel Benita (Universitat Politècnica de Catalunya, Spain)

Repetitive stimulation of a synapse often induces a decrease in the post-synaptic potential, a process called short-term synaptic depression (STD). STD is a property of numerous synapses in the cerebral cortex. However, it has been demonstrated that ongoing activity in the cortical network reduces short-term synaptic depression over time. According to recent experiments made by Reig et al, see [2], this reduction is related to the intensity and duration of the rhythmic activity. We present a biophysical network model that reproduces this reduction of shortterm synaptic depression measured over the amplitud of EPSP's. We compare evoked synaptic potentials in two different conditions: in a silent cortex ("classical" ACSF) versus an active, oscillatory cortical network ("modified" ACSF). The "modified" ACSF achieves an increased excitability in the network, that results in the generation of oscillatory activity due to the recurrent connections between neurons. We try to replicate this situation in our model by means of an increase of the potassium reversal potential, that accounts for an increase of potassium in the extracellular medium. Our network model is taken from that of [1], used for the study of slow oscillatory activity in the cortex. The richness of ionic currents enables us to analyze different sources that can account for the reduction of the STD. The synaptic depression is modelled through the probability of release, which follows an exponential decay to a certain resting value, plus a depressive effect driven by the parameter $f_D = 0.8$. The initial conditions of the different voltages, the choice of the target neuron and the probability of synaptic connectivity are the sources of noise of the model. These properties allow us to recreate a realistic activity in the cortical network. We observe that, in contrast to the silent state of the cortical network, the EPSP's in the active network present less short-term synaptic depression. We claim that this is due to the existing activity in the network that we induced by modifying the potassium reversal potential. Our results are coherent with the hypothesis made by [2] of being the activity of the network the mechanism responsible for the reduction of the STD.This is joint work with Antoni Guillamony, Gustavo Decoz, and María V. Sánchez-Vives.

References:

[1] A. Compte, M.V. Sánchez-Vives, D.A. McCormick and X.-J. Wang, *Cellular and Network Mechanisms of Slow Oscillatory Activity (¡1 Hz) and Wave Propagations in a Cortical Network Model*, J. Neurophysiol, **89** (2003), 2707-2725.

[2] R. Reig, R. Gallego, L.G. Nowak and M.V. Sánchez-Vives, *Impact of Cortical Network Activity on Short-term Synaptic Depression*, Cereb Cortex. , Aug 17.

Email address: Jose.Manuel.Benita@upc.edu

Estimation of cortical microcircuit model from joint thalamic singleunit and cortical laminar-electrode recordings in rat whisker-barrel.

Patrick Blomquist (Norwegian Uni, Norway)

Joint recordings of cortical population firing activity in rat barrel cortex and the thalamic firing activity in the homologous barreloid following single whisker flicks in anesthetized rats are used to estimate population firing-rate models for the barrel column. The cortical population activities in the barrel column are obtained from lineararray (laminar) multielectrodes while the thalamic (VPM) firing, representing the dominant input to the column, is obtained from a separate single electrode. The laminar electrode measures the extracellular potential at 23 different cortical depths (spacing 0.1 mm), and the population firing rates are estimated from the high-frequency part of the signal (multi-unit activity). In the present example with stimulus-averaged data from 27 different stimulus conditions (varying in amplitude and duration of whisker displacement), four cortical populations are identified: granular, supragranular and two infragranular. From their putative population firing rates and the independently measured thalamic firing rate, we extract firing-rate based cortical circuit models reproducing the experimentally observed stimulus-evoked responses given the measured thalamic input. The models are framed as coupled, non-linear (temporal) integral equations with adjustable parameters specifying the shape of the static firing-rate functions and the weight and dynamics of the synaptic connections between the populations. The dynamics of granular (layer 4) firing rate is seen to be well accounted for by a simple model with a relatively weak but fast excitatory thalamic input combined with a strong recurrent interaction with fast excitation and a slow balanced inhibition. However, the firing-rate of the supragranular populations, for example, are found to be well described by a model with an excitatory feedforward projection from the granular population with little recurrent interaction. Thus while the response transformation from thalamus to layer 4 mimics a temporal differentiation, the response transformations between the cortical populations seem to be more amplitude conserving. This is joint work with U.G.Indahl, A.Devor, I. Ulbert, G. T. Einevoll and A. M. Dale.

Email address: patrick.blomquist@umb.no

Multibursting phenomena in Coupled Neuronal Maps.

Hongjun Cao (Beijing Jiaotong University, China and Universidad Rey Juan Carlos, Spain)

Bursting oscillations are commonly observed in a wide variety of neurobiological and endocrine systems. Besides the classical ODE bursting neuron models, the bursting mechanism of map-based neuron models has recently received much attention for simulating collective behaviors in large scale neuron networks.

Map-based bursting neuron models usually display fast and slow time scales. This feature simplifies analysis by allowing to consider the slow variables as parameters and profit from the techniques of bifurcation analysis to gain insight into the dynamics of the neuron and of neuron networks. In the latter case, another useful simplification is symmetry. When all neurons in a network have the same parameters, including their slow variables, the dimension of the problem is dramatically reduced. Unfortunately, it is only in the case of perfect synchronization that the uniformity of the slow variables can be justified. In most cases of interest, asymmetry in the slow variables needs to be considered. This gives rise to complex dynamic phenomena that have not received due attention so far.

In this paper, bursting phenomena of map-based neuron models coupled through the chemical and electrical synapses is discussed. The main goal of this paper is to investigate the mechanisms of bursting both in the symmetric case, with uniform slow variables, and in the general asymmetric case. We use the geometrical bifurcation theory techniques based on a two-dimensional fast subsystem, while many results for bursting just consider a one-dimensional fast subsystem. Our main result shows that there exists bursting both when symmetric and asymmetric fixed points lose stability, and different routes leading to bursting oscillations are given. The origin of bursting is derived from four different stable branches on the fixed point curves, of which one belongs to the symmetric (on-diagonal) branch on the fixed point curve, and the rest belong to the asymmetric (off-diagonal) branches on the fixed point curves. We show how multistabilities and multibursting phenomena can interact in a network of coupled map neurons. The results are strongly dependent on the coupling strength, multistabilities and the initial conditions of the model. But, as the coupling strength is increased, the multistability and the subsequent bursting will disappear for both the symmetric and the asymmetric stable fixed points, separately.

The study demonstrates that although the bursting behavior resulting from both symmetric and asymmetric fixed points of the two-dimensional fast subsystem is more complicated than that of the one-dimensional fast subsystem, the bursting behavior can provide much more information about the complex networks of coupled map neurons and are much more useful. As a consequence, due attention should be payed to the asymmetric fixed points besides the symmetric fixed points when considering the collective behavior of bursts in large scale networks of coupled map neurons. This is joint work with Borja Ibarz and Miguel A. F. Sanjuán.

Email address: hjcao@center.njtu.edu.cn, hongjun.cao@urjc.es

A generalization of the FitzHugh-Nagumo system on a neuronal network.

Stefano Cardanobile (University of Ulm, Germany)

FitzHugh-Nagumo equations fit well into the theory of semilinear perturbations of analytical semigroups. By imposing quadratic, Ermentrout-Kopell type boundary condition, we prove in a rigorous mathematical fashion the existence of solutions of the generalization of the FitzHug-Nagumo equations on a whole network. Certain qualitative properties, e.g. non-positivity, are also proven. This is joint work with Delio Mugnolo.

Email address: stefano.cardanobile@mathematik.uni-ulm.de

Software for simulating calcium-triggered exocytotic processes.

Germán Carrera (Universidad de Cantabria, Spain)

Software for the simulation of exocytotic events from readily releasable pools of secretory vesicles in neuroendocrine cells and presynaptic terminals is presented. The visual package Ca3D_Exolab simulates the entry of Ca^{2+} through the calcium channels, the kinetic reactions of calcium with buffers, the diffusion of calcium and mobile buffers and the kinetic reactions of calcium with the secretory vesicles. The location of both channels and secretory vesicles can be set by using a graphical interface. Calcium and buffer concentrations at different depths from the cellular membrane and capacitance time courses are obtained as outputs. The software also provides a descriptive statistical data analysis of the different output data. This is a joint work with Amparo Gil, Javier Segura and Bernat Soria.

Web page: http://personales.unican.es/gila/bbva.html

Identification and modelling of neural micro circuits using spike trains recorded in the dorsal column nuclei under tactile stimulation.

Nazareth P. Castellanos (Universidad Complutense de Madrid, Spain)

The central nervous system continuously receives and processes external world tactile information. The stimuli are coded in the form of spatiotemporal patterns of electrical pulses which then are conveyed through nerve fibres to the Dorsal Column Nuclei (DCN), the first relay station in the lemniscal pathway. Exact mechanisms of the processing of the tactile information in the DCN still remain unclear. Electrophysiological experiments show that most of the neurons in the DCN do not significantly differ in their electrical properties; however the neural assembly does carry out different functional tasks. Accordingly we assume that the DCN neuron ensembles perform like dedicated processing devices whose stimulus responses are in a large extent conditioned not by a complex intrinsic neural dynamics but by complex connectivity patterns made of individual afferent and efferent connections. Thus the identification and modelling of neural microcircuits in the DCN may shed light on the problem of processing of the tactile information in the DCN. We mechanically stimulated the hind limb of a rat and recorded extracellularly (using PLEXON acquisition system with multi-channel Michigan tetrodes) the response activity in the Gracilis nucleus. Recorded spikes have been sorted off-line with a custom package based on Principal Component and Wavelet Analyses. The collected recordings provide spike trains of up to five simultaneously recorded neurons in different stimulation conditions. In our recent work (Makarov et al, 2005) we have been able to show that spike trains can be used for deducing the effective connectivity between the neurons. The method relies on the spiking activity of experimentally observed neurons and makes use of an IF model for description of their intrinsic dynamics. Synaptic currents (excitatory or inhibitory) are modelled by exponentially decaying electrical pulses. Then the connectivity pattern and the basic characteristics of the neural microcircuit are deduced by fitting the model into the available data. Although this tool has been shown to be very reliable, in experimental conditions of tactile stimulation the dynamics of experimentally observed neurons may be strongly altered by "hidden", experimentally unobservable neurons. Here we extend our method providing a way to conclude on the presence and dynamical characteristics of hidden neurons. Namely, we assume that a sensory fibre leaves collaterals on both observed and hidden neurons and excites them. First the observed spike trains are used to infer the dynamics of the hidden neurons and then using a second order Akaike's information criterion we adjust the parameters of the model minimizing the difference among the prediction and experiment. We assessed the method performance with simulated data resembling the experimental recordings. Our results show that inferring the dynamics of hidden neurons is possible and reliable. Then we applied the method to real recordings and constructed neural microcircuits participating in the information processing in the DCN. We demonstrated that the knowledge on the hidden neuron activity allows a significant improvement of the fidelity of the mathematical model of the stimulus processing in the DCN. This work has been supported by the Spanish Ministry of Education and Science under the program Ramon y Cajal, and by a grant from Universidad Complutense $PR1/06 - 14482 - B$. This is joint work with Valeri A. Makarov.

References: Makarov V.A., Panetsos F. and De Feo O. J *Neurosci Methods* $144 : 265 - 279 (2005)$.

Network Topology and Weak Synchronization in Models of Neural.

Christof Cebulla (Universität Bonn, Germany)

Synchronization of neural systems plays a crucial role in many phenomenaof the brain activity (also concerning brain dysfunctions like those occurring during epileptic seizures). In this context we are interested in an analysis of systems exhibiting a synchronizable state, i.e. which can be (but are not perpetually) synchronized (in the meaning of the emergence of synchronization phenomena) by some external input. In particular we are interested in the role played by the spatial topology of the system. For a suitable analysis we choose a class of recurrent neural network models of Hopfield type with arbitrary network topology. Considering it as a dynamical system,we analyze the time asymptotic behaviour of the model. Introducing the notion of mean activity synchronization ('weak synchronization'), we use then the analytical results to investigate the dependence of the neural network synchronizability on the topology of the network. As particular examples, we discuss the one-parametric set of networks of the Small World type considering the parameter dependence of the synchronizability. Morover we compare thesynchronizability of the model for the cases of the classical random network topology and the scale free network. We discuss particularly the transition region between the synchronizable and the non-synchronizable state of a network (with respect to some parameter). Furthermore we apply the synchronizability analysis to other model classes: the spiking neuron ensembles using the Fokker-Planck equation approach and the stochastic Hopfield model. This is joint wotk with Sergio Albeverio.

Email address: cebulla@wiener.iam.uni-bonn.de

Long-range synchronization of gamma-frequency oscillatory activity between cortical areas during a selective attention task: a biophysical network model.

Albert Compte (Universidad Miguel Hernández, Spain)

Oscillatory neural activity in the gamma range of frequencies (30-80 Hz) has been associated with some cognitive functions through neurophysiological experiments. Recently, evidence is accumulating that selective attention allocation correlates with an increase in the gamma-range spectral power of neural population activity in extrastriate visual areas, which in turn correlates with behavioral performance. However, both the mechanisms of such increased synchronization and its instrumental behavioral advantage in these tasks are still unknown. Here, we analyze these synchronization mechanisms by means of a biophysical computational model of two reciprocally connected cortical areas. The first circuit area represents a visual area (like MT) that receives both direct sensory inputs, and top-down attentional signals from the second, association, circuit area (such as prefrontal cortex or posterior parietal cortex). The latter maintains behavioral cues in self-sustained persistent activity and is in charge of attentional control. We further constrain our model with available neurophysiological evidence in visual selective attention tasks with respect to neural firing rate responses. We show that a topographic cortico-cortical input can induce oscillations selectively in neural subpopulations of the downstream area irrespective of firing rate. This is because the upstream area is endowed with strong reverberating dynamics that naturally gives rise to selective oscillatory activity in the gamma frequency range. In our computational model of the attentional system we analyze thoroughly the synchronization effects of top-down and bottom-up inputs when oscillation-inducing mechanisms are present in the local circuit of either cortical area or in both of them. Our model shows how cortico-cortical long-range interactions between a visual area and a working memory area can mediate mechanistically both the synchronization effects of selective attention, and firing rate correlates of selective attention (gain modulation, biased competition, selectivity enhancement). Support from the Volkswagen Foundation and from the Spanish Ministry of Education and Science. This is joint work tih Salva Ardid and Xiao-Jing Wang.

Email address: acompte@umh.es

Period of Oscillation vs. Input Strength in Two Neuronal Competition Models: A Comparative Study.

Rodica Curtu (Transilvania University of Brasov, Romania.)

We consider two neuronal firing rate models implementing competition through reciprocally inhibitory populations, each of them subject to a slow negative feedback, and receiving an external (equally) constant input I. The negative feedback variable acts in the fast equation either in a subtractive, or, respectively, in a divisive way.

Using input strength I as a control parameter, we focus on its effect on the period T (and existence) of oscillations.

A numerical investigation of both models previously revealed similar types of behaviour. If the inhibition is large enough, five regions of distinct dynamics are observed: for high (low) input values, both populations are active at high (low) level; at intermediate input values, as I is decreased, the systems enter an oscillatory regime with a monotonic decreasing curve of the period T versus I (let us call it: MDC), then go to a winner-take-all regime, and then again to oscillations which now are characterized by a monotonic increasing curve of T versus I (say: MIC).

However, while in the model with subtractive slow process, MDC and MIC have comparable ranges, in that with divisive slow process MDC is much more pronounced. We aimed to understand the reason for these differences.

We prove some analytical results that explain the observations from the numerical simulations, and provide a 'recipe' for competition models to reducing (or even eliminating) any of the regions MDC and MIC, while maintaining the other one. The degree of asymmetry in the bifurcation diagram of T vs. I depends on the position of the 'synaptic threshold' of both active and inactive units during the oscillation. This is joint work with Asya Shpiro, John Rinzel and Nava Rubin (New York University, NY).

Email address: rodicacurtu@unitbv.ro

Homeostasis in neuronal networks.

Daniela Dossing (RWTH Aachen, Germany)

Neurons maintain their electrical activity patterns over long periods of time despite of ongoing channel turnover, cell growth and varying extracellular conditions. In order to maintain these fixed patterns Abbott et al. suggested in 1992 that neurons may regulate the maximal conductances for various currents, which leads to a variant of the classical Hodgkin-Huxley model (1952), where the maximal conductance of each ionic current was assumed to be a fixed parameter rather than a dynamical. The regulation process requires feedback systems capable of reacting to changes of electrical activity on different time scales. In the model under consideration, the intracellular calcium concentration serves as such a regulatory feedback element for the regulation of maximal conductances, because this concentration links neuronal conductances to electrical activity. If the activity pattern leaves the equilibrium state the calcium sensors ensure that the values of the conductances are adapted to the modified activity level. Abbott et al. investigated this model and several variants, mostly with the help of numerical simulations. The purpose of our work is a mathematical analysis of these types of models. Based on the models of Abbott et al. we developed a five-dimensional system of differential equations, which in turn is based on a new simplified two-dimensional Hodgkin-Huxley model. The functions in the model equations are generally characterized by properties like positivity or monotonicity, rather than by concrete functional expressions, and the analysis proceeds accordingly.

Email address: daniela.dossing@matha.rwth-aachen.de

Representational capacity of cortical tissue measured by topological analysis of its activity set.

Tomer Fekete (Weizmann Institute of Science and The Hebrew University Jerusalem, Israel)

The ability to make distinctions is one of the fundamental capacities underlying cognition, from perception through abstract (categorical) thought. The distinctions a cognitive system is capable of making, are manifested in its neural activity. Given a set of distinctions, the natural question that arises is whether this imposes constraints on the activity spaces which could embed such a set. We hypothesize that an activity space can embed a given set of distinctions only if its structure corresponds in some sense to the set of distinctions (that is it does not cause collapse of distinctions or undue elaborations within domains or clusters). Thus, we reason that the homology of an activity space approximates the rough structure of the underlying set of distinctions that is realized by the system's activity. Therefore, we refer to the structure of a given activity set as its representational capacity. We hypothesize that activity sets corresponding to different states of vigilance (for example wakefulness as compared to sleep) exhibit disparity in their representational capacity. To render such general sentiments in tractable form we proceed as following : 1.) We assume that crude features of the signal which we refer to as the "structure" of activity suffice to determine it's membership in a class. 2.) Instances of activity are registered at different states of vigilance (anesthesia/quiet wakefulness/attention). We conjecture that what constitutes a state in terms of activity is similarity (invariance) in the structure of instances of activity. Thus, real (structure sensitive) functions can be utilized to classify activity according to state. 3.) The level sets of the typical value corresponding to a state can be calculated explicitly within a boundary of ϵ from the set of measurements 4.) Finally, the Betty numbers of such level sets, which give the rank of the corresponding homology groups, and the corresponding statistics (such as the dependency on ϵ), can be computed following (Munkres, 84, Robins, 2000, Kaczynski et al. 2004). We present preliminary results obtained from analysis of voltage sensitive dye imaging (Grivald, 2005) data obtained from the primary visual cortex behaving primates. This is joint work with David B. Omer and Amiram Grinvald from Weizmann Institute of Science, Israel.

Email address: tomer.fekete@weizmann.ac.il

Modulation of STDP by a global reward signal leads to reinforcement learning.

Razvan V. Florian (Babes-Bolyai University, Romania)

The dependence of long-term changes in synaptic efficacy on the relative timing of pre- and postsynaptic action potentials is a phenomenon that has been experimentally observed in the brain and is known as spike-timing-dependent plasticity (STDP). By applying an abstract reinforcement learning algorithm (Baxter and Bartlett, 2001) to standard models of spiking neurons (e.g., the integrate-and-fire model or the Simple Response Model) we also get spike-timing-dependent forms of plasticity, modulated by the reward (Florian, 2005, 2006). For positive reward, we get associative spike-timing-dependent potentiation and non-associative depression. For negative reward, the sign of plasticity is reversed (a form of STDP observed in the electric fish). Bidirectional associative modulated STDP can be obtained for a model where neurons adapt homeostatically their firing thresholds to keep the average postsynaptic activity constant. The plasticity of the firing threshold can also contribute to learning, through a form of spike-timing-dependent intrinsic plasticity.

We also get reinforcement learning by simply modulating STDP with the reward signal (having standard, Hebbian STDP for positive reward and anti-Hebbian STDP for negative reward). We call this model MSTDP. Inspired by the analytical derivation, we can also introduce an eligibility trace stored at each synapse that keeps a decaying memory of the relationships between recent pairs of pre- and postsynaptic spikes (modulated STDP with eligibility trace, MSTDPET).

Through computational studies, we have shown that MSTDP and MSTDPET allow solving the XOR problem, learning a target firing rate pattern, leading a simulated worm to find food in its environment. MSTDPET allows learning even with delayed reward, while MSTDP does not. The causal nature of the STDP window is an important factor for the efficacy of learning with modulated STDP. We show that the proposed learning mechanisms scale well with network size and have high biological plausibility. The mechanisms are robust and work well for random, recurrent networks; various neural models; various forms of modulated STDP. Farries and Fairhall (2005), Soula et al (2005) have also demonstrated similar mechanisms for learning (in feedforward networks with modulated STDP, and respectively for robot learning by alternating Hebbian and anti-Hebbian STDP).

The studied learning rules may be used in applications for training generic artificial spiking neural networks, and suggest the experimental investigation in animals of the existence of reward-modulated STDP.

References:
Baxter, J. and Bartlett, P. L. (2001), *Infinite-horizon policy-gradient estimation, Journal of Artificial Intelligence.*

Email address: florian@coneural.org

Modeling cortical activity with a continuum of cortical columns.

François Grimbert (INRIA Odyssee project, France)

In this poster, we model the cortical sheet by a continuum of cortical columns. The behaviour of one cortical column is described by a nonlinear dynamical system accounting for the local cortical processing. It can be studied in terms of its bifurcations according to an input parameter. We give an example of such a bifurcation analysis with Jansen's neural mass model (see *Jansen and Rit 1995*). We then form a continuum of columns, giving rise to a (multidimensional) integro-differential equation in which delays can be taken into account. Without delays, this equation can be seen as an ordinary differential equation in a Banach space and we can solve it numerically using Picard iterations. As we include delays due to signal transmission via white matter, we obtain a genuine integro-differential equation for which we have to write good numerical schemes. We discuss the existence and unicity of the solution for both cases. Eventually, we try to analyze our results at the light of mathematical techniques like those presented in *Coombes 2005* for the study of waves and bumps. Our work aims at better understanding the influence of the cortical column (dynamical system) and connectivity (integration kernel) models in the production of different cortical activities. This is joint work with Olivier Faugeras.

Email address: francois.grimbert@sophia.inria.fr

Concepts for a dynamical complexity of formal languages.

André Grüning

Artifical neural systems can all by seen as dynamical systems or analogue computers. It is unclear how to assess the complexity of an analogue computational process in terms of its dynamics. We review previously suggested concepts and propose some new directions.

For symbolic computational systems there exist a series of measures of complexity: e.g. the Chomsky hierarchy, computational complexity and finally Kolmogoroff complexity.

In many cases input and output of a dynamical system need to be interpreted symbolically (e.g. language processing). Yet, it is not clear how symbolic complexity of the input/output language relates to dynamical complexity.

It has e.g. been noted that the – in symbolic computation – big step from context-free to context-sensitive processes is only a tiny one for a dynamical system.

We will concentrate on "dynamical recognisers" (DR) (Pollack 1991) that are abstractions of simple recurrent networks. A DR is essentially a system of iterated functions $F_1, ...F_n$ on a state space X. The system processes an input i of a finite alphabet $1, ...n$ by applying F_i to its current state. After a finite sequence of inputs it is checked whether the current state lies in a distinct region, the accept region. In that case a DR is said to accept the input string. Thus DRs can be used to decide grammatically questions.

Moore (1998) uses the classes of functions (linear, polynomial etc.) in DR construction to classify formal languages. These classes partially cut across the Chomsky hierarchy.

Tabor (2000) defines similarity of formal languages: given a simple recurrent network working as a DR, it will essentially be defined by the network's weight matrix. Slight variations of the weights will lead to different DRs that process different languages. Thus a measure of similarity of formal language can be based on the distance of the corresponding weight matrices. Tabor presents a family of DRs varying along a single parameter that accept a context-free language when the parameter is rational and a non-context-free otherwise. A classification based on this similarity will cut across Chomsky hierarchy, too.

These two approaches have disadvantages: Moore's DR language classes are based on the function classes the DR and networks are constructed with, i.e. external properties of a dynamical systems, and not on dynamical invariants of the dynamical system itself.

The problem with Tabor's approach is that unrelated weight matrices can give rise to DRs with the same language: determining whether two languages possess DR representations that are close to each other seems to be difficult. A standard or canonical dynamical implementation of a language would be useful.

We do not have complete solutions to these challenges, but we want to lay out what is desirable and thus what future roads of research could be, basing a classification of formal languages on intrinsic invariants of dynamic systems. We will discuss candidate invariants, their advantages and drawbacks.

Email address: gruening@sissa.it

The ring model of cortical dynamics: delayed insights.

David Hansel (CNRS-Université René Descartes Paris)

Electrophysiological and anatomical data indicate that many regions of the cerebral cortex are functionally organized. For instance, in primary visual cortex (V1), where neurons display selective responses to the orientation of elongated stimuli, cells with similar preferred orientations tend to interact more than those with different preferred orientations. These patterns of connectivity can influence the intrinsic dynamics of cortical circuits as has been shown theoretically in the framework of the classical “ring model” that has been used in modeling local cortical circuits for more than ten years.

Several biophysical processes induce delays on the order of milliseconds in neuronal interactions. These include spike generation, finite-velocity propagation of action potentials, synaptic dynamics and dendritic integration.

My talk focuses on the dynamics of networks consisting of an excitatory and an inhibitory population of neurons with a “ring architecture”. I will briefly review the spatio-temporal patterns that arise when interactions are instantaneous, as in the classical ring model. Then I will show that the presence of delays gives rise to a wealth of new bifurcations leading to a very rich phase diagram. In particular I will show that the network can display synchronous chaotic activity when the interactions are dominated by inhibition at short range and excitation at long range. I will conclude by briefly discussing the possible physiological significance of these varieties of states for sensory processing and memory storage.

Email address: David.Hansel@biomedicale.univ-paris5.fr

Persistent activity patterns in a neural field model composed of bistable neurons.

Cláudia Horta

Pattern formation processes in neural fields of lateral inhibition type have been widely studied in the context of Computational Neurosciences, Biology or Robotics. Many neural field models are based on recurrent networks with 'continuous attractors'. The connectivity in these models supports the existence of a continuum of self-stabilized activity patterns. A transient external input acts as a switch between a uniform rest state and one of the stable active states. Such self-sustained patterns are thought to be the neural basis of working memory and have been applied to explain orientation tuning in the visual cortex or the planning of goal directed hand and eye movements. In the domain of autonomous robotics, activity patterns have been used to endow robots with cognitive capacities such as decision making, memory or forgetting.

Typically, the network connections are organized in a Mexican-hat profile with strong excitation between near neurons flanked by strong "surround" inhibition. The continuity of the attractor states requires a perfect spatial symmetry in the connection profile, since arbitrarly small deviations cause a drift in the spatial position of the activity pattern. However, to serve as as realistic models for short term memory, the network must be sufficiently robust to perturbations in the symmetry.

Here we analyze persistent activity patterns in a single layer neural field model composed of bistable neurons. In particular, we describe how a perturbation of the assumed symmetry affects the existence and stability of stationary patterns. We show that these patterns remain close to the position of the transient external input in spite of a substantial asymmetry in the connection profile. Moreover, there is a threshold for the asymmetry above which a transition to a travelling activity pattern occurs. Using approximation techniques, we derive a simple analytical expression for the threshold value in dependence of the network parameters. This is joint work with Wolfram Erlhagen.

Email address: claudia@mct.uminho.pt

Linghai Zhang (Lehigh University, USA)

Nonlinear traveling waves are of fundamental importance in neurobiology and in applied mathematics. Motivated by several important papers, we are concerned with a biophysically motivated nonlinear nonlocal firing rate model equation, which involves the convolution of a kernel function with the Heaviside step function. The model also involves spatial temporal delay resulting from the finite conduction velocity of action potentials along axons.

We are going to investigate how various neurobiological mechnisms, in particular, lateral inhibition (modeled by Mexican hat kernel function), lateral excitation (modeled by upside down Mexican hat kernel function) and spatial temporal delay influence traveling wave front, speed and wave stability. We are concerned with asymptotic behaviors of the speed as various parameters approach zero or infinity. We will also construct and investigate speed index function and its relation to stability index function.

We plan to establish the existence and stability of a traveling wave front of the model. We also will derive formula on wave-speeds and then compare speeds corresponding to different kinds of kernels, including symmetric and asymmetric, nonnegative, Mexican hat and upside down Mexican hat kernels. These results can be applied to computational neuroscience and dynamical systems.

Email address: liz5@lehigh.edu

A fluctuation-driven mechanism for slow decision processes in reverberant networks with fast synapses.

Daniel Martí (Universitat Politècnica de Catalunya, Spain)

Recent physiological findings suggest that neurons in association areas are involved in decision making. When subjects are presented with patterns of random dots and have to decide whether they move to the left or to the right with a saccadic response, the neuronal activity in lateral intraparietal area seems to reflect the gradual accumulation of evidence in favor of one choice over the other [1]. Neurons in LIP receive input from direction-selective cells in visual area MT, which are thought to represent the instantaneous fluctuations in motion strength that need be integrated to reach a decision.

The need to explain such slow decision mechanisms as a result of neural dynamics at the population level motivated the development of a stochastic model [2], which incorporates two populations of excitatory neurons, initially in a symmetric spontaneous state, which get destabilized when driven by direction-sensitive input. The two populations engage in competition via inhibitory interneurons, which make the network relax into one of two attractor states which represent the decision taken. Neurometric measures obtained from the model, including response times and performance accuracies, are consistent with experimental results. The slow typical decision times were suggested to be strictly related to the slow NMDA components of the excitatory synaptic input.

Here we propose an alternative mechanism for slow decision, in which the stimulus does not destabilize the spontaneous state, but increases the probability of a fluctuation-driven transition to one of the decision attractor states. The noise driving the transition is not chosen ad hoc, but is due to the finite size of the network. Decision is slow because the system remains in the spontaneous state for a long time; when fluctuations eventually drive it out of the spontaneous state the transition is relatively fast. This mechanism depends only mildly on the time scales of the synaptic transmission. Instead, the time course of the decision is dictated by the amplitude of noise and the attractor configuration, given by the connectivity and the external input. We show that the proposed fluctuation-driven scenario entails distinctive predictions on the statistical distribution of the decision times.This is joint work with Gustavo Deco, Guido Gigante, Paolo Del Giudice and Maurizio Mattia.

References:
[1] Shadlen MN, Newsome WT, *J Neurophysiol*, Vol. 86 (2001)
[2] Wang X-J, *Neuron*, Vol. 36 (2002).

Email address: daniel.marti@upf.edu

Frequency Based Mutual Information Measures Between Clusters Of Brain Regions In Functional Magnetic Resonance Imaging.

A. Martínez (Fundació Sant Joan de Déu-SJD SSM, Barcelona, Spain)

Several mutual information measures have been recently applied to quantify the connectivity between brain regions in functional magnetic resonance imaging (fMRI). Besides the description of pairwise connections, mutual information can be extended, as well, to describe the degree of connectivity between clusters of brain regions. This multivariate approach, though, has been hardly used by the brain imaging community.

While most of the statistical tools applied to find links between brain areas in fMRI, such as cross-correlations, the dynamic causal model, or multivariate autoregressive models have been developed in a time framework, frequency based connectivity methods have been also recently used. Such techniques in the frequency domain allow describing the patterns of covariability between brain areas occurring at different time scales.

Here we develop frequency based measures of mutual information to evaluate the degree of covariability of time series of clusters of brain regions extracted from sequences of fMRI volumes. Taking advantage of the decorrelating properties of the discrete Fourier transform, we decompose the mutual information of a multivariate stationary stochastic process in a sum of values over the Fourier frequencies. This is applied to quantify the mutual information of vectors (clusters) of time series of brain regions extracted from an fMRI sequence acquired from a healthy individual lying quietly in the scanner. Values observed are rather high over the whole spectrum, with maxima in the low frequencies for both the mutual and conditional mutual information, pointing to a high degree of covariability in the brain. A strong association is observed between the number of regions in the clusters and the information measures. Far from being an artefact in the estimates, this is an intrinsic pattern of the mutual information between vectors. Consequently, the measures developed here will not be adequate to compare the levels of covariability of different pairs of clusters with different number of brain regions. However, they will be suitable for inter-subject and group comparisons. In that case, they may be readily used without the need to know the distributional properties of the plug-in estimates. This is joint work with R. Salvador.

Spatiotemporal periodic waves in a one-dimensional network of integrate-and-fire neurons

Noelia Montejo (LORIA , France)

Traveling waves in networks of spiking neurons have been the subject of many studies [3], [2]. Theoretical analysis, with few exceptions, required that the network is continuous in space and traveling waves are regular, i.e. they appear as a straight line in the (t, x) plane where t is time and x the one-dimensional coordinate of neurons. This paper focuses on traveling waves with a spatiotemporal periodicity in the discrete spiking neural network

$$C\frac{dv_i}{dt} \quad = \quad -\frac{v_i}{\tau} + \sum_k w_{ik}\alpha(t - t_k^f) \tag{1}$$

where v_i is the membrane potential of the neuron located at i, C is the capacity, τ the membrane time constant, w_{ik} the synaptic weights and α a post-synaptic current describing the effect of an incoming spike. Times t_k^f are the firing times defined by the threshold criterion $v_k(t_k^f) = \vartheta$. It is shown that in the single-spike framework there exists simple waves with different velocities [1], where the propagation occurs with the same time duration $1/c$ between successive threshold crossings of neurons where c is the velocity of the wave. Depending on the synaptic connectivity and the synapse time constants we show that complex waves could propagate.
These waves are characterized by the existence of a sequences δ_k such that the firing times are given by

$$t_{pi+k}^f = \frac{pi + k}{c} + \delta_k \tag{2}$$

where $k \in \{0, \ldots, p-1\}$ and p is the spatial period. These waves are reminiscent to the lurching waves obtained in continuum spiking networks even if inhibition and delay are not required in our discrete network for their propagation. We present analytical results about their existence in the case $p = 2$. This is joint work with Arnaud Tonnelier.

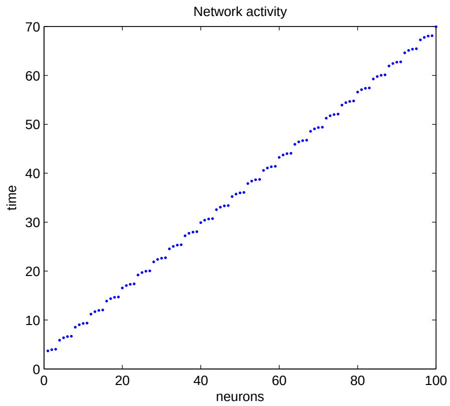

Figure 1: Traveling wave with a spatio-temporal periodicity.

References:

[1] Badel, L. and Tonnelier, A. (2004), Pulse propagation in discrete excitatory networks of integrate-and-fire neurons, *Phys. Rev E* **70**, 1.

[2] Bressloff, P.C. (1999). Synaptically generated wave propagation in excitable neural media. *Phys. Rev. Lett.* **82**, 2979-2982.

[3] Ermentrout, G.B. (1998). The analysis of synaptically generated traveling waves. *J. Comput. Neurosci.* **5**, 191-208.

Email address: montejo-@loria.fr

Modeling Neuronal Growth Cone Navigation.

Junalyn Navarra-Madsen (Texas Woman's University, USA)

Proper wiring of the nervous system requires precise guidance of extending axons, the long processes that stretch out from neurons. Axon extension is mediated by a specialized structure located at the leading edge, called the neuronal growth cone. Experimental data suggest that growth cone shape and navigation is regulated by dynamics of its cytoskeletal elements, microtubules and actin filaments [1]. Dynamic rearrangements of the growth cone cytoskeleton is directed by several biochemical signaling pathways [2]. We hypothesize that activation of small guanine nucleotide triphosphatases (GTPases) of the Rho subfamily is central to this signaling regulation. Specifically, we postulate that activation of a particular Rho GTPase, Rac1, increases growth cone advance by promoting actin filament rearrangements [3]. Here, we develop a mathematical model using graph-theoretical concepts to describe and predict growth cone morphological changes, based on actin filament rearrangements and Rac1 activation. In this model, the vertices of the graph represent finger-like portions, technically called filopodia, and the edges represent the distance between the tips of these fingers. Kernel methods will be used to analyze the influence of both the activation and non-activation of Rac1 and subsequent effects on actin filament dynamics. One intuitive motivation for using kernel methods is that problem solving is easier in the new space after finding the mapping $\phi\colon \mathbb{R}^n \mapsto \mathbb{R}$. The kernel represents the similarity between two objects defined as the inner product in this new vector space. Graph kernels based random walks are used [4]. We validate this model by pharmacologically perturbing actin dynamics (using cytochalasin D and jasplakinolide) and Rac1 activation (using 8-bromoadenosine-5',3'-cyclic monophosphate (8-bromo-cAMP) and NSC27366) and measuring changes to actin filament content and growth cone morphology using biochemical assays and light, epifluorescence and atomic force microscopy.This is joint work with DiAnna L. Hynds from Texas Woman's University, Denton.

References:

[1] Zhou F.Q. and Cohan C.S., *How actin filaments and microtubules steer growth cones to their targets*, J. Neurobiol. **58(1)** (2004), 84-91.

[2] Meyer G. and Feldman E.L., *Signaling mechanisms that regulate actin-based motility processes in the nervous system*, J. Neurochem. **83(3)** (2002), 490-503.

[3] Kuhn T.B. Brown M.D. and Bamburg J.R., *Rac1-dependent actin filament organization in growth cones is necessary for β1-integrin-mediated growth cone advance but not for growth on poly-d-lysine*, J. Neurobiol. **37** (1998), 524-540.

[4] Kondor R.I. and Lafferty J., *Diffusion kernels on graphs and other discrete structures*, Proceedings of the ICML, 2002.

Email address: jnavarramadsen@mail.twu.edu, dhynds@twu.edu

Inferring causal subnetworks within neuronal networks.

Duane Nykamp(University of Minnesota-Minneapolis, USA)

If one could measure simultaneously and individually the spiking activity of all neurons in a neural network, fitting a network model to the data might reveal causal connections among the neurons. However, connections from unmeasured neurons could create the illusion of causal influence among the measured neurons. We have developed a framework that addresses effects from unmeasured neurons in order to reveal causal influence among the measured neurons. The approach exploits predictions from a point process model of the relationship between neuron spikes and external variables such as a stimulus. The resulting analysis can be potentially applied to a large range of experiments where the spikes of multiple neurons are recorded simultaneously.

Email address: nykamp@umn.edu

Cluster networks for coupled oscillators with heteroclinic attractors.

Gabor Orosz (University of Exeter, United Kingdom)

We consider a network of coupled phase oscillators as one of the simplest representation of a weakly connected neural network. To model a highly connected neuronal network, such as an antennal lobe of an insect, all-to-all connections are assumed. Both the oscillators and the connections are considered to be identical. By using an asymmetric coupling function partially synchronized states are found which consist of several clusters of synchronized oscillators. By symmetry, several cluster states can be found with the same number of clusters containing the same number of neurons. Moreover, stable heteroclinic connections are detected between these cluster states; these realise 'winnerless competition' dynamics between cluster states.

A typical trajectory of the system approaches this heteroclinic network spending more and more time close to the synchronized cluster states. By perturbing individual oscillators the system can be forced to maintain this cycling if the time interval between perturbations is appropriate. When before the perturbation is applied the system stays close to a cluster state and the input triggers a "switch", that is, a quick transition happens along a heteroclinic connection and the system moves close to another cluster

state. For each synchronized state a certain connection is chosen according to which oscillator is perturbed. Performing a long sequences of switches a critical period is found below which the cycling becomes unpredictable due to fact that certain connections break The above dynamics shows qualitative features which can be found in real biological networks, namely the network produces the desired output for a given input even in the presence of background noise.

We demonstrate that such heteroclinic dynamics exist for a particular near-symmetric cluster configuration for arbitrarily many oscillators and show that the heteroclinic network may robustly possesses structure that is at least as complicated as an odd graph structure (this is a type of highly connected graph that for $2k+1$ oscillators has $k+1$ vertices from each node and a number of nodes that grows exponentially with k). The network exists in an open domain of parameters which area shrinks as the number of oscillators is increased. This is joint work with Jon Borresen and Peter Ashwin.

Email address: g.orosz@exeter.ac.uk

A Genetic Algorithm For Curve Fitting: A Possible Choice For Unsatisfactory Gradient Nonlinear Regressions.

David Roche (UAB, Spain)

The Hill equation is likely the most used model for curve-fitting in pharmacological research (Christopoulos and Lew, 2001). However, it presents a possible drawback as it cannot account for asymmetric concentration-effect curves (Giraldo et al., 2002). The Richards function solves this problem by including an additional parameter (s). Hill and Richards models are nested, being the Hill function a particular case of Richards equation if the s parameter is equal to one. A value of s different from one allows a theoretical curve to display an asymmetric shape. Regretfully, it has been found that, in a number of cases, the Richards function performs deficiently in curve fitting if gradient nonlinear regression is used (Van Der Graaf and Schoemaker, 1999). The reason for that may lay in the strong correlation found between some of the parameters of the Richards model. This correlation can affect the location, slope, and symmetry parameters yielding nonsensical values, very large errors or even failing to converge. A genetic algorithm (GA) can be a useful methodology to the determination of the parameters of difficult fitting problems (Maeder et al., 2004). In particular, this technique avoids the sensitivity of local optima to the initial estimates supplied to the nonlinear regression procedure.

$$R \underset{}{\overset{K_1/4}{\rightleftharpoons}} AR \overset{2K_2/3}{\rightleftharpoons} A_2R \overset{3K_3/2}{\rightleftharpoons} A_3R \overset{4K_4}{\rightleftharpoons} A_4R \overset{K_E}{\rightleftharpoons} A_4R^* \tag{1}$$

where $K1, \cdots, K4$ are the microscopic equilibrium dissociation constants and $K_E = \frac{[A_4R^*]}{[A_4R]}$ is the equilibrium constant for the opening reaction. If we define the effect as the proportion of receptors in the open state, Equation 2 is obtained:

$$E = \frac{[A]^4 K_E}{K_1K_2K_3K_4 + 4K_2K_3K_4[A] + 6K_3K_4[A]^2 + 4K_4[A]^3 + [A]^4(1 + K_E)} \tag{2}$$

This study presents a GA approach for the estimation of function parameters, in particular Richards function parameters. To test the performance of our algorithm the four binding sites ligand-gated ion channel (Equation 1) is selected as a case study.

It can be shown (Giraldo, 2003) that Equation 2 tends to a Richards function in the case of very low efficacy ($K_E << 1$) and absence of co-operativity ($K_i = K$ for each binding step). In the cases tested ($K_i = 10^{-6}$, and K_E either equal to 1 or equal to 10^{-5}), our GA provided similar or better estimates than the nonlinear regression method when the latter performed well or badly, respectively. Because the assessment of asymmetry may be important both for accurate estimation of empirical pharmacological parameters and for the mechanistic analysis of those biological systems where asymmetry is an intrinsic and relevant feature, our approach could be a possible choice in those situations in which gradient nonlinear regression (in particular of Richards function) is unsatisfactory. This is joint work with Juan Serra, Xavier Rovira and Jesús Giraldo (Grup Biomatemàtic de Recerca, Institut de Neurociències and Unitat de Bioestadística, Facultat de Medicina, UAB, Spain).

References:

Christopoulos A, Lew MJ (2001) In: Christopoulos A (ed) CRC Press, Boca Raton, pp 195-231

Giraldo J (2003) *Trends Pharmacol Sci.* 24:63-5

Giraldo J et al (2002) *Pharmacol. & Ther.* 95:21-45

Maeder M et al (2004) *Chemom. Intell. Lab. Syst.* 70:193-203

Van Der Graaf PH and Schoemaker RC (1999) *J. Pharmacol. Toxicol. Methods* 41:107-15

Email address: david.roche@uab.es

Switching from integrators to resonators

Uwe Roehner (Humboldt University Berlin, Germany)

They are two types of neurons, known as integrators and resonators. They are distinguished by the bifurcation type they undergo when excited. Integrators show a Saddle- node bifurcation while resonators a Hopf bifurcation, resulting in a negative or positive derivative of the steady-state Current(I)-voltage(V)-curve dI/dV, respectively. We investigate general conductance-based neuron models. For each parameter we detemine its possible influence on the transition from integrators to resonators, by looking at the derivative dI/dV. Our results show that the capacities C and the time constants τ have no influence. When considering passive currents we find that only their conductance g has an influence, while their reversal potential E does not. For currents equipped with gating variables we show analytically under which conditions g and E have an influence. We treat the parameters within the gating variables numerically and show that the midpoint potential $V_{1/2}$ has an essential influence. To be more exactly, for two gating variables within one current we show that the overlap of both is crucial for the transition from integrators to resonators or viceversa.

Email address: u.roehner@biologie.hu-berlin.de

The Traffic-Light Controller: A Three-State Model For Metabotropic Glutamate Receptors.

Xavier Rovira (UAB, Spain)

Metabotropic glutamate receptors (mGluRs) belong to class C G-protein-coupled receptors (GPCRs) (Kunishima et al., 2000). mGluRs perform crucial roles in changing synaptic efficacy or plasticity, by inducing various cell responses via coupling to various types of G proteins (Tateyama and Kubo, 2006). These receptors are composed of three main structural domains, the Venus flytrap domain (VFT) where agonists and antagonists bind, the cysteine-rich domain (CRD) that interconnects the VFT to the heptahelical domain (HD), and HD (Pin et al., 2005). Class C GPCRs are constitutive dimers, being stabilized by a disulfide bridge in the case of mGluRs. An activation mechanism has been proposed for mGluRs, which includes three states for the VFT domain: open-open (oo), closed-open (co), and closed-closed (cc). The conformational states of VFT and HD domains are coupled. It has been suggested that in the absence of agonist, the receptor is in a resting state (Roo-HD), and switches to a partially active state upon binding of a first agonist (Aco-HD(*)), and to a fully active state upon binding of a second agonist (Acc-HD*) (Kniazeff et al., 2004). Moreover, this fully active state is stabilized by cations such as Ca^{2+} and Gd^{3+}. Fluorescence Resonance Energy Transfer analysis showed (Tateyama and Kubo, 2006) that the effect of Gd^{3+} is complex: low concentrations of Gd^{3+} induce dimeric rearrangement of the intracellular domains of mGluRα as does glutamate whereas high concentrations of Gd^{3+} induce the inactivated state. In addition to agonists and antagonists, other ligands can act as positive or negative allosteric modulators by binding to the HD domain (Goudet et al., 2005). Mathematical models can be of prime importance in signal transduction studies for the analysis of complex mechanisms (Giraldo et al., 2002; Giraldo, 2004; Kenakin, 2004; Leff et al., 1997). In this study, a mathematical model (the traffic-light controller) is constructed by including three receptor states: inactive (R), partially active (R^p), and fully active (R^*). This preliminary model is redesigned by making dimeric all three states. The ability of the resulting model to represent the VFT domain is analyzed by systematic curve simulations. In particular, cooperative behaviours and biphasic curves are examined in detail. Further work which includes the presence in the model of both cations and allosteric modulators will be shown. Although the model has been developed taking the mGluRs as a reference system, it could be of general applicability to others receptors in which three states (inactive, partially active and fully active) were thought to be present. This is joint work with David Roche, Juan Serra and Jesús Giraldo (Elisabet Vila) (Grup Biomatemàtic de Recerca, Institut de Neurociències and Unitat de Bioestadística,Facultat de Medicina, UAB, Spain.)

References:

Giraldo J (2004) *FEBS Lett.* 556:13-8
Giraldo J et al (2002) *Pharmacol. & Ther.* 95:21-45
Goudet C et al (2005) *J. Biol. Chem.* 280:24380-5
Kenakin T (2004) *Trends Pharmacol. Sci.* 25:186-92
Kniazeff J et al (2004) *Nat. Struct. Mol. Biol* 11:706-13
Kunishima N et al (2000) *Nature* 407:971-7
Leff P et al (1997) *Trends Pharmacol. Sci.* 18:355-62
Pin JP et al (2005) *FEBS J.* 272:2947-55
Tateyama M and Kubo Y (2006) *Proc. Natl. Acad. Sci. U. S. A* 103:1124-8

A mechanism of neural homeostasis in a medial entorhinal cortex biophysical model of Layer II Stellate Cell: Differentiation of gain curves.

Shirley-Eva Sanchez

Neuronal gain is a mechanism by which a cell can alter or modulate its input-output relationship in response to external or internal changes (Burrone et al 2003). One mechanism of such modulatory control has been speculated to be a modulation of voltage gated channels as observed in various experimental works (MacLean 2003; Poolos 2002). In this project we focused on balanced changes in H-currents (I_H) and persistent sodium current (I_{Nap}) as complementary currents that work to maintain baseline behavior and are modulated to give rise to a type of intrinsic gain regulation similar to Burdakov's work in a somatogastric ganglion neural model (2005). We use a single compartment Hodgkin-Huxley type model of stellate cells in the Medial Entorhinal Cortex (MEC) Layer II that incorporates I_H and I_{Nap}. This region is of particular interest due to its critical position as the entry pathway to the main memory system, the hippocampus. Our preliminary results do indicate a prominent role for both I_H and I_{Nap} in the gain modulation of a stellate cell's firing frequency. How such gain modulation will affect network dynamics and the formulation of neural assemblies is being considered. This mechanism of gain modulation may provide a key to understanding the robustness and stability of the theta firing frequency for the MEC stellate cells. This is joint work with Nancy Kopell and Horacio G. Rotstein.

Analytical Derivation Of Complex Cell Properties From The Slowness Principle

Henning Sprekeler (Humboldt Universität zu Berlin, Germany)

Ever since the seminal experiments by Hubel and Wiesel, cells in primary visual cortex are conceived as edge or line detectors. Based on the degree of invariance with respect to phase shift of their preferred stimulus, they are categorized as simple and complex cells. Their receptive fields have been shown to be selective for a variety of stimulus properties, e.g. for orientation and spatial frequency.

Recently, Berkes and Wiskott (Journal of Vision 5(6), 2005) have demonstrated that the unsupervised learning principle of temporal slowness can account for a wide range of complex cell properties, including optimal stimuli, phase shift invariance and orientation and frequency selectivity. The structure of the simulated receptive fields was shown to crucially depend on the transformations present in the image sequences used for training while being largely independent of the statistics of natural images.

Using this observation as a starting point, we have developed a mathematical framework for the simulations that is based on the Lie group of the transformations in the training data. We show that the optimal receptive fields are the solutions of a partial differential eigenvalue equation that can in certain cases be solved analytically. The properties of the resulting non-linear receptive fields are in agreement with those of simulated and physiological cells.

The theory demonstrates that the results of the simulations can be largely understood analytically and provides an intuitive explanation why the simulated receptive fields are optimal for temporal slowness learning. This is joint work with Laurenz Wiskott (Bernstein Center for Computational Neuroscience, Berlin, Germany).

Email address: h.sprekeler@biologie.hu-berlin.de

Finding the most sensitive measures for sleep stages detection

Kristína Šušmáková (Slovak Academy of Sciences Dúbravská, Bratislava, Slovak Republic)

Electroencephalogram (EEG) is one of the most often used electrophysiological measures in human clinical and basic sleep research. Through the use of EEG it is possible to indicate various states of the brain as levels of vigilance or sleep stages. The evaluation of sleep stages is done after broadly appreciated Rechtschaffen - Kales manual [1], which involves parameters, techniques and wave patterns of three physiological signals - EEG, electrooculogram (EOG) and electromyogram (EMG) needed for definitive assignation of sleep stages. The convenience of developing a computerized system for automated analysis and classification of sleep states has been recognized by different authors. A few commercial systems are also available and they showed substantial differences from the visually scored paper polysomnography in the distribution of the sleep stages. The objective of this study is to find the most sensitive measure, which could discriminate between different psycho-physiological states of brain. We have computed a variety of measures from classical spectral theory (e.g. total and relative powers in various frequency bands, measures of coherence) as well as complexity measures (spectral exponent, fractal dimension, histogram-based entropy) and from information theory (...) . Data with all-night polysomnographic records were kindly provided by Prof. G. Dorffner, received by The Siesta Group Schlafanalyse GmbH. The records were obtained from 20 healthy subjects, 10 men and 10 women. Ages ranged from 23 to 82 years old with an average 50 ± 21.5 years. All measures were computed on 30s window length, for 1 channel of EMG, EOG and 6 EEG channels (derivations: Fp1-M2, C3-M2, O1-M2, Fp2-M1, Fp2-M1, C4-M1, O2-M1, where M1, M2 are the left and right mastoids). In the poster statistical analysis of evaluation of the measures will be introduced and the most sensitive measure for discrimination between sleep stages will be presented.

References:
[1] Rechtschaffen, A., and Kales, A. (Eds.): *A Manual of Standardized Terminology, Techniques and Scoring System for Sleep Stages of Human Subject*, US Government Printing Office, National Institute of Health Publication, Washington DC, 1968.

Email address: umersusm@savba.sk

A computational model for motor pattern switching in a central pattern generator.

David Terman (Ohio State University at Columbus, USA)

The mechanism of switching neuronal activity patterns in a central pattern generator (CPG) is fundamental to the generation of multiple complex behaviors. The underlying mechanism by which a multifunctional neural substrate in the brainstem switches between the motor outputs of ingestion (licking) and rejection (gaping) upon gustatory stimulation is unknown. The purpose of this study is to use computational techniques to construct a network model for the multifunctional brainstem CPG that switches between patterns similar to taste-induced licks and gapes. The goal is to make predictions about the biological mechanisms underlying the switch. The network consists of three neurons each representing a class of premotor neurons. Each neuron is modeled as a single-compartment conductance-based model based on the Hodgkin-Huxley formalism; cells within the network are coupled through mutual inhibition. Geometric dynamical systems methods are used to describe conditions under which a switch between licks and gapes occurs. Results show that the model generates patterns similar to licks and gapes in terms of rate and phase sequence of neural activity. Thus the model supports the hypothesis that a single network configuration can produce both activity patterns. A switch from licks to gapes is produced by decreasing the rate of decay of inhibition for some network neurons. Studies on brainstem motoneurons indicate that decay kinetics of GABAA receptor-mediated inhibitory post-synaptic currents (IPSCs) are slower than glycine receptor IPSCs on the same motoneuron. In the lick-gape circuit, previ-

ous studies have demonstrated a role for the inhibitory neurotransmitters GABA and glycine. Prolonged inhibition predicted from our model, together with empirical evidence on GABA-glycine receptor kinetics, have led to the formulation of new hypotheses on the role of GABA and glycine in the lick-gape circuit. In particular, we suggest that the timescale of inhibition can be a significant factor in motor pattern switching. This is joint work with S.Venugopal and J.B.Travers.

Email address: terman.1@osu.edu

Branched dendritic tree with active spines.

Yulia Timofeeva (University of Nottingham, UK)

The dendrites of many nerve cells are complex branching structures that receive and process thousands of synaptic inputs from other neurons. As first observed by Ramón y Cajal (Rev. Cienc. M. Barcelona, 1891, vol.22, p. 23) in 1891, dendritic spines are loci for receiving excitatory synaptic input. They are small mushroom like appendages with a bulbous head and a tenuous stem and are present in large densities on the dendritic trees of many neural cells. Experimental evidence indicates that dendritic spines are equipped with excitable channels and that they can support an all-or-nothing action potential response to an excitatory synaptic input. Relatively recently, confocal and two-photon microscopy observations have confirmed the generation of action potentials in dendrites. It is believed that the spread of current from one spine along the dendrites may bring adjacent spines to threshold for impulse generation, resulting in a saltatory propagating wave in the distal dendritic branches. The saltatory nature of the wave may be directly attributed to the fact that active spines are physically separated. Here we introduce a mathematical model of a branched dendritic tree based upon a generalisation of the analytically tractable Spike-Diffuse-Spike. The active membrane dynamics of spines are taken as an integrate-and-fire process and the spines are coupled to the passive dendritic branches via a spine-stem resistance at discrete points. We obtain a quasi-analytical solution using the 'sum-over-paths' approach formulated by Abbott et.al. (Biol. Cybern., 1991, vol.66, pp. 49-60). The resulting model is ideally suited for the study of spatio-temporal filtering properties and neural responses to different patterns of synaptic input. This is joint work with Stephen Coombes (University of Nottingham, UK) and Gabriel J Lord (Heriot-Watt University, UK).

Email address: yulia.timofeeva@nottingham.ac.uk

Dynamics of noisy inhibitory networks of integrate-and-fire neurons: a stochastic network theory approach.

Jonathan Touboul (INRIA Odyssee project, France)

The dynamics of large networks of inhibitory neurons with noisy external drive has been studied by several authors using the Fokker-Planck equation (Brunel and Hakim (1999), Neural Computation 11, 1621-1671). Under the assumption of a sparse random connectivity, they found that the network can be in one of two regimes, according to the parameters: a desynchronized stationary regime, and a weakly synchronized oscillatory regime. Independently, other authors in the field of probability theory have studied stochastic networks of interacting nodes with linear dynamics (i.e., $dX = -dt$) and random reset (Cottrell (1992), *Stochastic Processes and their Applications* 40, 103-127; Fricker, Robert, Saada and Tibi (1994), *Annals of Applied Probability* 4, 1112-1128). They found in locally connected networks that, the dynamics can be ergodic or not ergodic depending on the parameters. In the former case, they found an expression for the invariant probability measure. In the latter case, they showed that part of the network stops firing. We try to build a bridge between these two approaches. We show that the stochastic network model considered in Fricker et al (1994) is formally equivalent to a network of noisy perfect integrators with instantaneous inhibitory interactions. We interpret their results in this context. The duality between the two frameworks corresponds to the duality between time-driven and eventdriven simulation (see Reutimann, Giugliano and Fusi (2003), *Neural Computation* 15: 811-830). We show that replacing perfect integrators by the classic leaky integrate-and-fire models used in the computational neuroscience community (used e.g. in Brunel and Hakim 1999) amounts to replacing state-independent interactions by state-dependent interactions in the stochastic network analyzed in Fricker et al (1994). Within this framework, we exhibit Markov processes representing the state of the network. We extend the ergodic theory to this new model and find that the non-ergodic case disappears in the leaky integrate and fire network. We study various network topologies and we examine the limit of large networks using scaling limits (also called fluid limits). We show that synaptic delays can also be included in this framework. We don't need to assume in this study that the network is sparsely connected. In summary, our approach provides a new theoretical tool, complementary to the more customary Fokker-Planck framework, to the analysis of spiking neural

networks This work was supported by the European Commission (FACETS Project, FP6-2004-ISTFET). This is joint work with Romain Brette (INRIA Odyssee project, France).

Email address: jonathan.touboul@ens.fr

Amplitude equations for a class of neural field models.

Nikola Venkov (University of Nottingham , United Kingdom)

The ability of neural field models to exhibit complex spatio-temporal dynamics has been studied intensively since their introduction in the 1970s. They have found wide application in interpreting experiments in vitro e.g. electrical stimulation of slices of neural tissue and phenomena in vivo such as the synchronisation of cortical activity during epileptic seizures, feature selectivity in visual cortex, or geometric visual hallucinations. One commonly investigated aspect of neural field models is spontaneous pattern formation due to instability of Turing type which leads to static periodic patterns.

In view of the oscillatory patterns obtained by some authors in (one-population) scalar neural fields, we were interested in constructing the normal form for a Turing-Hopf instability in this context. We wanted to investigate what model features are needed to obtain dynamic patterns as opposed to static ones, and to achieve patterns in models with realistic local inhibition - distal excitation (inverted Mexican hat) type of connectivity. Further we were curious about the selection between travelling and standing waves. We have developed the weakly nonlinear analysis for a general system that encompasses the class of neural fields with time-dependent connectivities (for example incorporating delays). The relevant amplitude equations were shown to be the mean-field Ginzburg-Landau equations. The generality of our initial work allowed us to apply the results to a wide variety of models suggested in the literature. Our focus has been on models with space-dependent axonal delays and with delays due to passive dendritic cable, and on a number of extensions of these such as spike-frequency adaptation, combined axo-dendritic delays and even two-population variants. The theoretical predictions have become the basis for a number of numerical codes that allow us to produce and compare plots of the models parameter spaces showing the critical instability curves and the regions of preference of the various types of weakly non-linear solutions - a static pattern, travelling wave, standing wave or homogeneous (bulk) oscillation. Looking at a plenthora of related models in such unified context enables one to make a number of general observations.

All models are carefully checked by simulation of the full equations. This is joint work with Stephen Coombes.

Email address: nikola.venkov@maths.nottingham.ac.uk

Hebbian reinforcement learning with stochastic binary synapses.

Boris Vladimirski

Stochastic reinforcement learning is commonly used to train a neural network to maximize the expected reward for an association task (Williams, 1992; Xie and Seung, 2004; Fiete and Seung, 2006; Seung, 2003). Algorithms, however, can be biologically unrealistic or quite slow, and appear to work very poorly for binary synapses (their existence was first suggested by Petersen et al. (1998). O´Connor et al. (2005) showed that graded synaptic plasticity is a sum of individual postsynaptic conductance steps that are all-or-none and stochastic.)

Here, we introduce a new synaptic model generalizing the works of Amit and Fusi (1992), Fusi (2002) and Fusi and Senn (2005) to a multilayer neural network architecture with stochastically switching binary synapses and discrete time. We propose a Hebbian-like, biologically feasible learning rule, in which the probability of a synaptic weight switch (i.e., LTP/LTD) is determined by the global reward signal and the correlation between the presynaptic and postsynaptic activities.

We prove that our learning rule implements an approximation of the expected reward gradient. Applying our model to the benchmark XOR problem, we show that the performance improves strongly with the number of hidden neurons and exceeds that of the only alternative learning rule that we were able to generalize to binary synapses by at least an order of magnitude. We conclude that this is due to the "Hebbiness" of our learning rule and slower varying LTP/LTD threshold. This is joint work with Eleni Vasilaki, Stefano Fusi and Walter Senn.

Email address: bbv201@nyu.edu

Stability properties of background states in simplified population firing-rate models with non-exponential temporal coupling kernels.

John Wyller (Norwegian Uni, Norway)

Successful cortical models should simultaneously account for both background and stimulus-evoked activity [1]. We here present results for the existence and stability of the background state in generic firing-rate based, cortical network models where an excitatory and an inhibitory population interact with themselves and with each other. These models are given by a system of two coupled Volterra integral equations with recurrent connections, cross-connections and external inputs. In most studies on such firing-rate models exponentially decaying temporal integral (coupling) kernels are chosen, and in many of those studies the time constants of the synaptic source terms are chosen to be identical [2]. This is partially for mathematical convenience, since the system in this case can be reduced to a two-dimensional dynamical system [2].

Here we investigate models with other choices for temporal coupling kernels and investigate the effect of the choice of temporal kernel on the stability of equilibrium (background) states, i.e., with constant synaptic input. Lateral spatial connections are presently omitted, and the models may thus mimic the situation for populations confined to a cortical column where the local cortical connections dominate (for example, layer 4 in rat barrel cortex) [3]. We consider piecewise linear activation functions [4] and various temporal coupling kernels. In particular we study models with (A) so called α-function $[texp(-t/tau)]$ temporal coupling kernels instead of exponentially decaying kernels, (B) mixed kernels, i.e., an exponentially decaying kernel for one population and an α-function kernel for the second population, and (C) models with exponential kernels with different time constants in the synaptic source terms. By using the linear chain trick [5] these two-population models can be recasted to four-dimensional (A, C) and three-dimensional (B) autonomous dynamical systems. Even if, for example, the models of type A and B have the same constant solutions as the corresponding model with only exponential kernels [4], the dynamical properties are different.

The stability of the constant solutions for the various models has been investigated by means of stability analysis of the equilibrium solutions of the corresponding autonomous dynamical systems by means of the Routh-Hurwitz criterion. Results from this analysis will be presented, in particular phase diagrams showing stable and unstable regions of the model parameter space. Further, we have investigated the excitation of temporal oscillations as the outcome of a Hopf bifurcation due to a breakdown of the Routh-Hurwitz stability criterion.This is joint work with Øyvind Nordbø and Gaute T. Einevoll (Norwegian Uni, Norway).

References:

[1] T.P. Vogels et al., *Ann. Rev. Neurosci.* **28**, 357 (2005).
[2] B. Ermentrout, *Rep. Prog. Phys.* **61**, 353 (1998).
[3] D.J.Pinto et al., *Cereb. Cort.* **13**, 33 (2003).
[4] M.Tsodyks et al., *J. Neurosci.* **17**, 4382 (1997).
[5] J.M.Cushing, *Integrodifferential equations and delay models in population dynamics.* Lecture notes in biomathematics **20**, Springer, Heidelberg, 1979. **Email address:** john.wyller@umb.no

---

Mathematical Modeling of Tinnitus Neural Correlates.

Yin Fen Low (Saarland University Hospital, Germany)

Neural correlates of psychophysiological tinnitus models in humans may be used for their neurophysiological validation as well as for their refinement and improvement to better understand the pathogenesis of the tinnitus decompensation and to develop new therapeutic approaches. In this paper we make use of neural correlates of top-down projections, particularly the neural phase stability measure, together with a Large Scale Evoked Response Potential model in order to study and evaluate tinnitus decompensation by using a hybrid inverse-forward mathematical methodology. The neural phase stability, which according to the underlying model is linked to the focus of attention on the tinnitus signal, follows the inverse direction and allows to discriminate between a group of compensated and decompensated tinnitus patients. The large scale evoked response model, which works in the forward direction, is able to strongly support the idea of the connection between attention on the tinnitus signal and the tinnitus decompensation phenomenon. It is concluded that both methodologies agree and support each other in the description of the discriminatory character of the neural correlate proposed, but also help to fill the gap between the top-down adaptive resonance theory of Grossberg and the Jastreboff model of Tinnitus. This is work joint with Carlos Trenado, Wolfgang Delb, Roberto D'Amelio, Peter Falkai, Daniel J. Strauss.

Email address: yinfen@cdb-unit.de

The Role of Cannabinoids in the Neurobiology of Sensory Gating: A firing rate model study.

M. Zachariou (University of Nottingham, United Kingdom)

Gating of sensory (e.g. auditory) information has been demonstrated as a reduction in the auditory-evoked potential responses recorded in the brain of both normal an- imals and human subjects. Auditory gating is perturbed in schizophrenic patients and pharmacologically by drugs such as amphetamine, phencyclidine or ketamine, which precipitate schizophrenic-like symptoms in normal subjects. The neurobio- logical basis underlying this sensory gating can be investigated using local field potential recordings from single electrodes. In this poster we use such technology to investigate the role of cannabinoids in sensory gating. Cannabinoids represent a fun- damentally new class of retrograde messengers which are released postsynaptically and bind to presynaptic receptors. In this way they allow fine-tuning of neuronal response, and in particular can lead to so-called depolarization-induced suppression of inhibition (DSI). Our experimental results show that application of the exoge- nous cannabinoid WIN55, 212-2 can abolish sensory gating as measured by the amplitude of local field responses in rat hippocampal region CA3. Importantly we develop a simple firing rate population model of CA3 and show that gating is heavily dependent upon the presence of a slow inhibitory (GABAB) pathway . Moreover, a simple phenomenological model of cannabinoid dynamics underlying DSI is shown to abolish gating in a manner consistent with our experimental findings. This is joint work with W.D.N.Dissanayake, M.R.Owen , R.Mason and S.Coombes.

Email address: pmxmz@nottingham.ac.uk

5 List of Participants

Abbassian, Hossein	abbnet@ipm.ir
Acker, Corey	acker@uchc.edu
Aersten, Ad	aertsen@biologie.uni-freiburg.de
Almeida, Rita	ritap.almeida@upf.edu
Ardid Ramirez, Joan Salvador	jsardid@umh.es
Barrett, Adam	adam.barrett@balliol.ox.ac.uk
Battaglia, Demian	demian.battaglia@univ-paris5.fr
Beauvais, Elisha	beauvais@maths.warwick.ac.uk
Benita Bordes, Jose Manuel	Jose.Manuel.Benita@upc.edu
Berdnikova, Anastasia	nastya28@mail.ru
Best, Janet	jbest@mbi.osu.edu
Blomquist, Patrick	patrick.blomquist@umb.no
Borisyuk, Alla	borisyuk@math.utah.edu
Bose, Amithaba	bose@njit.edu
Brown, Eric	ebrown@math.nyu.edu
Brunel, Nicolas	nicolas.brunel@univ-paris5.fr
Cao, Hongjun	hongjun.cao@urjc.es
Cardanobile, Stefano	stefano.cardanobile@mathematik.uni-ulm.de
Carrera, German	german.carrera@gmail.com
Caubergh, Magdalena	magdalena.caubergh@uhasselt.be
Cebulla, Christof	cebulla@wiener.iam.uni-bonn.de
Cohen, Ofir	ofir.ch@gmail.com
Coll Vicens, Bartomeu	Tomeu.Coll@uib.es
Compte Braquets, Albert	acompte@umh.es
Coombes, Stephen	stephen.coombes@nottingham.ac.uk
Curtu, Rodica	rodicacurtu@unitbv.ro
Darbas Barbe, Lauand	gauss2002@hotmail.com
Deco, Gustavo	gustavo.deco@upf.edu
Ding, Yiming	ding@wipm.ac.cn
Dossing, Daniela	daniela.dossing@matha.rwth-aachen.de
Ermentrout, Bard	bard@math.pitt.edu
Fekete, Tomer	tomer.fekete@weizmann.ac.il
Florian, Razvan Valentin	staff@staff.ubbcluj.ro
Françoise, Jean-Pierre	jpf@ccr.jussieu.fr
Gomez-Cabrero, David	david.gomez@uv.es
Grimbert, François	francois.grimbert@sophia.inria.fr
Grüning, André	gruening@sissa.it

Guillamon Grabolosa, Antoni	antoni.guillamon@upc.edu
Gutkin, Boris	bgutkin@pasteur.fr
Hansel, David	David.Hansel@biomedicale.univ-paris5.fr
Hertz, John	hertz@nordita.dk
Horta, Claudia	claudia@mct.uminho.pt
Huguet Casades, Gemma	gemma.huguet@upc.edu
Hussein, Anwar	anwarh@mct.uminho.pt
Hynds, Dianna	dhynds@twu.edu
Josic, Kresimir	josic@math.uh.edu
Kopell, Nancy	nk@bu.edu
Langemann, Dirk	langeman@math.uni-luebeck.de
Lansky, Petr	lansky@biomed.cas.cz
Latham, Peter	pel@gatsby.ucl.ac.uk
Lewis, Tim	tlewis@math.ucdavis.edu
Low, Yin Fen	yinfen@cdb-unit.de
Mankin, Emily	emily.mankin@colorado.edu
Martí Ortega, Daniel	daniel.marti@upf.edu
Matías, Manuel	manuel@imedea.uib.es
Medvedev, Georgi	medvedev@drexel.edu
Mirasso, Claudio	claudio@galiota.uib.es
Montejo, Noelia	montejo-@loria.fr
Mukundanunny, Shyam Diwakar	shyam.mukundanunny@unimi.it
Navarra-Madsen, Junalyn	jnavarramadsen@mail.twu.edu
Nykamp, Duane	nykamp@umn.edu
Orosz, Gabor	g.orosz@exeter.ac.uk
Perales Castellanos, Nazareth	nperales@opt.ucm.es
Pérez, Toni	toni@imedea.uib.es
Ponossov, Arkadi	arkadi@umb.no
Rinzel, John	rinzel@cns.nyu.edu
Roche, David	david.roche@uab.es
Roehner, Uwe	u.roehner@biologie.hu-berlin.de
Rotstein, Horacio G.	horacio@math.bu.edu
Rubin, Jonathan	rubin@math.pitt.edu
Rudolph, Michelle	Rudolph@iaf.cnrs-gif.fr
Salvador, Raimon	rs381@wbic.cam.ac.uk
Sánchez-Vives, María Victoria	mavi.sanchez@umh.es
Senn, Walter	wsenn@cns.unibe.ch
Serra, Juan	juan.serra@uab.es
Smith, Brian	brian.h.smith@asu.edu
Smith, Jeffrey C.	jsmith@helix.nih.gov
Sprekeler, Henning	h.sprekeler@biologie.hu-berlin.de
Susmakova,	

Kristina	umersusm@savba.sk
Svensson, Carl-Magnus	pmxcms1@nottingham.ac.uk
Tao, Louis	tao@njit.edu
Teicher, Mina	teicher@macs.biu.ac.il
Terman, David	terman.1@osu.edu
Timofeeva, Yulia	yulia.timofeeva@nottingham.ac.uk
Touboul, Jonathan	jonathan.touboul@ens.fr
Utzet, Frederic	utzet@mat.uab.es
van Hemmen, J. Leo	LvH@ph.tum.de
Venkov, Nikola	nikola.venkov@maths.nottingham.ac.uk
Vladimirskiy, Boris	bbv201@nyu.edu
Wyller, John	john.wyller@umb.no
Zachariou, Margarita	pmxmz@nottingham.ac.uk
Zela, Dritan	dzela@uat.edu
Zhang, Linghai	liz5@lehigh.edu