INTERNATIONAL WORKSHOP IN NEURODYNAMICS (NDY'14)

Castro Urdiales, Cantabria, Spain

July 14-17, 2014

Scientific committee

- Andrey Shilnikov
- Martin Wechselberger
- Stephen Coombes
- Toni Guillamón
- Roberto Barrio

Organizing committee

Computational Dynamics group

- F. Blesa
- A. Dena
- A. Lozano
- M. A. Martínez
- M. Rodríguez
- S. Serrano

http://cody.unizar.es/events/neurodynamics14/

UC UNIVERSIDAD DE CANTABRIA

CANTABRIA CAMPUS INTERNACIONAL

CIEM

EXCMO. AYUNTAMIENTO DE CASTRO URDIALES

Las Rocas Playa Hotel CASTRO URDIALES

1542

Universidad Zaragoza

Contents

1 INTRODUCTION

Neuroscience is nowadays one of the most collaborative and active scientific research fields as it has been increasingly involving the participation of experts from other disciplines. In particular, computational and mathematical aspects of neuroscience are currently playing an important role both in modeling and replicating experimental findings and in explaining the underlying mechanisms of neurophysiological or cognitive processes. Differential equations are ubiquitous in the modeling of such phenomena and, consequently, nonlinear dynamics and dynamical systems techniques become fundamental sources of new mathematical and computational tools to study neuroscience models.

The aim of this Workshop on Neurodynamics (NDy'14) is to present an overview of successful achievements in this rapidly developing collaborative field by putting together different types of applications of nonlinear dynamics (geometrical tools in dynamical systems, numerical methods, computational schemes, dynamical measures,...) to different problems in neuroscience (mononeuronal dynamics, network activity, cognitive problems,...). Additional emphasis will be put on experimental findings seeking for theoretical explanations, and therefore this meeting is focussed on using mathematics as the primary tool for elucidating the fundamental mechanisms responsible for experimentally observed behavior in the applied neurosciences. Importantly, it will draw attention to, those pieces of mathematical theory which are likely to be relevant to future studies of the brain. The final goal is spreading together mathematical methodology and neuroscience challenges and stimulating future cross-collaborations among participants, being Mathematical Neuroscience the generic topic for NDy'14.

2 PROGRAMME

	Monday	Tuesday	Wednesday	Thursday
9:30-10:00		A. Shilnikov	S. Coombes	M. Wechselberger
10:00-10:30		S. Luccioli	E. Vasilaki	P. Varona
10:30-11:00	Reception	M. Rodriguez	M. Komarov	G. Huguet
11:00-11:30	*Coffee break*	*Coffee break*	*Coffee break*	*Coffee break*
11:30-12:00	R. Barrio	J. Touboul	C. Gros	A. Roxin
12:00-12:30	C. Baesens	T. Guillamon	Z.K. Kilpatrick	B. Bruggemeier
12:30-13:00	D. Arroyo	D. Hwang	C. Laing	J.L. Pérez
13:00-13:30	D. Barbieri	P. Faria	A. Torres	T. Akam
13:30-16:00	LUNCH	LUNCH	LUNCH	LUNCH
16:00-16:30	R. Nicks	J. Wang	J. Torres	
16:30-17:00	C. Vich	Y. Wu	A.K. Alijani	
17:00-17:30	E. Avramidis	F. Han	S. Kyeong	

All the talks will be placed at the CIEM center, 4th Maria Aburto street (see the map at the end of the program).

3 COMMITTEES

3.1 Scientific Committee

Roberto Barrio
(Universidad de Zaragoza) Spain.

Stephen Coombes
(University of Nottingham) UK.

Antoni Guillamón
(Universidad Politcnica de Cataluña) Spain.

Andrey Shilnikov
(Georgia State University), USA.

Martin Wechselberger
(University of Sydney) Australia.

3.2 Organizing Committee

Computational Dynamics Group (CODY)
Universidad de Zaragoza, Spain
`http://cody.unizar.es/`

Roberto Barrio (Chair)
Fernando Blesa
Angeles Dena
Alvaro Lozano
M. Angeles Martínez
Marcos Rodríguez
Sergio Serrano

4 ABSTRACTS

Controlling oscillatory network dynamics through closed-loop optogenetic feedback.

T. Akam[1], **D. Kuzmin, F. Carpenter, E. Nicholson, I. Oren and D. Kullmann**

1. Champalimaud Centre for the Unknown, Lisbon, Portugal.
   Email: `thomas.akam@neuro.fchampalimaud.org`

Abstract

Oscillatory network dynamics are implicated in the functioning of healthy neural circuits and in disease pathology. Manipulating or controlling oscillatory dynamics hence has potential applications both for probing the functional role of oscillations in neural computation and as a therapeutic tool. We have explored the potential of closed-loop optogenetic feedback to manipulate oscillatory network dynamics in hippocampal networks in vitro. We create a feedback loop by using a filtered version of the local field potential recorded in the slice to modulate in real-time the intensity of blue light driving channelrhodopsin expressed in CA3 pyramidal cells. By varying the filtering that transforms the field potential into the feedback signal we can independently and bidirectional control the amplitude and frequency of network oscillations in the slice. This closed loop feedback can suppress oscillatory network dynamics without modifying the average firing rate of individual cells. Control experiments in which we use the stimulus generated in closed-loop on one trial to drive the slice in open-loop fashion on a subsequent trial demonstrate that this suppression is not simply an effect of adding noise to the system, but rather reflects active desynchronisation of the network activity by the feedback signal.

Navigational planning on a traveling wave

A.K. Alijani [1]

1. University of Bern. Email:alijani@pyl.unibe.ch

Abstract

Spatial navigation and planning is assumed to involve a cognitive map for evaluating trajectories towards a goal. How such a map is realized in neuronal terms, however, remains elusive. Here we describe a simple and noise robust neuronal implementation of a path finding algorithm in complex environments. We consider a neuronal map of the environment that supports a traveling wave spreading out from the goal location. At each position of the map, local phase differences between adjacent neurons indicate the shortest direction towards the goal. In contrast to diffusion or single-wave-front models, local phase differences build up in time at arbitrary distances from the goal, providing a minimal and robust directional information throughout the map. The time needed to reach the steady state represents an estimate of an animals waiting time before it is heading off to the goal. The model offers a functional interpretation of the enhanced coherence in hippocampal-cortical oscillations during navigational decision making and interprets hippocampal forward and backward replay as a readout and update, respectively, of the cognitive map.

Characterization of neural activity by means of the applied theory of symbolic dynamics

D. Arroyo[1]

1. Universidad Autónoma de Madrid, Spain. Email:`david.arroyo@uam.es`

Abstract

One major challenge in the control of complex dynamics is drawn from the specifics of event detection and characterization. Certainly, the controllability of nonlinear time-variant systems can only be achieved if event classification and categorization is performed in a automatic and fast fashion. In recent works we pinpointed the suitability of the applied theory of symbolic dynamics to such a goal. Indeed, we characterized intra and extra-cellular recordings by means of the corresponding ordinal time series. In this talk we further discuss the outcomes and the shortcomings of this procedure.

Fitting experimental nystagmus waveforms to computational models using multi-objective genetic algorithms executed on a GPU/CPU combination: application to an exemplar motor control system

E. Avramidis[1] **and O. E. Akman**[1]

1. Centre for Systems, Dynamics and Control, University of Exeter, UK.
Email:ea288@exeter.ac.uk; O.E.Akman@ex.ac.uk

Abstract

Infantile nystagmus is a condition that causes an involuntary, bilateral and conjugate oscillation of the eyes that are predominately restricted to the horizontal plane. Computational models are important in making predictions, and creating a quantitative framework for the analysis of the oculomotor system. Parameter estimation is a critical step in the construction and analysis of these models. The search space is often high dimensional and complex, and calculating the model output for each parameter combination is very computationally intensive. We show that a multi-objective genetic algorithm (MGA), with a fitness function that measures the period and shape of nystagmus waveforms, can fit the parameters of an exemplar oculomotor model to experimental recordings. We accelerated the MGA by running it on a central processing unit (CPU) - graphics processing unit (GPU) combination. This provided a speedup of 25 compared with running the same MGA on a midrange CPU. Moreover, we developed a method that fully exploits the GPUs capabilities by running multiple independent MGAs in parallel. This is critical for selecting the MGAs parameters, because the stochastic nature of MGAs requires multiple runs with the same MGA parameters to test the validity of the results generated. For the same reason, multiple runs are needed each time a new nystagmus waveform is used to fit the oculomotor model parameters. On our application to the exemplar model, this parallel method provided a speedup of 2.2 compared with running the same number of MGAs serially. This speedup depended on the MGA population size, meaning that greater speedups could potentially be obtained by applying the method to optimization problems requiring smaller populations. The accelerated version of the MGA proposed here alleviates the use of a computer cluster which is costly, and does not provide independent and exclusive use.

Chaotic Breathing

C. Baesens [1] **and R.S. MacKay** [1,2]

1. Mathematics Institute, University of Warwick, United Kingdom.
   Email: `Claude.Baesens@warwick.ac.uk`

2. Centre for Complexity Science, University of Warwick, United Kingdom.
   Email: `R.S.MacKay@warwick.ac.uk`

Abstract

On exposure to opiates, preparations from rat brain stems have been observed to continue to produce regular expiratory signals but to fail to produce some inspiratory signals [1]. The times between two successive inspirations form an apparently random sequence of multiples of the average expiratory period (see Figure 1), a phenomenon which has been coined "chaotic quantal slowing down of inspiration".

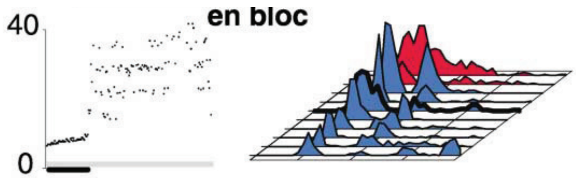

Figure 1: Sequential plot and histograms of inspiratory period for an en bloc in vitro preparation of rat brain stem before and after treatment with an opiate agonist, showing quantal slowing down of inspiration (reproduced with permission from J.L. Feldman).

Here we propose an explanation based on the qualitative theory of dynamical systems. A relatively simple scenario for the dynamics of interaction between the generators of expiratory and inspiratory signals produces pseudo-random behaviour of the type observed.

References

[1] Feldman, J.L., Del Negro, C.A.: Looking for inspiration: new perspectives on respiratory rhythm. *Nature Reviews Neuro.* **7** (2006) 232–42.

[2] Baesens, C., MacKay, R.S.: Analysis of a Scenario for Chaotic Quantal Slowing Down of Inspiration. *The Journal of Mathematical Neuroscience* (2013) **3**:18.

Cortical geometry and dynamics for motion integration

D. Barbieri[1]

1. Departamento de Matematicas, Universidad Autónoma de Madrid. Email: `davide.barbieri8@gmail.com`

Abstract

The cognitive problem of good continuation of spatio-temporal visual stimuli performed by the visual cortex can be addressed by taking into account the dynamics of orientation and speed-selective visual receptive fields together with their connections. The underlying geometry can be described in terms of the 5 dimensional fiber bundle of the local positions and activation times and the locally detected orientations and transversal speeds, endowed with a natural contact structure which defines the admissible connectivity. Signal propagation of boundaries and trajectories information can then be treated with partial differential equations describing geometric diffusion, extending works of D.Mumford to this higher dimensional geometry, combined with a nonlinear mechanisms of population activity based on the early works of H.Wilson, J.Cowan and B.Ermentrout. This approach is able to reproduce psychophysical and neurophysiological findings on cortical responses of motion detection such as those described in 2011 by W.Wu, P.Tiesinga, T.Tucker, S.Mitroff and D.Fitzpatrick, "Dynamics of Population Response to Changes of Motion Direction in Primary Visual Cortex". This is a joint work with G.Citti, G.Cocci and A.Sarti, appeared as "A Cortical-Inspired Geometry for Contour Perception and Motion Integration" on J. Math. Imaging Vis. and available at http://dx.doi.org/10.1007/s10851-013-0482-z Participation will be supported by the E.U. FP7-PEOPLE-IEF project "HAViX, Harmonic Analysis for optimal coding and the design principles of brains Visual corteX" (D.Barbieri).

Describing chaotic structures in the Hindmarsh-Rose model of bursting neurons

R. Barrio[1], **M.A. Martinez**[1], **S. Serrano**[1], **M. Lefranc**[2] **and A. Shilnikov**[3]

1. Computational Dynamics group, Department of Applied Mathematics, University of Zaragoza, Spain. Email: `rbarrio,geli,sserrano@unizar.es`

2. Laboratoire de Physique des Lasers, Atomes, et Molecules, CNRS, Villeneuve d'Ascq, France. Email: `Marc.Lefranc@univ-lille1.fr`

3. Neuroscience Institute and Department of Mathematics and Statistics, Georgia State University, USA. Email: `ashilnikov@gsu.edu`

Abstract

In this talk we study a plethora of chaotic phenomena in the Hindmarsh-Rose neuron model with the use of several computational techniques including the bifurcation parameter continuation, spike-quantification and evaluation of Lyapunov exponents in bi-parameter diagrams. We demonstrate how the organizing centers – points corresponding to codimension-two homoclinic bifurcations – along with fold and period-doubling bifurcation curves structure the biparametric plane, thus forming macro-chaotic regions resembling "onion bulb scales" and revealing spike-adding cascades that generate micro-chaotic structures due to the hysteresis. Moreover, we describe the topological changes in the structure of the chaotic attractors and their influence in the system.

References

[1] Barrio, R., Lefranc, M., Martinez, M.A., Serrano, S.: Successive topological changes in neuron models. *Preprint* (2014).

[2] Barrio, R., M., Martinez, M.A., Serrano, S., Shilnikov, A.: Macro- and micro-chaotic structures in the Hindmarsh-Rose model of bursting neurons. *Chaos* **24** (2014) 023128.

[3] Linaro, D., Champneys, A., Desroches, M., Storace, M.: Codimension-Two Homoclinic Bifurcations Underlying Spike Adding in the Hindmarsh–Rose Burster. *SIAM Journal on Applied Dynamical Systems* **11** (2012) 939-962. 11 (3), 939-962

Drosophila *courtship song: modeling behavioral pattern as function of neural and muscle dynamics*

B. Brüggemeier[1], **S. Goodwin**[1] **and M.A. Porter**[2]

1. Department of Physiology, Anatomy and Genetics, University of Oxford.

2. Mathematical Institute, University of Oxford, England.

Abstract

Background: Courtship patterns in fruit flies are innate, yet complex and variable. The male fruit fly *Drosophila melanogaster* sings to the female by extending and vibrating his wing. In this way, the male fly produces two modes of song: pulse and sine. The biological community has mapped song production to a set of neurons and muscles. However, this hard-wired system produces diverse and adaptive song. We aim to explain the variability of song with dynamic interaction of neurons and muscles.

Modeling efforts: We have developed a model with two essential components to it: a reaction part (mutual inhibition of neurons controlling pattern generation of sine and pulse) and a decay part (dynamics of muscle contraction).

Results: With preliminary simulations, we have reproduced empirical findings and mimicked the diversity of song patterns. There are two patterns to song we consider: amplitude of song bouts and switches between types of song. Song bouts typically start at low amplitudes, successively increase in amplitude until a maximum is reached and then decrease. Our model suggest that this structure can be explained by muscle contraction dynamics as we assume amplitude-modifying muscles: their level of contraction corresponds to song amplitude. Our model ascribe switches between sine and pulse song both to neuronal and muscle dynamics.

Outlook: Based on our model we assume muscle dynamics to play an essential role in behavioral pattern generation of courtship song of the male fruit fly. We aim to test the potential link between muscle dynamics and song structure with three approaches: 1. Playing back simulated courtship song to flies, to test their responsiveness to song structures associated with different muscle properties. 2. Comparing the song of *Drosophila* muscle mutants with hyper- and hypo-contractible muscles with predictions of our model. 3. Imaging of muscle contraction during courtship song with x-ray microtomography.

Networks of neural oscillators

S. Coombes [1]

1. Centre for Mathematical Medicine and Biology, School of Mathematical Sciences, University of Nottingham, University Park, Nottingham, NG7 2RD, UK.
   Email: `stephen.coombes@nottingham.ac.uk`

Abstract

A common approach in computational neuroscience is to assume that a single neuron or neural mass model with a strongly attracting limit-cycle can be described solely by its phase on cycle. Given the transform from the original phase space to the circle one can then build networks of phase-oscillators. This makes sense if the coupling is weak (so that limit-cycles persist), and one may use the infinitesimal phase response curve for the uncoupled unit to build network interactions. I use this approach to probe the way in which structural connectivity (anatomy) can affect functional connectivity (synchrony) in networks of interacting Wilson-Cowan mass models [1]. However, ignoring motion away from the limit cycle cannot capture shear-induced chaos, i.e., chaotic behaviour that results from the amplification of small perturbations by underlying shear [2]. To address this issue I will discuss the use of phase-amplitude coordinates that allow one to track the evolution of distance from the cycle as well as phase on the cycle. I will illustrate how this can provide a better description of single unit response to both periodic and stochastic forcing [3], and discuss how it can pave the way for a better understanding of network dynamics.

References

[1] Hlinka, J., Coombes, S.: Using computational models to relate structural and functional brain connectivity, *European Journal of Neuroscience*, **36** (2012) 2137-2145.

[2] Lin, K. K, Wedgwood, K. C. A., Coombes, S., Young, L-S.: Limitations of perturbative techniques in the analysis of rhythms and oscillations, *Journal of Mathematical Biology* (2013) **66** 139–161.

[3] Wedgwood, K. C. A., Lin, K .K., Thul, R., Coombes, S.: Phase-amplitude descriptions of neural oscillator models, *Journal of Mathematical Neuroscience* (2013) **3**.

An artificial model for single neuron behaviour: a computer-aided approach

P. Faria[1] and **C. Lourenço**[2]

1. Research Group Neurophysiology, University of Leuven, Belgium.
   Email: `pedrolaf@gmail.com`

2. Department of Informatics, Faculty of Sciences, University of Lisbon, Portugal. Instituto de Telecomunicações, Portugal. Email: `csl@di.fc.ul.pt`

Abstract

The Hodgkin-Huxley equations, first introduced in the early 50s, provided the framework for ensuing and more detailed studies on the properties of single neurons. The associated dynamical system, however, exhibits complex behaviour which makes it hard to analyze. To overcome this hindrance one usually reduces the dimension of the original system, with the help of ordinary dimensional reduction techniques, obtaining systems of two or three dimensions (instead of the original four) that still capture many of the same fundamental behaviours. In his book, *Dynamical Systems in Neuroscience: The Geometry of Excitability and Bursting* [1], Eugene Izhikevich introduces a few hybrid (partially discrete) bidimensional and tridimensional models which do exactly that, whilst having very low computational overhead when compared to the original Hodgkin-Huxley model. Inspired by an example mentioned in Izhikevich's book we decided to investigate how well one could approximate these behaviours, using an artificial continuous bidimensional model. To achieve this, a computational approach was taken, capitalizing on the high-level tools of *Mathematica*.

References

[1] Eugene M. Izhikevich. *Dynamical Systems in Neuroscience: The Geometry of Excitability and Bursting*, edited by Terrence J. Sejnowski and Tomaso A. Poggio, MIT Press, 2007.

[2] Alwyn Scott. *Neuroscience: A Mathematical Primer*, Springer-Verlag, New York, 2002.

Objective Functions Guiding Adaptive Neurodynamics

C. Gros[1]

1. Institute for Theoretical Physics, Goethe University Frankfurt, Germany. Email: `gros07@itp.uni-frankfurt.de`

Abstract

Two venues are open for modelling the constituent equations for neurodynamics. One may either attempt to reproduce experimental observations with high fidelity, or postulate governing principals for generating functionals, viz for objective functions, from which suitable equations of motions may then be derived. We discuss the pro and cons of using objective functions and present two information-theoretical generating functionals. The first objective functions is the Kullback-Leibler divergence for the neural firing rate used for optimizing the information content of the neural activity. From this functional adaption rates for the intrinsic neural parameters, such as the gain and the threshold, may be derived. We present results both for single neurons and recurrent networks of various sizes. One finds that generating functionals allow to guide neural behavior, such as chaotic intermittency, transient state dynamics and attractor metadynamics, via the higher parameters characterizing the respective objective function. The second objective function is given by the Fisher information for the neural firing rate. It may be used to derive Hebbian learning-rules for the synaptic weights, which are self-limiting and which lead to a principal component analysis of the statistics of the afferent inputs. We find that this approach leads to an important perspective. There are many ways to formulate Hebbian learning rules, like Ojas rule, which are all equivalent on a basic level. They differ however in important other aspects. For example when the input statistics changes, shall the system unlearn the old input statistics immediately or shall unlearning be a slow process? We show that the new Hebbian learning rules differs qualitatively in this and other secondary aspects.

Dynamics of phase and amplitude response functions in transient states

O.. Castejón[1], T. Guillamón[1] and G. Huguet[1]

1. Dept. of Applied Mathematics I, Universitat Politcnica de Catalunya, 08028, Barcelona. Email: `antoni.guillamon@upc.edu`

Abstract

The phase response curve (PRC) is a powerful tool to study the effect of a perturbation on the phase of an oscillator (limit cycle), assuming that all the dynamics can be explained by the phase variable. However, factors like the rate of convergence to the oscillator, strong forcing or high stimulation frequency may invalidate the above assumption and raise the question of how is the phase variation away from an attractor. The concept of isochron turns out to be crucial to answer this question; from it, we propose an extension of advancement functions to the transient states by defining the Phase Response Functions (PRF) and the Amplitude Response Function (ARF) to control changes in the transversal variables. Based on the knowledge of both the PRF and the ARF, we study the case of a pulse-train periodic stimulus, and compare the predictions given by the PRC-approach (a 1D map) to those given by the PRF-ARF-approach (a 2D map); we observe differences up to two orders of magnitude in favor of the 2D predictions, especially when the stimulation frequency is high or the strength of the stimulus is large. We identify the role of the hyperbolicity of the limit cycle as well as geometric aspects of the isochrons as possible explanations of these differences. Apart from the comparison between 1D and 2D predictions, we also pay attention to interesting bifurcations in the 2D maps that do not occur when using 1D prediction maps. Summing up, we aim at enlightening the contribution of transient effects in predicting the phase response and showing the limits of the phase reduction approach to prevent from falling into wrong predictions concerning synchronization.

Robust Synchronization of Inhibitory Burstin Hodgkin-Huxley Neuronal Networks with Synaptic Plasticity

F. Hang[1], **Y. Du**[2],**Z. Wang**[1]

1. College of Information Science and Technology, Donghua University, Shanghai, China. Email: yadiahan@163.com

2. Institute for Cognitive Neurodynamics, School of Science, East China University of Science and Technology, Shanghai, P. R. China.

Abstract

Synchronized firing of bursting neurons has been found in many neuronal systems. In this paper, a modified bursting Hodgkin-Huxley neuronal model is proposed and used to construct inhibitory neuronal systems with synaptic plasticity considered, and then the effect of the synaptic parameters and synaptic plasticity on synchronization of the system is studied. It is found that the robustness of the synchronization is sensitive to the parameter values of synaptic conductance and synaptic delay, but is less sensitive to the parameter values of synaptic decay time. It is also found that synaptic plasticity has little effect on synchronization of the neuronal system.

Neuronal excitability, oscillations and coincidence detection

G. Huguet [1]

1. U. Politécnica Cataluña, Spain. Email: gemma.huguet@upc.edu

Abstract

Some neurons fire only phasically, say, once or a few times, at the onset of an adequate depolarizing current step but not for steady or slow inputs. This property of phasic firing is known as Type III excitability. In contrast, tonic neurons (Type I or II excitability) fire repetitively under adequate constant stimulation, setting aside slow adaptation.

In this talk, I will first review the mathematical framework for understanding generic transitions from resting to repetitive firing activity in single neuron models. I will then discuss methods to study properties of periodically spiking neurons using the concepts of isochrons and phase response curves. In particular, I will present fast algorithms to compute these objects up to high order. Finally, I will focus on some features of Class III-excitable systems and contrast their potential for exquisite temporal precision with that of systems that can fire repetitively. We developed reduced models that permit phase-plane analysis and thereby prediction and insight into the phasic firing properties. For the reduced models we identify and interpret geometrically distinguishing features, such as nearness to threshold and a temporal integration window, that enable phasic spikers to out-shine tonic spikers for temporal precision and coincidence detection.

Functional relation between fluctuation and node degree in coupled stochastic dynamical systems

D. Hwang[1]

1. National Institute for Mathematical Sciences, Rep. of Korea.
Email: `duhwang@nims.re.kr`

Abstract

Recently there have been growing interests for inferring the network structure from measuring nodal time series. The source of these interests arises from many scientific areas. Examples are interacting proteins or genes, complex brain networks, ecological food webs, etc. In this regard, recently Wang et al. (2009) showed that from collective dynamics of oscillator network system that in the presence of noisy, the time averaged fluctuation of each node scales with node degree in coupled stochastic dynamical systems. We extend the approaches for obtaining functional relation to the weighted network whose link weight is dependent on the node degree such as proportional to $1/k^{\beta}$, where$k$ is degree of the node. The functional relation was measured in various network, such as Erdos Renyi random graphs, Watts-Strogatz small world networks, Barabasi-Albert scale-free networks, and configuration models, by using consensus dynamics, Rössler system, and Kuramoto oscillators. For the network with strong heterogeneity in degree distribution, we find that the theoretical result derived from the approaches in Wang et al. (2009) shows disagreement with numerical results especially in the case of when β is larger than 1 and configuration model irrespective of dynamical models. We found that this disagreement comes from neglecting fluctuation from first neighbor, which is marginal in previous studies. However, in our cases, the the contributed fluctuation from its neighbor becomes significant. In this respect, we propose novel approaches using the average of higher order moments and improve the accuracy of functional relation between noisy fluctuation and node degree by exploiting Fourier transformation. Our analytic results compensate previous disagreement significantly in lower degree nodes, and predict numerical results precisely. Also, we investigate the functional relation of noisy fluctuation versus node input strength. And more realistic situations where the dependence of interaction on degree are randomized, we can observe the influence coming from lower degree nodes, and confirm that this kind of fluctuation can give erratic results when one try to infer characteristics of network from nodal time series.

Pulse bifurcations in stochastic neural fields

Z.P. Kilpatrick[1] **and G. Faye**[2]

1. Department of Mathematics, University of Houston, Houston, Texas, United States of America. Email:zpkilpat@math.uh.edu

2. Department of Mathematics, University of Minnesota, Minneapolis, Minnesota, United States of America.

Abstract

We study the effects of additive noise on traveling pulse solutions in spatially extended neural fields with linear adaptation. Neural fields are evolution equations with an integral term characterizing synaptic interactions between neurons at different spatial locations of the network. We introduce an auxiliary variable to model the effects of local negative feedback and consider random fluctuations by modeling the system as a set of spatially extended Langevin equations whose noise term is a Q-Wiener process. Due to the translation invariance of the network, neural fields can support a continuum of spatially localized bump solutions that can be destabilized by increasing the strength of the adaptation, giving rise to traveling pulse solutions. Near this criticality, we derive a stochastic amplitude equation describing the dynamics of these bifurcating pulses when the noise and the deterministic instability are of comparable magnitude. Away from this bifurcation, we investigate the effects of additive noise on the propagation of traveling pulses and demonstrate that noise induces wandering of traveling pulses. Our results are complemented with numerical simulations.

The Kuramoto model of coupled oscillators with a bi-harmonic coupling function

M. Komarov[1]

1. Potsdam University, Department of Physics and Astronomy.
   Email: `maxim.a.komarov@gmail.com`

Abstract

We study the Kuramoto model of globally coupled oscillators with a bi-harmonic coupling function. We develop an analytic self-consistency approach to find stationary synchronous states in the thermodynamic limit, and demonstrate that there is a huge multiplicity of such states, which differ microscopically in the distributions of locked phases. These synchronous regimes exist already prior to linear instability transition of the fully asynchronous state. In the presence of white Gaussian noise the multiplicity is lifted, but the dependence of the order parameters on coupling constants remains nontrivial.

Brain network modular structure of two opposite temperament groups in dimensions of novelty seeking and harm avoidance

S. Kyeong[1] and E. Kim[2] and H.-J. Park[3] and D.-U. Hwang[1]

1. Division of Computational Sciences in Mathematics, National Institute for mathematical Sciences, Daejeon, S. Korea. Email: `skyeong@nims.re.kr`
2. Department of Psychiatry and Institute of Behavioral Science in Medicine, Yonsei University College of Medicine, Seoul, S. Korea.
3. Department of Nuclear Medicine, Yonssei University College of Medicine, Seoul, S. Korea.

Abstract

R. Cloninger [1] has confirmed that psychobiological model of personality to account for individual variations in temperament and character. Temperament dimensions were originally proposed to be independent of on another. However, a meta-analysis by Miettunen *et al.* (2008) [2] found a significant negative correlation between temperament traits, especially significant negative correlation between harm avoidance (HA) and novelty seeking (NS). Based on this negative correlation, the current study revealed the whole-brain connectivity modular architecture for two contrasting temperament groups. Here we analyzed modular architecture for the functional and morphometric brain network and measured similarity between two groups as well as between functional and morphometric network. Subjects and Methods: 40 healthy volunteers (mean age = 25.23.3 years) took part in this experiment. High resolution structural image and resting state fMRI were acquired. The Korean version of the temperament and character inventory (TCI) was used to assess temperament and character factors. To classify 40 subjects into two groups, we used k-means clustering algorithm with HA and NS as input vectors. Average functional networks for each group were constructed for studying modular architecture. The positive edge weights of the group-averaged functional network matrix formed by Pearsons correlations were subjected to the graph theoretical modularity estimation algorithm, which characterizes the segregation of a network [3]. Similarity measure defined by normalized mutual information was used to compare the modular architecture between two groups. .

40 healthy volunteers (mean age = 25.2 ± 3.3 years) took part in this experiment. High resolution structural image and resting state fMRI were acquired. The Korean version of the TCI (including 140-items) was used

to assess temperament and character factors. To classify 40 subjects into two groups, we used k-means clustering algorithm with HA and NS as input vectors. Average functional networks for each group were constructed for studying modular architecture. The positive edge weights of the group-averaged functional network matrix formed by Pearsons correlations were subjected to the graph theoretical modularity estimation algorithm, which characterizes the segregation of a network [3]. Similarity measure defined by normalized mutual information was used to compare the modular architecture between two groups.

Using the k-means clustering algorithm, 19 subjects were clustered into a group having high HA and low NS, 21 subjects were clustered into a group having low HA and high NS. In the functional network module analysis, we found that the overall network modular organizations showed a similar pattern except for sub-network structure among the prefrontal cortex (PFC), basal ganglia (BG), and limbic system. In high HA and low NS group, the regulatory brain regions, such as the PFC, are clustered together with the limbic system. This finding suggest that the neural basis of inhibited, passive, and inactive behaviors in the high HA and low NS group was derived from the increased network association between the PFC and limbic clusters.

References

[1] C. R. Cloninger: A Systematic Method for Clinical Description and Classification of Personality Variants, *Arch. Gen. Psychiatr* **44** (1987) 573–588.

[2] J. Miettunen, E. Lauronen, L. Kantojrvi, and J. Veijola: Inter-correlations between Cloninger's temperament dimensions – a meta-analysis, *Psychiatry Research* **160** (2008) 106–114.

[3] M. E. J. Newman: Finding community structure in networks using the eigenvectors of matrices, *Physical Review* E **74** (2006) 036104.

Waves in spatially-disordered neural fields

C.R. Laing[1]

1. Institute of Natural and Mathematical Sciences, Massey University, Auckland, New Zealand. Email: `c.r.laing@massey.ac.nz`

Abstract

Neural field models have been used for many years to model a variety of macroscopic spatiotemporal patterns in the cortex. Most authors have considered homogeneous domains, resulting in equations that are translationally invariant. However, there is an obvious need to better understand the dynamics of such neural field models on heterogeneous domains. One way to include heterogeneity is through the introduction of randomly-chosen "frozen" spatial noise to the system. We investigate the effects of including such noise on the speed of a moving "bump" of activity in a particular neural field model. The spatial noise is parameterised by a large but finite number of random variables, and the effects of including it can be determined in a computationally efficient way using ideas from the field of Uncertainty Quantification. To determine the average speed of a bump in this type of heterogeneous domain involves evaluating a high-dimensional integral, and a variety of methods are compared for doing this. We find that including heterogeneity of this form in a variety of ways always slows down the moving bump.

Functional hubs in developmentally regulated neural networks

S. Luccioli[1], **E. Ben-Jacob**[2], **A. Barzilai**[3], **P. Bonifazi**[2] **and A. Torcini**[1]

1. Consiglio Nazionale delle Ricerche, Istituto dei Sistemi Complessi, Italy. Email: `stefano.luccioli@fi.isc.cnr.it`
2. Beverly and Sackler Faculty of Exact Sciences School of Physics and Astronomy, Tel Aviv University, Israel.
3. Department of Neurobiology, George S. Wise Faculty of Life Sciences and Sagol School of Neuroscience, Tel Aviv University, Israel.

Abstract

It has recently been discovered that single neuron stimulation can impact network dynamics in immature and adult neuronal circuits [1]. In this work [2] we report a novel mechanism which can explain in developing neuronal circuits, typically composed of only excitatory cells, the peculiar role played by a few specific neurons in promoting/arresting the population activity. For this purpose, we consider a standard neuronal network model, with short-term synaptic plasticity, whose population activity is characterized by bursting behavior. The addition of developmentally regulated constraints on single neuron excitability and connectivity leads to the emergence of functional hub neurons, whose perturbation (through stimulation or deletion) is critical for the network activity. Functional hubs form a clique, where a precise sequential activation of the neurons is essential to ignite collective events without any need for a specific topological architecture.

References

[1] Bonifazi, P., Goldin, M., Picardo, M.A., Jorquera, I., Cattani, A., Bianconi, G., Represa, A., Ben-Ari, Y., Cossart, R.: Gabaergic hub neurons orchestrate synchrony in developing hippocampal networks. *Science* **326** (2009) 1419–1424.

[2] Luccioli, S., Ben-Jacob, E., Barzilai, A., Bonifazi, P., Torcini, A.: Clique of functional hubs orchestrates population bursts in developmentally regulated neural networks. *PLoS Comput. Biol.*, submitted.

Standing and travelling waves in a spherical brain model

S. Coombes [1], **R. Nicks** [2] **and S. Visser** [3]

1. School of Mathematical Sciences, University of Nottingham, UK.
   Email: `stephen.coombes@nottingham.ac.uk`
2. School of Mathematics, University of Birmingham, UK.
   Email: `r.nicks@bham.ac.uk`
3. School of Mathematical Sciences, University of Nottingham, UK.
   Email: `sid.visser@nottingham.ac.uk`

Abstract

In this talk we will discuss the Nunez model for the generation of electroencephalogram signals described as a neural field model on a sphere. We realise this model as an integrodifferential equation on the surface of a sphere with space-dependent delays. We will discuss the spatio-temporal patterns which can arise in this model due to a bifurcation from a steady state. These patterns are found and investigated using a mixture of Turing instability analysis, symmetric bifurcation theory, weakly non-linear analysis and direct simulations with a bespoke numerical scheme. We also show that the emergence of quasi-periodic behaviour observed in numerical simulations can be understood in terms of secondary bifurcations.

References

[1] S. Coombes, R. Nicks and S. Visser: Standing and travelling waves in a spherical brain model: the Nunez model revisited. In preparation.

Fluctuations in brain signals in health and pathology

J.L.. Pérez Velázquez [1], **R. Fernández Galán** [2], **V. Nenadovic** [1], **M. Tariqus Salam** [3] **and R. Genov** [3]

1. Neuroscience and Mental Health Programme, Brain and Behaviour Centre, Division of Neurology, Hospital for Sick Children; Institute of Medical Science and Department of Paediatrics, University of Toronto, Toronto, Ontario, Canada. Email: `jlpv@sickkids.ca`

2. Department of Neurosciences, School of Medicine, Case Western Reserve University, Cleveland, Ohio, USA

3. Department of Electrical and Computer Engineering, University of Toronto, Toronto, Canada.

Abstract

We have studied the fluctuations in the brains coordinated activity derived from magnetoencephalographic and electroencephalographic recordings in epilepsy, autism and traumatic brain injury. We present evidence for lower variability of the brain signals, and especially of the spatio-temporal patterns of synchronization, during pathological states. A certain high level of fluctuations in the collective activities of the nervous systems cell networks is required for adaptive behaviours, whereas decreased variability compromises the integration and segregation of information in the brain needed for efficient information processing. We present efficient approaches to discriminate between typical and atypical (or pathological) brains from macroscopic brain dynamics, and provide illustrations of the usefulness of assessing fluctuations of brain signals in patient prognosis after brain injury [1], in reducing seizures in epilepsy [2], and in differentiating individuals with and without autism [3]. However, the question of what the boundaries are in the level of fluctuations/variability in brain signals in order to optimally process information remains unanswered. We seek theoretical bases that could account for the possible existence of boundaries of the variability in brain activity and that could, in principle, be useful in clinical settings.

References

[1] Nenadovic, V., Pérez Velázquez, J.L., Hutchison, J.S.: Phase synchronization in electroencephalographic recordings prognosticates outcome in paediatric coma. *PLoS ONE* **9(4)** (2014) e94942.

[2] Pérez Velázquez, J.L., García Domínguez, L., Nenadovic, V., Wennberg, R.: Experimental observation of increased fluctuations in an order parameter before epochs of extended brain synchronization. *Journal of Biological Physics* **37** (2011) 141-152.

[3] García Domínguez, L., Pérez Velázquez, J. L., Fernández Galán, R.: A model of functional brain connectivity and background noise as a biomarker for cognitive phenotypes: application to autism. *PLoS ONE* **8(4)** (2013) e61493. doi:10.1371/journal.pone.0061493

Computational tools for analysis of bursting polyrhythms in 3-cell CPG

M. Rodríguez[1], **R. Barrio**[2], **S. Serrano**[2] **and A. Shilnikov**[3]

1. Computational Dynamics group, Centro Universitario de la Defensa Zaragoza, Spain. Email: `marcos@unizar.es`
2. Computational Dynamics group, Department of Applied Mathematics, University of Zaragoza, Spain. Email: `rbarrio,sserrano@unizar.es`
3. Neuroscience Institute and Department of Mathematics and Statistics, Georgia State University, USA. Email: `ashilnikov@gsu.edu`

Abstract

We study the formation of some rhythmic states in various 3-cell network motifs of a multifunctional central pattern generator (CPG) via several computational tools. The study is complemented with a detailed analysis of a single leech heart neuron, including bifurcations, spike-counting techniques and Lyapunov exponents, that gives a "roadmap" for the basic neuron. We locate a complete route of Andronov-Hopf and heteroclynic cycle connections in the 3-cell leech heart neurons and we illustrate the use of advanced GPU computing technologies and suitable numerical algorithms.

References

[1] Barrio, R., Rodríguez, M., Serrano, S., Shilnikov, A.: Computational techniques to describe low dimensional central pattern generators. *Preprint* (2014).

[2] Barrio, R., Rodríguez, M., Serrano, S.: Heteroclinic cycles in 3-cell central pattern generators. *Preprint* (2014).

[3] Wojcik, J., Clewley, R., Schwabedal, J., Shilnikov, A.: Key bifurcations of bursting polyrhythms in 3-cell central pattern generators. *PLoS ONE* **9** (2014), e92918.

Exact mean-field descriptions of networks of heterogeneous quadratic integrate-and-fire neurons

A. Roxin[1] and **D. Pazó**[2] and **E. Montbrió**[3]

1. Centre de Recerca Matemàtica, Bellaterra, Spain. Email: `aroxin@crm.cat`
2. Instituto de Física de Cantabria, Santander, Spain.
   Email: `pazo@ifca.unican.es`
3. University Pompeu Fabra, Barcelona, Spain.
   Email: `ernest.montbrio@upf.edu`

Abstract

Firing-rate models are a key tool for investigating the collective dynamics of large networks of neurons. They most often take the form of a single, first-order ordinary differential for each neuronal population, which allows for both rapid numerical simulation as well as detailed mathematical analysis. Nonetheless, firing-rate models do not represent exact mathematical reductions of the original network dynamics but rather are heuristic. As such, they provide at most qualitative insight into the network dynamics of interest, and there is in general no straightforward relationship between the parameters of the rate model and those of the network. Here we derive the exact low-dimensional model describing the mean-field dynamics in a population of recurrently coupled quadratic integrate-and-fire neurons. Interestingly, we find that the complete description of the meanfield dynamics is governed not only by the firing rate, but also by another meaningful macroscopic variable: the mean of the distribution of suthreshold potentials.

Key bifurcations of bursting polyrhythms in central pattern generators

J. Wojcik [1], **R. Clewley** [2,3], **J. Schwabedal** [2] **and** **A. Shilnikov** [2,3]

1. Applied Technology Associates, Albuquerque, New Mexico, USA.
2. Neuroscience Institute, Georgia State University, USA.
3. Department of Mathematics and Statistics, Georgia State University, USA. Email: `ashilnikov@gsu.edu`

Abstract

We identify and describe the key qualitative rhythmic states in various 3-cell network motifs of a multifunctional central pattern generator (CPG). Such CPGs are neural microcircuits of cells whose synergetic interactions produce multiple states with distinct phase-locked patterns of bursting activity. To study biologically plausible CPG models, we develop a suite of computational tools that reduce the problem of stability and existence of rhythmic patterns in networks to the bifurcation analysis of fixed points and invariant curves of a Poincare return maps for phase lags between cells. We explore different functional possibilities for motifs involving symmetry breaking and heterogeneity. This is achieved by varying coupling properties of the synapses between the cells and studying the qualitative changes in the structure of the corresponding return maps. Our findings provide a systematic basis for understanding plausible biophysical mechanisms for the regulation of rhythmic patterns generated by various CPGs in the context of motor control such as gait-switching in locomotion. Our analysis does not require knowledge of the equations modeling the system and provides a powerful qualitative approach to studying detailed models of rhythmic behavior. Our approach is applicable to a wide range of biological phenomena beyond motor control.

References

[1] Wojcik J., Clewley R., Schwabedal J. and Shilnikov A.L., Key bifurcations of bursting polyrhythms in 3-cell central pattern generators. *PLoS ONE* **9**(4): e92918, 2014. doi:10.1371/journal.pone.0092918

[2] Wojcik J., Clewley R, and Shilnikov A., Order parameter for bursting polyrhythms in multifunctional central pattern generators. *Physics Review E* **83**, 056209–6, 2011. doi:10.1103/PhysRevE.83.056209

Information processing in neural systems through stochastic resonance phenomena

J.J. Torres [1]

1. Institute "Carlos I" for Theoretical and Computational Physics and Department of Electromagnetism and Matter Physics, University of Granada, Spain. Email: `jtorres@onsager.ugr.es`

Abstract

In this talk, I review some of our recent research concerning the transmission of weak signals in different neural media in the presence of noise [1, 2, 3]. In particular, I focus my talk on the emergence of stochastic resonance phenomena in biologically inspired neural networks. I discuss, for instance, the relevance that synaptic mechanisms responsible for short-term synaptic plasticity have on the emergence and features of stochastic resonance in these systems. The results of our studies demonstrate that these synaptic processes allow the system to efficiently process the information encoded in the weak signals at different levels of the noise intensity, at which the system also present a phase transition, resulting in the appearance of stochastic multiresonances. Finally, I discuss on the relevance that the observation of stochastic multiresonances may have to detect phase transitions in the brain.

References

[1] Mejias, J.F., Torres, J.J.: Emergence of resonances in neural systems: the interplay between adaptive threshold and short-term synaptic plasticity. *PLoS ONE* **6**(3) (2011) e17255.

[2] Pinamonti, G., Marro, J., Torres, J.J.: Stochastic resonance crossovers in complex networks. *PLoS ONE* **7**(12) (2012) e51170.

[3] Torres, J.J., Elices, I., Marro, J.: preprint (2014)

Propagation of probabilistic uncertainty in neurodynamical systems

A. Torres Valderrama [1,2]

1. CWI, Science Park 123, 1098 XG Amsterdam, The Netherlands.

2. Department of Neurology and Neurosurgery, UMC Utrecht. Heidelberglaan 100, 3584 CX Utrecht, The Netherlands. Email: `atorresv@cwi.nl`

Abstract

Variability is a trademark of realistic neurodynamical systems, for instance, synaptic inputs can elicit responses in one cell but not in another, and neurons can have different responses to the same inputs or identical responses to distinct inputs. Experimental and computational evidence suggest that such variability is not a nuisance, but that it might be an integral component of brain computations. Deterministic models formulated as differential equations cannot account for such variability, but they can be extended to do so by incorporating random parameters. However, without the use of accurate dimensionality reduction algorithms, the computational cost grows exponentially with the number of parameters, challenging the capacities of current hardware. We will discuss computationally efficient methods to investigate uncertainty propagation in neurodynamical models, and obtain an accurate probabilistic interpretation of their output. We will study how variability affects neurocomputational properties of realistic neurons, and how uncertainty quantification methods can be employed to investigate complex systems beyond individual cells, such as small neural networks and signal transmission in neural media, at a feasible computational cost.

On retarded canards: Complex oscillations in delayed slow-fast systems

J. Touboul[1] **and Maciej Krupa**[2]

1. Mathematical Neuroscience Laboratory,Collge de France,France.
   Email: `jonathan.touboul@college-de-france.fr`

2. INRIA Paris-Rocquencourt Centre, France

Abstract

We analyze canard explosions in delayed differential equations with a one-dimensional slow manifold. This study is applied to explore the dynamics of the van der Pol slow-fast system with delayed self-coupling. In the absence of delays, this system provides a canonical example of a canard explosion. The presence of delays significantly enriches the dynamics, and varying the delay induces canard explosion, mixed mode oscillations as well as transitions to complex bursting periodic orbits. We show that as the delay is increased a family of 'classical' canard explosions ends as a Bogdanov-Takens bifurcation occurs at the folds points of the S-shaped critical manifold. Canard explosion and mixed-mode oscillations are investigated by means of geometric perturbation analysis, and bursting by means of slow-fast periodic averaging.

Models of transient sequential neural dynamics.

P. Varona[1]

1. Universidad Autonoma de Madrid, Spain. Email: `pablo.varona@uam.es`

Abstract

Transient dynamics in experimental neuroscience are often observed as a chain of sequentially changing activity. A straightforward mathematical image for robust transient neural dynamics is a stable heteroclinic channel consisting of a chain of saddles -metastable states- connected by unstable separatrices. Recent neurophysiological and cognitive experiments support the point of view that this image is adequate for the understanding, characterization and prediction of many features observed in experimental neural recordings ranging from the activity of simple sensory and motor systems all the way up to the dynamics of cognitive processes. In this talk, we will describe several models based on this theoretical formalism that are able to produce robust sequential dynamics at different description levels. We will also discuss their possible use to implement goal-driven closed-loop activity-dependent stimulation in neuroscience experimental research.

Emergence of connectivity motifs via the interaction of long-term and sort-term plasticity.

E. Vasilaki [1]

1. University of Sheffield, UK. Email: `e.vasilaki@sheffield.ac.uk`

Abstract

The identification of synaptic mechanisms that underlie learning and memory is a key challenge for neuroscience. These mechanisms are currently assumed to be captured by persistent modifications to the synaptic connections among neurons. Synaptic connections in microcircuits and networks are not random; experimental observations indicate the existence of specific microscopic patterns (or connectivity motifs), with non-random features. However, it is unclear how plasticity of individual synaptic connections contributes to the formation of the observed motifs. In particular, for cortical pyramidal neurons, the degree of bidirectional connectivity varies significantly between the visual and somatosensory cortex areas ([1, 2]). Recent evidence in prefrontal cortex ([3]) and in the olfactory bulb (Pignatelli, Markram, and Carleton, unpub. data) suggest that some other features of synaptic physiology, such as the short-term dynamical nature of the synapse, may be correlated to specific connectivity motifs. The causes for these structural differences are still unknown. I will present a theory based on a phenomenological, long-term synaptic plasticity "learning rule" ([4, 5]) that is able to accurately reproduce a vast corpus of experimental data. The rule captures dependencies on both the timing and frequency of neuronal signals, providing a very simple mechanistic explanation for the emergence of connectivity motifs ([5, 6, 7]) while shedding light on the long debate about the nature of the neuronal code.

References

[1] Song, S., Sjstrm, P.J., Reigl, M., Nelson, S. and Chklovskii, D.B.: Highly nonrandom features of synaptic connectivity in local cortical circuits. *PLoS Biol* **3** (2005) e350.

[2] Lefort, S., Tomm, C., Sarria, J.C.F. and Petersen, C.C.H.: The excitatory neuronal network of the C2 barrel column in mouse primary somatosensory cortex. *Neuron* **61** (2009) 301-316.

[3] Wang Y., Markram H., Goodman P., Berger T., Ma J., Goldman-Rakic, P.: Heterogeneity in the pyramidal network of the medial prefrontal cortex. *Nature Neurosci* **9(4)** (2006) 534-42.

[4] Pfister J.-P. and Gerstner W.: Triplets of spikes in a model of spike timing-dependent plasticity. *J. Neurosci.* **26** (2006) 9673-9682.

[5] Clopath, C., Buesing, L., Vasilaki, E. and Gerstner, W.: Connectivity reflects coding: a model of voltage-based STDP with homeostasis. *Nature Neurosci* **13** (2010) 344-352.

[6] Vasilaki, E. and Gugliano, M.: Emergence of Connectivity Patterns in Networks of Model Neurons from Long-Term and Short-Term Plasticities. *ICANN 2012*, Lausanne, Switzerland.

[7] Vasilaki, E. and Giugliano, M. *PLOS ONE* **9(1)** (2014) e84626. doi:10.1371/journal.pone.0084626.

Difficulties, challenges and solutions in the estimation of synaptic conductances

A. Guillamon[1] **and** **C. Vich**[2]

1. Department of Applied Mathematics I, EPSEB, Universitat Politècnica de Catalunya, 08028, Barcelona.

2. Department of Mathematics and Computer Science, Universitat de les Illes Balears, 07122, Palma. Email: `catalina.vich@uib.es`

Abstract

A "local" simplified situation to unveil brain's connectivity is finding out which signal is receiving a single neuron subjected to a bombardment of synaptic inputs and discerning the temporal contributions of excitation from those of inhibition. This quantitative information is important for the integrative properties of cortical neurons. Due to the multitude of synaptic contacts, obtaining direct measurements of the synaptic input becomes unrealistic. Therefore, inverse methods appear as an alternative to estimate the input conductances from experimental measurements. An extended strategy is filtering the voltage and then assume an input-output relationship. We have shown, using computational models, that this linearity hypothesis is unreliable both during spiking and in non-spiking regimes with ionic activity. We will illustrate the latest situation using a conductance-based model endowed both with an after hyperpolarizing and low-subthreshold currents to show that the subthreshold activity can lead to significant errors in synaptic conductance estimation. Our results add a warning message about extracting conductance traces from intracellular recordings and the conclusions concerning neuronal activity that can be drawn from them. We will also present new attempts to provide theoretical efficient methods to obtain realistic estimations from intracellular recordings. From a mathematical point of view, it is a problem of parameter estimation that can be treated as an inverse problem in dynamical systems or using other tools like Bayesian inference.

Fastest strategy to achieve given number of neuronal firing in theta model

J. Wang[1], **Q. Wang**[2] **and G. Chen**[3]

1. College of science, Tianjin University of Technology and Education, Tianjin 300222, China. Email: `jiaoyanwang@163.com`

2. Department of Dynamics and Control, Beihang University, Beijing 100191, China.

3. Department of Electronic Engineering, City University of Hong Kong, Hong Kong Special Administrative Region.

Abstract

We investigate the constrained optimization of excitatory synaptic input patterns to fastest generate given number of spikes in theta neuron model. Optimal input timings and strengths are identified by using phase plane arguments for discrete input kicks with a given total magnitude. Furthermore, analytical results are conducted to estimate the firing time of given number of spikes resulting from a given input train. We obtain the fastest strategy as the total input size increases. In particular, when the parameter $-b$ is large and total input size G is not so large, there are two candidate strategies to fastest achieve given number of spikes, which depend on the considered parameters. The fastest strategy for some cases of $G \gg -b$ to fire m spikes should partition m spikes into $m-n+1$ spikes for the highest band, with largest g, and one spike for each subsequent $n-1$ band. When G is sufficiently large, big kick is the fastest strategy. In addition, we establish an optimal value for the dependent variable, θ, where each input should be delivered in a non-threshold-based strategy to fastest achieve given output of subsequent spikes. Moreover, we find that reset and kick strategy is the fastest when G is small and $G \gg -b$. The obtained results can lead to a better understanding of how the period of nonlinear oscillators are affected by different input timings and strengths.

Neural bursts, averaging and canards

K.-L. Roberts [1], **J. Rubin** [2] and **M. Wechselberger** [1]

1. School of Mathematics & Statistics, University of Sydney, Australia.
   Email: `wm@maths.usyd.edu.au`

2. Department of Mathematics, University of Pittsburgh, USA.

Abstract

Bursting behavior in neurons has been the focus of significant theoretical attention due to both its mathematical complexity and its central role in driving repetitive actions such as respiration and hormone release. A wide variety of forms of bursting that arise in fast-slow single-neuron models are well understood based on fast-slow decomposition, identification of fast subsystem bifurcation structures, and averaging, and these methods also can be used to explain transitions between quiescence, bursting, and tonic spiking in single neurons. Transitions between such activity patterns in neuronal network models, however, are much less well understood.

In this talk, we identify generic bifurcation scenarios corresponding to transitions between bursting and tonic spiking solutions in a model for a coupled pair of burst-capable neurons, and we elucidate the central role of folded singularities in these scenarios. The folded singularities in our work arise in the context of fast-slow averaging (see, e.g., [1]) and hence our results link with the study of torus canards, a recently identified class of ordinary differential equation (ODE) solutions featuring oscillatory excursions along repelling structures in phase space [2]; in particular, our work extends this study to systems featuring two slow variables and symmetry and goes significantly beyond the analysis presented in [3].

References

[1] Cymbalyuk & Shilnikov (2005), *J. Comp. Neurosci.* **18**, 255-263.

[2] Burke et al (2012), *J. Math. Neurosci.* **2**, 3.

[3] Best et al (2005), *SIAM J. Appl. Dyn. Syst.* **4**, 1107-1139.

The dynamic behavior of spiral waves in Hodgkin-Huxley neuronal networks with ion channel blocks

Y. Wu[1] **and S. Liu**[1]

1. State key Laboratory for strength and Vibration of Mechanical Structure, School of Aerospace, Xi'an Jiaotong University, Xi'an, China.
   Email: `wying36@163.com`

Abstract

Chemical blocking is known to affect neural network activity. Here, we quantitatively investigate the dynamic behavior of spiral waves in stochastic Hodgkin-Huxley neuronal networks during sodium or potassium-ion channel blockages.When the sodium ion channels are blocked, the spiral waves first become sparse and then break. The critical factor for the transition of spiral waves (xNa) is sensitive to the channel noise. However, with the potassium-ion channel block, the spiral waves first become intensive and then form other dynamic patterns. The critical factor for the transition of spiral waves (xK) is insensitive to the channel noise. With the sodium-ion channel block, the spike frequency of a single neuron in the network is reduced, and the collective excitability of the neuronal network weakens. By blocking the potassium ion channels, the spike frequency of a single neuron in the network increases, and the collective excitability of the neuronal network is enhanced. Lastly, we found that the behavior of spiral waves is directly related to the system synchronization. This research will enhance our understanding of the evolution of spiral waves through toxins or drugs and will be helpful to find potential applications for controlling spiral waves in real neural systems.

5 PARTICIPANTS

A

Thomas Akam
Champalimaud Centre for the Unknown, Lisbon, Portugal.
thomas.akam@neuro.fchampalimaud.org

Azadeh Khajeh Alijani
University of Bern
alijani@pyl.unibe.ch

David Arroyo
Universidad Autónoma de Madrid.
david.arroyo@uam.es

E. Avramidis
Centre for Systems, Dynamics and Control, University of Exeter, UK.
ea288@exeter.ac.uk

B

Claude Baesens
Mathematics Institute, University of Warwick, United Kingdom.
Claude.Baesens@warwick.ac.uk

Davide Barbieri
Departamento de Matematicas, Universidad Autónoma de Madrid.
davide.barbieri8@gmail.com

Roberto Barrio
Computational Dynamics group, Department of Applied Mathematics, University of Zaragoza, Spain.
rbarrio@unizar.es

Fernando Blesa
Computational Dynamics group, Departamento de Física Teórica, University of Zaragoza, Spain.
fblesa@unizar.es

Birgit Brüggemeier
Department for Physiology, Anatomy and Genetics, University of Oxford, England.
birgit.bruggemeier@magd.ox.ac.uk

C

Stephen Coombes
Centre for Mathematical Medicine and Biology, School of Mathematical Sciences, University of Nottingham, Nottingham, NG7 2RD, UK.
stephen.coombes@nottingham.ac.uk

D

Angeles Dena
Computational Dynamics group, Centro Universitario de la Defensa Zaragoza, Spain.
adena@unizar.es

F

P. Faria
Research Group Neurophysiology, University of Leuven, Belgium.
pedrolaf@gmail.com

G

Claudius Gros
Institute for Theoretical Physics, Goethe University Frankfurt, Germany.
gros07@itp.uni-frankfurt.de

Antoni Guillamon
Department of Applied Mathematics I, EPSEB, Universitat Politècnica de Catalunya, 08028, Barcelona.
antoni.guillamon@upc.edu

H

Fang Han
Donghua University, China.
yadiahan@163.com

Gemma Huguet
Dept. of Applied Mathematics I, Universitat Politècnica de Catalunya, 08028, Barcelona.
gemma.huguet@upc.edu

Dong-Uk Hwang
National Institute for Mathematical Sciences, Rep. of Korea.
duhwang@nims.re.kr

K

Zachary P. Kilpatrick
Department of Mathematics and Center for Neuro-Engineering and Cognitive Science, University of Houston, Houston, Texas, United States of America.
zpkilpat@math.uh.edu

Maxim Komarov
Potsdam University, Department of Physics and Astronomy, Potsdam, Germany.
maxim.a.komarov@gmail.com

S. Kyeong
Division of Computational Sciences in Mathematics, National Institute for mathematical Sciences, Daejeon, S. Korea.
skyeong@nims.re.kr

L

Carlo R. Laing
Institute of Natural and Mathematical Sciences, Massey University, Auckland, New Zealand.
c.r.laing@massey.ac.nz

Alvaro Lozano
Computational Dynamics group, Centro Universitario de la Defensa Zaragoza, Spain.
alvarolozano@unizar.es

Stefano Luccioli
Consiglio Nazionale delle Ricerche, Istituto dei Sistemi Complessi, Italy.
stefano.luccioli@fi.isc.cnr.it

M

M. Angeles Martínez
Computational Dynamics group, Department of Applied Mathematics, University of Zaragoza, Spain.
gelimc@unizar.es

N

Rachel Nicks
School of Mathematics, University of Birmingham, UK.
r.nicks@bham.ac.uk

P

José L. Pérez
Neuroscience and Mental Health Programme, Brain and Behaviour Centre, Division of Neurology, Hospital for Sick Children; Institute of Medical Science and Department of Paediatrics, University of Toronto, Toronto, Ontario, Canada.
jlpv@sickkids.ca

R

Marcos Rodríguez
Computational Dynamics group, Centro Universitario de la Defensa Zaragoza, Spain.
marcos@unizar.es

Alex Roxin
Centre de Recerca Matemàtica, Bellaterra, Spain.
aroxin@crm.cat

S

Sergio Serrano
Computational Dynamics group, Department of Applied Mathematics, University of Zaragoza, Spain.
sserrano@unizar.es

Andrey Shilnikov
Neuroscience Institute, Georgia State University, USA.
ashilnikov@gsu.edu

T

Aldemar Torres Valderrama
CWI, Science Park 123, 1098 XG Amsterdam, The Netherlands.
atorresv@cwi.nl

Joaquín J. Torres
Institute "Carlos I" for Theoretical and Computational Physics and Department of Electromagnetism and Matter Physics, University of Granada, Spain.
jtorres@onsager.ugr.es

Jonathan Touboul
Mathematical Neuroscience Laboratory, France.
jonathan.touboul@college-de-france.fr

V

Pablo Varona
Universidad Autonoma de Madrid.
pablo.varona@uam.es

Eleni Vasilaki
University of Sheffield, UK.
e.vasilaki@sheffield.ac.uk

Catalina Vich
Department of Mathematics and Computer Science, Universitat de les Illes Balears, 07122, Palma.
catalina.vich@uib.es

W

Jiaoyan Wang
College of science, Tianjin University of Technology and Education, Tianjin 300222, China.
jiaoyanwang@163.com

Martin Wechselberger
School of Mathematics & Statistics, University of Sydney, Australia.
wm@maths.usyd.edu.au

Weronika Wojtak
University of Minho, Braga, Portugal.
w.wojtak@gmail.com

Ying Wu
State key Laboratory for strength and Vibration of Mechanical Structure, School of Aerospace, Xi'an Jiaotong University, Xi'an, China.
wying36@163.com

6 OTHER INFORMATION

All the talks will be placed at the CIEM center, 4th Maria Aburto street.

Lunches

Lunches will be served at Hotel Las Rocas at 13:30.

Figure 2: Location of the CIEM and the two main hotels.

Workshop Dinner

The Workshop Dinner will be on Wednesday 16th at 21:00 at Hotel Las Rocas.