OM&P

DYNAMICS IN LIFE SCIENCES, NEUROSCIENCE APPLICATIONS WORKSHOP

Experimental Studies of Anticipative Dynamics in Neuronal Networks

*José Jiun-Shian Wu**

Institute of Physics, Academia Sinica, Taipei, Taiwan 115,R.O.C.
* Presenting e-mail: coolneon@gmail.com

Understanding how neural systems integrate sensory signals to perceive time is a fundamental problem. However, the basic neuronal mechanism of temporal perception is still far from clear. Currently, there is a debate on whether a specialized clock is needed for time perception (TP). Our view is that TP can be a general property of neural networks endowed with short-term synaptic plasticity (STSP) and enough recurrent connections. Recent simulation studies of anticipative dynamics (one form of TP) support this later mechanism. The goals of our proposed experiments are: i) to demonstrate that STSP is crucial in the anticipative dynamics in the retina of frogs and ii) to induce anticipative dynamics in a cortical neuronal culture of rats by using a recently invented photo-sensitive technique based on the organic semi-conducting polymers, P3HT, and the optogenetic tool, Channelrhodosin-2. Since there are no special clock circuits in the retina and the cortical culture, results our proposed works will help to clear some of the controversies in the perception of time.

Temporal Correlations in Neuronal Spikes Induced by Noise and Periodic Forcing

*J. M. Aparicio Reinoso, M. C. Torrent and C. Masoller**

Departament de Fisica, Universitat Politecnica de Catalunya, Terrassa, Barcelona, Spain.
* Presenting e-mail: cristina.masoller@upc.edu

In sensory neurons the presence of noise can facilitate the detection of weak information-carrying signals [1], which are encoded and transmitted via correlated sequences of spikes. Here we investigate relative temporal order in spike sequences induced by a subthreshold periodic input, in the presence of white Gaussian noise. To simulate the spikes, we use two neuron models (FitzHugh-Nagumo, FHN, and integrate-and-fire, IF), and to investigate the output sequence of inter-spike intervals (ISIs), we use the symbolic method of ordinal analysis [2]. This method transforms the ISI sequence into a sequence of ordinal patterns, which are defined in terms of the relative ordering of consecutive ISIs. We find different types of relative temporal order, in the form of preferred ordinal patterns which depend on both, the strength of the noise and the period of the input signal [3]. We also demonstrate a resonance-like behavior, as certain periods and noise levels enhance temporal ordering in the ISI sequence, maximizing the probability of the preferred patterns. Our findings could be relevant for understanding the mechanisms underlying temporal coding, by which single sensory neurons represent in spike sequences the information about weak periodic stimuli.

Acknowledgements

This work has been supported in part by the Spanish MINECO (FIS2015-66503-C3-2-P) and ITN NETT (FP7- 289146). C. M. also acknowledges partial support from ICREA ACADEMIA.

References

1. L. Gammaitoni, P. Hnggi, P. Jung, and F. Marchesoni Rev. Mod. Phys. 70, 223 (1998).
2. C. Bandt and B. Pompe, Phys. Rev. Lett. 88, 174102 (2002).
3. JM. Aparicio Reinoso, MC Torrent and C. Masoller, http://arxiv.org/abs/1510.09035v2

Extreme Events in Bursting Neurons

*Arindam Mishra[1,2], Suman Saha[1], Hilda Cerdeira[3], Syamal K. Dana[1]**

[1] CSIR-Indian Institute of Chemical Biology, Jadavpur, Kolkata 700032, India;
[2] Department of Physics, Jadavpur University, Kolkata 700032, India;
[3] Instituto de Física Teórica, UNESP, Universidade Estadual Paulista, Rua Dr. Bento Teobaldo Ferraz 271, Bloco II, Barra Funda, 01140-070 São Paulo, Brazil.
* Presenting e-mail: syamaldana@gmail.com

Coexisting coherent and noncoherent subpopulations in networks of identical oscillators hitherto called as chimera states [1-3] is intriguing, however, existence of such pattern is observed in many systems under both nonlocal coupling and global coupling. We reported [4] such chimera-like states in globally coupled oscillators under the influence of both attractive and repulsive coupling, which is a common type of coupling in biological networks, in other words, there they are called as excitatory and inhibitory coupling. We further extended this work to an ensemble of bursting neurons taking the Hindamarsh-model as the dynamical units, however, using purely repulsive global coupling. We find clear evidence of chimera-like states in a parameter space. Surprisingly, in the noncoherent subgroup of oscillators, we observe signatures of extreme event as intermittent extreme value amplitude of the dynamical variable in the nearest neighbors of dynamical units. The temporal dynamics of the dynamical units in the noncohrent subgroup separately does not reveal signature of the extreme events, however, local mean-field as a microscopic dynamics clearly shows large excursion from their average value that follows a log-tail Gaussian distribution.

To understand the mechanism of the coexisting extreme events, we took a simple two dynamical units' model of the Hindmarsh-Rose system under pure repulsive coupling which shows presence of extreme events. Two coupled bursting neurons establish antiphase (out-of-phase) synchronization when the repulsive coupling strength crosses a threshold. Near the threshold, the coupled dynamics shows intermittent jumps from the antiphase synchronization manifold as large excursions. The large excursion amplitudes in a long run of the dynamical variable show dragon-king [5] like probability distribution with a long tail. For a network of large number oscillators, the coherent subpopulation is in regular dynamical state while the noncoherent population is in a chaotic mode where the temporal dynamics of some of the oscillators intermittently jumps to large values. This is reflected as large excursion in their mean field dynamics that follows non-Gaussian statistics.

Acknowledgements

A.M. is supported by the University Grant Commission (UGC), India. S.S and S.K.D. are supported by the CSIR (India) Emeritus Scientist Scheme. S.K.D. also acknowledges support by the FAPESP (Grant No.2011/11973-4), Sao Paulo, Brazil and the Indo-Russian programme supported by DST-RFBR.

References

1. Y. Kuramoto, Battogtokh, Nonlin. Phen. Complex Syst 5, 380 (2002).
2. D.M. Abrams and S.H. Strogatz, Phys.Rev.Letts. 93, 174102 (2004).
3. G. C. Sethia and A. Sen, Phys. Rev. Letts. 112, 144101 (2014).
4. A.Mishra, C.R.Hens, M.Bose, P.K.Roy, S.K.Dana, Phys. Rev. E 92, 062920 (2015); C. R. Hens, A.Mishra , P.K.Roy , A, Sen and S. K. Dana, Pramana —J. Phys. 84 (2), 229 (2015)
5. H.L. D. de S. Cavalcante, M. O., D. Sornette, E. Ott, D. J. Gauthier, Phys. Rev. Letts. 111, 198701 (2013).
6. A.Mishra, S. Saha, H. Cerdeira, S. K. Dana, (in preparation).

Semi-Analytical Approach to Criteria for Ignition of Excitation Waves

*B. Bezekci, I. Idris, R. D. Simitev, V. N. Biktashev**

College of Engineering, Mathematics and Physical Sciences, University of Exeter.
* Presenting e-mail: v.n.biktashev@exeter.ac.uk

We consider the problem of ignition of propagating waves in one-dimensional bistable or excitable systems by an instantaneous spatially extended stimulus. Earlier we proposed a method (Idris and Biktashev, PRL, vol 101, 2008, 244101) for analytical description of the threshold conditions based on an approximation of the (center-)stable manifold of a certain critical solution. Here we generalize this method to address a wider class of excitable systems, such as multicomponent reaction-diffusion systems and systems with non-self-adjoint linearized operators, including systems with moving critical fronts and pulses. We also explore an extension of this method from a linear to a quadratic approximation of the (center-)stable manifold, resulting in some cases in a significant increase in accuracy. The applicability of the approach is demonstrated on five test problems ranging from archetypal examples such as the Zeldovich--Frank-Kamenetsky equation to near realistic examples such as the Beeler-Reuter model of cardiac excitation. While the method is analytical in nature, it is recognised that essential ingredients of the theory can be calculated explicitly only in exceptional cases, so we also describe methods suitable for calculating these ingredients numerically. rameter (See equation 1). In many experimental setups, a model that allows for couplings which include higher harmonics is needed, such as electrochemical oscillators and φ-Josephson junctions. Moreover, coupling terms can be nonlinear functions of the order parameters. It has also been shown that such a model is microscopically equivalent to a fully connected hypernetwork where interactions are via triplets.

Neuroprotective Role of Gap Junctions in a Neuron Astrocyte Network Model

*David Terman**

Dept. of Mathematics, Ohio State University, USA.
* Presenting e-mail: terman.1@osu.edu

A detailed biophysical model for a neuron/astrocyte network is developed in order to explore mechanisms responsible for the initiation and propagation of cortical spreading depolarizations and the role of astrocytes in maintaining ion homeostasis, thereby preventing these pathological waves. Simulations of the model illustrate how properties of spreading depolarizations, such as wave-speed and duration of depolarization, depend on several factors, including the neuron and astrocyte Na-K ATPase pump strengths. In particular, we consider the neuroprotective role of astrocyte gap junction coupling. The model demonstrates that a syncytium of electrically coupled astrocytes can maintain a physiological membrane potential in the presence of an elevated extracellular potassium concentration and efficiently distribute the excess potassium across the syncytium. This provides an effective neuroprotective mechanism for delaying or preventing the initiation of spreading depolarizations.

Spike-Adding in Parabolic Bursting: the Role of Folded-Saddle Canards

*Mathieu Desroches**

Inria, Sophia Antipolis - Méditerranée, France.
* Presenting e-mail: mathieu.desroches@inria.fr

In this talk I will present a new approach to studying parabolic bursting. Looking at classical parabolic bursters such as the Plant model from the perspective of slow-fast dynamics, reveals that the number of spikes per burst may vary upon parameter changes. However the spike-adding process occurs in an explosive fashion that involves special solutions called canards. This spike-adding canard explosion phenomenon can be analysed by using tools from geometric singular perturbation theory in conjunction with numerical bifurcation techniques. The bifurcation structure persists across all considered parabolic bursters, namely the Plant model and the Baer-Rinzel-Carillo phase model. That is, spikes within the burst are incremented via the crossing of an excitability threshold given by a particular type of canard orbit, namely the true canard of a folded-saddle singularity. Using these findings, a new polynomial approximation of the Plant model is constructed, which retains all the key elements for parabolic bursting including spike-adding transitions organized by folded-saddle canards. Finally, I will briefly explain the presence of canard-mediated spike-adding transitions in planar phase models of parabolic bursting, namely the theta model (or Atoll model) by Ermentrout and Kopell.

Quantification of Fast Presynaptic Ca^{2+} Kinetics Using Non-Stationary Single Compartment Model

*Y. Timofeeva[1,2] *, D.A. Rusakov[3], K.E. Volynski[3]*

[1] Department of Computer Science ,
[2] Centre for Complexity Science, University of Warwick, Coventry, UK;
[3] UCL Institute of Neurology, London, UK.
* Presenting e-mail: Y.Timofeeva@warwick.ac.uk

Fluorescence imaging is an important tool in examining Ca^{2+} -dependent machinery of synaptic transmission. Classically, deriving the kinetics of free Ca^{2+} from the fluorescence recorded inside small cellular structures has relied on singe-compartment models of Ca^{2+} entry, buffering and removal. In many cases, steady-state approximation of Ca^{2+} binding reactions in such a model allows elegant analytical solutions for the Ca^{2+} kinetics in question1-3. However, the fast rate of action potential driven Ca^{2+} influx can be comparable with the rate of Ca^{2+} buffering inside the synaptic terminal. In this case, computations that reflect non-stationary changes in the system might be required for obtaining essential information about rapid transients of intracellular free Ca^{2+} refs4-6. Based on the experimental data we propose an improved procedure to evaluate the underlying presynaptic Ca^{2+} kinetics. We show that in most cases the non-stationary single compartment model provides accurate estimates of action-potential evoked presynaptic Ca^{2+} concentration transients, similar to that obtained with the full 3D diffusion model. Based on this we develop a computational tool aimed at stochastic optimisation and cross-validation of the kinetic parameters based on a single set of experimental conditions. The proposed methodology provides robust estimation of Ca^{2+} kinetics even when a priori information about endogenous Ca^{2+} buffering is limited.

References

1. Rozov et al. J. Physiol. (2001).
2. Maravall et al. Biophys. J. (2000).
3. Helmchen et al. Biophys. J. (1997).
4. Scott & Rusakov J. Neurosci. (2006).
5. Ermolyuk et al. PLoS Biol. (2012).
6. Ermolyuk et al. Nat. Neurosci. (2013).

Bursting Synchronization, Pattern Bifurcations and Control Strategies of Central Pattern Generators

*Roberto Barrio[1] *, Alvaro Lozano[2], Marcos Rodríguez[2], Sergio Serrano[1], Andrey Shilnikov[3]*

[1] University of Zaragoza, Zaragoza, Spain;
[2] Centro Universitario de la Defensa, Zaragoza, Spain;
[3] Georgia State University, Atlanta, USA.
* Presenting e-mail: rbarrio@unizar.es

The study of the synchronization patterns of small neuron networks that control several biological processes has become an interesting growing discipline (Wojcik et al., 2014). The development of new methods to help in the visualization and location of these synchronization patterns is currently a quite important task. A direct approach to study bursting rhythmic patterns of small neuron networks (see (Wojcik et al., 2014)) is the analysis of fixed points (FPs) and invariant cycles (ICs) in the Poincare return map for phase lags between neurons. That is, in a 3-cell network, we take one cell as the reference one and we study the phase lags φ_21, φ_31. With these data for several initial phase lags, we can generate a bidimensional picture with the evolution of the delays showing the convergence to different rhythmic patterns. Using the combination of these techniques we are able to aggregate big data to parametrically continue FPs and ICs of the maps and to fully disclose their bifurcation unfoldings as the network configuration is varied (Barrio et al., 2015). In Fig. 1 we show how the use of these techniques may reveal (Barrio et al., 2015) the existence of heteroclinic cycles (it is shown the previous limit cycle before the bifurcation giving rise to the heteroclinic cycle) between saddle fixed points (FP) and invariant circles (IC) in a 3-cell Central Pattern Generator (CPG) network of leech heart neurons. Such a cycle underlies a robust "jiggling" behavior in bursting synchronization (Barrio et al., 2015).

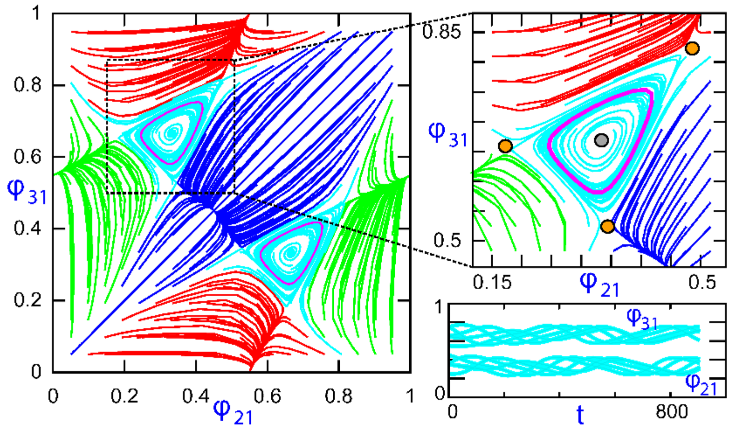

Fig. 1. *Evolution of the time delays after the Andronov-Hopf bifurcation in a 3-cell network of leech heart neurons*

Some of these synchronization patterns of individual neurons are related with some undesirable neurologic diseases, and they are believed to play a crucial role in the emergence of pathological rhythmic brain activity in different diseases, like Parkinson's disease. We show how, with a suitable combination of short and weak global inhibitory and excitatory stimuli over the network, we can switch between different stable bursting patterns in small neuron networks (in our case a 3-neuron network). We have developed a systematic study (Lozano et al., 2016) showing and explaining the effects of applying the pulses at different moments. Moreover, we apply the technique on a completely symmetric network and on a slightly perturbed one (a more realistic situation). The approach of using global stimuli, as in the case of applying a current or a chemical substance to all the network, allows one to avoid undesirable synchronization patterns with nonaggressive stimuli. In Fig. 2 we show the result of the use of the global stimuli to the symmetric network.

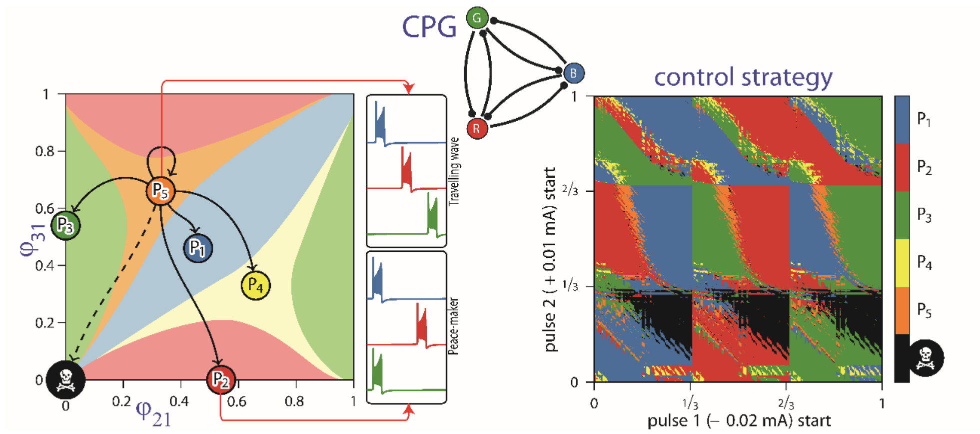

Fig. 2. *Different synchronization patterns and the result of the application of the control strategy to the network*

The control technique takes advantage of the information given by detailed biparametric "roadmaps" (Barrio & Shilnikov, 2011; Barrio et al., 2014). Such a roadmap provides an exhaustive information (Wojcik et al., 2014) about the dynamics of a single neuron that one must have in order to build small neuron networks and to study rhythmogenesis in central pattern generators (CPG).

Acknowledgements

R.B., M.R. and S.S. have been supported during this research by the Spanish Research projects MTM2012-31883 and MTM2015-64095-P, the University of Zaragoza/CUD project UZCUD2015-CIE-05 and by the European Social Fund and Diputacion General de Aragon (Grant E48). A.L. has been supported during this research by the Spanish Research project MTM2013-46337-C2-2-P, the University of Zaragoza/CUD project UZCUD2015-CIE-05 and by the European Social Fund and Diputacion General de Aragon (Grant E15). A.S. acknowledges the support from RFFI 11-01-00001, RSF grant 14-41-00044 at the Lobachevsky University of Nizhny Novgorod, and the grant in the agreement of Aug. 27, 2013 N 02.B.49.21.0003 between The Ministry of Education and Science of the Russian Federation and Lobachevsky State University of Nizhni Novgorod (Sections 2-4), as well as NSF grant IOS-1455527.

References

1. WOJCIK J, SCHWABEDAL J., CLEWLEY R. & SHILNIKOV A. (2014): Key bifurcations of bursting polyrhythms in 3-cell central pattern generators, PloS ONE, 9 (4), e92918.
2. LOZANO A., RODRIGUEZ M. & BARRIO R. (2016): Control strategies of 3-cell Central Pattern Generator via global stimuli, Scientific Reports, in press.
3. BARRIO R. & SHILNIKOV A. (2011): Parameter-sweeping techniques for temporal dynamics of neuronal systems: case study of the Hindmarsh-Rose model, J Mathematical Neuroscience, 1 (6), 1-22.
4. BARRIO R., MARTINEZ MA., SERRANO S. & SHILNIKOV A. (2014): Macro and micro-chaotic structures in the Hindmarsh-Rose model of bursting neurons. Chaos, 24 (2), 023128.
5. BARRIO R., RODRIGUEZ S., SERRANO S. & SHILNIKOV A. (2015): Mechanism of quasi-periodic lag jitter in bursting rhythms by a neuronal network, EPL, 112 (3), 38002.

Frequency and Hemispheric Specialization of Brain Activity in Convergent and Divergent Thinking: the Intelligence Effect

*O.M. Razumnikova[1,2] *, K.D. Krivonogova[1], A.A. Yashanina[1,2]*

[1] Novosibirsk State Technical University, Novosibirsk, Russia;
[2] State Research Institute of Physiology and Basic Medicine, Novosibirsk, Russia.
* Presenting e-mail: razoum@mail.ru

The actual problem of current research in cognitive activity is the study of the organization of different forms of thinking. J. P. Guilford introduced the concepts of convergent and divergent thinking, representing a fundamentally different form of solution to the problem: in the first case, the goal is to find the only correct solution to the problem, while the second - generation of set of alternative ideas [2]. A quantitative measure of the success of convergent thinking (CT) can be considered as the level of intelligence, since it used the criterion of measuring the only answer; the effectiveness of divergent thinking (DT) can estimate the parameters of creativity: fluency generation of ideas and originality. Transition from convergent to divergent thinking in creative problem solving, as well as different points of view on the relationship of intelligence and creativity [4, 7] induce the question about the causes of these differences, which can be resolved at the neurophysiological level. In this regard, the aim of the work was to study the relation of intelligence and changes of bioelectrical activity of the cerebral cortex in convergent and divergent thinking.

The study involved 46 students of NSTU. Verbal, figurative and arithmetic components of intelligence were determined by Amthauer's test. To register 19-channell EEG, the program "Mitsar EEG-201" (St. Petersburg, Russia) was used. EEG was recorded in three functional states: baseline, in situations of CT (sequential addition in the mind of the prime numbers) and DT (decision of heuristic problem). Throughout all experimental conditions (resting, CT, and DT) participants had their eyes closed. Data processing was based on 30 artifact-free EEG signals with Han windowed epochs of 2 s. The averaged spectral power density for the six frequency ranges from delta to beta 2 using fast Fourier transformation was calculated.

CT-induced EEG changes were found in the delta and theta range with increased power delta rhythm, significant for left-hemispheric activity and theta rhythm - the right hemisphere. Delta oscillations during DT increased in both the left and right hemisphere, another EEG correlate of DT was to strengthen the right-hemispheric alpha 2oscillations. The analysis of regional effects showed that the increase of CT associated delta rhythm was represented in the frontal areas, whereas DT - covering widespread cortical areas. The right hemispheric increase of alpha2 rhythm during DT was presented in posterior cortex whereas the left hemispheric effect as compared to the CT was generalized. Given that the change in the power of delta rhythm is associated with "internal" attention while enhancing cognitive load [3], we can conclude that the solution of the heuristic task requires the use of large brain resources, combining the functions of both hemispheres, and changes in the theta rhythm in the CT can be explained by increased support attention needed to perform arithmetic operations and preservation in the working memory of intermediate summation results [6]. DT related changes of alpha2 activity are consistent with the concepts of "defocused" or internal attention required finding an original idea [1,5].

It was found significant positive relationship between the arithmetic intelligence and the success of CT (calculated amount) (see Figure), and between verbal or figurative and spatial components of the intelligence and efficiency of DT (originality of ideas).

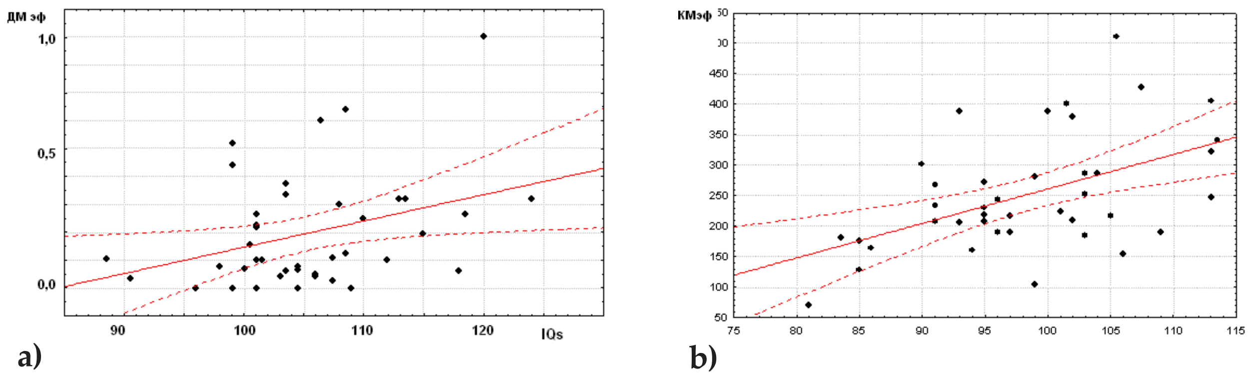

Figure 1. Relationships between convergent thinking efficiency (CT) and arithmetic intelligence (IQar) (a) and between efficiency of divergent thinking (DT) and spatial intelligence (IQs) (b)

Different patterns of correlation between IQ and EEG characteristics, registered at the CT or DT were obtained. The right hemispheric delta rhythm during CT was negatively associated with IQar. The alpha 2 in DT correlated with IQs and verbal intelligence component (IQv), this negative relationship was shown for the activity and the left and right hemispheres. Negative correlations between IQv and bilateral alpha 2 were significant for the CT.

In line with the detected correlation between IQ and an efficiency of CT and DT on the one hand, or EEG correlates of these forms of thinking - on the other, it is possible to conclude that the degree of functional activation cortex varies depending on the intellectual abilities, and a large activation represents lower IQ. Hemispheric brain activity during DM associated with IQv and IQs whereas during CT - with IQar and IQv. These effects indicate that the different components of IQ modulated thinking strategies to achieve efficient execution of tasks of different types.

References

1. M. Benedek, et al., Neuropsychologia, 2014, 56, 393-400.
2. J.P. Guilford The nature of human intelligence. New York, 1967.
3. T. Harmony, T.Fernandez, and J. Silva, Intern. J. Psychophysiol., 1996, 24, 161–171.
4. E. Jauk, et al., Intelligence, 2013, 41(4), 212-221.
5. C. Martindale, D. Hines, Biol. Psychol., 1975, 3, 91-100.
6. S. Micheloyannis, Human Brain Mapping, 2009, 30, 200-208.
7. F. Preckel, H. Holling, and M. Wiesem, Pers. Individ. Differ., 2006, 40, 159-170.

Modelling Noise-Induced Escape Problems in Networks

J. L. Creaser, P. Ashwin, K. Tsaneva-Atanasova*

EPSRC Centre for Predictive Modelling in Healthcare, University of Exeter, Exeter, UK.
* Presenting e-mail: j.creaser@exeter.ac.uk

Mathematical models of excitable cells, such as neurones, are often characterised by different dynamic regimes, such as alternating excited and rest states. The transient dynamics responsible for the transition between dynamic states are often discounted or overlooked. Analysis of the transition between dynamic states is crucial to understanding the evolution of epileptic seizures or the initiation of tremors associated with Parkinson's disease.

We consider a phenomenological model of seizure initiation of coupled bi-stable oscillators (represented by a subcritical bifurcation normal form) with noise. Using dynamical systems analysis and numerical simulations we investigate emergent transient dynamics for small motif networks of this model. Specifically, we build small dynamically perturbed motif networks and consider the effect of network structure, noise and separation of timescales on the exit (escape)-time problem.

Distributed Delay Differential Equation Models in Laser Dynamics

A. G. Vladimirov[1,2], G. Huyet[3,4,5] and A. Pimenov[1]

[1] Weierstrass Institute, Mohrenstr 39, Berlin, Germany;
[2] Lobachevsky State University of Nizhny Novgorod, 23 Gagarina av., 603950 Russia;
[3] Tyndall National Institute, University College Cork, Lee Maltings, Dyke Parade, Cork,Ireland;
[4] Centre for Advanced Photonics and Process Analysis, and Department of Applied Physics and Instrumentation, Cork Institute of Technology, Cork, Ireland;
[5] National Research University of Information Technologies, Mechanics and Optics, 199034 St.Petersburg, Russia.
* Presenting e-mail: vladimir@wias-berlin.de

Introduction

Mode-locking is a powerful technique to generate ultrashort optical pulses, which are used in numerous applications [1]. The most common way to model semiconductor mode-locked lasers is based on the use of the so-called traveling wave equations [2], a system of PDEs governing the space-time evolution of the amplitudes of two counter-propagating waves in the laser cavity coupled to the carrier density in the semiconductor medium. An alternative and simpler approach to the analysis of mode-locking based on a system of delay differential equations (DDEs) was proposed in [3]. Later a modification of DDE model was applied to describe the dynamics of Fourier domain mode-locked (FDML) [4] and sliding frequency mode-locked [5] lasers used in optical coherence tomography. However, despite of a remarkable success of the DDE model in describing the dynamics of mode-locked and FDML lasers, this model does not take into account such important phenomenon as chromatic dispersion of the intracavity media. In order to fill this gap, here we develop a new model of an FDML laser that takes into account chromatic dispersion of the fiber delay line. This is a system of DDEs, which in addition to a fixed delay contains a distributed delay term and can be reduced to an infinite chain of delay differential equations with a single fixed delay.

Model equations and CW stability analysis

We consider a multimode ring-cavity laser with the round trip time T consisting of a short semiconductor optical amplifier (SOA) gain section, linear frequency selective spectral filter, and a long dispersive fiber delay line [4]. We assume that this delay line is described by linear equations that account for the dispersion produced by a single detuned Lorentzian absorption line. Using the lumped element method together with the approach described in [3] we derive the following set of two differential equations for the amplitude of the electric field A and saturable gain G:

$$dA/dt + (\gamma - i\omega)A = \gamma\sqrt{\kappa}e^{(1-i\alpha)G/2}[A(t-T) + P(t-T)], \quad (1)$$

$$dG/dt = \gamma[g_0 - G - (e^G - 1)|A(t-T) + P(t-T)|^2]. \quad (2)$$

Here the „polarization" P(t) is given by

$$P(t) = -aL\Gamma\int_{-\infty}^{t} e^{-(\Gamma+i\Omega)(t-s)}\frac{J_1(\sqrt{4aL\Gamma(t-s)})}{\sqrt{aL\Gamma(t-s)}}ds. \quad (3)$$

Using the DDE model (1)-(3) we have performed analytical stability analysis of the continuous wave (CW) laser operation regimes in the limit of large delay time T, when the eigenvalues belonging to the so-called pseudo-continuous spectrum can be represented in the form: $\lambda = i\mu + \Lambda/T + O(1/T2)$ [6]. We have shown that in the case of sufficiently strong anomalous dispersion ($\Omega<0$) all the CW solutions are modulationally unstable. Furthermore, both normal and anomalous dispersion can cause instability close to the lasing thresghold. Finally, we have derived a necessary condition for the stability of CW solutions with respect to modulational instability, which resembles similar condition for the complex Ginzburg-Landau equation.

Conclusion

We have developed a DDE model of a multimode laser taking into account the chromatic dispersion of the fiber delay line and studied analytically the stability of CW regimes in this model in the limit of large delay time. We have demonstrated that in the anomalous dispersion regime a CW operation can be destabilized. Our DDE FDML laser model (1)-(3) satisfies automatically the causality principle and contains a distributed delay term similar to the one introduced in [7].

However, unlike the model discussed in [7], our model provides an explicit analytical description of the linear response function in (3) and, therefore, allows performing analytical stability analysis of the CW solutions. Apart from FDML lasers the approach discussed here can be applied to study the dynamics of mode-locked photonic crystal [7] and other types of multimode lasers.

Acknowledgements

We gratefully acknowledge useful discussions with Julien Javaloyes, Svetlana Gurevich, Svetlana Slepneva, and Shalva Amiranashvili. A.G.V. and A.P. acknowledge the support of SFB 787 of the DFG. A.G.V. acknowledges the support of the grant 14-41-00044 of Russian Scientific Foundation.

References

1. H. A. Haus, IEEE J. Sel. Top. Quantum Electron., 2000, 6(6), 1173-1185.
2. U. Bandelow, M. Radziunas, J. Sieber, and M. Wolfrum, IEEE J. Quantum Electron., 2001, 37, 183–188.
3. A. G. Vladimirov and D. Turaev, Phys. Rev. A, 2005, 72, 033808.
4. S. Slepneva, B. Kelleher, B. O'Shaughnessy, S. Hegarty, A. G. Vladimirov, and G. Huyet, Opt. Express, 2013, 21(16), 19240–19251.
5. S. Slepneva, B. O'Shaughnessy, B. Kelleher, S. Hegarty, A. G. Vladimirov, H. Lyu, K. Karnowski, M. Wojtkowski, and G. Huyet, Opt. Express, 2014, 22(15), 18177–18185.
6. S. Yanchuk and M. Wolfrum, SIAM J. Appl. Dyn. Syst., 2010, 9, 519–535.
7. M. Heuck, S. Blaaberg, and J. Mørk, Opt. Express, 2010, 18(17), 18003–18014.

Optimal Extraction of Collective Rhythmicity from Unreliable EEG Channels

*Justus Schwabedal**

Max-Planck-Institute for the Physics of Complex Systems,Germany.
* Presenting e-mail: jschwabedal@gmail.com

I present a novel data-processing method that facilitates the detection and analysis of the irregular-oscillatory dynamics. The method is particularly useful to EEG analysis, as I will demonstrate in polysomnographic EEG recordings. By design, the method copes well with unreliable recordings showing fluctuating signal amplitude, phase offsets, and substantial amounts of measurement noise. Under such relatively general conditions, I will show that the method optimally enhances a rhythm of interest, and demonstrate its use by the detection and analysis of EEG sleep spindles.

Active Wireless Networks for Experimental Study in Neuroscience

A.S. Dmitriev, R.Y. Emelyanov, M.Yu. Gerasimov*

Institute of Radio Engineering and Electronics. VA Kotelnikov RAS,
Moscow Institute of Physics and Technology
* Presenting e-mail: chaos@cplire.ru

The report examines the active wireless network, which can serve as an experimental tool in the study of various objects in neurodynamics. The network combines the nodes on which digital or analog neuron model (if necessary this may be living neurons), and programmable connections between them, which are implemented through wireless channels can be implemented. The latter circumstance allows the implementation of any type of connection (Linear. Non-linear, with delay, etc.) with any desired topology As an example, the modeling of the phenomenon of chimeras in the system of coupled oscillators is presented.

Chimeras - a popular and interesting phenomenon in the oscillator system [1], which are mainly studying by computer simulation. Experimental study of chimeras, in particular, in small ensembles requires special experimental setups. The active wireless network [2] is used as such experimental equipment in the report. Experiments were carried out with small ensemble of coupled oscillators. Ensemble of six phase oscillators [3] was using as the study system:

$$\dot{\theta}_{i+5j} = \omega + \sum_{k=1}^{5}\left[g\left(\theta_{i+5j} - \theta_{k+5j}\right) + \varepsilon g\left(\theta_{i+5j} - \theta_{k+5j+5}\right)\right],$$

where $g(\varphi) = -\sin(\varphi - \alpha) + r\sin(2\varphi)$ is coupling strength function, $i = 1, \dots, 3$, $j = 0, 1$.

Thus, the ensemble consists of two groups of three oscillators, the oscillators within the group connected with coupling coefficient equal 1 and oscillators of the various groups - with coupling coefficient ε. This ensemble demonstrates chimeric state in which one part of the oscillators is synchronized in frequency, and the other part of the oscillators – no. Each active node in the wireless network is implemented as a pair of ultra-wideband wireless transceiver and the connected actuator. The actuator is a card equipped with a microcontroller, as a calculating device, and multi-color LEDs as a visualization tool. To simulate an ensemble of coupled oscillators, each oscillator in the experiments of the ensemble is associated with a node is an active network. The equation of the oscillator are integrated on the microcontroller, the communication between the oscillators are realized through wireless channels, and the oscillator phase is visualized by means of colored LEDs. This approach allows an arbitrary network topology and a visual demonstration of dynamic patterns of the ensemble.

The report examines the technique of modeling with the help of the active wireless network, the experimental results of the observation of different dynamic regimes of the ensemble and their analysis.

The study was performed by a grant from the Russian Science Foundation (Project № 16-19-00084)

References

1. Kuramoto Y. Chemical oscillations, waves and turbulence. Berlin : Springer-Verlag. 1984.
2. Dmitriev A. S., Yemelyanov R. Yu., Gerasimov M. Yu., Itskov V. V. Active ultra wideband wireless networks usage for modelling ensembles of nonlinear continuous time dynamical systems //Nonlinear phenomena in complex systems. 2015. V. 18. №. 4. P. 456-466.
3. Ashwin P., Burylko O. Weak chimeras in minimal networks of coupled phase oscillators //Chaos: An Interdisciplinary Journal of Nonlinear Science. 2015. V. 25. №. 1. P. 013106.

On the Dynamics of Some Small Hypercycles with Short-Circuits

Josep Sardanyés[1], J. Tomás Lazaro[2], Toni Guillamon[3], and Ernest Fontich[4]*

[1] ICREA-Complex Systems Lab, Universitat Pompeu Fabra and Institut de Biologia Evolutiva CSIC-UPF, Barcelona, Spain;
[2] Departament de Matemàtiques Universitat Politècnica de Catalunya and Barcelona Graduate School of Mathematics BGSMath, Barcelona, Spain;
[3] Departament de Matemàtiques Universitat Politècnica de Catalunya and Barcelona Graduate School of Mathematics BGSMath, Barcelona, Spain;
[4] Departament de Matemàtiques i Informàtica Universitat de Barcelona and Barcelona Graduate School of Mathematics BGSMath, Barcelona, Spain.
* Presenting e-mail: jose.tomas.lazaro@upc.edu

It is known that hypercycles are sensitive to the so-called parasites and short-circuits. While the impact of parasites has been widely investigated for well-mixed and spatial hypercycles, the effect of short-circuits in hypercycles remains poorly understood. In this talk we will present, briefly, a description of the mean field and spatial dynamics of two small, asymmetric hypercycles with short-circuits: first, we consider a 2-member hypercycle with one of the species containing an autocatalytic loop, which represents the simplest case with a short-circuit; second, we add a third species which closes the 3-member hypercycle and preserving the initial autocatalytic short-circuit and the 2-member inner cycle. We characterize the bifurcations and transitions involved in the dominance of the short-circuits and in hypercycles' size. The spatial simulations reveal a random-like and mixed distribution of the hypercycle species in the all-species coexistence scenario, ruling out the presence of large-scale spatial patterns such as spirals or spots typical of larger hypercycles. MonteCarlo simulations reveal a drastic decrease of the probability of finding stable hypercycles with short-circuits when passing from the 2-member to the 3-member scenario.

Acknowledgements

We want to thank Ricard Solé and José Antonio Darós for their comments and fruitful discussions. This work has been partially funded by the Botín Foundation, by Banco Santander through its Santander Universities Global Division (JS); the Spanish grants MINECO MTM2013-41168-P (EF), MTM2015-71509-C2-2-R (TG) and MTM2015-65715-P (JTL); the Catalan grants AGAUR 2014SGR-1145 (EF) and 2014SGR-504 (TG, JTL); the grant 14-41-00044 of RSF at the Lobachevsky University of Nizhny Novgorod (Russia) (JTL); and the European Marie Curie Action FP7-PEOPLE-2012-IRSES: BREUDS (JTL).

References

1. Kauffman, Press Oxford University, 1993.
2. P. Eigen, M. Schuster, Springer-Verlag, 1979.
3. M. Eigen, J. McCaskill, and P. Schuster, J. Phys. Chem., 1988, 92(1), 6881-6891.
4. P. Boerlijst, M.C. Hogeweg, Phys. D Nonlinear Phenom., 1991, 48, 17-28.
5. Pan-Jun Kim and Hawoong Jeong, Phys. D, 2005, 203, 88-99.
6. J. Sardanyés and R. Solé, J. Theor. Biol., 2006, 243(4), 468-482.
7.M.B. Cronhjort, Phys. D, 1997, 101, 289-298.

Mechanical and Electrical Oscillations and Their Role in Sensory Hair Cells

*A.B. Neiman[1] * and R.M. Amro[2]*

[1] Department of Physics & Astronomy and Neuroscience Program, Ohio University, Athens, Ohio, USA;
[2] Department of Physics & Astronomy, Ohio University, Athens, Ohio, USA.
* Presenting e-mail: neimana@ohio.edu

Background

Hair cells are mechanoreceptors which transduce mechanical vibrations to electrical signals in peripheral organs of senses of hearing and balance in vertebrates. Somatic cell motility and active motility of the hair bundle, mechanically sensitive structure on the hair cell apex, are two main mechanisms by which hair cells can amplify mechanical stimuli. In amphibians and some reptiles active processes in hair cells result in noisy mechanical oscillation of hair bundles, which may lead to frequency selective amplification. The same cells often demonstrate spontaneous electrical oscillation of their somatic potentials, a signature of yet another amplification mechanism. Functional role of voltage oscillation is not well understood.

Aims and Methods

We use computational modeling to address the following questions: (i) how the interaction of two distinct unequally noisy oscillators, mechanical and electrical, embedded in the hair cell, affect its spontaneous dynamics; (ii) how synchronous oscillatory activity helps to battle inevitable noise, and (iii) shapes sensitivity of amphibian hair cells to external mechanical signals. The model employs a Hodgkin-Huxley-type system for the basolateral electrical compartment [1] and a nonlinear hair bundle oscillator for the mechanical compartment [2], which are coupled bidirectionally. In the model, forward coupling is provided by the mechanoelectrical transduction current, flowing from the hair bundle to the cell soma. Backward coupling is due to reverse electromechanical transduction, whereby variations of the membrane potential affect adaptation processes in the hair bundle.

Conclusions

Despite noise, the stochastic hair bundle oscillations can be synchronized by external periodic force of few pN amplitude in a finite range of control parameters of the model. Furthermore, the hair bundle oscillations can be synchronized by oscillating receptor voltage [3]. Electrical and mechanical self-oscillations can result from bidirectional coupling [4], and their coherence of can be maximized by tuning the coupling strengths [4,5]. Consistent with previous experimental work [6], the model demonstrates that dynamical regimes of the hair bundle change in response to variations in the conductances of basolateral ion channels [4]. We show that sensitivity of the hair cell to weak mechanical stimuli can be maximized by varying coupling strengths, and that stochasticity of the hair bundle compartment is a limiting factor of the sensitivity [4].

Acknowledgements

This work was supported by the Condensed Matter and Surface Science Program, Neuroscience Program and the Quantitative Biology Institute at Ohio University. AN acknowledges support from the RSF (Russia) grant 14-41-00044. The authors thank A. L. Shilinikov, B. Lindner, D. F. Russell, and M. H. Rowe for valuable discussions.

References

1. A.B. Neiman, K. Dierkes, B. Lindner, L. Han, and A.L. Shilnikov, The Journal of Mathematical Neuroscience, 2011, 1 (11), 1 – 24.
2. B. Nadrowski, P. Martin, and F. Jülicher, Proc. Natl. Acad. Sci. USA, 2004, 101, 12195 – 12200.
3. L. Han, and A.B. Neiman, Phys. Rev. E., 2010, 81(4), 041913.
4. R.M. Amro, and A.B. Neiman, Phys. Rev. E., 2014, 90(5), 052704.
5. R.M. Amro, B. Lindner, and A.B. Neiman, Phys. Rev. Lett., 2015, 115(3), 034101.
6. D. Ramunno-Johnson, C.E. Strimbu, A. Kao, L.F. Hemsing, D. Bozovic, Hearing Research, 2010, 268(1-2), 163 – 171.

Decision-Making Model and Experimental Study of the Influence of Stochastic Processes on Cognitive Brain Ability

Anastasiya E. Runnova, Vadim V. Grubov, Alexey A. Koronovskii, Maria K. Kurovskaya, Alexander N. Pisarchik, Alexander E. Hramov*

Yuri Gagarin State Technical University, Saratov, Russia.
* Presenting e-mail: anefila@gmail.com

The perception of ambiguous images [1, 2] is just one, but a very exciting task among an enormous number of open problems which appeared during recent intensive brain studies. Visual perception was often studied through perceptual alternations while observing ambiguous images [3, 4], although perceptual alternations were also described for other modalities [4]. This phenomenon is also tightly connected with the problem of the categorical perception [17]. Though the underlying mechanism of image recognition is not yet well understood, the metastable visual perception is known to engage a distributed network of occipital, parietal and frontal cortical areas [5]. The generally accepted concept that throws light on this phenomenon involves noise inherent to neural brain cells activity, whose origin may be explained as the result of random neuron spikes [6]. Internal noise seems to play a crucial role in brain dynamics related to both the perception activity and other brain functions [4–6]. Different manifestations of stochastic processes in brain were extensively studied, including the perception of ambiguous images, in terms of simple stochastic processes like the Wiener process from the viewpoint of statistical properties [3–6]. At the moment, the important problem lies in developing ways to quantitatively measure noise characteristics that can open up plenty of new opportunities both in a study of the brain functionality and a diagnosis of its pathologies.

In the present work, we develop the quantitative theory and propose the experimental technique for measuring noise intensity related to the perception of ambiguous images. Both our theoretical findings and the proposed experimental approach are proved by psychological experiments.

The experimental studies were performed in accordance to the ethical standards. Forty healthy subjects from a group of unpaid volunteers, male and female, between the ages of 20 and 45 with the normal or corrected-to-normal visual acuity participated in the experiments. As an ambiguous image, we used the Necker cube illusion. The contrast of the three middle lines centered in the left middle corner, I€[0; 1], was considered as a control parameter. During the experiment Necker cube images with different wireframe contrasts, i.e. with the different values of the control parameter I (Fig. 1), were repeatedly showed to a person in a random sequence, with each cube being placed in the middle of a computer screen as black lines on a white background. All participants were well aware about two possible orientations of the Necker cube, and both were really seen by all of them. All participants were instructed to press either the left or the right key on the control panel according to their first visual impression (left-oriented cube (Fig. 1(a)) or right-oriented cube (Fig. 1(e), respectively). Both the image presentation and the recording of personal responses were accomplished with the help of the equipment being a part of Electroencephalograph-recorder Encephalan-EEGR-19/26 (Medicom MTD).

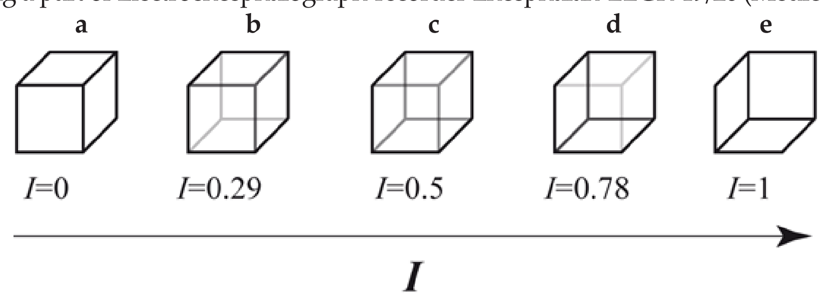

Fig.1. *Examples of distinct Necker cube images with different wireframe contrasts characterized by control parameter I*

Contrary to the traditional approach in our study we mainly focus on the theoretical and quantitative description as well as on the experimental measurement of the concrete relevant factor of the brain activity, namely, on the noise intensity characterizing the stochastic processes in the brain. Based on the methods of statistical physics, we develop a theory which helped us to derive the analytical (not empirical) expression for the experimental data and measure the noise intensity characterizing the stochastic processes in the brain. Also EEG recording volunteers were studied on the wavelet base [7]. Investigations have allowed revealing characteristic patterns for the perception of the Necker cube with different parameter I. The developed theory provides the solid experimentally approved basis for further understanding of brain functionality. We expect that our work will be interesting and useful for scientists carrying out interdisciplinary research at the cutting edge of physics, neurophysiology and medicine.

Acknowledgements

This work has been supported by the Russian Science Foundation (grant 16-12-10100).

References

1. J.-L. Schwartz, et al. Physophical Transactions of the Royal Society B 367, 896 (2012).
2. R. Cao, J. Braun, and M. Mattia, Physical Review Letters 113, 098103 (2014).
3. D. A. Leopold and N. K. Logothetis, Trends in Cognitive Sciences 3, 254 (1999).
4. A. N. Pisarchik, et al. Biological Cybernetics 108, 397 (2014).
5. P. Sterzer, A. Kleinschmidt, and G. Rees, Trends in Cognitive Sciences 13, 310 (2009).
6. R. Moreno-Bote, J. Rinzel, and N. Rubin, Journal of Neurophysiology 98, 1125 (2007).
7. A. E. Hramov, et al. Wavelets in Neuroscience, Springer Series in Synergetics (Springer, Heidelberg, New York, Dordrecht, London, 2015).

Chimeralike States in a Network of Oscillators

*P.K.Roy[1] *, A. Mishra[2,3], C. Hens[4], M. Bose[2], S, K. Dana[2]*

[1] Presidency University, Kolkata, India;
[2] NCSIR-Indian Institute of Chemical Biology, Kolkata, India;
[3] Jadavpur University, Kolkata, India;
[4] Bar Ilan University, Ramat Gan, Israel.
* Presenting e-mail: pkpresi@yahoo.co.in

We report chimeralike states in an ensemble of oscillators using a type of global coupling consisting of two components: attractive and repulsive mean-field feedback. We identify the existence of two types of chimeralike states in a bistable Li´enard system; in one type, both the coherent and the incoherent populations are in chaotic states (which we refer to as chaos-chaos chimeralike states) and, in another type, the incoherent population is in periodic state while the coherent population has irregular small oscillation. We find a metastable state in a parameter regime of the Li´enard system where the coherent and noncoherent states migrate in time from one to another subpopulation. The relative size of the incoherent subpopulation, in the chimeralike states, remains almost stable with increasing size of the network. The generality of the coupling configuration in the origin of the chimeralike states is tested, using a second example of bistable system, the van der Pol-Duffing oscillator where the chimeralike states emerge as weakly chaotic in the coherent subpopulation and chaotic in the incoherent subpopulation. Furthermore, we apply the coupling, in a simplified form, to form a network of the chaotic R¨ossler system where both the noncoherent and the coherent subpopulations show chaotic dynamics.

Acknowledgements

S.K.D. and P.K.R. acknowledge individual support by the CSIR (India) under the Emeritus Scientist Scheme.

References

1. A. Mishra, C. R. Hens, M.Bose, P. K. Roy, S. K. Dana, Chimeralike states in a network of oscillators under attractive and repulsive global coupling, Phys. Rev. 2015 E 92, 062920
2. C. R. Hens, A Misra, P. K. Roy, A. Sen and S. K. Dana, Chimera states in a population of identical oscillators under planar cross-coupling, PRAMANA- J Phys 2015, 84, 229

Towards Bifurcation Theory for Rhythmogenesis in Neural Networks

*A. Shilnikov[1] *, D. Alacam[1], J. Collens[1], A. Kelley[1] and J. Schwabedal[2]*

[1] Neuroscience Institute,Department of Mathematics & Statistics, Georgia State University, Atlanta USA;
[2] Max Planck Institute for the Physics of Complex Systems, Dresden, Germany.
* Presenting e-mail: ashilnikov@gsu.edu

Rhythmic motor behaviors such as heartbeat, respiration, chewing, and locomotion on land and in water are produced by networks of cells called central pattern generators (CPGs). A CPG is a neural microcircuit of cells whose interactions can autonomously generate an array of polyrhythmic patterns of activity that determine motor behaviors in animals and humans. Modeling studies have proven to be useful to gain insights into operational principles of CPGs. Although various models, reduced and feasible, of specific CPGs have been developed, it remains unclear how the CPGs achieve the level of robustness and stability observed in nature. Whereas a dedicated CPG generates a single pattern robustly, a multifunctional CPG can flexibly produce distinct rhythms, such as temporally distinct swimming and versus crawling locomotion, and alternation of direction of blood circulation in leeches. Switching between various attractors of a CPG network causes switching between locomotion behaviors. Each attractor is associated with a definite rhythm running on a specific time scale with well-defined and robust phase lags among the constituting neurons. The emergence of synchronous rhythms in neural networks is closely related to temporal characteristics of coupled neurons due to intrinsic properties and types of synaptic coupling, which can be inhibitory, excitatory and electrical, fast and slow.

We are interested in exploring repetitive dynamics generated by constituent building blocks, or ``motifs'' that make up more complex CPG circuits, and the dynamic principles underlying more general multi-stable rhythmic patterns. We have considered the range of basic motifs comprising three and four biophysical cells and their synapses, chemical inhibitory, excitatory and electrical, and how those relate, and can be understood and generalized onto from the known principles of minimal motifs.

We have developed a novel dynamical and bifurcation framework combining analytical approaches and computational tools to in-detail study oscillatory networks constituted by endogenously bursting, tonic spiking neurons and network bursters. The approaches let us reduce the problem of the stability and existence of bursting and other oscillatory rhythms generated by networks to bifurcation analysis of fixed points and invariant circles of Poincare return maps measuring the phase lags between the burst initiations in the neuro. The structure of the phase space of the map reflects all significant characteristics of the state space of the given network. Equipped with the powerful apparatus of such return maps we are able to predict and identify the set of robust bursting outcomes of CPGs, differentiated by phase-locked or periodically varying lags that correspond to stable fixed point and/or invariant circle attractors of the map. Comprehensive simulations of the transient phasic relationships in the network are based on the delayed release of cells from a suppressed, hyperpolarized state, and allow for thorough exploration of network dynamics with spiking and bursting cell.

Transient and Periodic Spatiotemporal Structures in a Reaction-Diffusion-Mechanics System

*V.A. Kostin[1,2], G.V. Osipov[1,2] **

[1] Lobachevsky State University of Nizhny Novgorod, 23 Gagarin ave, 603950 Nizhny Novgorod, Russia;
[2] Institute of Applied Physics, Russian Academy of Sciences, Ylyanova str., 46, Nizhny Novgorod 603950, Russia.
* Presenting e-mail: osipov@vmk.unn.ru

The reaction-diffusion-mechanics models are the models used to describe self-consistent electromechanical activity in a cardiac muscle. Such models couples two mechanisms of signal spreading in the tissue: the slow (reaction-diffusion) spreading of electrical excitation and the fast (almost instantaneous) spreading of mechanical deformations. This coupling may significantly modify the electrical excitation spreading and corresponding contractile activity with emergence of new spatiotemporal structures and patterns, which modification is not yet completely understood even in the one-dimensional case of a single muscle fiber. We propose clear convenient model which allows one to study the electromechanical activity of such a fiber in relation to the mechanical parameters of fiber fixation (such as stiffness of tissue fixation and the applied mechanical load, which can be easily controlled in experiments). Using this model, we determine and analyze the physical origin of the primary dynamical effects which can be caused by electromechanical coupling and mechanoelectrical feedback in a cardiac tissue.

On the basis of the reaction-diffusion-mechanics model with the self-consistent electromechanical coupling, we have numerically analyzed the emergence of structures and wave propagation in the excitable contractile fiber for various contraction types (isotonic, isometric, and auxotonic) and electromechanical coupling strengths. We have identified two main regimes of excitation spreading along the fiber: (i) the common quasi-steady-state propagation and (ii) the simultaneous ignition of the major fiber part and have obtained the analytical estimate for the boundary between the regimes in the parameter space. The uncommon oscillatory regimes have been found for the FitzHugh-Nagumo-like system: (i) the propagation of the soliton-like waves with the boundary reflections and (ii) the clusterized self-oscillations. The single space-time localized stimulus has been shown to be able to induce long-lasting transient activity as a result of the after-excitation effect when the just excited fiber parts are reexcited due to the electromechanical global coupling. The results obtained demonstrate the wide variety of possible dynamical regimes in the electromechanical activity of the cardiac tissue and the significant role of the mechanical fixation properties (particularly, the contraction type), which role should be taken into consideration in similar studies. In experiments with isolated cardiac fibers and cells, these parameters can be relatively easily controlled, which opens a way to assess electrical and mechanical parameters of the fibers and cells through analysis of dynamical regimes as dependent on fixation stiffness and external force. In real heart, high blood pressure and hindered blood flow play similar role to the applied external force and increased fixation stiffness. Our results provide a hint of how such global (i.e., associated with the large areas of the heart tissue) parameters can affect the heart electrical and contraction activity.

Chaos & Biological Information Processing: Coarse-Graining, Rough Set Approximations and Quantum Cognition in Decision Making

*V. Basios**

Interdisciplinary Centre for Nonlinear Phenomena and Complex systems, & Dept. de Physique des Systèmes Complexes et Mécanique Statistique, University of Brussels, Brussels, Belgium.
* Presenting e-mail: vbasios@ulb.ac.be

Aims

The role of chaos in biological information processing has been established as an important breakthrough of nonlinear dynamics, after the early pioneering work of J.S. Nicolis [1] (and notably in neuroscience by the work of Walter J. Freeman and co-workers spanning more than three decades, see Chapter 13 by Walter J. Freeman in [1]). Yet the models describing apprehension, judgment and decision making in various populations of biological systems, be it a large collective of neural networks, a colony of ants, a hive of bees or other communities of `agents', do not readily accommodate such an insight. With this work we aim at bridging this gap by considering recent advances in apprehension and judgment (see Chapter 15, by T. Arrechi in [1]). We propose a scheme [2] that underlies the mechanism of classification in judgememt and decision making, under uncertainty and conflict, by utilizing coarse-graining techniques from chaotic dynamics [5] based in `rough-set' theory with self-referential, non-linear, feed-back loops.

Methods

Our methods derive from an interdisciplinary framework combining tools from statistical mechanics, dynamical system theory and in particular coarse-graining (via 'rough-set' approximation) computational techniques. We use data coming from experiments targeted on recording populations of neurons under controlled decision-making processes. We have identified the basis of this scheme as compatible with the principles of quantum cognition [4] and investigated the properties of it's logical structure as an orthomodular lattice known from Quantum Logic. Bayesian inference based on the upper/lower approximation selects the modification and/or replacement of the algorithms for decision-making by a composition of two different equivalence relations.

Results

At this stage we have identified a minimal model for apprehension and judgment and interpreted data from human subjects [2]. The proposed 'non-algorithmic jumps' reveal the associated quantum-like effects reported in the literature. The composition of the two kinds of equivalence relations, leads to a logic structure expressed as an orthomodular lattice. Conversely it reveals that the modification or replacement of algorithms (i.e. replacement of equivalence relations) is affected by the reported quantum-like effects. Crowds of cortical neurons 'the workspace' provide the substratum, in terms of complexity flexibility, adaptability and plasticity, for collective agreement and synchronization in both instances of apprehension and judgment. A fascinating question that results from this line of investigations is whether or not this is the only such substratum in existence. Research in collective decision-making and event-anticipation in collectives, other than groups of neurons, i.e. super-organisms of social animals such as bee-hives, ant-colonies and other model systems [3,4,6] reveal certain analogies in recruiting, reinforcement and consensus building. Our approach instigates research toward this kind of investigations.

Conclusions

Given the successful synergy of mathematical, agent-based simulations and biological experiments in a common research platform a useful extension is to augment the setting in [3] with feedback mechanisms which can control the experimental constrains and launch trials according to the outcome of an in-situ monitoring. Results based on other biological models and neural networks enrich this research program [3,6]. In view of recent developments in data collecting & processing technology and the important advances in coarse-graining methods (especially in relation to autonomous agents and neural populations [6]) emphasis is to be placed in the complexity of the underlying dynamics. For example the role of the group's size, the complexity of the units or their propensities and their differentiation, the trends for forming sub-groups, clustering & cliques, environmental and dynamical constrains etc. By its nature such a `research platform' can only be truly interdisciplinary and fully integrated as a complex-system lab or network of such [3,6].

Acknowledgements

Special thanks to Professors Andrey Shilnikov (Georgia State), Dmitri Turaev (Imperial College), Y. Kevrekidis (Princeton), Yukio-Pegio Gunji (Waseda) and S. Nicolis, Jean-Louis Deneubourg (ULB) for fascinating & inspiring discussions.

References

1. 'Chaos, information processing and paradoxical games: the legacy of John S Nicolis', G. Nicolis, V. Basios, eds. World Scientific (2015).
2. `Quantum cognition based on an ambiguous representation derived from a rough set approximation', Y-P. Gunji, K. Sonoda & V. Basios. BioSystems 141, 55–66 (2016).
3. 'Coordinated Aggregation in Complex Systems: an interdisciplinary approach', V. Basios, S. Nicolis & J-L. Deneubourg, The European Physical Journal, Special Topics: Mathematical Modeling of Complex Systems, in press (2016).
4. 'Quantum probability and the mathematical modelling of decision making', E. Haven and A. Khrennikov, eds. Phil. Trans. R. Soc. A (Theme issue), 374, 2058 (2016).
5. 'Symbolic dynamics, coarse graining and the monitoring of complex systems'. V Basios, D Mac Kernan, International Journal of Bifurcation and Chaos 21 (12), 3465-3475 (2011).
6. 'Coarse-Grained Clustering Dynamics of Heterogeneously Coupled Neurons', S.J. Moon, K.A. Cook, K. Rajendran, I.G. Kevrekidis, J. Cisternas, C.R. Laing. Journal of Mathematical Neuroscience, 5,2 (2015).

The work of the International Workshop *Dynamics in Life Sciences, Neuroscience Applications* was supported by the RSF fund (grant 14-41-00044) and the RFBR fund (grant 16-02-20460\16).