Noise in Life 2007: Stochastic Dynamics in the Neurosciences

Max-Planck-Institut für Physik Komplexer Systeme

Dresden, November 7-9, 2007

Coordinators: Benjamin Lindner (MPIPKS), Lutz Schimansky-Geier (Humboldt-University Berlin), Jordi Garcia-Ojalvo (Universitat Politecnica de Catalunya, Terrassa, Spain)

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Noise in Life 2007 brought together statistical and nonlinear physicists with computational neuroscientists and neurophysiologists, and presented a wide overview of the influence of random fluctuations in the behavior of neuronal systems. We were happy to welcome a number of great and well-known speakers on this general problem — among them Wulfram Gerstner, Peter Jung, Alexander Neiman, Nestor Parga, Arkady Pikovsky, Luigi Ricciardi, Nigel Stocks, and Henry Tuckwell.

A number of talks were concerned with noise in single neurons and discussed in this context the following problems: the faithful modeling of the neuron's nonlinearity (W. Gerstner, M. Richardson); novel methods to calculate interval histograms for spiking cells (L. Ricciardi, T. Engel, A. Porporato) or the response to periodic stimulation (N. Brunel, P. Talkner); noise-induced effects in neural models (A. Torcini); detailed models of intrinsic channel noise (G. Schmid, M. Falcke), synaptic noise (P. Jung), and external conductance fluctuations (L. Wolff); effects of the spatial extension of the neuron (H. Tuckwell); the quantification, the theoretical calculation, and the biological function of interval correlations in neural spike trains (M. P. Nawrot, E. Müller, A. Neiman).

The questions of how precisely and how strongly correlated different neurons respond to a stimulus, and the details of this response on a fine temporal scale, were addressed

in the talks by A. Pikovsky, G. Schneider, and J. Ritt. There were a number of excellent talks on noisy neural networks devoted to one or more of the following issues: the detection of synchronous spikes in a neural population and the question of what these synchronous spikes code for (J. Benda, G. Pipa); the spontaneous and evoked stochastic activity in biological neural networks (N.Parga, M. V. Sanchez-Vives); the function of spike-timing dependent plasticity in the developmental phase of a network (O. Chibirova); experimental evidence for traveling waves in various extended neural systems (E. Manjarrez); and task performance by means of populations of spiking neurons (M. Mattia, R. Moreno-Bote).

There was also a lively Poster session of the remaining participants of the workshop (mostly students and younger scientists), including short oral presentation of the posters. The various topics of the posters were all related to stochastic neural dynamics and discussed specific models in detail.

In general there was a good connection of the various theoretical approaches (for instance, the spike train analysis and theorems on point processes, but also approximate solutions of the Fokker-Planck and Master equations as well as linear response theory) with exciting experimental findings (for instance, the emergence of oscillations in the spontaneous and evoked activity of single resonant cells and of networks on various time scales).

In summary, the workshop *Noise in Life 2007* provided a fruitful forum for the presentation and exchange of ideas in the interdisciplinary community studying noise and fluctuations in neural systems.

The contents of the talks, in chronological order, were the following:

- **Luigi Ricciardi** (University of Naples, Italy) presented an historical overview of mathematical methods used to solve first-passage time problems in neuronal dynamics, beginning with pioneering studies performed in the 1960s on the information content of spike trains. His talk showed how a biological question can lead to genuine mathematical problems.

- **Nicolas Brunel** (CNRS and University of Paris 5, France) presented a theoretical study, and its experimental confirmation, of the conciliation of a puzzling observation in neuronal networks: how fast periodic oscillations can arise in the local field potential in certain types of neuronal tissue, when single neurons exhibit very irregular and highly fluctuating membrane oscillations. His proposal involves an emerging instability of neuronal networks, caused by inhibitory coupling.

- **Tatiana Engel** (Max Planck Institute of Colloids and Interfaces, Potsdam, Germany) described an analytical method to determine the inter-spike interval (ISI) statistics of neurons that exhibit subthreshold activity. The method is applied to in resonant and nonresonant neurons in the entorhinal cortex in rats. Dr. Engel also reported on the existence of negative correlations in these neurons, and on potential consequences of these correlations.

- **Amilcare Porporato** (Duke University, USA) discussed similarities between the stochastic dynamics of the soil moisture during the hydrological cycle and that of neurons, both of which exhibit state-dependent jumps. The former system can be described by nonlinear stochastic differential equations driven by state-dependent Poisson process. The state dependence is shown to lead to non-exponential histograms of inter-event intervals. Analytical expressions were provided for these histograms.

- **Martin Paul Nawrot** (Free University of Berlin, Germany) presented an overview of different neuronal systems exhibiting negative auto-correlation, and presented new evidence of this type of behavior. He also described an autoregressive model of the inter-spike intervals that leads to predictions of the statistics of spike series.

- **Eilif Müller** (Ecole Polytechnique Fédérale de Lausanne, Switzerland) introduced a Markov process model to account for spike-frequency adaptation. He connected this model to more standard integrate and fire models via dimension reduction, and used it to calculate statistics, e.g. correlation, of inter-spike intervals.

- **Henry Tuckwell** (Max Planck Institute for Mathematics in the Sciences, Leipzig, Germany) presented studies on the response of single neurons to noisy input, as modeled with stochastic partial differential equations with spatiotemporal noise. In the second part of the talk, Dr. Tuckwell described the silence of oscillations occurring in two coupled neurons. Finally a phenomenological model of spreading depression was presented.

- **Peter Talkner** (University of Augsburg, Germany) described an approach to solve semi-analytically the Fokker-Planck equation with external driving, in order to obtain the long-time behavior of stochastic systems with coexisting attractors. An application to neuronal systems was also presented.

- **Alessandro Torcini** (Institute of Complex Systems, Florence, Italy) reported on the existence of noise-induced coherence in a FitzHugh-Nagumo neuronal model driven by correlated noise trains. The phenomenon reported occurs for both excitatory and inhibitory inputs, and is termed double coherence resonance.

- **Lars Wolff** (Max Planck Institute for the Physics of Complex Systems, Dresden, Germany) presented an analytical method that allows one to determine the statistics of subthreshold activity in resonant neurons. The efficiency of the method is compared with that of the effective-time-constant approximation.

- **Gerhard Schmid** (University of Augsburg, Germany) described the consequences of taking into account the displacement of gating charges during the opening and closing of ion channels, specially regarding the effects of ion channel noise. The results reported showed that the "channel current" changes the effective value of the noise.

- **Magnus Richardson** (University of Warwick, United Kingdom) reported on a new experimental method to extract the nonlinear I-V response curve of a neuron from intracellular voltage data. Additionally, he described new analytical methods to compute the steady state and firing rate response on nonlinear integrate-and-fire models.

- **Jason Ritt** (Massachusetts Institute of Technology, USA) described studies of the transient response of neurons to non-stationary stimuli. Through computation of the probability density for random initial conditions, he analyzed the reliability dynamics and compared the relative effectiveness of different input statistics.

- **Alexander Neiman** (Ohio State University, USA) described experimental results in paddlefish electroreceptors showing that spontaneous oscillations occur both in populations of sensory hair cells and in primary afferents. He subsequently discussed how these stochastic self-sustained oscillations affect information transmission, by increasing for instance the variability of inter-spike intervals. A mathematical model of the process supports a role of these oscillations in reducing the low-frequency noise and shaping the response of the neurons.

- **Wulfram Gerstner** (Federal Technical School of Lausanne, Switzerland) discussed the relative validity of different types of integrate-and-fire models, and showed how an exponential integrate-and-fire model with adaptation, together with refractoriness introduced by a spike response model, is able to predict 85% of spikes. Furthermore, he advocated they use of phenomenological noise models, in the same way that phenomenological models are used for the deterministic part of the neuron dynamics (in integrate-and-fire models, for instance).

- **Jan Benda** (Humboldt University at Berlin, Germany) showed how spike synchronization of electroreceptor neurons in weakly-electric fish lead to the encoding of external signals, in particular of high frequency. He also reported on how noise

reduces the number of synchronous spikes, and described the effect of such reduction.

- **Maurizio Mattia** (Italian National Institute of Health, Rome, Italy) described the implementation of a computational machine, based on the principles of neuronal networks, that is able to count events in an efficient way. He compared the predictions resulting from that method with recent experimental results on counting and timing tasks, both in animals and humans.

- **Gordon Pipa** (Max Planck Institute for Brain Research, Frankfurt, Germany) showed, in the first part of his talk, that neuronal networks shaped by neuronal plasticity are a promising concept for spatiotemporal self-organized computation. In the second part of the talk, he presented experimental evidence showing that synchronous spiking occurs during stimulation, stressing the importance of synchronous activity for information processing in the mammalian cortex.

- **Nigel Stocks** (University of Warwick, United Kingdom) addressed the question of how information flow can be maximized in a population of noisy neurons, in the context of the phenomenon of suprathreshold stochastic resonance. Evidence for this phenomenon was offered, and it was also shown that negatively correlated noise further increases information transfer.

- **María V. Sánchez-Vives** (University Miguel Hernandez, Alicante, Spain) reported experimental evidence of spontaneous activity in the cerebral cortex. She discussed several mechanisms that determine different rhythmic patterns, based on both experimental and modeling results. Finally, she showed how the alteration of some of these control mechanisms result in faulty activity, such as in epileptic seizures.

- **Néstor Parga** (Autonomous University of Madrid, Spain) presented a model based on linear integrate-and-fire neurons, extended with a nonlinear intrinsic property, which reproduces the spontaneous transitions between depolarized and hyperpolarized states. He also showed that the model generates responses to sensory stimulation that depend on the state of the network at the time of the application of the stimulus.

- **Rubén Moreno-Bote** (New York University, USA) discussed psychophysical experiments of bistable perception, and addressed the question of how transitions between the two perception states arise. In contrast with standard view associating these switches with firing rate adaptation or synaptic depression, Dr. Moreno-Bote argued that they are noise-induced phenomena. To that end, he described a spiking network model with attractor dynamics, and with a precise balance between

noise and adaptation, that produces realistic distributions of dominance durations. The model also describes recently introduced statistical properties of perceptual bistability.

- **Martin Falcke** (Hahn Meitner Institute, Berlin, Germany) argued that intracellular calcium oscillations in cells are more consistent with a noisy process than with deterministic oscillations. Subsequently, he presented an exact method for the calculation of waiting time distributions for the state transitions associated with these calcium oscillations, and in general of complex molecules with independent subunit dynamics such as, for instance, ion channels in neuronal dynamics.

- **Peter Jung** (Ohio State University, USA) discussed the reason for which the probability of vesicle release in neuronal synapses is so low (on the order of 20%. Making use of a release model that includes synaptic depression, and which satisfactorily reproduces the experimental observations, Dr. Jung showed that low-fidelity synapses allow for tuning and hence dynamic plasticity. Furthermore, astrocytes play the role of tuning the synapses close to the optimal efficiency.

- **Olga Chibirova** (University Joseph Fourier, Grenoble, France) described a large-scale spiking neural network including an initial developmental phase, characterized by cell death driven by excessive firing rate, and followed by spike timing dependent plasticity (STDP). The response of the network to temporally structured stimuli, and its behavior in absence of stimulation, was analyzed. Dr. Chibirova presented the analysis of effective spike trains recorded throughout the network, and in particular the detection of recurrent spikes, their structure and their dynamics.

- **Gaby Schneider** (University of Frankfurt, Germany) presented experimental results of multi-unit recordings of the visual cortex in anesthetized cats in the presence of visual stimulation, that exhibit near-zero phase delays, smaller than 2 ms, in the cross correlation between different electrodes. The phase delays prove to be highly precise, stimulus-specific, and have an additive structure. Dr. Schneider described a simple model that satisfactorily accounts for the experimental observations.

- **Arkady Pikovsky** (Potsdam University, Germany) described analytically the phenomenon of synchronization by common noise of identical and nearly identical oscillators, in particular neurons. His talk showed that a global description of the evolution of the ensemble's parameters is possible via the phase approximation, and revealed the existence of desynchronization (antireliability) for strong noise, beyond the region of validity of the phase approximation.

- **Elías Manjárrez** (Autonomous University of Puebla, Mexico) presented experimental evidence of traveling waves of activity in the human brain and in the spinal cord of cats, under different sensory, cognitive and motor conditions. Dr. Manjárrez introduced a phenomenological theory based on the center of mass concept, in order to quantify the trajectory of the traveling waves, and conjectured that these structures might provide an additional neuronal code.

Max Planck Institute for the Physics of Complex Systems, Dresden

International Workshop

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PROGRAM

Scientific Coordinators:

Benjamin Lindner
MPI für Physik komplexer Systeme
Dresden, Germany

Lutz Schimansky-Geier
Humboldt-Universität
Berlin, Germany

Jordi Garcia-Ojalvo
Universitat Politècnica de Catalunya
Terrassa, Spain

Local Organization:

Claudia Pönisch
MPI für Physik komplexer Systeme
Dresden, Germany

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Max-Planck-Institut für Physik komplexer Systeme
Nöthnitzer Str. 38, 01187 Dresden, Germany
Telefon: +49-(0)351-871-2198, Fax: +49-(0)351-871-2199
E-mail: noise07@mpipks-dresden.mpg.de
http://www.mpipks-dresden.mpg.de/~noise07

Program[1]

Tuesday, November 6

16:30 - 20:00	Registration
19:00 - 22:00	Welcome banquet

Wednesday, November 7

08:50 - 09:00	Opening Frank Jülicher (Director MPIPKS) and Scientific Coordinators
09:00 - 09:30	**Luigi Ricciardi** (Universita di Napoli) *On diffusion and first passage time problems in biological modeling*
09:30 - 10:00	**Nicolas Brunel** (CNRS - Université Paris 5) *Dynamics of the instantaneous firing rate of single neurons and networks*
10:00 - 10:30	**Tatiana Engel** (MPI für Kolloid- und Grenzflächenforschung) *Firing statistics in resonant and nonresonant neurons: The first passage time approach*
10:30 - 11:00	Coffee break
11:00 - 11:30	**Amilcare Porporato** (Duke University) *Dynamical systems with state-dependent jumps*
11:30 - 12:00	**Martin Paul Nawrot** (Freie Universität Berlin) *Serial inter-spike interval correlations in spiking neurons: Phenomenology, stochastic modeling and statistic predictions*
12:00 - 12:30	**Eilif Müller** (EPFL Lausanne) *An adapting Markov process: Beyond renewal descriptions of neuronal firing*
12:30 - 14:30	Lunch break
14:30 - 15:00	**Henry Tuckwell** (MPI f. Mathematik i. d. Naturwissenschaften) *Single neurons, coupled neurons and spreading depression*
15:00 - 15:30	**Peter Talkner** (Universität Augsburg) *Dynamics of metastable states in externally driven Fokker-Planck processes*

[1]Abstracts available at http://www.mpipks-dresden.mpg.de/~noise07/

Program[1]

15:30 - 16:00	**Alessandro Torcini** (Istituto dei Sistemi Complessi Firenze) *Double coherence resonance in neuronal models driven by correlated noise*
16:00 - 16:30	Coffee break
16:30 - 17:00	**Lars Wolff** (MPIPKS Dresden) *Exact mean, variance, and autocorrelation function of neural subthreshold voltage*
17:00 - 17:30	**Gerhard Schmid** (Universität Augsburg) *Gating charge effects: An intrinsic mechanism for channel noise reduction*
18:00 - 19:30	Dinner
19:30 - 20:00	Poster Presentations
20:00	Poster Session

Thursday, November 8

09:00 - 09:30	**Magnus Richardson** (University of Warwick) *Response properties of reduced neuron models to fluctuating synaptic drive*
09:30 - 10:00	**Jason Ritt** (Massachusetts Institute of Technology) *Transience in stimulus driven neural dynamics*
10:00 - 10:30	**Alexander Neiman** (Ohio University) *Stochastic oscillations and their role in information transfer in hair-cell – Afferent electrosensory system of paddlefish*
10:30 - 10:35	Group Photo
10:35 - 11:00	Coffee break
11:00 - 11:30	**Wulfram Gerstner** (EPFL Lausanne) *Predicting neural activity spike by spike: The power (and limits) of simple neuron models*
11:30 - 12:00	**Jan Benda** (Humboldt-Universität zu Berlin) *Neural population codes in weakly-electric fish*

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Program[1]

12:00 - 12:30	**Maurizio Mattia** (Istituto Nazionale di Fisica Nucleare) *Counting, timing, integrating by multi-modular networks of spiking neurons*
12:30 - 14:30	Lunch
14:30 - 15:00	**Gordon Pipa** (MPI für Hirnforschung) *Neuronal self organization in theory and experiment: Behaviourally relevant cell assemblies and plasticity in the liquid state machine*
15:00 - 15:30	**Nigel Stocks** (Warwick University) *Noise enhance information processing in neural populations*
15:30 - 16:00	**Maria V. Sanchez-Vives** (Universidad Miguel Hernandez) *Spontaneous emergent activity from the cerebral cortex network*
16:00 - 16:30	Coffee break
16:30 - 17:00	**Nestor Parga** (Universidad Autonoma de Madrid) *Network model of low frequency oscillations exhibiting synchronous transitions between up and down states*
17:00 - 17:30	**Ruben Moreno-Bote** (New York University) *Noise-induced alternations in attractor models of perceptual bistability*
19:30	Conference Dinner

Friday, November 9

09:00 - 09:30	**Martin Falcke** (Hahn-Meitner-Institut Berlin) *Waiting time distributions for clusters of complex molecules*
09:30 - 10:00	**Peter Jung** (Ohio University) *Optimal synaptic design, information transfer and noise*
10:00 - 10:30	**Olga Chibirova** (Université Joseph Fourier) *Emergence of precise firing sequences driven by temporally structured stimuli in large scale neuron networks*
10:30 - 11:00	Coffee break
11:00 - 11:30	**Gaby Schneider** (Universität Frankfurt) *A simple model for near-zero phase delays*

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Program[1]

11:30 - 12:00 **Arkady Pikovsky** (Universität Potsdam)
Synchronization by common noise: Application to neuron's reliability

12:00 - 12:30 **Elias Manjarrez** (Benemerita Universidad de Puebla)
Neurodynamics of the center of mass for traveling electrical waves within the central nervous system of humans and cats

12:30 - 12:40 Closing

12:40 Lunch

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Poster Presentations[2]

01	Becq, Guillaume	*Noisy observations and modelisations of three neurons networks*
02	Ciszak, Marzena	*Mechanism of phase transition in locally coupled oscillators*
03	Clopath, Claudia	*An online Hebbian learning rule that performs independent component analysis*
04	Del Giudice, Paolo	*Perceptual stochastic integration as a model for binocular rivalry*
05	Dierkes, Kai	*Mechanical properties of coupled hair bundles*
06	Farkhooi, Farzad	*Spike history matters!*
07	Fuwape, Ibiyinka	*Homoclinic spike adding in a neuronal model in the presence of noise*
08	Memmesheimer, Raoul-Martin	*Stable propagation of synchronous spiking in purely random networks with non-additive coupling*
09	Patzelt, Felix	*Self-organised critical noise amplification in human closed loop control*
10	Pérez, Toni	*Study of the role of diversity in synaptically-coupled neurons*
11	Pons-Rivero, Antonio J.	*Synchronization loss in large-scale brain dynamics*
12	Pototsky, Andrey	*Excitable systems with noise and delay with applications to control: Renewal theory approach*
13	Rüdiger, Sten	*Localization and noise in intracellular calcium dynamics*
14	Schreiber, Susanne	*The influence of subthreshold membrane properties on neuronal firing*
15	Skupin, Alexander	*Constructive use of noise in intracellular calcium oscillations*
16	Strefler, Jessica	*Leaky integrate-and-fire neuron driven by long-correlated Gaussian noise*
17	Tabarelli, Davide	*Feedback control over criterion setting in visual perception*
18	Ullner, Ekkehard	*Noise-induced rhythmicity in an ensemble of circadian oscillators*
19	Vicente, Raul	*Dynamical relaying: A novel mechanism for zero-lag long-range neuronal synchronization*
20	Vilardi, Andrea	*Stochastic resonance in human hearing*
21	Vilela, Rafael	*Spectral measures of three different integrate-and-fire neurons and how stimulus-induced synchrony varies among them*

The number in front of the name corresponds to the number on the poster wall!

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Participants

BECQ, Guillaume
guillaume.becq@gipsa-lab.inpg.fr
CNRS
Département Image et Signal
Saint Martin d'Heres, France

BENDA, Jan
j.benda@biologie.hu-berlin.de
Humboldt Universität
Institut für Theoretische Biologie
Berlin, Germany

BRUNEL, Nicolas
nicolas.brunel@univ-paris5.fr
CNRS
Neurophysics and Physiology
Paris, France

CHIBIROVA, Olga
olga.chibirova@ujf-grenoble.fr
Université Joseph Fourier
Institut de Neurosciences
Grenoble, France

CISZAK, Marzena
marzena.ciszak@inoa.it
C.N.R.
Istituto Nazionale di Ottica Applicata
Florence, Italy

CLOPATH, Claudia
claudia.clopath@epfl.ch
EPFL
Brain Mind Institute
Lausanne, Switzerland

DEL GIUDICE, Paolo
paolo.delgiudice@iss.infn.it
Italian National Institute of Health
Technology and Health
Rome, Italy

DIERKES, Kai
kai@mpipks-dresden.mpg.de
MPI für Physik komplexer Systeme
Biologische Physik
Dresden, Germany

ENGEL, Tatiana
engel@mpikg.mpg.de
MPI für Kolloid- und Grenzflächenforschung
Theorie und Bio-Systeme
Golm, Germany

FALCKE, Martin
falcke@hmi.de
Hahn-Meitner-Institut
Theoretische Physik
Berlin, Germany

FARKHOOI, Farzad
farzad@zedat.fu-berlin.de
Freie Universität Berlin
Institut für Biologie/Neurobiologie
Berlin, Germany

FUWAPE, Ibiyinka
fuwape@helios.phy.ohiou.edu
Ohio University
Physics and Astronomy
Athens, USA

GARCIA-OJALVO, Jordi
jordi.g.ojalvo@upc.es
Universitat Politècnica de Catalunya
Departament de Física i Enginyeria Nuclear
Terrassa, Spain

Participants

GERSTNER, Wulfram
wulfram.gerstner@epfl.ch
EPFL
Computational Neuroscience Laboratory
Lausanne, Switzerland

JUNG, Peter
pjungp@gmail.com
Ohio University
Physics and Astronomy
Athens, USA

LINDNER, Benjamin
benji@pks.mpg.de
MPI für Physik komplexer Systeme
Biological Physics
Dresden, Germany

MANJARREZ, Elias
eliasmanjarrez@gmail.com
Benemérita Universidad Autónoma de Puebla
Instituto de Fisiología
Puebla, Mexico

MATTIA, Maurizio
mattia@iss.infn.it
Italian National Institute of Health
Technology and Health
Rome, Italy

MEMMESHEIMER, Raoul-Martin
rmm@nld.ds.mpg.de
MPI für Dynamik und Selbstorganisation
Nichtlineare Dynamik
Göttingen, Germany

MORENO-BOTE, Ruben
rmoreno@cns.nyu.edu
New York University
Center for Neural Science
New York, USA

MÜLLER, Eilif
emueller@kip.uni-heidelberg.de
EPFL
Laboratory for Computational Neuroscience
Lausanne, Switzerland

NAWROT, Martin Paul
nawrot@neurobiologie.fu-berlin.de
Freie Universität Berlin
Institut für Biologie/Neurobiologie
Berlin, Germany

NEIMAN, Alexander
neimana@ohio.edu
Ohio University
Physics and Astronomy
Athens, USA

PARGA, Nestor
nestor.parga@uam.es
Universidad Autónoma de Madrid
Departamento de Física Teorica
Madrid, Spain

PATZELT, Felix
felix@neuro.uni-bremen.de
Universität Bremen
Institut für Theoretische Neurophysik
Bremen, Germany

PÉREZ, Toni
toni@ifisc.uib.es
University of Balearic Islands
Inst. for Cross-Disciplinary Physics and Complex Systems
Palma de Mallorca, Spain

Participants

PIKOVSKY, Arkady
pikovsky@uni-potsdam.de
Universität Potsdam
Institut für Physik
Potsdam, Germany

PIPA, Gordon
gordon@pipa.biz
MPI für Hirnforschung
Neurophysiologie
Frankfurt am Main, Germany

PONS-RIVERO, Antonio J.
a.pons@upc.edu
Universitat Politècnica de Catalunya
Departament de Física i Enginyeria Nuclear
Terrassa, Spain

PORPORATO, Amilcare
amilcare@duke.edu
Duke University
Department of Civil and Environmental Engineering
Durham, USA

POTOTSKY, Andriy
a.pototskyy@lboro.ac.uk
Loughborough University
School of Mathematics
Loughborough, U.K.

RICCIARDI, Luigi M.
luigi.ricciardi@unina.it
Universita di Napoli Frederico II
Matematica e Applicazioni
Napoli, Italy

RICHARDSON, Magnus
magnus.richardson@warwick.ac.uk
University of Warwick
Systems Biology Department
Coventry, U.K.

RITT, Jason
jritt@mit.edu
Massachusetts Institute of Technology
McGovern Institute for Brain Research
Cambridge, USA

RÜDIGER, Sten
stenruediger@gmail.com
Humboldt Universität
Institut für Physik
Berlin, Germany

SÁNCHEZ-VIVES, María V.
mavi.sanchez@umh.es
Universidad Miguel Hernández-CSIC
Instituto de Neurociencias de Alicante
San Juan de Alicante, Spain

SCHIMANSKY-GEIER, Lutz
alsg@physik.hu-berlin.de
Humboldt Universität
Institut für Physik
Berlin, Germany

SCHMID, Gerhard
Gerhard.Schmid@physik.uni-augsburg.de
Universität Augsburg
Institut für Physik
Augsburg, Germany

SCHNEIDER, Gaby
gaby.schneider@math.uni-frankfurt.de
Universität Frankfurt
Computer Science and Mathematics
Frankfurt am Main, Germany

Participants

SCHREIBER, Susanne
s.schreiber@biologie.hu-berlin.de
Humboldt Universität
Department of Biology
Berlin, Germany

SKUPIN, Alexander
alexander.skupin@hmi.de
Hahn-Meitner-Institut
Theoretische Physik
Berlin, Germany

STOCKS, Nigel
ngs@eng.warwick.ac.uk
Warwick University
School of Engineering
Coventry, U.K.

STREFLER, Jessica
strefler@physik.hu-berlin.de
Humboldt Universität
Institut für Physik
Berlin, Germany

TABARELLI, Davide
tabarell@science.unitn.it
University of Trento
Department of Physics
Trento, Italy

TALKNER, Peter
Peter.Talkner@Physik.Uni-Augsburg.DE
Universität Augsburg
Institut für Physik
Augsburg, Germany

TORCINI, Alessandro
alessandro.torcini@isc.cnr.it
Consiglio Nazionale delle Ricerche
Istituto dei Sistemi Complessi
Firenze, Italy

TUCKWELL, Henry
tuckwell@mis.mpg.de
MPI für Mathematic in den Naturwissenschaften
Leipzig, Germany

ULLNER, Ekkehard
ekkehard.ullner@upc.edu
Universitat Politecnica de Catalunya
Departament de Fisica i Enginyeria Nuclear
Terrassa, Spain

VICENTE, Raul
raulvicente@mpih-frankfurt.mpg.de
MPI für Hirnforschung
Abteilung Neurophysiologie
Frankfurt am Main, Germany

VILARDI, Andrea
andrea.vilardi@gmail.com
University of Trento
CiMeC - Center for Mind/Brain Sciences
Mattarello, Italy

VILELA, Rafael
rdvilela@pks.mpg.de
MPI für Physik komplexer Systeme
Biological Physics
Dresden, Germany

WOLFF, Lars
wolff@pks.mpg.de
MPI für Physik komplexer Systeme
Biological Physics
Dresden, Germany