1. **Sari Andoni** University of Texas at Austin
   Thalamocortical Coupling During Spontaneous and Stimulus-evoked Activity in the Visual System

   Boris V. Zemelman
   Nicholas J. Priebe

   We investigate the bidirectional coupling between the visual thalamus and primary visual cortex in the presence of ongoing slow-wave oscillations characteristic of sleep and behavioral quiescence. The spontaneous fluctuations in the membrane potential of cortical neurons, between a hyperpolarized quiescent down-state and a depolarized active up-state, were compared to thalamic activity to derive the coupling functions that govern the synchronization between the two structures. Based on spontaneous activity alone, the coupling functions indicated that the thalamocortical pathway was mainly excitatory while the corticothalamic projections had a suppressive effect. We compared spontaneous coupling to the thalamocortical phase response curves (PRCs) derived under stimulus-evoked conditions, by either stimulating the thalamus using a visual stimulus and measuring the phase response at the cortex, or directly stimulating the cortex using optogenetics and recording its effect on thalamic activity. The coupling functions derived under either spontaneous or stimulus-evoked activity were similar. In both cases, activation of thalamocortical projections pushes the cortex towards the up-state, whereas activation of corticothalmic projections elicits a suppressive influence on the thalamus, prolonging thalamic down-states and shortening up-states. Our results suggest that feedback from the visual cortex acts as a gatekeeper or a governor that controls the flow of sensory information by means of direct or indirect inhibitory projections to the visual thalamus.

2. **Andrea K. Barreiro**

   Southern Methodist University

   How bifurcation structure determines correlation transfer from common input

   Alessio Franci, University of Liege

   Correlations among neural spike times are found widely in the brain; they can be used to modulate or limit information in population coding, as well as opening the possibility for cooperative coding of sensory inputs across neural populations. A potential source of such correlations is common external input, which is transformed into correlated output through the neural dynamics. This process can depend on internal neural dynamics and downstream neuron properties in interesting and non-intuitive ways, as demonstrated by Bard Ermentrout and his students in a series of recent papers. In this talk, we explore correlation transfer in a set of models with a novel bifurcation structure that can arise in the presence of calcium currents.

3. **Ernest Barreto**
   George Mason University

   Tanushree B. Luke, Paul So

   Complete Classification of the Macroscopic Behavior of a Heterogeneous Network of Theta Neurons

   We design and analyze the dynamics of a large network of theta neurons, which are idealized Type-I neurons. The network is heterogeneous in that it includes both inherently spiking and excitable neurons. The coupling is global, via pulse-like synapses of adjustable sharpness. Using recently-developed analytical methods, we identify all possible asymptotic states that can be exhibited by a mean-field variable that captures the network's macroscopic state. These consist of two equilibrium states that reflect partial synchronization in the network, and a limit cycle state in which the degree of network synchronization oscillates in time. Our approach also permits a complete bifurcation analysis, which we carry out with respect to parameters that capture the degree of excitability of the neurons, the heterogeneity in the population, and the coupling strength (which can be excitatory or inhibitory). We find that the network typically tends towards the two macroscopic equilibrium states when the neuron's intrinsic dynamics and the network interactions reinforce one another. In contrast, the limit cycle state, bifurcations, and multistability tend to occur when there is competition between these network features. Finally, we show that our results are exhibited by finite network realizations of reasonable size.

4. **Christy Contreras**
   Arizona State University

   Modeling the Lymphocytic Choriomeningitis Virus: insights into understanding its epidemiology in the wild

   Susan Holechek, John McKay

   The lymphocytic choriomenigitis virus (LCMV) is a rodent-spread virus commonly recognized as causing neurological disease that exhibits asymptomatic pathology. The virus is a pathogen normally carried among rodents that can be transmitted to humans by direct or indirect contact with the virus in excretions and secretions from rodents and can cause aseptic meningitis and other conditions in humans. We consider an epidemiological system within rodent populations modeled by a system of ordinary differential equations that captures the dynamics of the disease's transmission and present our findings. The asymptotic nature of the pathogen plays a large role in its spread within a given population, which has motivated us to expand upon an existing SIRC model (Holechek et al in preparation) that accounts for susceptible-, infected-, recovered-, and carrier-mice on the basis of their gender. We are interested in observing and determining the conditions under which the carrier population will behave endemically, and we focus our investigation on the sensitivity of our model to pregnancy-related infection, total and reproduction rate conditions. The reproduction rate is characterized by the reproduction number, "R" _0, which in turn influences the behavior of the disease-free equilibrium. The disease-free equilibrium is unstable; therefore all values will converge at the origin if the reproductive number is less than or equal to the critical value one but if the number exceeds one, then there exists a stable, endemic equilibrium.

5. **Danilo Diedrichs**

Wheaton College

Mathematical Model of the Dynamics of the Unfolded Protein Response in Mammalian Cells under Endoplasmic Reticulum Stress

Curtu, R Diedrichs, D Gomez, J Rutkowski, DT

The unfolded protein response (UPR) is a cellular mechanism whose primary functions are to sense perturbations in the protein-folding capacity of the endoplasmic reticulum and to take corrective steps to restore homeostasis. Although the UPR is conserved across all eukaryotic cells, it is considerably more complex in mammalian cells due to the presence of three interconnected pathways triggered by separate sensor proteins, a translation attenuation mechanism, and a negative feedback loop. The present model uses a system of nonlinear ordinary differential equations based on chemical rate equations to describe the dynamics of the UPR as a network of interacting proteins and mRNAs. This quantitative model is calibrated to data collected on mouse embryonic fibroblasts treated to induce the UPR experimentally. The model attempts to shed light on the observed switch mechanism between cell survival and apoptosis, caused by the strength and persistence of the inducing stress, as well as by feedback loops intrinsic to the network of interacting proteins.

6. **Casey Diekman**

New Jersey Institute of Technology

Modeling the Causes and Consequences of Hyperexcitation in Central Clock Neurons

Mino Belle, Robert Irwin, Charles Allen, Hugh Piggins, and Daniel Forger

Daily rhythms in the behavior and physiology of mammals are coordinated by a group of neurons that constitute the central circadian (~24-hour) clock. Clock neurons contain molecular feedback loops that lead to rhythmic expression of

clock-related genes. Much progress has been made in the past two decades to understand the genetic basis of the molecular circadian clock. However, the relationship between the molecular clock and the primary output of clock neurons—their electrical activity—remains unclear. Here, we explore this relationship using computational modeling of an unusual electrical state that clock neurons enter at a certain time of day. We predict that this state causes high concentration of calcium ions inside clock neurons, which activates transcription of clock genes. We demonstrate that this additional feedback promotes 24-hour gene expression rhythms. Thus, we propose that electrical activity is not just an output of the clock, but also part of the core circadian timekeeping mechanism that plays an important role in health and disease.

7. **Farzad Farkhooi**

Theoretical Neuroscience, Freie Universität Berlin, Germany

Calculation of inter-spike interval distribution of neurons with multiplicative noise

Carl van Vreeswijk, Neurophysics, Paris Descartes University and Carson C. Chow, Laboratory of Biological Modeling, NIH, USA

The inter-spike interval distribution has important experimental and biological implications. For a given neuron model, this requires the calculation of the first passage time distribution which is notoriously difficult. Here, we present a straightforward recursive method to compute moments of the first passage time distribution for an arbitrary neuron model with noisy inputs. The neuron is first cast as a Langevin equation on a restricted domain. The method translates the problem to the computation of the probability transition density for the Langevin equation on an unbounded domain. We show that these densities can be computed for arbitrary non-linear Langevin equations with multiplicative noise perturbatively using path integral methods.

8. **Chris Fietkiewicz**

Case Western Reserve University

Variability in respiratory rhythm generation: in vitro and in silico models

Christopher G. Wilson (Loma Linda University)

The variability inherent in rhythmic physiological patterns may arise from both stochastic and deterministic sources. Though variability is disruptive when in excess, it may also be functional in evolved systems. Here we focus on the neural control of respiration which is critical for survival in many animals. The sources

of respiratory variability, as well as its possible function, are unknown. A fundamental component of respiratory pattern generation is the preBötzinger complex (preBötC) which is part of the ventral respiratory column located in the brainstem. Here we use in vitro and in silico models of the preBötC to study the variability of respiratory rate. The in vitro model exhibits a bounded range of variability in which the upper and lower limits are functions of the respiratory rate. The in silico model consists of two types of neurons: intrinsically bursting "pacemaker" cells and tonically spiking cells that relay chemosensory and mechanosensory feedback. When fitted to the experimental data, the in silico model shows the existence of both stochastic and deterministic sources for variability in the respiratory rate. The upper and lower limits of variability seen experimentally are reproduced in silico using a range of network connection strengths. Simulations demonstrate that stochastic spiking in sensory relay neurons may be utilized to stabilize changes in variability when the respiratory rate changes due to physiological demand.

9. **Stefanos Folias**

On the spatial structure of solutions bifurcating from activity bumps in neural field models

In neural field models, stationary activity bumps are equilibria representing spatially-localized neuronal populations that are actively firing either intrinsically or in response to a stimulus input. In celebration of Bard Ermentrout's work with his Ph.D. student David Pinto on stationary bumps in an E/I neural field and a disinhibited neural field with adaptation, we present an overview of a collection of results that were inspired by this original work. By studying the stability of such equilibria from a dynamical systems perspective, we use bifurcation theory to identify new types of solutions that bifurcate from these stationary activity bumps in a variety of neural field models that incorporate excitatory and inhibitory synaptic interactions, adaptation, and/or multiple neural field layers. In particular, we concentrate on the relationship between the spatial structure of the eigenfunctions in the linearization about the activity bump and the spatial structure of the bifurcating solutions, which include both stationary (time-independent) and oscillatory solution types. One goal of neural field theory is to facilitate the understanding and analysis of mechanisms that underlie the large scale activity patterns in cortical tissue. Therefore the next decade will be exciting as the development and advancement of new technology is slowly beginning to elucidate the spatiotemporal activity patterns in cortical tissue in vivo.

10. **Kameron Decker Harris**
University of Washington Applied Mathematics

Sparse network models of the breathing rhythm and the effect on variability and modulability

Eric Shea-Brown, Jan-Marino Ramirez, Tatiana Dashevskiy

The pre-Botzinger complex (preBot), part of the ventral respiratory group, is recognized as the source of the breathing rhythm. This area contains a few hundred neurons and exhibits rhythmic bursts of activity which drive downstream motoneurons to generate breaths. The preBot contains many classes of neurons, including intrinsically bursting, tonic, and quiescent, all of which can be recruited through synaptic interaction into the population burst. We believe that the population bursts generated by the preBot emerge from network interactions among neurons. This contrasts the original hypothesis of certain pacemaker neurons that regulate the population burst. The true network structure of preBot is mostly unknown. We investigate a model that considers sparse, random networks of connections with realistic neuron and synapse dynamics. We are also examining the synchronization behavior of simpler phase-oscillator models (such as the theta model) in these networks. The immediate goal is to better describe experimentally observed cycle-to-cycle variability of individual neurons' participation in the rhythm. We also want to investigate whether changes in synaptic strength and leak conductances, which could be regulated by neuromodulators in preBot, can tune macroscopic properties of the rhythm such as its frequency. This is a step towards understanding how the preBot generates a rhythm that is both robust and flexible. We think this is an interesting context to ask these questions, because breathing is an activity that is essential to life but also adjusts its pattern according to arousal, stress, speech, etc.

11. **Avinash J. Karamchandani**
Northwestern University,
Engg. Sci. & Appl. Math.
Hermann Riecke

Synchrony and Phase-Locking of Subthreshold Oscillations in Neurons Coupled with Chemical Synapses

In the mammalian olfactory system various rhythms are observed: a fast gamma rhythm that arises in the olfactory bulb from the reciprocal interaction between the excitatory mitral cells and inhibitory granule cells and a slower beta rhythm that requires cortical input to the olfactory bulb. A characteristic feature of the gamma rhythm is the appearance of subthreshold oscillations in the mitral cells and the absence of significant spiking of granule cells. To investigate the appearance of these rhythms, we explore the dynamics of a minimal model in which principal cortical cells, driven by mitral cells, excite granule cells. Thus, each mitral cell receives inhibitory input via two overlapping pathways, a direct mitral-granule-mitral and an indirect mitral-cortical-granule-mitral pathway. As a first step, we introduce an effective direct synaptic inhibition among mitral cells, and investigate the dynamics of this system as a function of the delays associated

with these pathways. We use a Hodgkin-Huxley model of the mitral cells, based on [1], which exhibit subthreshold oscillations between spikes. We obtain the phase response curve for this model, and investigate the population dynamics in the weak-coupling limit. We find that for short delays, which model the direct pathway only, the synchronous state is linearly unstable. This matches the experimental observation that, during the gamma rhythm, mitral cells do not spike synchronously. The resulting population rhythm is faster than the spiking of individual cells, reflecting the shorter period of the subthreshold oscillations. We find that the synchronous state becomes globally attractive with the addition of sufficient inhibition with longer delays, which can arise from the indirect pathway. In this state the population rhythm has a longer period, corresponding to the spiking of mitral cells. We interpret this as the cortically induced beta rhythm. We compare the weak-coupling results with those from numerical simulations of the Hodgkin-Huxley mitral cells interacting via the effective inhibition. [1] Jorge N. Brea, Leslie M. Kay, and Nancy J. Kopell. “Biophysical Model for Gamma Rhythms in the Olfactory Bulb via Subthreshold Oscillations.” PNAS, 106 (2009): 21954–21959.

12. **Jung Eun Kim**
The Ohio State University

Stochastic Mean Field Model for Sleep Wake Transition Dynamics

Fatih Olmez, Janet Best, Deena Schmidt, John McSweeney, Peter Kramer

Wake bout durations of newborn rats are exponentially distributed but become power law distributed within three weeks. To gain insight into network processes that may underlie sleep-wake transitions in these animals, we developed a simple model consisting of two mutually-inhibitory Erdos-Renyi random graphs of spiking nodes; the two graphs alternate between high and low levels of activity with durations that can have either exponential or power law distribution depending upon parameters. Here we describe numerical and analytical studies of dynamics of stochastic differential equations related to the model, including the four-dimensional stochastic mean field equations. Methods include large deviation theory and minimum action method, penalization of the drift term and penalization of the probability measure.

13. **Kiyoshi Kotani**
Graduate School of Frontier Science,
The University of Tokyo

A. Akao*, L. Yoshida*, Y. Ogawa*, Y. Jimbo*, and G.B.Ermentrout**
*Graduate School of Frontier Science, The university of Tokyo **Department of Mathematics, University of Pittsburgh

Excitatory and inhibitory neuronal population of modified theta model

Gamma oscillation plays important functional roles in the cortex and hippocampus. Recent experiments of pharmacological blockade show that the gamma oscillation can be emerged by two different mechanisms, namely PING (pyramidal-interneuron gamma) and ING (interneuron gamma). However, little is known about how these differences contribute to synchronization with the different region of the brain. We investigate the population dynamics of Excitatory-Inhibitory neurons composed of modified theta neuron models, which possess voltage-dependent dynamics and appropriate forms and strengths of the synaptic interactions. The phase response functions of the E-I population are systematically derived by the adjoint method for their Fokker-Planck equations. It is revealed that PING and ING have largely different characteristics of the phase response functions, which indicate the different ability to synchronize to external stimuli. Possible functional roles of PING and ING in the brain are discussed under the point of view of the phase dynamics.

14. **Giri Krishnan**
UC Riverside

Giri P Krishnan, Andrey Shilnikov, Maxim Bazhenov

Direct influence of ion concentration changes on seizure dynamics through Na+/K+ pump current

Ion concentrations in intra and extracellular space are known to fluctuate significantly during seizures. Indeed, substantial fluctuations of extracellular K+ concentration ([K+]o) were found during electrically- or pharmacologically-induced paroxysmal activity, along with decreases of extracellular Na+ ([Na+]o), which corresponds to increase of [Na+]i. These changes of the ionic concentrations can have profound effects on the network dynamics through different mechanisms including changing reversal potential for currents and activating ionic pumps such as Na+/K+ ATPase. In many studies, the change in the reversal potential was considered to be the main effect of ion concentration changes, while the change in pump currents was generally ignored. In this study, we use computational modeling and bifurcation analysis to reveal that electrogenicity of Na+/K+ pump plays critical role in maintaining stability of the neuronal dynamics and the changes of the pump currents mediate seizure initiation and termination. First, we show that the increase in Na+/K+ pump current due to accumulation of [Na+]i leads to spontaneous termination of seizure. The increase in Na+/K+ pump current shifts the saddle-node bifurcation point between silent and spiking state rendering the bistable region, which is critical for sustaining seizure, unreachable. Second, we show that Na+/K+ pump current is critical for maintaining stability of the neuronal dynamics. A small reduction in Na+/K+ pump current led to onset of seizure, through a unique bursting mechanism. Bifurcation analysis revealed a novel topology for bursting that involved a smooth transition between silent branch and spiking manifold due a safe bifurcation of a homoclinic orbit. This novel topology of bursting also translated to a unique high frequency activity of neurons at the burst onset similar to that found in vitro after injection of pilocarpine (non-selective muscarinic receptor agonist). Overall, our study demonstrates profound role of the Na+/K+ pump current on neuronal dynamics.

15. **Paola Malerba**
UC Riverside

Mechanisms of ripple generation and sequence repetition in the hippocampus

Giri Prashanth Krishnan Maxim Bazhenov

Hippocampus is a brain structure involved in memory encoding and retrieval. Among hippocampal-specific activity patterns associated with memory formation and consolidation, sharp-wave ripple complexes are brief high-frequency events, during which the firing sequences of previously activated cells are re-played. It is believed that sequence reactivation during ripples contributes to memory formation in awake patterns and to memory consolidation during sleep. Commonly, during a ripple only a few pyramidal (excitatory) cells are recruited, and spike at the peak of the event, while perisomatic interneurons (a type of inhibitory cells) spike across the duration of the event. The distribution of spike timing with respect to ripple peak is different for different types of interneurons. In hippocampal area CA1, axo-axonic cells cells tend to spike only at ripple initiation and be suppressed in the later part of a ripple. Since axo-axonic cells are in a crucial position to suppress the spikes of the pyramidal cell they impinge upon, we hypothesize that they can regulate the initiation of cell specific activity replay. In this work, we design designed a computational model of ripple generation in a hippocampal network. The model incorporates different cell types and emphasizes the role of axo-axonic cells in selecting which pyramidal cells are participating in ripple activity, hence what spiking sequence is replayed during a given ripple event.

16. **Ava Mauro**
Boston University

Samuel Isaacson

A numerical method for simulating stochastic reaction-drift-diffusion systems.

We have developed a new numerical method for simulating stochastic reaction-drift-diffusion systems, in which the drift arises from spatially varying potential

fields. Such potential fields are useful for modeling the spatially heterogeneous environment within a cell. The method combines elements of the First-Passage Kinetic Monte Carlo (FPKMC) method for reaction-diffusion systems with the Wang-Peskin-Elston discretization of drift-diffusion. In this combined method, which we call Dynamic Lattice FPKMC, each molecule undergoes a continuous time random walk on its own lattice, and the lattices change adaptively and dynamically over time. This allows for the use of smaller lattice spacings when and where they are needed for accuracy; coarser lattice spacings can be used elsewhere to improve efficiency. In this poster, we will present results demonstrating the convergence and accuracy of our method. We will also show applications to cell biology.

17. **John McKay**
    Arizona State University
    Multi-scale dynamical network of social insects *Pogonomyrmex californicus* and their labor division

    Ioulia Besplova, Oyita Udiani, Dr. Jennifer Fewell, Dr. Yun Kang

    Research has shown that antennation patterns within ant colonies may be one way that ants modulate which task they perform. We collected data on four colonies of Pogonomyrmex californicus of each ant's antennations and identified task over a two minute span. Using this, we applied graph theoric techniques to better understand the network dynamics of the colonies from both an individual ant and a task group level including how information patterns emerged over time and how ants biased their communication based on tasks.

18. **Kartheek Medathati**
    INRIA
    James Rankin Guillaume Masson Pierre Kornprobst

    Exploring the richness of center-surround dynamics: A bifurcation study

    The balance of excitatory and inhibitory interactions between neurons is one of the characteristic aspects of neural computation. In both neural network and neural field models these interactions have been modeled using center-surround connectivity kernels. Depending on the relative strength of excitation and inhibition these networks have been found to exhibit rich and interesting dynamical behavior. Although many models have been reported in the literature using center-surround connectivity kernels and many experimental studies have shown evidence for changes in observed behavior from winner-take-all to gain control, a thorough bifurcation analysis of these networks in terms of sensitivity of the network to peak strength, discriminability of the peaks and speed of convergence has not been done. In our present work we visit this question in order to identify the parameter regimes where this important switch in the behavior of the network occurs and also establish the trade offs that arise with the choice of a particular connectivity kernel.

19. **Stanislav Mintchev**
The Cooper Union

Bastien Fernandez, Oscar E. Lanford III

Generation and Stability of Traveling Wave Solutions in Unidirectional Chains of Phase Oscillators

We study the generation of traveling waves in unidirectional chains of coupled oscillators communicating via a phase-dependent pulse-response interaction borrowed from mathematical neuroscience. Preliminary numerical results indicate the existence of a periodic traveling wave solution as well as the asymptotic relaxation of a single oscillator to the wave when it is forced with the wave generator. Using this evidence as an assumption, we analytically prove global stability of waves in the infinite chain, with respect to initial perturbations of finitely many sites. We conclude with an analytic proof of existence and local stability of traveling wave solutions in a simplified, piecewise-affine interaction model that inherits the main features of the original motivation. In conjunction with the global stability theorem (that holds for a rather general class of models), this latter study proves, in a idealized situation, that families of globally-cstable traveling wave solutions are supported in all parameter regimes.

20. **Jeff Moehlis**

University of California, Santa Barbara
Improving the Precision of Noisy Oscillators

We consider how the period of an oscillator is affected by white noise, with special attention given to the cases of additive noise and parameter fluctuations. Our treatment is based upon the concepts of isochrons, which extend the notion of the phase of a stable periodic orbit to the basin of attraction of the periodic orbit, and phase response curves, which can be used to understand the geometry of isochrons near the periodic orbit. This includes a derivation of the leading-order effect of noise on the statistics of an oscillator's period. Several examples are considered in detail, which illustrate the use and validity of the theory, and demonstrate how to improve a noisy oscillator's precision by appropriately tuning system parameters or operating away from a bifurcation point. It is also shown that appropriately timed impulsive kicks can give further improvements to oscillator precision.

21. **Hiroya Nakao**

Graduate School of Information Science and Engineering
Tokyo Institute of Technology
Dr. Wataru Kurebayashi, Sho Shirasaka

A phase reduction method for strongly perturbed limit cycle oscillators and its applications

The phase reduction method for weakly perturbed limit-cycle oscillators has significantly contributed to theoretical studies of various rhythmic phenomena. We here propose a generalized phase reduction method that is also applicable to strongly perturbed limit-cycle oscillators. Under the assumption that the perturbations can be decomposed into a slowly varying component as compared to the amplitude relaxation time and remaining weak fluctuations, we introduce a generalized phase parameterized by the slowly varying component and derive a closed equation for the generalized phase describing the oscillator dynamics. The proposed method enables us to study a more general class of rhythmic phenomena, in which the shape and frequency of the oscillation may significantly vary because of the perturbations. We illustrate our method by analyzing the synchronization dynamics of limit-cycle oscillators driven by strong periodic signals. It is shown that the proposed method accurately predicts the synchronization properties of the oscillators. We also consider two strongly coupled nonlinear oscillators and analyze their synchronization dynamics by the generalized phase reduction method.
(*) W. Kurebayashi, S. Shirasaka, and Hiroya Nakao, "Phase reduction method for strongly perturbed limit cycle oscillators", Physical Review Letters 111, 214101 (2013).

22. **Wilten Nicola**

University of Waterloo
Sue Ann Campbell

Non-smooth Bifurcations in Mean-Field Systems for Networks of Integrate-and-Fire Neurons

For many types of networks of integrate and fire neurons, one can often derive a system of mean-field equations for the networks as the network size becomes arbitrarily large. The mean-field system is typically a small, coupled set of ordinary differential equations for the first moments of key network variables, such as the synaptic gating variable or the adaptation currents. However, the analytically derived mean-field systems often contain a degree of non-smoothness which complicates the bifurcation analysis. Non-smooth dynamical systems can have both classical bifurcations as well as the newer and more poorly understood non-smooth bifurcations. Here, we show that the mean-field system for an all-to-

all coupled network of Izhikevich neurons has a rich sequence of non-smooth bifurcations, including a variety of codimension-1 non-smooth bifurcations, and a codimension-2 non-smooth collision between a saddle-node bifurcation and a switching manifold. Applications to other biological systems where non-smoothness is a feature are also discussed.

23. **Arkady Pikovsky**
University of Potsdam, Germany

G. P. Krishnan, M. Bazhenov

In vivo cardiac phase response curve from ECG and respiration measurements

We present a general method for obtaining the phase coupling function from the bi-variable observations of the coupled oscillating systems. We show how this coupling function can be further decomposed into the forcing and the phase response curve. The method is applied for obtaining the in vivo cardiac phase response curve from the ECG and respiratory measurements, Furthermore we demonstrate, that the method allows one to cleanse the cardiac data to extract the respiration-independent component of the heart rate variability.

24. **Siwei Qiu**

NIH
Carson Chow

Bump solution for the theta model

We use the Feynman path integral method to analyze perturbatively the dynamics of a synaptically coupled spiking neural network of theta neurons with spatial structure. Starting from the microscopic neural network equations, we derived the action for the synaptic drive and the neuron phase density as a function of position, angle, and time. We first compute the mean field equations and compare the resulting bump solutions to simulations of the neural network equations. Then we do perturbation theory in the inverse system size and compute the activity equation for the network. In this way, we get the finite size effect due to the correlation between neurons.

25. **James Rankin**
NYU Center for Neural Science
Differential effects of stimulus strength and volitional control on dominance durations in bistable perception

John Rinzel, NYU Center for Neural Science and Courant Institute of Mathematical Sciences.

Bistable perception has been widely studied in the visual system where ambiguity in sensory information coming from, for example, binocular, depth or motion cues leads to spontaneous shifts in perception. Indeed, Moreno-Bote et al. (2010) investigated rivalrous dynamics induced by ambiguity in these sensory cues and generalized Levelt's proposition II (Levelt, 1968) that describes the effect of stimulus strength manipulations around equidominance: ``the mean dominance duration of the stronger percept changes more than that of the weaker percept". Bistability also occurs in auditory streaming experiments for stimuli with alternating high- A and low-frequency tones B appearing in a repeating ABA- pattern. Pressnitzer and Hupé (2006) showed that auditory and visual bistability share the common traits of perceptual bistability using such ABA- sequences and visual motion plaids. In each modality there are alternations between a grouped percept (a galloping ABA-ABA- stream; coherent pattern motion) and a split percept (segregated streams A-A-A-A- and -B---B--; drifting transpent motion). They further investigated the effect of volitional control at equidominance and found that attending to one percept (grouped or split) reduced mean dominance durations of the unattended (weaker) percept. These findings are incompatible with the generalized Levelt's Proposition II if one assumes that volition increases the strength of the targeted percept. Starting with a canonical rivalry model we propose a new volitional mechanism with state-dependent inputs that resolves this apparent conflict by accounting for differences between direct input strength manipulations and top-down attention. We further present a new three-population model with periodic inputs for the auditory case to which our general result extends. Our modeling results can explain important differences between input strength and attention that generalize across sensory modalities.

26. **Hermann Riecke**
Northwestern University

Intrinsic Bursting of AII Amacrine Cells Underlies Oscillations in the rd1 Mouse Retina

Hannah Choi, Lei Zhang, Mark S. Cembrowski, William L. Kath, Joshua H. Singer

In retinal degeneration the majority of the photoreceptors die, leaving large parts of the remaining retinal circuitry intact. With a view toward exploiting the remaining circuitry for retinal prostheses, various mouse models of retinal degeneration have been investigated. In the rd1 mouse, characteristic oscillations are observed in ganglion cells as well as in the gap-junction coupled network of AII amacrine cells and ON cone bipolar cells. Such oscillations could undermine the capability of the remaining network to process sensory input. It has been suggested that these oscillations are an emergent property of the AII-network. Combining electrophysiology with computational modeling, we demonstrate, however, that the gap junction network only plays a role insofar as it affects the

membrane potential of the AIIs. Instead, these oscillations arise from an intrinsic behavior of AIIs: bursting driven by an M-type potassium current. The model exhibits a surprising bistability between bursting and tonic spiking.

27. **Alan Saul**
Georgia Regents University

Phase shifts arising from NMDA and GABAa receptors in a model of thalamic neurons

Simulations of thalamic neurons based on a model of Bard Ermentrout were made to explore known behaviors of cells in the lateral geniculate nucleus, a visual area in the thalamus. The model has 11 parameters corresponding to various cellular mechanisms. Three of these parameters were systematically varied to explore whether the model could reproduce timing seen experimentally in lagged and nonlagged neurons, which differ in the phases of their responses to visual stimuli. The fidelity of the simulations was tested using data kindly provided by David Mastronarde. We found that the membrane conductances mediated by GABAa and NMDA receptors can explain these timing differences that are seen at frequencies in the range of 0.25-8 Hz, although additional mechanisms are needed to predict spike timing.

28. **Deena Schmidt**
Case Western Reserve University

Peter J. Thomas

Measuring edge importance for random processes on graphs

Mathematical models of cellular physiological mechanisms often involve random walks on graphs representing transitions within networks of functional states. Schmandt and Galan recently introduced a novel stochastic shielding approximation as a fast, accurate method for generating approximate sample paths from a finite state Markov process in which only a subset of states are observable. For example, in ion channel models, such as the Hodgkin-Huxley or other conductance based neural models, a nerve cell has a population of ion channels whose states comprise the nodes of a graph, only some of which allow a transmembrane current to pass. The stochastic shielding approximation consists of neglecting fluctuations in the dynamics associated with edges in the graph not directly affecting the observable states. We consider the problem of finding the optimal complexity reducing mapping from a stochastic process on a graph to an approximate process on a smaller sample space, as determined by the choice of a particular linear measurement functional on the graph. The partitioning of ion channel states into conducting versus nonconducting states provides a case in point. In addition to establishing that Schmandt and Galan's approximation is in

fact optimal in a specific sense, we use recent results from random matrix theory to provide heuristic error estimates for the accuracy of the stochastic shielding approximation for an ensemble of random graphs. Moreover, we provide a novel quantitative measure of the contribution of individual transitions within the reaction graph to the accuracy of the approximate process.

29. **Michael Schwemmer**

Mathematical Biosciences Institute

Jay Newby

Effects of moderate noise on a limit cycle oscillator: counter rotation and bistability

The effects of noise on the dynamics of nonlinear systems is known to lead to many counter-intuitive behaviors. Using simple planar models exhibiting limit cycle dynamics, we show that the addition of moderate noise leads to qualitatively different behaviors. In particular, the system can appear bistable, rotate in the opposite direction of the deterministic limit cycle, or cease oscillating altogether. Utilizing standard techniques from stochastic calculus and recently developed stochastic phase reduction methods, we elucidate the mechanisms underlying the different dynamics and verify our analysis with the use of numerical simulations. Lastly, we demonstrate that similar behavior is found when moderate noise is applied to the more biologically realistic FitzHugh-Nagumo model.

30. **Gregory D. Smith**

The College of William & Mary

Seth H. Weinberg

Department of Applied Science, The College of William & Mary, Williamsburg, VA 23187, USA

The influence of calcium buffers on free [Ca2+] fluctuations and the effective volume of calcium microdomains

Intracellular calcium (Ca2+) plays a significant role in many cell signaling pathways, some of which are localized to spatially restricted “microdomains” in the cell. calcium binding proteins (calcium buffers) play an important role in regulating calcium concentration ([Ca2+]). Buffers typically slow [Ca2+] temporal dynamics and increase the effective volume of calcium domains. Because fluctuations in [Ca2+] decrease in proportion to the square root of a domain's physical volume, one might conjecture that buffers decrease [Ca2+]

fluctuations and, consequently, mitigate the significance of small domain volume vis-a-vis calcium signaling. We test this hypothesis through mathematical and computational analysis of idealized buffer-containing domains and their stochastic dynamics during free calcium influx with passive exchange of both calcium and buffer with bulk concentrations. We derive Langevin equations for the fluctuating dynamics of calcium and buffer and use these stochastic differential equations to determine the magnitude of [Ca2+] fluctuations for different buffer parameters (e.g., dissociation constant and concentration). In marked contrast to expectations based on a naive application of the principle of effective volume as employed in deterministic models of calcium signaling, we find that mobile and rapid buffers typically *increase* the magnitude of domain [Ca2+] fluctuations during periods of calcium influx, while stationary (immobile) calcium buffers do not. Also contrary to expectations, we find that in the absence of calcium influx, buffers influence the temporal characteristics, but not the magnitude, of [Ca2+] fluctuations. We derive an analytical formula describing the influence of rapid calcium buffers on [Ca2+] fluctuations and, importantly, identify the stochastic analogue of (deterministic) effective domain volume. Our results demonstrate that calcium buffers alter the dynamics of [Ca2+] fluctuations in a non-intuitive manner, and raise the intriguing question of whether or not [Ca2+] fluctuations are a physiologically significant aspect of local calcium signaling.

31. Abigail Snyder
University of Pittsburgh

Jonathan Rubin

Multiple rhythms from one network: Phase plane analysis of rhythmic activity in turtle motor circuits

We analyze a proposed central pattern generator's ability to produce differing motor patterns from a single pool of neurons under different tonic drives. A key issue is a particular motoneuron's response to different phasic synaptic inputs. We study the impact of these phasic inputs on motoneuron phase space and on properties of associated trajectories and show how these yield sufficient conditions for reproduction of observed rhythms. A contraction argument leads to existence of a stable solution.

32. **Paul So**

Krasnow Institute for Advance Study, George Mason University

Tanushree B. Luke, Ernest Barreto

Classification and control of complex macroscopic dynamics from a network of theta neurons

Using recently developed analytical techniques, we study the macroscopic dynamics of a large heterogeneous network of theta neurons in which the neurons' excitability parameter varies in time. We demonstrate that such periodic variation can lead to the emergence of macroscopic chaos, multistability, and final-state uncertainty in the collective behavior of the network. Finite-size network effects and rudimentary control via an accessible macroscopic network parameter is also investigated.

33. **Lucy Spardy**
Mathematical Biosciences Institute

The effects of long-range coupling on neural activity in the crayfish swimmeret system

Timothy J. Lewis Brian Mulloney

During forward swimming of crayfish, four pairs of limbs called swimmerets swing rhythmically through power and return strokes. Neighboring limbs move in a back to front metachronal wave with a delay of approximately 25% of the period. Interestingly, this posterior to anterior progression is maintained over the entire range of behaviorally relevant stroke frequencies. Previous work modeled the neural circuitry coordinating this motion as a chain of nearest neighbor coupled oscillators, and it was shown that the architecture of this circuitry could provide a robust mechanism for this behavior. Here we discuss how the long range coupling, whose presence was previously ignored, affects the mechanism for rhythm generation.

34. **Tracy Stepien**
School of Mathematical and Statistical Sciences, Arizona State University
Mechanics of Collective Cell Migration in Animal Cap Explants of Varying Sizes Holley Lynch and Lance Davidson (Department of Bioengineering, University of Pittsburgh)

Collective cell migration plays an important role in maintaining the cohesion of cell layers in embryonic development. We investigate the migration of epithelial and deep mesenchymal cells of animal cap explants of varying sizes from aquatic frog Xenopus laevis embryos during gastrulation, an early phase of development. Differences in mechanical properties of the explants are analyzed via parameter estimation using a two-dimensional continuum mechanical model of cell layer migration based on an assumption of elastic deformation of the cell layer coupled with a novel data extraction method. Understanding the mechanics of collective cell migration during gastrulation will aid in developing tools to perturb pathological cases such as during wound healing and cancer and to aid in the prediction and early detection of birth defects.

35. **Yayoi Teramoto**
Princeton University   Student

Daniel Takahashi Asif Ghazanfar Philip Holmes

Title: A model of marmoset call production Abstract: Human infant crying is a powerful signal that elicits responses from caregivers. Spectrograms of infant cries contain irregularities, known as nonlinearities, that make them hard to habituate to or ignore. We study this phenomenon in marmosets (Callithrix jacchus), whose vocal development and infant-caregiver interactions resemble those in humans. While the spectral irregularities have been characterized, and it is known that they decrease during development in both humans and marmosets, their neuromechanical origin is poorly understood. To investigate how irregularities arise, and why they decline throughout development, we extend a two-mass mechanical model due to Herzel (1993) and Ishizaka and Flanagan (1972) that describes the trachea and vocal fold dynamics during speech production. In addition to passive vibrations of the vocal folds due to constant pressure airflow from the lungs, we allow variable pressure flow and include neuromuscular actuation that modulates stiffness and hence resonant frequencies. Model simulations will be compared with spectrograms of marmoset cries during development in an attempt to determine whether neural or mechanical mechanisms dominate the changes that are observed as cries become adult calls. References: Herzel, H. (1993). Bifurcations and chaos in voice signals. Applied Mechanics Reviews, 46, 399-413. Ishizaka, K. and Flanagan, J.L. (1972), Synthesis of voiced sounds from a two-mass model of the vocal cords, Bell Syst. Techn. J. 51 1233-1268.

36. **Ruediger Thul**
University of Nottingham

Neuronal spike-train responses in the presence of threshold noise

Stephen Coombes, Jonathan Laudanksi, Alan R Palmer and Chris J Sumner

The variability of neuronal firing has been an intense topic of study for many years. From a modelling perspective it has often been studied in conductance based spiking models with the use of additive or multiplicative noise terms to represent channel fluctuations or the stochastic nature of neurotransmitter release. Here we propose an alternative approach using a simple leaky integrate-and-fire model with a noisy threshold. Initially, we develop a mathematical treatment of the neuronal response to periodic forcing using tools from linear response theory

and use this to highlight how a noisy threshold can enhance downstream signal reconstruction. We further develop a more general framework for understanding the responses to large amplitude forcing based on a calculation of first passage times. This is ideally suited to understanding stochastic mode-locking, for which we numerically determine the Arnol'd tongue structure. An examination of data from regularly firing stellate neurons within the ventral cochlear nucleus, responding to sinusoidally amplitude modulated pure tones, shows tongue structures consistent with these predictions and highlights that stochastic, as opposed to deterministic, mode-locking is utilised at the level of the single stellate cell to faithfully encode periodic stimuli.

37. **Shashaank Vattikuti**

Laboratory of Biological Modeling, NIDDK, NIH

Carson C Chow

The effects of recurrent excitation in neuronal competition models.

Recently perceptual rivalry experiments have been used to investigate excitation-inhibition imbalance in cognitive disorders; although, the theoretical implications of such perturbations have not been thoroughly investigated. Significant modeling work of such tasks has been done using neuronal competition models of the basic form of mutually inhibitory neuronal firing rate models with slow adaptation; however, for the most part these models lacked recurrent excitation. In this study, we investigate the effects of recurrent excitation under a number of modeling assumptions including type of adaptation and gain function.

38. **Sergio Verduzco-Flores**
University of Colorado

Stochastic synchrony and feedforward inhibition: the case of the cerebellum

The cerebellum is involved in a variety of behaviors, such as motor control and classical conditioning. The computations performed in the cerebellar cortex are conveyed through the axons of the tonically firing Purkinje cells, which inhibit Neurons in the Deep Cerebellar Nuclei (DCN). DCN neurons tend to have a higher firing rate when the input from Purkinje cells is synchronized, and synchronization of Purkinje cells innervating the same group of DCN neurons has been observed experimentally. The mechanism used by Purkinje cells to synchronize is still unknown, but it is hypothesized that it may be the result of recurrent inhibitory collaterals. These collaterals, however, seem to form weak and sparse connections. On the other hand, Purkinje cells receive correlated inputs from cells in the granule layer of the cerebellum, opening the possibility of stochastic synchronization. The phenomenon of stochastic synchronization

happens when uncoupled oscillators synchronize due to the influence of correlated inputs. This type of synchronization has not been considered for Purkinje cells, perhaps due to the additional complication of feed-forward inhibition, which takes place when the granule cells stimulate molecular layer interneurons, which in turn inhibit the Purkinje cells. This work studies two aspects of the possible stochastic synchronization in Purkinje cells. First, it explores how an oscillator receiving two types of stimuli (excitatory and inhibitory) with a different Phase Response Curve for each one, can be understood in terms of a an equivalent oscillator receiving a single type of stimulus. Second, it shows how known mechanisms of synaptic plasticity in the cerebellar cortex could modify stochastic synchronization so as to enable learning.

39. **Sid Visser**
University of Nottingham
Delayed neural fields on spheres: analysis and simulations
Rachel Nicks (University of Birmingham) Stephen Coombes (University of Nottingham)

Pattern formation of neural fields with transmission delays is generally studied in spatial domains being one- or two-dimensional. Commonly, the domain is chosen either unbounded, resulting in an infinite line or plane, or periodically, giving rise to a circle or torus. Since none of these shapes is topologically equivalent to the neocortex, it appears more natural to represent the full neocortical surface as two spheres: one for each hemisphere. To study standing and traveling waves, as well as the competition between them, in this setting, we choose to analyze the relevant dynamics on a single sphere first. Assuming spatially homogeneous connectivity, analytic expressions are found for the linear stability of the spherical harmonics. It is shown that, in the case of a single population with inverted Wizard/Mexican hat connectivity, transmission delays are necessary for dynamic instabilities, e.g. Hopf. Results from the linear stability analysis are followed by weak-amplitude expansion which allows identification of secondary bifurcation of resulting limit cycles. Simulations are desired to validate analytical results and explore the dynamics beyond the theory, e.g. chaotic solutions. Therefore, an efficient numerical scheme is formulated for simulation of (discretized) integro-differential equations on large meshes. Linear features of Cubic-Hermite spline interpolation and numerical integration are exploited to express the majority of operations in sparse matrix-vector products.

40. **Xueying Wang**

Washington State University
James P Keener

Neural Excitability and Stochastic Resonance with Channel and Synaptic Noise.

In this work, we study neural excitability and resonance behavior using stochastic Morris-Lecar neuron models. In the first model, noise are formulated by a discrete birth-death processes to describe opening and closing of slow potassium channels and fast synaptic channels. Empolying the WKB approximations, we study the stationary distribution of the process. The second model is formulated by a stochastic differential equation. I will present our findings and understanding on neural excitability and stochastic resonance, and the interplay with channel and synaptic noise.

41. Yangyang Wang

University of Pittsburgh
Pingyu Nan, Vivien Kirk and Jonathan Rubin

Understanding and Distinguishing Three Time Scale Oscillations

The goal of this project is to understand bursting dynamics in three time scale systems. Such systems arise in biological settings such as the interaction of intrinsic calcium oscillations with a calcium-dependent, voltage-gated membrane potential oscillation mechanism within a neuron. With this motivation, we construct a model consisting of two copies of Morris-Lecar equations with three time scales. Using techniques from geometric singular perturbation theory, we explain the mechanisms underlying the dynamics and elucidate which characteristics truly represent three time scale features. Our investigation involves certain reductions to two time scales as well as additional analysis of the parameter dependence of solution features in the three time scale framework.

42. **Dan Wilson**

UC Santa Barbara

Jeff Moehlis, UC Santa Barbara

Optimal Chaotic Desynchronization of Neural Populations

We develop a procedure which suggests a powerful alternative to the use of pulsatile stimuli for deep brain stimulation treatment of Parkinson's disease. The procedure finds an energy-optimal stimulus which gives a positive Lyapunov exponent, and hence desynchronization, for a neural population, and only requires knowledge of a neuron's phase response curve, which can be measured experimentally. We illustrate the procedure for a model for thalamic neurons, which are believed to play an important role in Parkinson's disease.

43. Jun Xia

Georgia State University

Classification of neural patterns in olfaction
Remus Osan, Georgia State University

The size and complexity of neural data is increasing at a dramatic pace due to rapid advances in experimental technologies. As a result, the data analysis techniques are shifting their focus from single-units to neural populations. The goal is to investigate complex temporal and spatial patterns, as well as to present the results in an intuitive way, allowing for detection and monitoring of relevant neural patterns, using dimensionality-reduction methods such as Principal Component Analysis and Multiple Discriminant Analysis.
These techniques can be used directly on neural patterns obtained using optical imaging data. On these data sets, we are investigating how dynamics of odor responses in the primary receptor neurons of awake rats are shaped by the temporal features of the active odor sniffing and how odors are encoded in the olfactory receptor neurons of the lobster.

44. **Jie Zhang**
Georgia State University

Transient Propagation and Traveling Waves of Activity in Integrate-and-Fire Neural Networks

Remus Osan, Georgia State University

The study of traveling waves of activity in disinhibited neural slices can provide valuable insights into the normal functions of the brain or during abnormal states such as epilepsy. Large-scale networks containing integrate-and-fire models of the neurons have been successfully used to model these wave phenomena. For these models, a common assumption is that while the strength of the synaptic connections between two neurons changes as a function of distance, this interaction does not depend on other local parameters, typically leading to at least two traveling waves solutions (a slow unstable wave and a fast stable wave). In this work, we examine how epsilon-small inhomogeneities affects the dynamics of the activity propagation. In particular, we seek to determine the conditions leading to propagation failure, using solutions or recursive equations of n-the order in epsilon, which lead to improved approximations for the activity propagation solutions.