Abstracts for Invited Speakers

(1) Amari, Shun-ichi
(2) Ba, Demba
(3) Curto, Carina
(4) Diesmann, Markus
(5) Eden, Uri
(6) Fukai, Tomoki
(7) Grün, Sonja
(8) Hwang, Eunjung
(9) Itskov, Vladimir
(10) Kass, Robert
(11) Nakahara, Hiroyuki
(12) Pesaran, Bijan
(13) Sasaki, Takuya R
(14) Sharpee, Tatyana
(15) Shimazaki, Hideaki
(16) Shinomoto, Shigeru
(17) Smith, Spencer
(18) Takiyama, Ken
(19) Tanaka, Yasuhiro
(20) Teichart, Tobias
(21) Uchida, Naoshige
(22) Victor, Jonathan
(23) Yamamori, Tetsuo
Shun-ichi Amari  
amari@brain.riken.jp

Title: Information Integration and Consciousness

Integrated information theory (IIT) of consciousness, proposed by G. Tononi, quantifies the degree of consciousness by the amount \( \phi \) of information integration taken place in a neural network. However, there have been proposed many candidates of \( \phi \). We give plausible postulates from which \( \phi \) is uniquely derived. This is given by the loss of information by disconnecting branches in a system. Information geometry is used to define \( \phi \). We compare the new \( \phi \) with other \( \phi \)'s so far proposed and show the superiorities of ours. This is a joint work with M. Oizumi (RIKEN BSI) and N. Tsuchiya (Monash University).

Demba Ba  
demba@seas.harvard.edu

Title: Estimating a Separable Two-Dimensional Random Field from Point Process Data

I introduce a separable two-dimensional (2D) random field (RF) model of neural spike rasters for which the intensity function over time and trials depends on two latent Markovian state sequences that evolve separately but in parallel. The two state sequences are intended to capture the variability within and across trials respectively. We derive a Monte Carlo EM algorithm for maximizing the marginal likelihood of the data from this separable 2D RF. The algorithm provides a more precise delineation of both the time and trial at which ACC neurons learn fear response.

Carina Curto  
cpc16@psu.edu

Title: Emergent dynamics from network connectivity: a minimal model

Many networks in the brain display internally-generated patterns of activity – that is, they exhibit emergent dynamics that are shaped by intrinsic properties of the network rather than inherited from an external input. While a common feature of these networks is an abundance of inhibition, the role of network connectivity in pattern generation remains unclear.

In this talk I will introduce Combinatorial Threshold-Linear Networks (CTLNs), which are simple "toy models" of recurrent networks consisting of threshold-linear neurons with binary inhibitory interactions. The dynamics of CTLNs are controlled solely by the structure of an underlying directed graph. By varying the graph, we observe a rich variety of emergent patterns including: multistability, neuronal sequences, and complex rhythms. These patterns are reminiscent of population activity in cortex, hippocampus, and central
pattern generators for locomotion. I will present some theorems about CTLNs, and explain how they allow us to predict features of the dynamics by examining properties of the underlying graph. Finally, I'll show examples illustrating how these mathematical results guide us to engineer complex networks with prescribed dynamic patterns.

Markus Diesmann
diesmann@fz-juelich.de
Title: Progress and challenges in bottom-up network modeling

The talk presents the state of the art of simulation technology for brain-scale simulations at the level of resolution of neurons and synapses. The capabilities and challenges are exemplified by a model of macaque visual cortex (http://arxiv.org/abs/1511.09364).

Uri Eden
tzvi@bu.edu
Title: Receptive field models of multiunit activity and the decoding of hippocampal replay events

We discuss multiple statistical challenges associated with the problem of identifying and decoding hippocampal replay events in real time for closed loop experiments. We develop methods to model the joint receptive field properties of a neural population using marked point processes. We then develop estimation algorithms to track dynamics in the population firing patterns and estimate replay content in real time. This work is part of a larger project to allow investigators to manipulate neural populations in a content-specific way, altering spiking activity related to certain learning and memory patterns while leaving activity related to other patterns intact.

Naoki Hiratani¹ and Tomoki Fukai²
tfukai@riken.jp
Title: Optimal learning by neurons with redundant synaptic connections

1. RIKEN Brain Science Institute, Hirosawa 2-1, Wako, Saitama 351-0198, Japan
2. CREST, Japan Science and Technology, 4-1-8 Honcho, Kawaguchi, Saitama, 332-0012, Japan

Sensory events often occur with a certain level of uncertainty, and hence neural information processing is essentially probabilistic. However, how neurons achieve an efficient sampling of probabilistic synaptic events remains largely unknown. Recent experimental studies have revealed the presence of multiple synaptic contacts between cortical excitatory neuron pairs. Here, we propose that this redundancy in synaptic contacts gives the neural substrate for a near-optimal sampling of synaptic inputs. By constructing a neuron model with dendritic
trees and spatially distributed synapses, we derive learning rules for modifying the wiring diagrams and weights of synaptic connections between neuron pairs. In our model, the plasticity of synaptic weights approximates particle filtering algorithm, whereas the plasticity of wiring diagrams describes the resampling process of synaptic inputs. Predictions of our model well account for various experimental findings on the spatial distributions of cortical synapses and the spatial dependence of plasticity rules. Furthermore, we extend the proposed framework of learning to recurrent neural networks. Thus, our results show a novel conceptual framework for the computational roles of synaptic weight plasticity and structural plasticity in neural circuits. This study was partly supported by Kakenhi (no 15H04265) to T.F.

Sonja Grün
s.gruen@fz-juelich.de
Title: Progress and challenges in analysis of massively parallel spike data

The analysis of massively parallel spike trains (MPST) for network interactions is challenging. Pairwise correlation methods do not allow us to detect correlations of larger groups of neurons and also lead to a severe multiple testing problem. To overcome these challenges we develop methods that enable an extensive search for temporal sequences of synchronous events and spatio-temporal spike patterns. An important aspect is the ability to extract patterns occurring in significant excess. First applications to experimental data reveal relations to behavior.

EunJung Hwang
eunjunghwang.phd@gmail.com
When animals repeatedly encounter the same environmental stimuli, their response to the stimuli is not constant, but instead varies over time. Behavioral studies have suggested that a significant portion of the variability stems from the animals internal bias that continuously changes with their past action-outcome experience. Neural activity in several brain areas has been shown to encode the past action and/or outcome information, the essential components of internal bias. However, it remains unknown where in the brain those history components are integrated to form internal bias that affects subsequent action selection. Here we combine behavioral modeling, two photon calcium imaging, and optogenetic perturbation in mice performing a two-alternative forced choice task and show that the posterior parietal cortex (PPC) is critically involved in transforming the action-outcome history into bias. In this task, mice were briefly presented with drifting gratings (forward or downward; 1sec) and were required to press the joystick in the remembered direction of the gratings after a 2-sec memory period. Despite the fixed stimulus-response rule, the choice of mice was highly variable. By fitting their behavioral variability with a regression model, we found that mice updated their internal bias on a trial-by-trial basis depending on their choice-reward history. The strategy of weighing different variables (e.g., choice history and reward history) changed from animal to animal and from session to session. In
spite of such idiosyncratic and time-varying strategies, however, the trial-by-trial fluctuation of the internal bias was highly correlated with pre-stimulus activity of a subpopulation of PPC neurons which encode a mixture of previous trial reward, previous trial choice, and upcoming trial choice information during the inter-trial interval. This subpopulation was a distinct population from classically considered pre-motor neurons that become active during the peri-movement period. Furthermore, optogenetic perturbation of pre-stimulus activity in PPC, but not post-stimulus/pre-motor activity, altered the history-dependency of choice selectively in the perturbed trials. These findings suggest that PPC consists of distinct neural subpopulations, one producing history-dependent internal action-selection bias, and another reflecting pre-motor plans that are formed as a result of integrating both internal bias and external stimulus information.

Vladimir Itskov
vladimir.itskov@psu.edu
Title: Clique topology reveals intrinsic geometric structure in neural correlations

We introduce a novel approach to matrix analysis, called clique topology, that extracts features of the data invariant under nonlinear monotone transformations. These features can be used to detect both random and geometric structure, and depend only on the relative ordering of matrix entries. We then analyzed the activity of pyramidal neurons in rat hippocampus, recorded while the animal was exploring a 2D environment, and confirmed that our method is able to detect geometric organization using only the intrinsic pattern of neural correlations. Remarkably, we found similar results during nonspatial behaviors such as wheel running and rapid eye movement (REM) sleep. This suggests that the geometric structure of correlations is shaped by the underlying hippocampal circuits and is not merely a consequence of position coding. We propose that clique topology is a powerful new tool for matrix analysis in biological settings, where the relationship of observed quantities to more meaningful variables is often nonlinear and unknown.

Rob Kass
kass@stat.cmu.edu
Title: Welcome!

I am looking forward to a meeting that is fun and productive, leading to a molding of ideas from sharing perspectives. There are big challenges in understanding neural data. We need to attack them by every means we can think of, especially by working across both disciplines and international borders.
Title: Several neural computations underlying social decision-making

Hiroyuki Nakahara
Laboratory for Integrated Theoretical Neuroscience
RIKEN Brain Science Institute

A fundamental challenge in social cognition is elucidating how one learns to predict the mind of others and also adjust their decisions by the concerns for others’ welfare, and what the underlying neural mechanisms are. We aim to develop quantitative understanding of social decision-making. We approach this challenge by using computational frameworks to link behavior and neural systems: extending reinforcement learning theory into the realm of social cognition and combining human fMRI with modeling, or using so-called model-based fMRI analysis. I mention two studies. The first study addressed how one learns to simulate the decision-making of others. We found that learning is realized by using two simulation signals in a hierarchical arrangement, pointing to a basic mechanism for learning others minds. The second ongoing study examines computational primitives for exchanging others’ reward into neural decision currency. While presenting these studies, I also hope to take this workshop’s opportunity for a dialogue on how research on quantitative social decision making can be progressed and what quantitative approaches might help us do so.

Title: Coding of reward prediction errors by midbrain dopamine neurons

Naoshige Uchida
uchida@mcb.harvard.edu

It has been proposed that midbrain dopamine neurons signal reward prediction errors, that is the discrepancy between the predicted and expected reward. I will discuss what dopamine neurons signal, how dopamine neurons jointly code their signals, and the neural circuit mechanisms underlying its computations.

Title: Hippocampal network activity in support of spatial working memory

Takuya Sasaki
t.sasaki.0224@gmail.com

The hippocampal network plays a crucial role in working memory. To understand neuro-physiological mechanisms underlying memory function, we monitored the activity patterns of hippocampal circuits as animals solve a spatial working memory task using a multiunit recording system. Hippocampal ripple events were specifically increased during reward period, which are predictive of behavioral performance. In a previous work, we revealed that the reward-associated ripples were abolished specifically at recording sites determined
to lack mossy fiber projections and the reduction in reward-associated ripple events was accompanied by a selective decrease in slow gamma power. In addition, hippocampal representation of future trajectories specifically occurred during reward-associated ripples periods and that the emergence of these reward-related firing patterns is supported by direct inputs from dentate granule neurons to the CA3 recurrent circuit, suggesting that this pathway may be critical for spatial working memory through the dynamic regulation of a distinct class of network activity. Currently, we are analyzing the detailed activity patterns of hippocampal place cells during CA1 ripple. Ripple-triggered replay of hippocampal cells consists of sequential firing activity of goal-directed place cells that were identified in a two-dimensional open space. Also we are constructing a new spatial working memory task in which rats are required to learn the association of sensory cues and spatial trajectories to obtain a reward. The task will be useful to analyze firing patterns of place cells for planning of future behavior.

Tatyana Sharpee
sharpee@salk.edu

I will describe low rank methods for characterizing feature selectivity and invariance of high level neurons probed with natural stimuli. The methods will be illustrated with analysis of high level visual and auditory neurons.

Hideaki Shimazaki
shimazaki@brain.riken.jp

Collective spiking activity of neurons is the basis of information processing in the brain. However, characterizing the population activity is non-trivial because the number of activity patterns combinatorially increases with the number of neurons. To infer the statistical structure of neural activity from limited amount of data, the maximum entropy principle has been successfully applied. Conventionally, the maximum entropy distribution is characterized by interaction parameters of different orders, where the orders refer to the numbers of subset neurons that these parameters constrain. Interactions beyond the 2nd order are collectively termed higher-order interactions (HOIs). Recent studies reported that neural populations express statistically significant HOIs, and they are relevant for information coding. However, the previous studies have not identified a key feature in HOIs that summarizes a principal role of seemingly diverse HOIs. Here we examined HOIs in population activity of the hippocampal CA3 networks in cultured slices [Shimazaki et al. Sci Rep 2015]. To investigate the structure of HOIs, we propose a maximum entropy model that adds a single HOI parameter that accounts for the level of simultaneous silence of all neurons to the previously proposed pairwise maximum entropy model. This single parameter introduces structured HOIs with alternating signs with respect to the order of interactions, namely, negative triple-wise interactions followed by positive quadruple-wise interactions, and then negative quintuple-wise interactions and so on. Using this model, we found that most groups of neurons that expressed HOIs exhibited significantly longer periods of simultaneous silence than predicted by the pairwise maximum entropy model.
Indeed, about 20% of the entropy due to HOIs in these groups was explained by the simultaneous silence. We then directly confirmed presence of the specific alternating structure of HOIs predicted from the SS in the spontaneous activity of the hippocampal neurons. Through a modeling approach, we also demonstrate that population activity caused by correlated inputs and nonlinear thresholding reproduces the same structure of HOIs, and that this structure conveys information of input. The ubiquitous structure of HOI observed in the activities of both experimental and model neural populations suggests that neurons are operating in a unique regime where they are constrained to be silent simultaneously.

Shigeru Shinomoto
shinomoto@scphys.kyoto-u.ac.jp

Title: Review of single spike train analyses

In these past few decades, there has been a significant progress in the methods for analyzing spike trains. In particular, state-of-the-art analysis methods developed on the machine learning theory such as the state space method have renovated quantitative analysis of neuronal big data such as inferring connections across neurons from the simultaneously recorded multiple spike trains. Though I am moving toward multiunit data analysis, here I would like to review the single unit data analysis we have developed up to the present. Firstly, we have developed methods for evaluating firing regularity or irregularity, and revealed that neuronal firing regularity exhibit systematic difference across different functional regions of the brain, while it is similar across homologous regions in different animal species [1]. Secondly, we have established methods for estimating inhomogeneous firing rate [2,3]. We recently applied the rate estimation method to the self-excitation systems and revealed that the systems exhibit transition between stationary and non-stationary states at small reproduction ratio [4].


Spencer Smith
slab@email.unc.edu

Title: New two-photon mesoscopy for simultaneous imaging of neural coding in primary and higher visual areas in the mouse
Two-photon calcium imaging can sample neuronal activity with single neuron resolution in dense populations, but its field-of-view is typically limited to a portion of a single cortical area. We have developed new optical systems that offer an expanded field-of-view that covers primary and higher visual areas in mice. We are now measuring neuronal activity in multiple cortical areas simultaneously, and examining the features of neural coding that are embedded in the statistical dependencies of neuronal activity distributed across multiple cortical areas.

Ken Takiyama  
ken-taki@cc.tuat.ac.jp

Diverse features of motor learning have been reported by numerous studies, but no single theoretical framework concurrently accounts for these features. Here, we propose a model for motor learning to explain these features in a unified way by extending a motor primitive framework. The model assumes that the recruitment pattern of motor primitives is determined by the predicted movement error of an upcoming movement (prospective error). To validate this idea, we perform a behavioural experiment to examine the models novel prediction: after experiencing an environment in which the movement error is more easily predictable, subsequent motor learning should become faster. The experimental results support our prediction, suggesting that the prospective error might be encoded in the motor primitives. Furthermore, we demonstrate that this model has a strong explanatory power to reproduce a wide variety of motor-learning-related phenomena that have been separately explained by different computational models.

Yasuhiro Tanaka, Yasuyo Tanaka, Masanori Matsuzaki  
ytnk@m.u-tokyo.ac.jp

Title: Temporal dynamics of motor thalamic activities during forelimb movements

Yasuhiro Tanaka, Yasuyo Tanaka, Masanori Matsuzaki

For animals and humans, generation and refinement of intentional movements are fundamental to survival. The basal ganglia and cerebellum play pivotal roles in motor learning and execution, and transmit their calculated results to the motor cortex via thalamocortical (TC) pathways to cortical layer 1 (L1) and 3 (L3), respectively. However, the temporal dynamics of TC axonal activity during motor learning are poorly understood. Using two-photon calcium imaging during the learning of a self-initiated lever-pull task, we found that TC activities in the primary motor cortex (M1) evolved their representation of movements throughout learning, and that the temporal dynamics differed between L1 and L3. In the late stage of learning, L1 TC axonal boutons had sparse lever-relevant representation, whereas L3 TC axonal boutons exhibited robust activity, especially at the onset and end of the movement. The population activity of the TC axons possessed a lever-relevant sequential structure that was longer in L1 than in L3 in the late stage of learning. Our results suggest that L1 TC axons may represent a sequence of the movement, including
cognitive processes, assembled in the basal ganglia and L3 TC axons may convey real-time feedback developed in the cerebellum, both of which are essential for motor learning.

Title: Auditory Refractoriness and Perceptual Short-term Memory Deficits in Schizophrenia

Individuals with schizophrenia (SZ) show decreased performance in simple auditory tasks that have been linked to impaired encoding of information into perceptual short-term memory (pSTM). These encoding deficits are accompanied by abnormal auditory refractoriness, a non-invasive electroencephalographic (EEG) measure believed to reflect the formation and gradual decay of a basic pSTM trace. In this talk I will describe experiments to determine the functional properties of this memory trace using EEG and laminar recordings in non-human primates in order to link the behavioral deficits to the widely accepted EEG biomarker.

Some challenges in neural data analysis

New technologies capable of simultaneously recording the activity of thousands of neurons are on the horizon. As is well-recognized, exploiting the potential of these large datasets is highly nontrivial, as direct extension of methods that work well for traditional neurophysiologic datasets quickly runs into the bounds of practical computation. The talk will offer a few thoughts on strategies that may be viable, and reasons for optimism that further progress can be made.

Title: Brain mapping in the marmoset brain

Marmoset is a small New World monkey which shares many common features with other primate. Recent success of generating germline transmittable transgenic marmosets has attracted a quite attention on the research as a model primate system (Sasaki et al., 2009). In parallel with the transgenic approaches, we have developed virus vector systems so that we are able to visualize and manipulate the gene expression in primates. We have applied virus vector mediated fluorescent protein to the marmoset cortex in combination with two-photon microscopy for visualizing neural connections. In my talk, I will present our recent approach to map prefrontal neural connections at the mesoscopic level in the marmoset, and
would like to discuss the problems to be solved in our project, which includes integration of
different levels of information, objectivity (reproducibility and quantification), and tracing.