

Conference on Brain Network Dynamics

University of California at Berkeley

January 26-27, 2007

THE STUDY OF HUMAN BRAIN FUNCTION is arguably one of our society's most important endeavors in this new century. Although there has been an explosive amount of research in basic neurobiology, progress in understanding the integrated functioning of the brain remains a significant scientific problem.

It is now clear that even "simple perception" is an act of creation that involves many distributed brain regions, and discovering the network interactions among these regions is important for understanding a range of issues in neuroscience, psychology, neurology, and psychiatry, as well as related fields such as computational intelligence and philosophy. Essential for understanding human brain function is a detailed knowledge of the spatio-temporal dynamics of neuronal populations and their interactions during cognitive function.

The conference will explore the dynamics of distributed brain function from multidisciplinary perspectives. It is being organized at Berkeley in honor of Walter Freeman for his contributions to brain dynamics over the past five decades on the occasion of his 80th birthday.

The aims of this conference are as follows:

- To present the audience with an overview of the present state of research on brain dynamics from various perspectives, including neurobiology, functional brain imaging, and cognitive science;
- To target issues in the brain sciences for which progress may be facilitated by the closer interaction of multiple disciplines;
- To promote the application of tools from mathematical statistics, network science, and neural network modeling to facilitate new thinking about the dynamics of brain function;
- To outline avenues of approach to the application of insights from dynamical brain studies to clinical questions for the improved development of biomarkers for disease diagnosis.

The conference agenda will include the following major themes:

Cortical Network Dynamics
Brain Network Imaging
Brain Network Modeling
Cognitive Dynamics

We expect the conference to lead to an exchange of ideas and perspectives from these themes and to an exploration of ways by which each can be informed or constrained by the others.

Conference Organizers

Vinod Menon (Stanford University)
Steven Bressler (Florida Atlantic University)
Robert Kozma (University of Memphis)
Robert Knight (UC Berkeley)

Conference Website

http://scsnl.stanford.edu/conferences/NSF_Brain_Network_Dynamics_Jan2007

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Program

Friday, January 26

Lipman Room, Barrows Hall, UC Berkeley

08:00 – 08:15 **Welcoming Remarks:** Vinod Menon, *Stanford* and Chris Kello, *NSF*

08:15 – 08:30 **Opening Address:** Steven Bressler, *FAU*

Session I: Cortical Network Dynamics

Moderator: Steven Bressler

08:30 – 09:30 **Keynote Address:** Walter Freeman, *UC Berkeley*
My legacy: A launch pad for exploring neocortex

09:30 – 10:00 Leslie Kay, *U Chicago*
Manipulating fast and slow neural synchrony in olfactory processing

10:00 – 10:30 Gyorgy Buzsaki, *Rutgers*
Oscillations organize hippocampal cell ensembles

10:30 – 10:45 *Coffee Break*

10:45 – 11:15 Robert Knight, *UC Berkeley*
High gamma and human behavior

11:15 – 11:45 Charles Gray, *Montana State*
Distributed processing in the cerebral cortex: How can we get the data to ask the questions?

11:45 – 12:15 Steven Bressler, *FAU*
The dynamic formation of large-scale cortical networks by coordination of oscillatory assemblies

12:15 – 14:00 *Lunch Break*

Friday, January 26

Lipman Room, Barrows Hall, UC Berkeley

Session II: Brain Network Imaging

Moderator: Vinod Menon

14:00 – 15:00	Keynote Address: Marcel Mesulam, <i>Northwestern</i> Imaging distributed networks
15:00 – 15:30	David Leopold, <i>NIMH</i> The role of the primary visual cortex in multistable perception
15:30 – 16:00	Marcus Raichle, <i>Washington U</i> Spontaneous intrinsic network dynamics: An fMRI perspective
16:00 – 16:15	<i>Coffee Break</i>
16:15 – 16:45	Mark D'Esposito, <i>UC Berkeley</i> Neural mechanisms of working memory
16:45 – 17:15	Joaquin Fuster, <i>UCLA</i> Distributed memory and the Perception-Action Cycle
17:15 – 17:45	Vinod Menon, <i>Stanford</i> Dynamic brain networks: Relation to behavior and cognition
17:45 – 18:00	<i>Coffee Break</i>
18:00 – 18:30	Special Lecture: Hubert Dreyfus, <i>UC Berkeley</i> Freeman's Merleau-Pontian neurodynamics: Similarities and differences

Friday, January 26

Bancroft Hotel, 2680 Bancroft Way, Berkeley

19:00 – 22:30

Reception and banquet in honor of Walter Freeman
Banquet Speaker: Michael Merzenich, *UCSF*

Saturday, January 27

Lipman Room, Barrows Hall, UC Berkeley

Session III: Brain Network Modeling

Moderator: Robert Kozma

08:30 – 09:30	Keynote Address: Olaf Sporns, <i>Indiana U</i> Brain network modeling: Connectivity, dynamics, and embodiment
09:30 – 10:00	Friedrich Sommer, <i>UC Berkeley</i> Spike timings relative to retinal oscillations carry visual information to cortex
10:00 – 10:30	Anil Seth, <i>Sussex</i> Causal networks in neural systems: Lessons from brain-based devices
10:30 – 10:45	<i>Coffee Break</i>
10:45 – 11:15	Eugene Izhikevich, <i>NSI</i> Simulating 10^{11}
11:15 – 11:45	Barry Horwitz, <i>NIDCD</i> Combined use of brain network modeling and functional brain imaging: Integrating neuroscientific data across different spatiotemporal scales
11:45 – 12:15	Robert Kozma, <i>U Memphis</i> Modeling cortical phase transitions
12:15 – 14:00	<i>Lunch Break</i>

Saturday, January 27

Lipman Room, Barrows Hall, UC Berkeley

Session IV: Cognitive Dynamics

Moderator: Chris Kello

14:00 – 15:00	Keynote Address: Jay McClelland, <i>Stanford</i> Dynamics of cognitive processing and learning: Linking connectionist, neuroscience, and dynamical systems approaches
15:00 – 15:30	Alan Yuille, <i>UCLA</i> Vision as Bayesian inference: Analysis by synthesis
15:30 – 16:00	Gregory Ashby, <i>UC Santa Barbara</i> A neurobiological theory of automaticity in perceptual categorization
16:00 – 16:15	<i>Coffee Break</i>
16:15 – 16:45	Patricia Carpenter, <i>Carnegie Mellon</i> A catalytic theory of perception and action
16:45 – 17:15	Michael Spivey, <i>Cornell</i> Continuous temporal dynamics in perception and cognition
17:15 – 17:45	Guy Van Orden, <i>U Cincinnati</i> Prospects at hand for cognitive dynamics
17:45 – 18:00	<i>Coffee Break</i>
18:00 – 18:30	Special Lecture: Stan Leung, <i>Western Ontario</i> Electrophysiology of mass action
18:30 – 19:00	Special Lecture: Giuseppe Vitiello, <i>U Salerno</i> Relations between many-body physics and nonlinear brain dynamics

Abstracts

Keynote Address, 08:30, Friday January 26

My Legacy: A Launch Pad for Exploring Neocortex

Walter J Freeman

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Fifty years ago EEG was widely regarded as noise, the roar of a crowd. It still is, advisedly, because cortical neurons form great crowds, and the task of systems neuroscience is to comprehend them. I perceived EEG as an opportunity to make a contribution. I chose to study three-layered allocortex in the olfactory system as simpler than neocortex yet closer to the senses than the hippocampus. I began by pulsing it with pairs of electric shocks in order to identify a small-signal near-linear range, in which I could model the dynamics with linear equations. From the patterns of relaxation on perturbation — evoked potentials — I modeled the system with differential equations, evaluated the parameters, solved them to simulate the evoked potentials, and deduced the mechanisms of stabilization. I summarized 20 years of linear analysis in my 1975 book, from which I concluded that I had reached the limits of linear analysis. Trying to understand brain function that way was like trying to cross an ocean in a dugout canoe. I conceived a boundary in the imaginary axis of the complex plane. Contemplating that, I felt as Isaac Newton felt, playing with pebbles on a seashore.

In the following 30 years I have explored the design of foundations for ocean crossings. You will hear five promising approaches in this Conference on Brain Network Dynamics. Steve Bressler will describe nonlinear metastability in terms of basin-attractor theory deriving in part from Hermann Haken's synergetics. Robert Kozma will describe phase transitions in terms of neuropercolation, which he derives from random graph theory. Bert Dreyfus will describe the isomorphism he perceives between brain dynamics and the phenomenology of Martin Heidegger and Maurice Merleau-Ponty. Giuseppe Vitiello will describe the mapping of dissipative brain dynamics into quantum field theory, stemming from the pioneering work of Ricciardi and Umezawa. I will try to show how to map solution sets of nonlinear differential equations into a phase portrait in the self-organizing, far-from-equilibrium thermodynamics that leads from disorder to order: Ilya Prigogine's 'dissipative structures' that feed on energy.

None of these five tools can be used alone with full success; each approach contributes necessary insights. Together they provide a launch pad for vehicles that will carry us arduously but freely to new discoveries across the ocean of nonlinear brain dynamics before us. Like other true explorers, we don't know what we will find, and we don't yet have the proper framework in which to describe whatever is there. This broad view from an open mind is my legacy.

Invited Talk, 09:30, Friday January 26

Manipulating Fast and Slow Neural Synchrony in Olfactory Processing

Leslie Kay

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The mammalian olfactory bulb receives dense synaptic and neuromodulatory input from many central olfactory and limbic areas. Central input to the olfactory bulb granule cell layer desynchronizes fast oscillatory activity in waking mammals, and when it is temporarily or permanently abolished results in high amplitude narrow band gamma (40-100 Hz) oscillations. In waking animals, the olfactory bulb transitions from high amplitude gamma oscillations and burst firing of mitral cells during slow breathing in waiting or resting behaviors to irregular gamma oscillations and tonic firing of mitral cells during fast directed odorant sniffing. This change in temporal dynamics is correlated with a change in cognitive or attentive state. This suggests switching of the system from a monitoring state to one involved in sensory processing, similar to changes which occur in sensory thalamus and cortex. One mechanism which may effect this state change is a transfer from slow breathing to fast sniffing. Fast sniffing can affect olfactory bulb dynamics by two pathways, the afferent signal from the olfactory nerve and centrifugal input from brainstem or cortical areas. Thus, both central synaptic input and changes in behavior converge on the olfactory bulb and manipulate both fast and slow temporal structure.

Invited Talk, 10:00, Friday January 26

Oscillations Organize Hippocampal Cell Ensembles

György Buzsáki

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How does the brain orchestrate perceptions, thoughts and actions from the spiking activity of its neurons? Previous single neuron recording research has regarded spike pattern variability as noise that should be averaged out to reveal the brain's representation of invariant input. An alternatively view is that variability of spikes is centrally coordinated and that this brain-generated ensemble pattern in cortical structures is a potential source of cognition. Large-scale recordings from neuronal ensembles now offer opportunities for challenging and testing these competing theoretical frames. A postulated signature of the cell assembly is that its participants show a higher probability of spiking together than with members of other assemblies, even in the absence of external inputs. Interactions among parallel-recorded hippocampal neurons revealed a consistent temporal structure beyond that predicted from the environmental inputs. We find that prediction of spike times of hippocampal pyramidal neurons is improved using the spike times of simultaneously recorded neurons, over prediction from the animal's trajectory in space, or a spatially-dependent theta phase modulation. Thus, we suggest that the assembly organization arises from the internal dynamics of neuronal circuits. Assemblies are organized most efficiently within 10-30ms, suggesting that cell assemblies are synchronized at this timescale (gamma cycles). Seven to nine cell assemblies form assembly sequences within a theta cycle. The most active assemble occupies the trough of theta representing "here and now", flanked by representation of past and future places on the descending and ascending phase of theta, respectively. The "lifetime" of an assembly in the dorsal hippocampus is 1-2 sec, corresponding to 7 to 14 cycles of theta. The lifetime of oscillating assemblies is internally regulated and can be accelerated by the locomotion speed of the rat and possible other gain factors. The internally generated assemblies can give rise to a perpetually changing composition of assembly membership even in the absence of environmental or idiothetic inputs. We hypothesize that the mechanisms underlying the intrinsically shifting assembly sequences is the substrate of episodic memory.

Harris KD, Csicsvari J, Hirase H, Dragoi G, Buzsáki, G. Organization of cell assemblies in the hippocampus. **Nature** 424:552-556, 2003.

Dragoi G, Harris KD, Buzsaki G. Place representation within hippocampal networks is modified by long-term potentiation. **Neuron** 39:843-853, 2003.

Buzsaki G, Draguhn A. Neuronal oscillations in cortical networks. **Science** 304: 1926-1929, 2004.

Buzsaki G. **Rhythms of the Brain**. Oxford University Press (2006).

Invited Talk, 10:45, Friday January 26

High Gamma and Human Behavior

Robert T. Knight

Helen Wills Neuroscience Institute and Department of Psychology
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<http://bic.berkeley.edu/knightlab/>

We observed robust coupling between the high- and low-frequency bands of ongoing electrical activity in the human brain. In particular, the phase of the low-frequency theta (4 to 8 hertz) rhythm modulates power in the high gamma (80 to 150 hertz) band of the electrocorticogram, with stronger modulation occurring at higher theta amplitudes. Furthermore, different behavioral tasks evoke distinct patterns of theta/high gamma coupling across the cortex. The results indicate that transient coupling between low- and high-frequency brain rhythms coordinates activity in distributed cortical areas, providing a mechanism for effective communication during cognitive processing in humans.

Invited Talk, 11:15, Friday January 26

Distributed Processing in the Cerebral Cortex: How Can We Get the Data to Ask the Questions?

Charles Gray

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Anatomical, physiological and functional imaging studies have established that mammalian cognitive functions involve the concerted action of populations of interconnected neurons distributed throughout the brain. Although this perspective is widely accepted, we continue to know surprisingly little about the details of distributed neuronal processing, its underlying physiological mechanisms, and its relation to behavior. This lack of understanding stems largely from technical limitations in our ability to make appropriate electrophysiological measurements. To overcome this limitation, we have designed a new class of instrumentation that will enable investigators to simultaneously monitor neuronal activity from hundreds of independently movable microelectrodes that are semi-chronically implanted in widespread regions of the brains of awake, behaving monkeys. I will present this design and discuss its implications, as well as its limitations, for gaining a greater understanding of large scale brain dynamics.

Invited Talk, 11:45, Friday January 26

The Dynamic Formation of Large-Scale Cortical Networks by Coordination of Oscillatory Assemblies

Steven L. Bressler

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It is becoming increasingly clear that the utilization of knowledge by humans and other primates requires the involvement of distributed large-scale networks in the cerebral cortex. The facility with which primates manipulate items of knowledge that are related within a complex cognitive structure suggests that a brain mechanism exists for the flexible creation of cognitive constructs through the dynamic configuration of large-scale cortical networks. Given the functional specialization of cortical areas and their intricate anatomical interconnectivity, it is likely that this mechanism involves the transient establishment of functional interdependency between interconnected areas. A leading candidate as a mechanism for functional interdependency is the temporal coordination of oscillatory population activity. Temporal coordination in the form of partial phase synchronization of oscillatory activity offers several potential advantages to the cortical system. First, it could allow the system to maintain a critical balance between locally independent and large-scale integrative processing. Second, it provides a basis for operation in a metastable regime in which the system dynamics is able to visit global attractor states without becoming trapped in them. Third, it presents a means by which the cortex may rapidly reorganize the functional relations among oscillatory assemblies in distributed areas.

These capabilities may be crucial for allowing the brain to create combinatorial arrangements of coordinated cortical areas representing cognitive constructs. The successive manifestation of such constructs may be central to a variety of cognitive functions, including working memory, decision making, and linguistic expression. A major objective for cognitive neuroscience is to elucidate the principles underlying their formation, transition, and, critically, their trajectory to goals such as the solution of problems, the production of decisions, and the articulation of syntactic structure.

Keynote Address, 14:00, Friday January 26

Imaging Distributed Networks

Marsel Mesulam

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Dynamic interactions among 20 billion cortical neurons generate, in ways that are still mysterious, phenomena we identify as language, memory and emotion. Alternative models have been proposed for linking the neural substrate of the brain to these mental phenomena. Each model has some merits, though none is perfect. Functional imaging has been particularly fruitful in addressing these issues. I will review some alternative approaches to the localization of function, based on patients with brain lesions, neuroanatomy, and functional imaging. I will focus on spatial attention as a model network and explore the value of the resulting principles for understanding the organization of other large-scale networks in the human brain.

Invited Talk, 15:00, Friday January 26

The Role of the Primary Visual Cortex in Multistable Perception

David A. Leopold

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http://intramural.nimh.nih.gov/research/pi/pi_leopold_d.html

The role of the striate cortex (area V1) in shaping our perception of visual patterns and scenes is of fundamental importance in understanding how we see. Visual illusions where a salient stimulus can be temporarily rendered invisible have provided a paradigm by which neuroscientists can isolate neural processes directly involved in perception. This approach has been applied to study electrophysiological activity in monkeys, as well as fMRI activation patterns in humans. Interestingly, the different types of studies have provided divergent results regarding the role of V1 in perceptual processing. Human neuroimaging (fMRI) studies have repeatedly shown that during perceptual suppression there is a marked decrease in the BOLD response in V1. In contrast, single unit studies in monkeys have reported the near absence of such suppression in the firing of individual V1 neurons. Here I will present new data in which we directly compare neurophysiological and fMRI responses during perceptual suppression in monkey area V1. By monitoring the two signals in a variety of conditions within the very same monkeys, we found that the single-unit and BOLD activation specifically ceased to be correlated during periods of perceptual suppression. Slow changes in some bands of the local field potential reflected perception, but only over short time scales. I will discuss how the spatiotemporal pattern of neural events in V1 might contribute to shaping the BOLD response, and will argue that the fMRI signal provides a complementary, rather than incorrect, perspective on neural processing within a cortical area.

Invited Talk, 15:30, Friday January 26

Spontaneous Intrinsic Network Dynamics: an fMRI Perspective

Marcus E. Raichle

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Functional neuroimaging has played a dominant role in the development of cognitive neuroscience. The overwhelming majority of this work has focused on studies of the response of the brain to controlled stimuli and carefully controlled tasks. This approach reflects a long-standing view of the brain as primarily reflexive, driven by the momentary demands of the environment. An alternative view of brain function is that the brain's operations are mainly intrinsic involving the maintenance of information for interpreting, responding to and even predicting environmental demands. The former has motivated most neuroscience research including that with functional neuroimaging. This is likely the case because experiments designed to measure brain responses to controlled stimuli and carefully designed tasks can be very productive whereas evaluating the behavioral relevance of intrinsic brain activity can be an illusive enterprise.

Motivation for studies of the brain's intrinsic activity has come, in part, from the realization that it commands most of the brain's enormous energy budget, upwards of 80% by some estimates. Evoked activity on the other hand represents a very small fraction (~ 1-5%). The challenge is how to evaluate intrinsic activity. Neurophysiologists have focused on spontaneous activity in the form of oscillations in various frequency bands. Neuroimaging with fMRI provides an important extension of that work as revealed by spatial patterns of coherence in the spontaneous fluctuations of the fMRI BOLD signal. This presentation will focus on the nature and significance of these observations and their possible relevance to the underlying neurophysiology.

Invited Talk, 16:15, Friday January 26

Neural Mechanisms of Working Memory

Mark D'Esposito

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<http://bioeng.berkeley.edu/graduate/cvs/D'Esposito.html>

Working memory refers to the temporary retention of information that was just experienced or just retrieved from long-term memory but no longer exists in the external environment. These internal representations are short-lived, but can be stored for longer periods of time through active maintenance or rehearsal strategies, and can be subjected to various operations that manipulate the information in such a way that makes it useful for goal-directed behavior. Empirical studies of working memory using neuroscientific techniques such as neuronal recordings in monkeys and functional neuroimaging in humans have provided a rich dataset that can be reconciled with behavioral findings derived by testing cognitive models of working memory. In this talk, I will review the progress that has been made towards understanding the neural mechanisms underlying working memory.

Invited Talk, 16:45, Friday January 26

Distributed Memory and the Perception-Action Cycle

J. M. Fuster

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Empirical evidence from single-unit recording and functional neuroimaging points to the identity of cortical substrates for working memory (WM) and for long-term memory (LTM). Thus, that evidence informs and conforms to the neural definition of WM as the temporary activation of an updated cortical network of LTM for the pursuit of a behavioral, linguistic or logical goal. Structurally, the network is made of associations between dispersed neuronal assemblies representing the perceptual and executive components of a LTM gestalt (cognit) of goal-directed action. Functionally, the network must be orderly activated for the orderly attainment of each intermediate sub-goal. Whenever that pursuit requires the mediation of cross-temporal contingencies between percepts and acts, WM comes into play. WM consists of the persistent and recurrent activation of the network for as long as necessary to mediate those contingencies. The executive, controlling, role of the prefrontal cortex derives exclusively from its role in the representation, and therefore enactment, of complex goal-directed performance--including cross-temporal contingencies. Two forms of reentry are essential to that performance: (1) The recurrent reentry--in WM--between prefrontal (executive) and posterior (perceptual) cortical networks at the top of the perception-action cycle; and (2) The external reentry that closes that cycle at the bottom, through the environment, between motor effectors and sensory receptors.

Invited Talk, 17:15, Friday January 26

Dynamic brain networks: Relation to behavior and cognition

Vinod Menon

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Brain imaging studies have typically focused on localization of function. I will describe recent work on developing a more unified approach to brain function using network models. I will first discuss methodological and conceptual issues involved in characterizing networks from brain imaging data. I will then focus on three key canonical brain networks that reflect strong intrinsically-coupled neural activity (1) an executive control network (ECN) anchored in the dorsolateral prefrontal cortex and posterior parietal cortex, (2) a salience network (SN) anchored in the orbital frontoinsular cortices and the dorsal anterior cingulate (dACC) with robust connectivity to subcortical and limbic structures, and (3) a “default-mode” network (DMN) anchored in the ventromedial prefrontal cortex (VMPFC) and the posterior cingulate cortex (PCC). I will summarize recent research regarding dynamic interactions between these brain networks in the endogenous “resting-state” and during cognitive information processing. When combined with EEG, the temporal dynamics within such brain networks can be investigated with a precision of about 10 milliseconds, yielding new insights into some of the mechanisms underlying cognitive control. The relation between individual variations in intrinsic network connectivity and differences in behavior and cognition will be explored. Finally, I will describe some clinical applications and show how these brain networks are perturbed in Alzheimer’s disease and major depression, and how these investigations inform us in new ways about the neurobiological substrates of each disorder.

Special Lecture, 18:00, Friday January 26

Freeman's Merleau-Pontian Neurodynamics: Similarities and Differences

Hubert Dreyfus

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Our experience of the everyday world is given as already organized in terms of significance and relevance. Yet, all that the organism can receive is meaningless physical energy. How can such senseless physical stimulation be experienced directly as significant and acted upon? To suggest an answer to this basic question I will draw on Walter Freeman's model of rabbit learning and of acting which resembles Maurice Merleau-Ponty's account of perception and action.

To bring out the structural similarities and differences, I will consider two examples, one of convergence (Freeman's account of learning new attractors and Merleau-Ponty's description of what he calls the intentional arc), and one of possible divergence concerning the role of expectation in the perception/action loop. The question then will be: How does Freeman's account of preaffection relate to Merleau-Ponty's account of maximum grip?

Keynote Address, 08:30, Saturday January 26

Brain Network Modeling: Connectivity, Dynamics, and Embodiment

Olaf Sporns

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Bloomington, IN 47405

The relationship between structure and function is of central importance for all biological systems, and it remains a particularly important challenge for our understanding of neural systems. My talk will be about emerging links between aspects of brain structure (connectivity) and brain function (dynamics and embodiment). In recent years, many studies have demonstrated that brain networks can be characterized by specific attributes such as reciprocal pathways, short path lengths, high clustering, an abundance of specific motifs, and highly economical wiring volume or length. How do these structural attributes relate to functional characteristics of brain networks, to their dynamic patterns, to their processing power, robustness, or capacity to support flexible behavior in embodied systems? I will review a series of computational approaches ranging from graph theory to robotics that attempt to identify how complex brain networks are organized, how they process and integrate information, and how brain, body and environment dynamically interact.

Lungarella M, Sporns O. (2006) Mapping information flow in sensorimotor networks. **PLoS Computational Biology** 2, 1301-1312.

Sporns O, Tononi G, Kötter R. (2005) The human connectome: A structural description of the human brain. **PLoS Computational Biology** 1, 245-251.

Sporns O, Kötter R. (2004) Motifs in brain networks. **PLoS Biology** 2, 1910-1918.

Sporns O, Chialvo D, Kaiser M, Hilgetag CC. (2004) Organization, development and function of complex brain networks. **Trends in Cognitive Sciences** 8, 418-425.

Sporns O, Zwi J. (2004) The small world of the cerebral cortex. **Neuroinformatics** 2, 145-162.

Invited Talk, 09:30, Saturday January 26

Spike Timings Relative to Retinal Oscillations Carry Visual Information to Cortex

Friedrich T. Sommer

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http://redwood.berkeley.edu/wiki/Fritz_Sommer

Visually evoked changes in retinal firing rate convey information downstream to the thalamus and to cortex. It is widely held that retinal spike trains code information about the visual stimulus solely by a process that depends on how reproducibly firing rates lock to stimulus onset, that is, by stimulus-locked coding. Yet retinal firing patterns are not only influenced by external stimuli but also by dynamics of intrinsic neuronal networks. In fact, work in other systems suggests that information can be encoded by stimulus-induced changes in ongoing oscillatory activity. Thus it is natural to ask if the early visual system processes sensory information not only by means of stimulus-locked coding but also by a mechanism that compares spike timing to intrinsic activity. To address this question we used whole-cell recording *in vivo* to record retinal EPSPs and the spikes they evoke from relay cells in the lateral geniculate nucleus of the thalamus in response to naturalistic stimuli. Using information theory to interpret the results, we found that visual information can indeed be transmitted by two separate channels. The first channel transmits stimulus locked information about patterns within the receptive field and is limited to relaying visual signals slower than 30 Hz. The second, novel, channel uses spike timing relative to intrinsic retinal oscillations at fine temporal scales, corresponding to the gamma band (50-70 Hz). Remarkably, the amount of information in the second channel could match or even exceed that conveyed by the first, a result that we were able to reproduce in a simple model of a relay cell. Because retinal oscillations involve large-scale networks, the novel channel could convey distributed, contextual aspects of the stimulus that complement stimulus-locked information about local features.

Invited Talk, 10:00, Saturday January 26

Causal Networks in Neural Systems: Lessons from Brain-Based Devices

Anil Seth

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Neurons engage in causal interactions with one another and with the surrounding body and environment. Neural systems can therefore be analyzed in terms of causal networks, without assumptions about information processing, neural coding, and the like. In this talk, I will describe the analysis of causal networks in simulated neural systems – “brain-based devices” - using a combination of time-series analysis (“Granger causality”) and network theory. I will draw implications for possible causal pathways in the hippocampus and for the relation between synaptic plasticity and behavioral learning. With respect to the latter, I will explore the notion that learning involves the selection of specific causal pathways from diverse repertoires of neuronal interactions, resulting in dynamic “causal cores” that drive behavior.

Invited Talk, 10:45, Saturday January 26

Simulating 10^{11}

Eugene M. Izhikevich

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<http://vesicle.nsi.edu/users/izhikevich/>

I will describe what it takes to simulate a brain model that has the size of the human brain - 10^{11} (one hundred billion) neurons and almost 10^{15} (one quadrillion) synapses. The simulation consists of a detailed model of thalamocortical system with 6-layered cortical structure and 3 thalamic nuclei. It has 18 neuronal cell types with anatomical arrangements corresponding to the striate cortex of cats. Simulation of 1 second of the model took 50 days on a cluster of 27 computers. I will describe what we learned from it and what we need to proceed further.

Details of the simulation can be found in: <http://vesicle.nsi.edu/users/izhikevich/interest/index.htm>.

Invited Talk, 11:15, Saturday January 26

Combined Use of Brain Network Modeling and Functional Brain Imaging: Integrating Neuroscientific Data Across Different Spatiotemporal Scales

Barry Horwitz

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Formidable conceptual problems exist in interpreting human functional neuroimaging data in terms of the underlying neural activity. To overcome these difficulties, we have developed two neurobiologically realistic brain network models (one for vision, one for audition) of the object recognition pathway in human neocortex in which data at different spatiotemporal levels can be simulated and cross-validated by multiple disciplines, including PET and fMRI. Our models, based on neurophysiological and neuroanatomical data from primate and human studies, enable us to simultaneously simulate cellular electrophysiological and PET/fMRI activities in multiple, interconnected brain regions (including primary and secondary sensory cortex, anterior temporal cortex, and prefrontal cortex). This type of network modeling provides a mechanism by which assumptions about the neural bases for high-level cognitive, sensorimotor and emotional processes can have their physiological consequences tested.

Invited Talk, 11:45, Saturday January 26

Modeling Cortical Phase Transitions

Robert Kozma

Division of Computer Science

Department of Mathematical Sciences

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Recent experiments indicate the presence of frequent abrupt changes in brain dynamics covering large parts of each cerebral hemisphere. These large-scale oscillations show a characteristic frequency in the theta temporal band and plenty there is ample of evidence showing that they are markers of the subject's cognitive activity. We have introduced neuropercolation models as a mathematical framework to describe phase transitions in the cortex. Neuropercolation is a generalization of cellular automata, Hopfield memory arrays, and Conway's game of life, by merging the concepts of random graph theory and non-local interactions represented by axonal connections. Random noise plays a central role in the model, which is rooted in the pioneering work of Erdos and Renyi. We have indicated several key factors which determine phase transitions in our cortical model, including endogenously generated noise, the structure of the connectivity of neural populations with or without small-world effects, and the sparseness of the interactions between excitatory and inhibitory neural populations. Unlike phase transitions in physical systems, cortical phase transitions progress through metastable states, which have an intermittent character. The role of external input is described through stabilization of spatial patterns of amplitude modulation oscillations of the gamma carrier wave.

Keynote Address, 14:00, Saturday January 26

Dynamics of Cognitive Processing and Learning: Linking Connectionist, Neuroscience, and Dynamical Systems Approaches

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Connectionist or parallel-distributed processing models provide mechanistic accounts of cognitive processes, demonstrating how emergent dynamics of higher-order cognitive states such as percepts, decision states, and actions can arise from the micro-dynamics of the interactions of simple neuron-like processing units. These models can also address changes in representation and processing that occur as a result of experience, via adjustments in the strengths of the connections among the units that participate in processing. As such these models make several points of contact with the literature on dynamical systems in development. The models also link to many other recent models on the neural population dynamics underlying decision making in the brain. This talk will discuss recent developments related to these issues, building on a model of the dynamics of simple perceptual decision making (Usher and McClelland, 2001).

Invited Talk, 15:00, Saturday January 26

Vision as Bayesian Inference: Analysis by Synthesis

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We argue that the study of human vision should be aimed at determining how humans perform natural tasks on natural images. Attempts to understand the phenomenology of vision from artificial stimuli, though worthwhile as a starting point, risk leading to faulty generalizations about visual systems. In view of the enormous complexity of natural images, they are similar to trying to evaluate the performance of a soldier in battle from his ability at playing with a water pistol. Dealing with this complexity is daunting, but Bayesian inference on structured probability distributions offers the ability to design theories of vision that can deal with the complexity of natural images and which use analysis by synthesis strategies with intriguing similarities to the brain.

Invited Talk, 15:30, Saturday January 26

A Neurobiological Theory of Automaticity in Perceptual Categorization

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A biologically detailed computational model is described of how categorization judgments become automatic in tasks that depend on procedural-learning. The model assumes there are two neural pathways from the relevant sensory association area to the premotor area that mediates response selection. A longer and slower path is as follows: sensory association cortex – striatum –globus pallidus – thalamus – premotor area. A faster, purely cortical path projects directly from the sensory association area to the premotor area. The model assumes that the subcortical path, although slower, has greater neural plasticity because of a dopamine-mediated learning signal from the substantia nigra. In contrast, the faster cortical-cortical path learns more slowly via dopamine independent) classical two-factor Hebbian learning. Because of its greater plasticity, early performance is dominated by the subcortical path, but he development of automaticity is characterized by a transfer of control to the aster cortical-cortical projection. The model includes differential equations hat describe activation in each of the relevant brain areas as well as a set of difference equations that describe the relevant two- and three-factor learning. A variety of simulations are described showing that the model accounts for some classic single-cell recording and behavioral results.

Invited Talk, 16:15, Saturday January 26

A Catalytic Theory of Perception and Action

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This talk describes a Fractal Catalytic theory of mind/body relations grounded in biology (Davia, 2006). It builds on the twin themes of invariance, emphasized by Gibsonian Ecological Psychologists, and 'resonating' or standing neural waves, emphasized by Gestaltists and some neuroscientists, notably Walter Freeman. Both behavioral and physiological measures characterize living systems as non-linear, parallel processes that self-organize and manifest emergent properties. Such descriptions are from the perspective of an observer, whereas this talk focuses on the organism's perspective, its experience. The theory proposes that an entity lives by virtue of mediating (catalyzing) its environment and that a general form of catalysis occurs at multiple levels, not just at the level of the enzyme, but also at levels that include cells, organs and organisms. Finally, it proposes that an entity's experience is the process of catalysis.

The essential theme of enzyme catalysis in metabolism involves overcoming structural constraints to dissipate energy. It is a vibrationally-assisted process thought to involve soliton-like waves -- localized, non-linear waves whose form and duration depend on the invariance (symmetries) of the environment. Examples include neuronal action potentials. Catalysis can be generalized to the levels of the brain and entire organism. The brain can be understood as an excitable medium; glucose metabolism is dissipated by standing neural waves whose form depends on the invariance arising from the organism's interaction in its environment. The organism unfolds its environment (Maturana & Varela, 1980) through this generalized catalysis. This proposal is supported by 'sensory substitution,' in which individuals who are blind use other modalities to recognize visuo-spatial events (Bach-y-Rita et al., 2003). Other empirical paradoxes are also clarified by this subtle but important shift from the assumption that an organism represents an independent environment.

Bach-y-Rita P, Tyler ME, Kaczmarek KA (2003). Seeing with the brain. **International Journal of Human-Computer Interaction**, 15, 285-295.

Davia CJ. (2006). Life, catalysis and excitable media: A dynamic systems approach to metabolism and cognition. In J. Tuszynski (Ed.). **The emerging physics of consciousness**. Springer-Verlag.

Maturana HR, Varela FJ. (1980). **Autopoiesis and cognition: The realization of the living. (Boston Studies in the Philosophy of Science)**. Springer.

Invited Talk, 16:45, Saturday January 26

Continuous Temporal Dynamics in Perception and Cognition

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Rather than a sequence of logical operations performed on discrete symbols, real-time cognition is better described as continuously changing patterns of neuronal activity. The continuity in these dynamics indicates that, in between describable states of mind, much of our mental activity does not lend itself to the linguistic labels relied on by much of psychology. I will discuss eye-tracking and computer-mouse-tracking evidence for this temporal continuity in spoken word recognition, categorization, and even decision-making. I will also provide geometric visualizations of mental activity depicted as a continuous trajectory through a neuronal state space. In this theoretical framework, close visitations of labeled attractors may constitute word recognition events and object recognition events, but the majority of the mental trajectory traverses unlabeled regions of state space, resulting in multifarious mixtures of mental states.

Invited Talk, 17:15, Saturday January 26

Prospects at Hand for Cognitive Dynamics

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The intrinsic flux of brain, body, and behavior reveals the dynamics of self-organization. I describe three theory constitutive metaphors that result from this new way of viewing cognitive activity. They illustrate prospects at hand for cognitive dynamics: fractal time (cognitive activity as temporal coordination across scales), duality (qualitative change to macro-level organism behavior from interactions in the embodied micro-world), and tensegrity (brain and body as excitable media). These prospects, seeded in the work of Walter Freeman, will shape 21st century cognitive science.

Special Lecture, 18:00, Saturday January 26

Electrophysiology of Mass Action

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Walter Freeman has developed a paradigm of mass action in the nervous system. Walter argues that perception and actions of the brain cannot be understood from properties of single neurons, but rather from cooperative activity among many neurons. The “neural set”, a population of interacting neurons, is the element, and EEG (waves) and action potential (pulses) probabilities are described by nonlinear partial differential equations in time and space. Electrophysiological study requires recordings from many neurons and local EEGs at multiple sites

Connections among neurons give rise to different neural sets, called K0 to KIV (K after Katchalsky) illustrated by the olfactory system. Non-interacting primary olfactory neurons form a K0 set. Positive feedback neurons in the olfactory glomeruli form a KI set. Interesting and complex dynamics are derived from interacting inhibitory and excitatory neurons, forming KII and higher sets. The dynamics include gamma oscillations in the olfactory system, hippocampus, and other cortices. Olfactory gamma oscillations are highly dependent on the behavioral significance of the odor, and a new odor is represented by the spatial amplitude profile of gamma waves in the olfactory cortex. Nonlinear neuronal interactions result in chaos, which Walter contends is necessary for perception, insight and consciousness. Data from my own laboratory corroborate Walter’s vision that the limbic system is essential for sensorimotor functions. Inactivation of the hippocampus, medial septum and nucleus accumbens enhanced the response to a general anesthetic (decreased consciousness) and suppressed the schizophrenia-like behaviors induced by psychomimetic drugs and complex partial seizures.

Dynamics become mainstream in neuroscience decades after Walter’s pioneering work in the 1960s. Oscillations caught up with the cellular physiologists in the 1980s. Gamma oscillations took on additional meaning after discovery of gamma synchronization in the visual cortex (Gray, Singer et al., 1989). In the developing field of functional magnetic resonance imaging, it remains to be seen whether the BOLD (blood oxygen-level dependent) effect is a good correlate of the local field potential. In summary, Walter’s paradigm of electrophysiology of mass action sets the stage for fertile interactions among wide ranging disciplines that attempt to understand the brain.

Special Lecture, 18:30, Saturday January 26

Relations Between Many-Body Physics and Nonlinear Brain Dynamics

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In a recent paper [1] it has been proposed a many-body model of nonlinear brain dynamics based on the thesis that mammalian neocortex supports dynamics sufficiently similar to the one of cooperative domains, such as cooperative domains in spin glasses ensembles of phonons in crystals, coherent photons in lasers, condensation of vapors in crystal formation, etc., to warrant exploration of neurophysiological data and models in terms well-known by physicists. Our approach is evolving from the quantum field theory model proposed in 1967 [2] by Umezawa and Ricciardi where the mechanism of spontaneous breakdown of symmetry was proposed to be the basic mechanism originating brain functions such as memory recording and recall. By considering the fact that brains are open, dissipative systems that consume free energy in creating large-scale behaviorally related spatiotemporal patterns, we extend the Umezawa-Ricciardi model to dissipative dynamics, thus relating microscopic many-body dynamics to Prigogine's nonequilibrium thermodynamics and Haken's synergetics. Much attention is devoted in our model to the connection between specific features of the many-body dynamics, characteristic of the theory of quantum fields, and the rich phenomenology of neurophysiological data. We compare and contrast ECG pattern formation in neocortex in terms of phase transitions in classical physics and spontaneous breaking of symmetry in quantum physics. A novel perspective in brain dynamics seems to emerge, unifying brain studies and condensed matter physics.

[1] Freeman WJ, Vitiello G (2006) Nonlinear brain dynamics as macroscopic manifestation of underlying many-body field dynamics. **Physics of Life Reviews** 3: 93-118. <http://dx.doi.org/10.1016/j.plrev.2006.02.001>, <http://repositories.cdlib.org/postprints/1515>, <http://arxiv.org/q-bio.OT/0511037>

[2] Ricciardi L M, Umezawa H(1967) Brain physics and many-body problems. **Kibernetik** 4: 44-48.