Fourteenth Annual Computational Neuroscience Meeting
CNS*2005

July 17-21, 2005
Madison, Wisconsin

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Acknowledgement

Organizing a scientific event is a collective effort and CNS*05 is no exception. Many individuals have assisted the organizing committee and the local staff. Amir Assadi would like to warmly thank the indispensable advice, help and support from Christiane Linster who has spent endless hours on all aspects, large and small, visionary and details. Phil Ulinski has shared generously his experience from the highly successful Chicago CNS meeting, and Linda Prior-Larson on the fine financial details. Without their support and help, this event could not have been organized.

On behalf of CNS officers and members, we wish to express our appreciation to University of Wisconsin-Madison community at large who has provided all kinds of help and support. In particular, we wish to acknowledge the contributions of the meeting co-sponsors Center for Neuroscience, Department of Mathematics, Department of Neurology and The Genome Center of Wisconsin, the staff: Deborah Faupel (GCW), Mark Castillo, Sharon Paulson, Steve Roberts and Vicky Whalen (Mathematics), and the staff of UW-Madison Pyle Center.

CNS*05 is supported by grants from NIH, NIMH whose continuing interest in development of computational neuroscience have been invaluable. Finally, we thank our corporate sponsors and the institutions that have supported various expenditures.

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CNS*05 Satellite Meeting
Perspectives in Neuroscience

The **Satellite Meeting of CNS 2005** will be on Saturday July 16th (Pyle Center, 8:00am-5:pm) followed by a reception and social at Pyle Center (cash bar 5:30pm - 9:30pm).

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The Next CNS Meeting

The next **Annual Meeting of CNS** will be held from July 23-27, 2006 in Edinburgh, UK, and the local organizer is **Mark van Rossum**.

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CNS 2005 WWW and Local Links

CNS 2005: *www.cnsorg.org*
Local Information:
http://www.setupandsupportsystems.com/CNS/cns_wis.html
Sattelite Meeting: use the link provided in the URL:
http://www.nmrfam.wisc.edu/%7Eeghbalni/dyn_osc/index.html

Meeting Overview

Sunday July 17th, 2005

9:00 am	Welcome by CNS President Christiane Linster
9:10 am	Invited talk: Michael Hasselmo
10:10 am	Oral Session 1: *Information Coding*
10:30 am	Break
11:00 am	Oral Session 1: *(continued)*
12:20 am	Lunch Break
1:50 pm	Announcements
2:00 pm	Oral Session 2: *Dendritic Computation and Models*
3:20 pm	Break
3:50 pm	Oral Session 2: *(continued)*
5:10 pm	Announcements
6:00 pm	Banquet

Monday, July 18th, 2005

9:00 am	Announcements
9:10 am	Invited talk: Gyorgy Buzsaki
10:10 am	Oral Session 3: *Hippocampus and Learning*
10:30 am	Break
11:00 am	Oral Session 3: *(continued)*
11:40 am	Oral Session 4: *Spike Timing Dependent Placticity*
12:20 pm	Lunch Break
2:00 pm	Announcements
2:10 pm	Oral Session 4: *(continued)*
2:50 pm	Oral Session 5: *Visual System*
3:10 pm	Break
3:40 pm	Oral Session 5: *(continued)*
4:40 pm	Announcements
5:00 pm	Dinner Break
6:30-9:30 pm	Poster Session I

Tuesday, July 19th, 2005

9:00 am	Announcements
9:10 am	Invited talk: Lucia Jacobs
10:10 am	Oral Session 6: *System and Network Dynamics*
10:30 am	Break
11:00 am	Oral Session 6: *(continued)*
12:30 pm	Lunch Break
1:50 pm	CNS Business Meeting Higher Function
2:10 pm	Oral Session 7: *Higher Function*
3:10 pm	Break
3:40 pm	Oral Session 8: *Network Properties*
4:40 pm	Announcements, Workshop plans

Tuesday, July 19th, 2005 (continued)

5:00 pm	Dinner Break
6:00-9:30 pm	Poster Session II
9:00 pm	Party

Wednesday, July 20th, 2005

9:00 am – 12:00 pm, 2:00 pm – 5:00 pm	Workshops
5:30-9:30 pm	Workshop Social & Party

Thursday, July 21st, 2005

8.30 am – 11.30 pm, 1.30 pm – 3.00 pm	Workshops

CNS*05 Satellite Meeting
PERSPECTIVES IN NEUROSCIENCE

Saturday, July 16th, 2005

8:00 am – 9:00 am	Continental Breakfast and Coffee
9:00 pm, 10:00 pm	Keynote Lecture in Neurodynamics
10:00 pm, 12:00 pm	Panel Discussion: Future Neurodynamics
12:00 noon-1:30 pm	Lunch Break
1:30pm - 3:30 pm	Panel Discussion: Future Neuroinformatics
3:30 pm- 4:00 pm	Coffee Break
4:00 pm, 5:00 pm	Keynote Lecture in Neuroinformatics
5:30 pm- 9:30 pm	Reception and Social (cash bar opens at 5:30pm)

*Fourteenth Annual Computational Neuroscience Meeting CNS*2005*

Welcome to CNS*2005! This is the fourteenth annual meeting of an interdisciplinary conference addressing a broad range of research approaches and issues involved in the field of computational neuroscience. These meetings bring together experimental and theoretical neurobiologists along with engineers, computer scientists, physicists andmathematicians interested in the functioning of biological nervous systems. Peer reviewed papers are presented all related to understanding how the nervous systems compute. As in previous years, CNS*2005 will equally emphasize experimental, model-based and more abstract theoretical approaches to understanding neurobiological computation.

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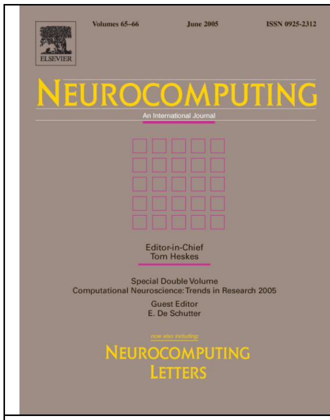	**Neurocomputing Magazine**
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General Information

Location: The meeting will be held in the Madison and Wisconsin Ballroom at the Concourse Hotel in downtown Madison from Sunday, July 17th to Tuesday, July 19. The Satelite Meeting (July 16, Perspectives in Neuroscience) and Workshops (from Wednesday, July 20 to Thursday, July 21) will take place at the University of Wisconsin's Pyle Center.

Registration: Meeting registration will be open in the hallway outside the Madison and Wisconsin Ballroom in the Concourse Hotel beginning Saturday, July 16th through Tuesday, July 19th, from 9-12 in the morning.

Oral Sessions: An LCD projector will be available for all speakers to use and the main meeting room is supplied with a large screen and an amplification system.

Poster Sessions: Posters should be set up in the afternoon and removed at the end of the night session to which it is assigned. Both evenings of poster sessions will take place at the Pyle Center. A cash bar and snacks will be provided at each session. *Poster board are numbered according to abstract numbers as they appear in the index.*

CNS*05 Satellite Meeting: On Saturday July 16th **PERSPECTIVES IN NEUROSCIENCE (**Pyle Center 9:00am-5:pm) explores the future challenges facing computational neuroscience, from neuronal stem-cells and interface of brain with nanoscience to Neurodynamics and Neuroinformatics. The reception will be at Pyle Center, 5:30pm (cash bar) until 9:30pm.

CNS*05 Banquet: On Sunday July 17th, the CNS Banquet will take place the University of Wisconsin's Pyle Center. A cash bar will open starting 5:30pm – 9:30 pm. A brief musical prelude to Banquet Dinner is planned for 6:00pm-6:30pm, follwed by dinner overlooking the sunset at Lake Medota. The Banquet lounge will be available to CNS guests until 11:00pm for socializing, dance and music.

CNS*05 Party: On Tuesday, July 19th at 9:00 pm CNS participants are invited to Paisan's Restaurant on University Avenue near campus for our party.

Workshops: Workshops will take place at the University of Wisconsin's Pyle Center, in the Auditorium, rooms 111, 205, 217, 220, 317, 320 and the Alumni Lounge. Up-to-date information regarding room numbers for specific workshop will be posted on large electronic boards.

Workshops Reception: On Wednesday July 20th, there will be a reception at Pyle Center, starting at 5:30pm with a cash bar and continuing until 9:30pm.

Best Presentation Awards: Prizes will be awarded to the best student presentations. These prizes were generously donated by Elsevier, publisher of *Neural Computing,* a corporate sponsor of the meeting. Prizes will be awarded after review by the judging panel.

Lunches and Dinners: In the pages following the abstracts, a listing of Madison dining establishments for guests to enjoy. More information can be obtained at the hotel concierge desk.

Sunday, July 17, 2005

Sunday July 17th

9:00 am	Welcome by CNS President Christiane Linster
9:10 am	Invited talk: Michael Hasselmo *Modeling the role of the prefrontal cortex and hippocampal formation in decision making and memory guided behavior.*

Information Coding

10:10	Rick Jenison *Copula Point Process Models of Neural Dependence*
10:30	BREAK
11:00	Nhamoinesu Mtetwa, Leslie Smith *Smoothing and thresholding in neuronal spike detection*
11:20	Esther Stern, Charles Peskin, Vladimir Brezina *A method for decoding neurophysiological responses to arbitrary spike trains*
11:40	Bjoern Naundorf, Maxim Volgushev, Fred Wolf *The Impact of Subthreshold Action Potential Threshold Adaptation on Neural Coding*
12:00	Guido Gigante, Maurizio Mattia, Paolo DelGiudice *Spike-frequency adaptation and the collective dynamics of neurons*
12:20	LUNCH BREAK
13:50	Announcements
14:00	Featured Oral William Levy, Xiangbao Wu *External Activity and the Freedom to Recode*

Dendritic Computation and Models

14:40	Gregor Kiddie, Arjen van Ooyen, Bruce Graham *Modelling the variation in dendritic outgrowth between different neuronal types*
15:20	BREAK
15:50	William Mehaffey, Brent Doiron, Leonard Maler, Raymond Turner *Deterministic Multiplicative Gain Control From Active Dendrites*

16:10 Fernanda Saraga, Xiao-Lei Zhang, Liang Zhang, Peter L. Carlen, Frances Skinner
Predicting gap junction location and density in electrically coupled hippocampal oriens interneurons

16:30 Yulia Timofeeva, Gabriel Lord, Stephen Coombes
Dendritic cable with active spines: a modeling study in the spike-diffusespike framework

16:50 Christina Weaver, Susan Wearne
Role of action potential shape and parameter constraints in optimization of compartment models

17:10 Announcements

18:00 BANQUET at Pyle Center (Alumni Lounge and Lake Mendota Terrace)

Monday, July 18, 2005

Monday, July 18th

9:00 am	Announcements
9:10 am	Invited talk: Gyorgy Buzsaki *Hippocampus and Learning*

Hippocampus and Learning

10:10	Hiroaki Wagatsuma, Yoko Yamaguchi *Disambiguation in spatial navigation with theta phase coding*
10:30	BREAK
11:00	Mark Fuhs, David Touretzky *The Mixture Modeling Theory of Hippocampal Place Cell Remapping*
11:20	Jadin C. Jackson, Adam Johnson, A David Redish *Hippocampal sharp wave events increase during behavior with experience within session Spike Timing Dependent Plasticity*

Spike Timing Dependent Placticity

11:40	Taro Toyoizumi, Jean-Pascal Pfister, Kazuyuki Aihara, Wulfram Gerstner *Optimal spike-timing dependent learning rule that maximizes information transmission*
12:00	Patrick Roberts, Christine Portfors, Nathaniel Sawtell, Richard Felix *Model of auditory prediction in the dorsal cochlear nucleus via spiketiming dependent plasticity*
12:20	LUNCH BREAK
14:00	Announcements
14:10	Featured Oral Alex Proekt, Nataliya Kozlova, Klaudiusz Weiss, Vladimir Brezina *Predicting salient features of the environment from central nervous system dynamics Visual System*

Visual System

14:50	Ruediger Kupper, Marc-Oliver Gewaltig, Ursula Körner, Edgar Körner *Spike-latency coding of topological feature homogeneity*
15:10	BREAK

15:40 Alexander Dimitrov, Melissa Sheiko, Jonathan Baker, Shih-Chen Yen
Effects of stimulus transformations on estimated functional properties of visual sensory neurons

16:00 Nadja Schinkel, Udo Ernst, Klaus Pawelzik
Optimal Contour Integration: When Additive Algorithms Fail

16:20 Yiu Fai Sit, Risto Miikkulainen
Self-Organization of Hierarchical Visual Maps with Feedback Connections

16:40 Announcements

DINNER BREAK

18:30 - 21:30

POSTER SESSION I

Visual System

System and Network Dynamics

Synchronization and Oscillations

Network Properties

Cortex General

Functional Imaging and EEG/EMG

Attention

Thalamus

Poster session I – July 18th

Visual System

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Urs Köster, Aapo Hyvärinen, Patrik Hoyer **#114**
Modelling Complex Cells with Generalized Independent Subspace Analysis of Natural Images

Martin Rehn, Friedrich T. Sommer **#133**
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Rodrigo Publio, Rodrigo Oliveira, Antonio Roque **#148**
A realistic model of rod photoreceptor for use in a retina network model

Asli Ayaz, Frances Chance **#190**
Modeling Nonlinear Responses of Primary Visual Cortex Neurons

Paul Sajda, An Luo, Marios Philiastides, Jim Wielaard **#193**
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Neil Bruce, John Tsotsos **#198**
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Junmei Zhu, Christoph von der Malsburg **#207**
Associative Memory of Connectivity Patterns

Sugihara Tadashi, Fangtu Qiu, Rudiger von der Heydt **#209**
Onset Kinetics of Edge Definition and Border Ownership Assignment by Neurons in

James Bednar, Risto Miikkulainen **#45**
Joint maps for orientation, eye, and direction preference in a self-organizing model of V1

Stefanie Jegelka, James Bednar, Risto Miikkulainen **#70**
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Akhil Garg, Basabi Bhaumik **#48**
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Brett Graham, David Northmore **#66**
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Amir Assadi, Arash Bahrami, Hamid Hamid Eghbalnia **#92**
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Jacek Turski **#47**
Computational Harmonic Analysis for Human and Robotic Vision Systems

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Discrete Approximation of Continuous K-Set Population Model

Joanna Pressley, Todd Troyer **#145**
Temporal Processing in the Exponential Integrate-and-Fire Model is Nonlinear

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Modelling single neuron behaviour using stochastic differential equations

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Influence of spike sorting errors on spike correlation

Carlos Aguirre, Doris Campos, Pedro Pascual, Eduardo Serrano **#150**
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Stimulus competition by inhibitory interference

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Jeremy Reynolds, Todd Braver, Josh Brown, Stefan Van der Stigchel **#84**
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CoThaCo: A Comprehensive Model of the Thalamocortical Pathway

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Effects of interneuron feedforward inhibition via the F2 terminal on retinogeniculate transmission

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The fidelity of thalamic relay and implications for Parkinson's disease and deep brain stimulation

Tuesday, July 19, 2005

Tuesday, July 19th

9:00 am Announcements

9:10 am Invited talk: Lucia Jacobs
System and network dynamics

System and Network Dynamics

10:10 Adam Weaver, Ronald Calabrese
A Role for Compromise: Inhibitory & Electrical Synapse Effects on Phasing in the Leech Heartbeat CPG

10:30 BREAK

11:00 Itsaso Olasagasti, Emre Aksay, Guy Major, David Tank, Mark Goldman
Persistent neural activity in a bilateral neural integrator model

11:20 Roberto Fernández Galán, Bard Ermentrout, Nathaniel Urban
Predicting synchronized neural assemblies from experimentally estimated phase-resetting curves

11:40 Georgi Medvedev
Using one-dimensional maps for analyzing neuronal dynamics

12:00 Funding opportunities--Dennis Glanzman, Ken Whang, Yuan Liu

12:30 LUNCH BREAK

13:50 CNS Business Meeting

Higher Function

14:10 Jeremy Caplan, Eve De Rosa, Anthony R. McIntosh
Basal-forebrain dependent versus independent networks for successful resolution of proactive interference

14:30 Franziska Koepke, Marco Loh, Albert Costa, Gustavo Deco
Neurodynamical approach to the picture-word interference effect

14:50 Benoit Gaillard, Jianfeng Feng, Hilary Buxton
Neural model of decision making

15:10 BREAK

Network Properties

15:40 Nadav Raichman, Vladislav Volman, Eshel Ben-Jacob
Collective Plasticity and Individual Stability in Cultured Neuronal Networks

16:00 Wei Chen, Clayton Haldeman, Jon Hobbs, Aonan Tang, Shaojie Wang, John Beggs
Networks with fewer and stronger connections may store more information in neuronal avalanches

16:20 Einat Fuchs, Amir Ayali, Eshel Ben-Jacob, Eyal Hulata
Evolving functional complexity in neuronal networks' behavior

16:40 Announcements, Workshop plans

DINNER BREAK

18:00 – 21:30 POSTER SESSION II

Information Coding

Hippocampus

Databases and Software

Cellular Mechanisms

Learning and Memory

Synaptic Mechanisms and Plasticity

Sensory Systems

Behavior

21:00 PARTY Paisan's Restaurant

Poster session II – July 19th

Information Coding

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Denis Sheynikhovich, Ricardo Chavarriaga, Thomas Stroesslin, Wulfram Gerstner
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Rozell Christopher, Don Johnson **#118**
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Vladimir Itskov **#157**
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Wednesday, July 20th : Workshops

9:00 am - 12:00 pm	**Oscillations and Networks**
	Exploring Large Spike Networks Using NEST
	Information Theoretic Basis of Neural Computation
12:00 pm - 1:00 pm	Lunch Break
1:00 pm – 5:00 pm	**Oscillations and Networks**
	Exploring Large Spike Networks Using NEST
	Information Theoretic Basis of Neural Computation
5:30 pm - 9:30 pm	Workshop Reception and Party

Thursday, July 21st : Workshops

9:00 am - 12:00 pm	**Model Databases and Genetic Algorithms**
	Oscillations and Networks
	Exploring Large Spike Networks Using NEST
	Information Theoretic Basis of Neural Computation
12:00 pm – 1:00 pm	Lunch Break
1:00 pm - 5:00pm	**Model Databases and Genetic Algorithms**
	Oscillations and Networks
	Exploring Large Spike Networks Using NEST
	Information Theoretic Basis of Neural Computation

Abstracts

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Extraction of an activity pattern language from EEG data

Andras, Peter
School of Computer Science

Recent research shows that activity patterns play an important role in neural information processing. This seems to be the case both at micro and macro level processes within the nervous system. An important question is how to extract such activity pattern languages from neural data. Here we present a methodology that we use to extract an activity pattern language from high resolution EEG data. First we determine typical activity patterns in the data, and then we establish probabilistic continuation rules describing which typical activity patterns follow earlier activity patterns present in the data. The accuracy of the established rules is tested using previously unseen data.

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A Parallel and Efficient Algorithm for Multicompartment Neuronal Modeling

Zhuang, Yu
Texas Tech University

The quantitative understanding of the dynamics of neuronal membrane potential is essential for the functional understanding of neurobiological systems. The sheer complexity of neurobiological systems and the experimental inaccessibility of some variables necessitate the investigation approach through computer simulation. The quality of a simulation algorithm is measured by its accuracy and efficiency, that is, how good the algorithm can reveal the details of neurobiological properties, and how much computation cost the algorithm takes to reach the required accuracy. A remarkable achievement in efficiency is the Hines method which substantially reduces the computation cost of matrix inversions required in implicit temporal integration. However as pointed out by Hines himself, the Hines method does not work for circuits containing gap junction loops. In this talk, we propose an algorithmic approach with which the Hines method extends its applicability to loop-containing circuits with an efficiency almost the same as that of the Hines method for loop-free circuits. Furthermore, our approach also creates high algorithmic parallelism, allowing algorithms to better utilizing the parallel computing power of increasingly affordable parallel computing systems like PC clusters.

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Stimulus competition by inhibitory interference

Tiesinga, Paul
University of North Carolina, Chapel Hill

When two stimuli are present in the receptive field of a V4 neuron, the firing rate response is between the weakest and strongest response elicited by each of the stimuli alone (Reynolds et al, 1999). When attention is directed towards the stimulus eliciting the strongest response (preferred stimulus), the response to the pair is increased, whereas the response decreases when attention is directed to the poor stimulus. When attention is directed to either of the two stimuli presented alone, the firing rate remains the same or increases slightly. We reproduced these results in a V4 model neuron by assuming that attention modulates the activity of local interneuron networks. The V4 model neuron received stimulus-specific asynchronous excitation from V2 and synchronous inhibitory inputs from two local interneuron networks in V4. Each interneuron network was driven by stimulus-specific excitatory inputs from V2 and was modulated by a projection from the frontal eye fields. The model suggests that top-down attention biases the competition between V2 columns for control of V4 neurons by changing the relative timing of inhibition rather than by changes in synchrony of interneuron networks. This modulation of gain by inhibitory interference may have general applicability to cortical information processing.

22

A temporal learning rule in recurrent systems supports high spatio-temporal stochastic interactions

Wennekers, Thomas; Ay, Nihat
Centre for Theoret. and Comput. Neuroscience

We recently proposed an information theoretic optimization principle called Stochastic Interaction Maximization (or TIM) as an alternative to the classical Infomax concept. TIM maximizes the total amount of correlations in a system [2]. Both principles bear similarities [1], but TIM can also be applied to recurrent systems and spatio-temporal activity [2,3], where it induces context-dependent receptive fields, input-dependent internal state transitions, and complex spatio-temporal patterns similar to correlation structures in multi-unit recordings like partial synchronization or synfire chains. Whereas Infomax is closely related to Hebbian coincidence learning, preliminary work suggests that TIM in recurrent systems is supported by temporal learning rules comparable to spike-timing-dependend plasticity. The present work investigates this for Markov chains comprising N units equipped with a learning rule that adapts state transitions according to pre- and post-synaptic activity. It is shown that such rules (1) confine activity to almost deterministic global transitions, but single units fire virtually randomly (synfire chains), (2) lead to almost maximal Stochastic Interaction, and (3) enforce a high flow of information from input to internal units (as Infomax in the pure feedforward case). [1] N Ay. Neural Computation 14, 2959--2980, 2002. [2] N Ay & T Wennekers. Neural Networks 16, 1483--1497, 2003. [3] T Wennekers & N Ay. Neural Computation, submitted.

23

Neurodynamical approach to the picture-word interference effect

Deco, Gustavo; Koepke, Franziska; Loh, Marco; Costa, Albert
ICREA

Speech production involves the retrieval of several types of information. A crucial stage in this processing is the retrieval of the lexical items from the lexicon. One of the most used methods to explore the principles governing lexical selection is the picture-word interference paradigm. In this paradigm, participants name pictures while ignoring the presentation of a distractor word. Interestingly, by manipulating the relationship between the picture and the distractor word different effects are observed. For example, interference produced by semantically related distractors. This Stroop-like effect has been interpreted as revealing the competitive nature of the lexical selection mechanism. In the present article we gain insights about the issue by developing a dynamic model that, using a computational neuroscience perspective, consider the neuronal and cortical mechanisms underlying behavior in the picture-word interference paradigm. Neurodynamics, described at the level of spiking and synaptic activity, is used to provide a quantitative formulation for the underlying dynamical evolution. We use the mean-field approach to fits the experimental observations (reaction time differences of the basic level phenomena, the identity effect, the semantic interference effect and the category naming).

24

A Dynamical Systems Model of Turtle Visual Cortex

Kim, Chris; Ulinski, Philip
The University of Chicago

Visual stimuli evoke waves in turtle visual cortex. We have used a large-scale model to study the waves, but the Genesis model is too complex to analyze with methods from dynamical systems and control theory. In this study, we used our large-scale simulations to formulate a family of non-autonomous, linear ordinary differential equations that can be used for mathematical analyses of the properties of the cortex. The large-scale model is used to simulate the responses of the cortex to visual stimuli. The fractions of each of population of cortical cells that are above the threshold for action potential production are plotted as a function of time. The response of the cortex to an input stimulus, u(t), is given by the matrix ordinary differential equation, dX(t)/dt = A(t) X(t) + u(t). X(t) = [xl(t), x2(t), …, xN(t)]T is a column vector that represents the fractions of each population of cells in the model that are active, and A(t) is a square matrix whose elements specify the time course of the interactions between the ith and jth populations of cells. This work was supported by award from the CRCNS program at NSF.

25

A model of dual control mechanisms through anterior cingulate and prefrontal cortex interactions

De Pisapia, Nicola; Braver, Todd
Research Associate

We introduce a network model of dual control mechanisms involving the human Prefrontal Cortex (PFC) and Anterior Cingulate Cortex (ACC). The first mechanism, reactive control, consists in the transient activation of PFC, based on conflict detected in ACC over a short time-scale. The second mechanism, proactive control, consists in the sustained active maintenance of task-set information in a separate PFC module, driven by long time-scale conflict detected in a separate ACC unit. The computational function of the first mechanism is to suppress the activation of task-irrelevant information just prior to when it could interfere with responding. The role of the second mechanism is to prime task-relevant processing pathways prior to stimulus-onset, in a preparatory fashion. We examined how well the model could account for previous detailed empirical data regarding human behavioral performance and brain activation in the color-word version of the Stroop task, a benchmark experimental preparation for studying response conflict and cognitive control. The model provided an excellent fit to both the behavioral and brain imaging data, it captured changes in reaction times across conditions, in the pattern of reaction time distributions, in accuracy, and in both transient (within-trial interval) and sustained (inter-trial interval) activation of conflict and task-units.

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Human trajectory planning in the Presence of Signal-dependent Noise

Yasuhiro, Wada; Matsui, Akira
Nagaoka University of Technology

Two types of criterion, the minimization criterion based on smoothness and on signal-dependent noise, have been proposed to explain several universal features in point-to-point human arm movement. We investigated whether criterion based on signal-dependent noise is considered in human trajectory planning. In our experiments, movement with a via-point on the sagittal plane was tested. The via-point was located vertically at a center between a start point and an end point. (I) We examined the relation between the highest position the hand passes through and the variance of the end-point positions. (II) Simulated, larger signal-dependent noises were added to the motor commands of subjects as they performed the same reaching movement as in the first experiment. The result of experiment (I) showed that the variance of the end-point positions became smaller as the highest position of the hand became higher. The experiment (II) showed that the end-point variance became larger than without simulated signal-dependent noises. However, as the experiment progresses, the highest position varied toward higher and the variance became smaller. Results suggested that the subjects reduced the variance of the end-point positions and the minimum variance criterion is considered in human motor planning.

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Examinations on human arm trajectory and posture planning in three-dimensional space

Yasuhiro, Wada; Yamanaka, Kazuhiro; Soga, Yousuke; Tsuyuki, Kimitaka; Kawato, Mitsuo
Nagaoka University of Technology

The following two characteristics have been well demonstrated about the feature of a point-to-point human arm movement on a plane. (1) The path is a roughly straight line. (2) The velocity profile is bell shaped. Several models have been proposed to explain these features. Several criteria for trajectory planning based on optimal principles have been proposed. It has shown that trajectories generated by the minimum commanded-torque change model correspond well with measured trajectories in a horizontal and sagittal work space. However, previous works had been restricted to trajectories on a two-dimensional plane. Trajectories and final arm postures had not been examined in three-dimensional space. We measured many point-to-point movements in three-dimensional and performed comparative examinations using measured trajectories and optimal trajectories based on these criteria. We quantitatively discuss predictions based on these criteria for human arm trajectories and arm postures in three-dimensional space. We report that minimum commanded torque change trajectories are closest to trajectories measured in three dimensional space as well as on a two-dimensional plane and the minimum commanded torque change criterion can explain measured arm postures well. We point out the possibility that both hand trajectories and arm postures can be predicted by the optimization criterion.

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Spatial Filtering by Locally Connected Neurons

Naoki, Masuda; Okada, Masato; Aihara, Kazuyuki
RIKEN Brain Science Institute

Inputs to neurons are local in many cases, both in terms of external inputs and feedback inputs. Previous model studies have revealed that such neural networks robustly show various dynamical/static states such as activated bumps, traveling waves, and local oscillations. They are suggested to be functionally important in, for example, orientation selectivity and working memory. By analytical calculations and numerical simulations, we have examined how the extents of spatial inputs and those of recurrent coupling interact with each other and identified which profiles of spatially localized neural activities are relevant to information processing. The idea is that the spatial Fourier modes of firing rates can be used as order parameters, as addressed by, e.g., Ben-yishai, Bar-Or, Hansel, and Sompolinsky. A summary of our main results is: (1) inputs are spatially filtered, (2) the upper cutoff of the spatial frequency is determined by the spatial resolution of the recurrent connectivity, (3) spatial filters work both for the common noise inputs and the bias inputs, (4) the uncommon noise inputs controls the possibility of bistable states and neural excitability.

31

Genetic Algorithm for Optimization and Specification of a Neuron Model

Purvis, Liston; Gerken, William; Butera, Robert
Georgia Institute of Technology

We present a novel approach for neuron model specification using a Genetic Algorithm (GA) to develop simple firing neuron models consisting of a single compartment with one inward and one outward current. The GA not only chooses the model parameters, but also chooses the formulation of the ionic currents (i.e. single-variable, two-variable, instantaneous, or leak). The fitness function of the GA compares the frequency output of the GA generated models to an I-F curve of a nominal Morris-Lecar (ML) model. Initially, several different classes of models compete among the population. Eventually, the GA converges to a population containing only ML-type firing models with an instantaneous inward and single-variable outward current. Simulations where ML-type models are restricted from the population are also investigated. This GA approach allows the exploration of a universe of feasible model classes that is less constrained by model formulation assumptions than traditional parameter estimation approaches. While we use a simple model, this technique is scalable to much larger and more complex formulations.

32

Event-based simulation strategy for conductance-based synaptic interactions and plasticity

Rudolph, Michael; Destexhe, Alain
UNIC

The immense computational and adaptive power of biological neural systems emerges from the collective dynamics of large populations of interacting neurons. Thus, for theoretical investigations, optimal modelling strategies are required. Recently, an efficient event-based approach was proposed in which the computational complexity scales linearly with the number of neuronal units, compared to their square as in synchronous methods. So far, neuronal models made available for the event-based simulation strategy restrict to integrate-and-fire dynamics and extensions of its current-based descriptions. However, neuronal dynamics in vivo, in particular in the mammalian cortex during "activated" states such as wakefulness, is determined by synaptic noise. The latter originates from the sustained and intense activity in the cortical network, and sets the cellular membrane into a high-conductance state. Here, we propose an extension of the "classical" IF neuronal model, the gIF model, which incorporates various aspects of high-conductance state dynamics seen in cortical neurons in vivo. Moreover, event-based models of activity-dependent modulation of synaptic weights, in particular STDP rules, are proposed. The relative simplicity of these extensions will allow these neuronal models to be used together with event-based simulation strategies, therefore providing the basis for efficient simulations of large-scale neuronal networks with realistic synaptic interactions.

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Goal Construction for Muscle Actions

Freeman, Walter; Kozma, Robert
University of California at Berkeley

Brains create meaning by creating intentional relationships with others in their environments. They communicate their intentions by expressing them in information through actions, gestures, and language. They select and pre-process the information carried by sensory stimuli as sense data, from which they construct knowledge. They post-process cognitive knowledge into commands controlling goal-directed interactions that support meaning. The process of perception by which brains construct knowledge from information received through the senses is explained by analyzing the neural activity in human and animal brains as subjects engage in meaningful behaviors. Measurement is followed by decomposition and modeling of the neural activity to deduce brain operations. Brains function hierarchically with neuronal interactions within and between three levels: microscopic of single neurons and local networks, mesoscopic of local populations forming modules, and macroscopic of the global self-organization of the cerebral hemispheres by the organic unity of neocortex. Information is carried in continuous streams of microscopic axonal pulses. Knowledge is manifested in mesoscopic local mean fields of dendritic currents in discontinuous frames resembling cinemas, each frame having a spatial pattern of amplitude modulation of an aperiodic carrier wave. The limbic system plays the most crucial role in the organization of intentional behavior.

34

The interaction between facilitation and depression of two release mechanisms in a single synapse

Zhou, Lian; Lomauro, Robert; Nadim, Farzan
Biological Science, Rutgers University

The synapse from the lateral pyloric (LP) to the pyloric dilator (PD) neuron in the stomatogastric nervous system of the crab has both a graded and a spike-mediated component. However, these two components have opposite short-term dynamics: the spike-mediated component is usually facilitating, while the graded component is depressing. These two different synaptic dynamics provide two possibilities in adjusting the output rhythm of the pyloric network. Furthermore, these two synaptic components interact in a complex manner depending on the membrane potential waveform and action potentials of the presynaptic LP neuron. We built a model of these two synaptic components and their interactions, based on the concept of quantal release evoked by calcium influx. This model is able to accurately predict the postsynaptic response of the PD neuron to any temporally patterned presynaptic LP neuron activity.

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PDF-Content Management System Based on PubMed Database

Aoyama, Toshihiro; Usui, Shiro
Suzuka National College of Technology

A management of referenced articles is one of the most important works for researchers. Recently, most publishers provide not only paper version of articles but also PDF (Portable Document File) version. Researchers have to manage a lot of PDF files of articles. However, the work is not important work to progress the research; we don't want to spend much time for this boring routine. PubMed is the largest database site for references of biological studies. We can search articles by some keywords, and access the citation information of articles. We described an application to manage PDF files based on PubMed database. Users can not only automatically import citation information of the downloaded PDF files by drag and drop operation, but can also download a PDF file from a publisher site though PubMed site on the application and automatically import the downloaded file. The application can also be imported PDF files that are not in PubMed manually. The application, whose name is iPapers, is free software worked on MacOS X (10.3 or later). This application will help researchers to manage a lot of PDF files of articles

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Modelling self-sustained rhythmic activity in lamprey hemisegmental networks

Mikael, Huss; Cangiano, Lorenzo; Hellgren Kotaleski, Jeanette
Royal Institute of Technology

In the lamprey spinal cord, the smallest unit capable of independent rhythm-generation was long believed to be a segment, consisting of two reciprocally connected and mutually inhibitory hemisegments. However, recent studies have shown that even single hemisegments can display rhythmic activity generated in response to a constant input drive. This activity is believed to be generated by a network of recurrently connected excitatory interneurons. A recent study found and characterized self-sustaining rhythmic activity – locomotor bouts – in response to brief electrical stimulation of hemisegmental preparations. These locomotor bouts can last for minutes and have a frequency range of 2-15 Hz. The mechanisms behind the bouts are still unclear. In tandem with the experimental studies, we are developing a computational model of the hemisegmental network, where each individual neuron is modeled using a detailed and up-to-date electrophysiological model. Initial simulations found that the self-sustaining rhythmic activity could be replicated with our model, and that the model could be used to predict unknown parameters of the system such as number of and connection probability between excitatory interneurons. Further studies will use the model to address the possible involvement of metabotropic glutamate receptors, acetylcholine synapses and axonal delay distributions in the locomotor bout phenomenon.

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Dynamics of Acto-Myosin Interaction:

Sun, Sean
Johns Hopkins University

The mechanics and dynamics of myosin molecular motors are explored using coarse-grained computational techniques. Specifically, we examine the role of myosins in actin-based transport and muscle contraction. A remarkable feature of these systems is that the molecular motors are dynamically synchronized. A mechanism that generates synchrony is proposed. The computational model connects molecular level motions with physiologically movement and completely explains the experimental results.

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Parallel processing of multiple stimulus parameters and the emergence of combination sensitivity

Carlson, Bruce; Kawasaki, Masashi
University of Virginia

We used information theoretic approaches to study the encoding and processing of multiple stimulus parameters in the electrosensory system of the weakly electric fish Gymnarchus niloticus. We recorded intracellularly from primary afferents, hindbrain, and midbrain electrosensory neurons during stimulation with low-pass filtered, Gaussian-distributed, random amplitude modulation (AM) and phase modulation (PM), presented both separately and simultaneously. Primary afferents encoded the detailed time course of both AM and PM when presented alone, but in response to joint AM/PM, reliably encoded only one of the two stimulus features. Hindbrain neurons did a poor job of encoding the detailed time course of stimuli, and instead acted as feature detectors, signaling the occurrence of specific stimulus features. Similar to the primary afferents, hindbrain neurons exhibited selectivity to a particular stimulus parameter only when both were simultaneously modulated. However, combination-sensitive neurons in the midbrain acted like neuronal AND gates, signaling the joint occurrence of specific stimulus features in both parameters. This study is the first to apply information theoretic approaches to the encoding of multiple stimulus parameters in parallel sensory pathways. Our findings underscore the importance of considering each potential source of variation in natural signals when analyzing information processing by the nervous system.

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Neuronal avalanches and criticality

Hsu, David; Beggs, John
University of Wisconsin

The dynamics of microelectrode local field potentials from animal brain slices and cultures has been shown to demonstrate critical behavior. A desirable feature of criticality is that information transmission is optimal in this state. We explore a biologically plausible mathematical model that can dynamically converge on criticality and that can return to criticality if perturbed away from it. Our model assumes the presence of a spontaneous local activity plus activity due to excitatory interregional connections. Both the spontaneous activity and interregional connection strengths are dynamically adjusted so that the firing rate tends toward a target firing frequency. Depending on how quickly the firing rate is made to approach the target firing frequency, it is also possible to approach the critical state. We suggest that mechanisms for maintaining firing rate homeostasis may also maintain a neural system at criticality.

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Role Of Frequency-Dependent Weighing Of Inputs On Frequency Regulation Of A Pacemaker-Driven Rhythm

Manor, Yair; Saraf-Sinik, Inbar
Ben-Gurion University

We examined the frequency-dependent efficiency of positive and negative inputs onto pacemaker neurons of the pyloric circuit (frequency rhythm around 1Hz). In synaptically isolated and quiescent pyloric pacemaker neurons, we injected series of sinusoidal currents at different frequencies. At low frequencies (< 0.7 Hz), we found that the peak amplitudes were significantly larger than the troughs. This reversed at frequencies higher than 0.7 Hz, which we refer to as the fixed point. Pharmacological work suggests that two types of ionic currents could be responsible for this profile: a rapid transient potassium (A-type) and a slower transient calcium (T-type) current. This hypothesis was supported by a computational model of a pyloric pacemaker cell. The model predicts that manipulation of these two conductances changes the fixed point and affects the rhythm accordingly. Hence, the differential frequency dependence of negative and positive inputs impinging onto the pyloric pacemaker neurons could play a role in stabilization of the rhythm frequency, without impairing the ability of this network to vary its rhythm when such flexibility is required. The functional implications of this mechanism for regulation of rhythmic activity are examined.

41

An Explanation of Emergence of Reward Expectancy Neurons Using Reinforcement Learning and Neural Net

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In an experiment of multi-trial task using a monkey in which some successful trials are required until it gets a reward, some neurons that relate to reward expectancy have been observed in the anterior-cingulate in its brain. The reward expectancy neuron is activated in each trial except for the reward trial. Therefore, it is difficult to explain the emergence of the neurons simply by reinforcement learning. In this paper, a model that consists of a recurrent neural network trained based on reinforcement learning is proposed. From the simulation of the model, it is suggested that such neurons can emerge to realize an appropriate value function in the transition period from the single-trial task to the multi-trial task. The relation between the reason of emergence and the function of "reward expectancy" should be considered in the future, but we think that the result supports the idea that reinforcement learning is a main principle of learning in the brain.

42

Reconstruction and simulation for three-dimensional morphological structure of insect neurons

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In these days, details of morphological structure of neurons have been measured by confocal laser scanning microscope. Even it could be measured three-dimensional detail structure of neurons, several futuristic groups are reconstructing and exploiting structural models for their analysis. In this study, we are developing the system for 3D morphological structure of neurons from confocal laser scanning microscopic images. Center line and cross-sectional area in the dendritic branches can be extracted by the single-seed distance transform method (SSDT). It was tested the effectiveness of our system by applying to reconstruction of interneurons in an antennal lobe of silkworm moths. Delay and persistence of response strongly depended upon the starting position of firing in dendrites. Furthermore, it was confirmed that asymmetric property in neuronal response was provided by branching and radius changes even in the homogeneous ionic current components.

43

Biophysical Limits on Axonal Transmission Rates in Axons

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We use detailed biophysical models to calculate the maximum rate at which action potentials can be generated in a squid giant axon such that pairs of action potentials do not interfere with each other and corrupt the interspike interval (ISI) more than other sources of intrinsic noise. The results suggest that this rate, which is directly related to the maximum information transmission rate of the axon, is highly model dependent. The absolute and relative refractory periods of the action potential and how they are related to biophysical parameters must therefore be taken into account when analyzing the information-theoretic properties of axons.

44

Copula Point Process Models of Neural Dependence

Jenison, Rick
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One of the most important questions in computational neuroscience is what role coordinated activity of ensemble neurons plays in the neural coding of sensory information. One approach to understanding this role is to formally model the ensemble responses as multivariate probability distributions. We have recently demonstrated alternatives to linear assumptions of gaussian dependence in neural ensembles using the probabilistic copula approach. In probability theory the copula "couples" marginal distributions to form flexible multivariate distribution functions for characterizing ensemble behavior. In this talk I will demonstrate how the copula can be introduced into marginal point process models based on single unit recordings from primary auditory cortex of cat. The resulting copula models can be analyzed directly to evaluate multi-information of the ensemble spike trains. Furthermore the copula approach offers a natural method for simulating different forms of spike train dependence given independently modeled point processes.

45

Joint maps for orientation, eye, and direction preference in a self-organizing model of V1

Bednar, James; Miikkulainen, Risto
The University of Edinburgh

Primary visual cortex (V1) in mammals contains multiple overlaid maps for visual features, such as orientation (OR), motion direction selectivity (DR), and ocular dominance (OD). Neurons in these maps have spatiotemporal receptive fields (RFs) selective for multiple features, and are connected laterally in specific long-range patterns that follow the feature preferences. Previous computational models have shown that OR/OD or OR/DR maps can develop through input-driven self-organization, but none has yet shown how the connection patterns can develop for OR/OD/DR maps, and their computational role is not yet clear. Using the LISSOM model we show how these maps can self-organize using Hebbian learning from moving natural images. The model develops realistic single-feature and joint maps, with OR patches subdivided into opposite directions of motion, and OD lines perpendicular to OR patches. Neurons in the map develop realistic spatiotemporal RFs and patchy long-range lateral connections. Lateral connections are strongest between neurons with similar OR and DR preferences, and connect to neurons from both eyes. These results suggest that a single self-organizing system may underlie the development of feature preferences and lateral connectivity, and predict how the lateral connections will align with the DR map.

46

A Role for Compromise: Inhibitory & Electrical Synapse Effects on Phasing in the Leech Heartbeat CPG

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The leech heartbeat central pattern generator (CPG) consists of seven bilateral pairs of heart interneurons that coordinate heart motor neuron activity. In the CPG, front and rear premotor interneurons are coordinated differently on both sides by intervening switch interneurons. We have extended an existing network model in GENESIS to construct a model of the entire heartbeat CPG. In our CPG model, we implemented known synaptic and neuronal properties. An activity-based model of the switch interneurons was constructed that was tuned to fit experimentally recorded burst phase characteristics. The rear premotor interneurons show similar activity to and were modeled in the same manner as the front premotor interneurons. To reproduce experimentally observed CPG phasing, we systematically varied synaptic strength onto the rear premotor interneurons. We found that neither inhibitory synapses nor electrical coupling alone was sufficient to produce proper phasing on both sides, but instead a balance between inhibitory synapses and electrical coupling is required. This phase shift is because the inhibitory synapses and electrical coupling have opposing effects on the peristaltic side and reinforce one another on the synchronous side. Our search of parameter space has thus led to a CPG model that well approximates the experimentally observed phase relations.

47

Computational Harmonic Analysis for Human and Robotic Vision Systems

Turski, Jacek
Computer and Mathematical Sciences

An image representation has been constructed in the framework of Fourier analysis on SL(2,C), the group providing image projective transformations in the conformal camera. It's designed for active vision that mimic the brain process in which visual information is transmitted from the retina in a topographic arrangement---retinotopic mapping---to the primary visual cortex. In this analysis, images are decomposed in terms of unitary representations of the Borel subgroup---analogues of exponentials in the standard Fourier integral, with coefficients given by projective Fourier transform. It becomes the standard Fourier transform in log-polar coordinates identified with the complex logarithm that models the retinotopic mapping. Therefore, to apply FFT, images must be sampled with nonuniform log-polar geometry (retinal image) and resampled uniformly in the log-polar coordinate plane (cortical image). We explain how the conformal camera identifies projections with the same image and still being pertinent to the way the human vision acquires 3D understanding from 2D images. We extend our modeling with the Lie group formulation of the eye (conformal camera)-head system kinematics and the corresponding algorithms, including fixation, motion parallax and disparity. Finally, we show how our results relate a remarkable construction by Mumford to perspectively-covariant imaging.

48

Simple cell's response property: Implications of feedforward inhibition.

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Recent experimental study reports existence of two (complex and simple) functionally distinct types of inhibitory cells in primary visual cortex. Role of these inhibitory cells has been studied theoretically, it has been shown that the inhibitory inputs provided by these cells in combination with feedforward excitatory inputs is sufficient to explain sharp contrast invariant orientation tuning and low-pass temporal tuning of simple cells. Here we critically examine the role of the feedforward (LGN input to cortical cell via these interneurons) inhibition provided by these cells on neural output pattern and in sharpening of tuning characteristics of the simple cells. We demonstrate that inhibition provided by complex type of inhibitory cells balances the feedforward excitatory input to keep the spike response of cortical cell sharply tuned and contrast invariant. In addition it provides more variability to the neural output pattern in comparison to that provided by inhibition from simple type inhibitory cells. Furthermore, we studied the temporal structure of average membrane fluctuations due to complex and simple type inhibition respectively. We find that inhibition due to simple type interneuron leads to very large fluctuations in average mebrane potential of a cortical cell, especially for the stimulus of preferred orientation.

49

Spatiotemporal clustering of synchronized bursting events in neuronal networks

Barkan, Uri; Horn, David
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In vitro neuronal networks display Synchronized Bursting Events (SBEs). Thousands of SBEs can be registered over a day. We describe the raster plot of each SBE on a common spatiotemporal template, with fixed length and common location of the peak of activity. After applying SVD for dimensional reduction, clusters of SBEs can be observed. We use quantum clustering to extract these clusters. We demonstrate that our clustering procedure is in accord with Pearson correlations between raster plots of SBEs: correlations within the clusters are significantly higher than correlations between SBEs that belong to different clusters. The clusters correspond to different modes of activity that occur throughout the experiment. We demonstrate some characteristics of differences between clusters: firing profiles of single neurons, and relative temporal ordering of pairs of neurons.

50

From oscillatory synchronization with spiking neurons to binary neurons

Martinez, Dominique
Loria

In this study, we consider an excitatory-inhibitory spiking neural network exhibiting oscillatory synchronization as a model of the insect antennal lobe. We present a procedure to reduce this model to a more abstract model using binary neurons. The process of abstraction consists in determining single neuron response probability, conditional to field potential oscillations. We found that phase-locking probability for excitatory cells is a bell-shaped function while firing probability for inhibitory cells is well described by a sigmoid-shaped function. Moreover, single neuron activity is regulated by the mean activity of the neuronal population and this regulation could act as a gain control mechanism.

51

Dependence of the spike-triggered average voltage on membrane response properties

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The spike-triggered average voltage (STV) is studied as a function of the subthreshold voltage-response characteristics of neurons. Three different types of subthreshold dynamics are considered: passive decay, as exhibited by the integrate-and-fire model neuron; rebound/sag, as seen in pyramidal cells that express the Ih current; and damped voltage oscillations, as seen in neurons in the entorhinal cortex. These subthreshold dynamics are supplemented by a threshold and reset for spike emission. The theory of large deviations is used to derive analytical expressions for the STV, for each of these cases, that are correct in the low-noise limit. However, for stronger noise this method misses the power-law behaviour of the STV near the threshold. A second, asymptotically exact, result is also derived that gives an accurate account of the run-up to the spike for such threshold models. Our analysis demonstrates that the STV is strongly affected by subthreshold membrane properties - a result with implications for models of spike-time-dependent plasticity.

53

Modelling single neuron behaviour using stochastic differential equations

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In this study we model the dynamic behaviour of a cerebellar granule neuron using stochastic differential equations. The basis of the work is a deterministic biophysical model which was previously used to simulate the basic firing properties of the cerebellar granule neuron in vitro. In our model stochasticity is incorporated by describing the activation and inactivation of the six different ionic conductances using stochastic differential equations. We consider the resulting stochastic integrals as Itô-integrals and use the Euler-Maruyama method for simulating different realisations of the system. We show that our novel stochastic approach to model excitability is capable of reproducing realistically all experimentally recorded firing patterns of the cerebellar granule neuron. We conclude that the stochastic model outperforms all previously presented computational models for cerebellar granule neuron excitability.

54

A Computational Model of Acute and Delayed Tissue Damage Resulting From Ischemic Stroke

Revett, Kenneth
University of Westminster

Stroke is the 3rd leading cause of pre-mature death in the world according to the World Health Organisation, afflicting approximately 500,000 people per annum in the United States alone. Ischemic stroke, either from an embolism or thrombosis accounts for 85% of stroke incidence. Although stroke research has not found a "cure," great progress has been made from experimental models of stroke. The primary results from experimental models of ischemic stroke are: i) the glutamate excitotoxicity hypothesis and the ii) cortical spreading hypothesis. Experiments, which have prevented these events from occurring (applying glutamate antagonists), result in decreased tissue damage of the order of 30% below that of controls. Although these results are promising, clinical trials have not yielded the same level of tissue protection. The amount of money required to bring a drug through clinical trials can be prohibitive – therefore any methodology, which reduces the cost of therapeutic drug design, would be advantageous. It is hoped that computational models of diseases such as stroke might provide a fast, efficient, and cost-effective method to evaluate mechanisms of action in disease. In this paper, an extension of a biologically realistic model of ischemic stroke is presented outlining current adaptations and future plans

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Aspects of efficient simulation of large heterogeneous networks

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Honda Research Institute Europe GmbH

The Neural Simulation Tool NEST is a simulation environment for large heterogeneous networks of point neurons or neurons with a small number of compartments, developed and maintained by the NEST Initiative (see www.nest-initiative.org). NEST is implemented in C++, using an object-oriented approach, and has been in constant use and development since 1995. In previous work, we have focused on the general design of NEST and its collaborative development process. In this contribution, we concentrate on the design and implementation of NEST's simulation engine (kernel). We describe in detail how networks are constructed, represented, and simulated in the NEST simulation kernel. Special emphasis will be put on issues regarding parallel simulation using threads. Although our main topic is the NEST simulation kernel, our arguments and conclusions are interesting for all researchers who want to simulate large neural systems. We also give practical hints on how multi-threading can be used to significantly speed up simulations and discuss possible drawbacks and common pitfalls of multi-threading in the context of neural systems simulation.

57

Real-time simulations of networks of Hodgkin-Huxley neurons using analog circuits

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We describe here a prototype system for real-time simulation of networks of neurons based on the Hodgkin-Huxley (HH) formalism and conductance-based synaptic interactions. The system is based on analog custom integrated circuits (ASICs), which solve the membrane equations of the neurons. Each ASIC neuron contains a leak conductance, the INa and IKd voltage-dependent conductances for generating action potentials (HH model), a slow voltage-dependent K+ conductance for spike-frequency adaptation, and two conductance-based synaptic currents that implement kinetic models of glutamate and GABA receptors. The connectivity between the neurons is entirely managed digitally using a computer, which is interfaced in real-time with the board containing the ASIC neurons. We demonstrate here the functionality of this system for small networks of excitatory and inhibitory neurons with excitatory synapses endowed with spike-timing dependent plasticity and fixed inhibitory synapses. We compare the behavior of ASIC neurons with numerical simulations of the same models. Besides variability due to component noise, the ASICs and simulations match remarkably well. This approach should yield efficient platforms for real-time simulations of large-scale networks of conductance-based neurons in a near future. Supported by CNRS, HFSP and the European Community (Future and Emerging Technologies program).

58

CoThaCo: A Comprehensive Model of the Thalamocortical Pathway

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We present CoThaCo, a biologically realistic model of the primate early visual pathway from the retinal ganglion cell layer via the lateral geniculate nucleus to primary visual cortex, as a substrate for such modeling studies. CoThaCo comprises P, M, and K pathways, each containing ON/OFF sub-paths. Neurons are largely modeled as leaky integrate-and-fire-or-burst neurons connected by conductance based synapses. CoThaCo is implemented using the Neural Simulation Tool NEST. It will provide a unique substrate for in computo experiments investigating the mechanisms underlying signal processing in the early visual pathway.

59

Temporal organization of sleep oscillations

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The human sleep EEG is characterized by the occurrence of distinct oscillatory events such as delta waves, sleep spindles, and alpha activity. We investigated their temporal structure of occurrence and the interrelationship between the different events. Of particular interest was the question whether these oscillatory events are related to cortical "slow oscillations" - an alternation of the cortex between a depolarized "up-state" and a hyperpolarized "down-state". Sleep spindles occurred with a period of approximately 4 s and they lasted between 1 and 2 s. Delta events also occurred with a period around 4 s. These main features, a maximum around 4 s in the inter-event interval distribution and a maximum at 2 s for the spindle duration were also observed in synthetic data generated by stationary AR-processes without the assumption of an additional slow process. On the other hand we found evidence for an interrelation between oscillatory events in different frequency bands: 1) delta oscillations and sleep spindles tended to occur simultaneously; 2) alpha oscillations preferentially followed after delta oscillations.

60

Effects of interneuron feedforward inhibition via the F2 terminal on retinogeniculate transmission

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X-type thalamocortical (TC) relay cells of the dLGN receive feedforward inhibition from local interneurons (IntN) via a dendrodendritic pathway (F2 terminals). Here we investigate the effects of feedforward inhibition via the F2 pathway on retinogeniculate transmission by constructing a minimal TC-IntN(F2) network model. The TC model utilizes the integrate and fire or burst (IFB) formalism and the IntN dendrite is a non-spiking compartment. When stimulated with realistic spontaneous retinal ganglion cell (RGC) input of constant mean rate the TC response is not necessarily monotonically related to the RGC firing rate at higher stimulation frequencies. We explore the contributions of synaptic conductances on this biphasic response. Using RGC input consistent with modulated full-field visual stimulation, our poster presentation will utilize Fourier analysis and stimulus reconstruction methods to probe the effect of feedforward inhibition on input/output properties of the TC-IntN(F2) network.

61

Recurrent inhibition can enhance spontaneous neuronal firing

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Inhibitory interneurons in neocortex, while dampening some behaviors, can also facilitate activity, e.g., helping to sharpen transients and synchronize gamma oscillations. We propose that feedback from fast inhibition can also enhance the spontaneous firing of principal cells. Here we study an idealized feedback model. We drive the Hodgkin-Huxley conductance-based model by external Poisson alpha-function excitatory synaptic input. Its output spikes lead (1 for 1) to recurrent inhibitory synaptic inputs (delayed by δ). We find that the recurrent inhibition can enhance the neuron's firing rate if τ_{inh} is fast enough; the dependence of this enhancement on δ is weak. The spontaneous firing without inhibition is due to temporal summation of subthreshold inputs. The recurrent inhibition (that occurs δ ms later) may reduce the spike threshold of the membrane briefly (e.g, by transiently reducing g_K) and thereby facilitates the next subthreshold excitatory event to evoke a new spike. This mechanism is different from classical postinhibitory rebound, and occurs in the current model for a wide range of δ values, and for short decay times of inhibition. This may have interesting ramifications in understanding the role of inhibitory synapses in neocortex.

62

Predicting synchronized neural assemblies from experimentally estimated phase-resetting curves

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Assemblies of (transiently) synchronized neurons have been observed in a variety of neural systems. This phenomenon is reminiscent of the formation of clusters in models of coupled phase oscillators. To investigate real neural networks as systems of coupled oscillators, we have recently proposed an efficient method to estimate phase-resetting curves (PRCs) in real neurons with whole-cell patch-clamp procedures. In particular, we have applied our approach to the study of the neural dynamics in the mammalian olfactory bulb (OB). First we found that i) the estimated PRC of the mitral cells have positive and partially negative regions (type II neurons or resonators); ii) these PRCs possess higher order harmonics, a necessary condition for the formation of more than one oscillator clusters. The PRC-based phase models showed that neurons quickly organized into subsets of synchronized assemblies. The type and pattern of synaptic interactions determined the nature of these assemblies. For excitatory connections neurons divided into three equidistant assemblies were obtained. For inhibitory connections two close assemblies were found. These examples suggest that this simple model can reproduce many features of (transient) synchronization and have led us to begin a more thorough investigation of these phenomena in phase models.

63

A novel approach to model neuronal signal transduction using stochastic differential equations

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We introduce a new approach to model the behavior of large neuronal signal transduction networks using stochasticity incorporated into deterministic reaction rates. Previously, we have studied a deterministic model for protein kinase C signal transduction pathway in neurons. In this study, we implement a stochastic model for this pathway in order to model larger signal transduction networks. We solve the Itô form of the stochastic protein kinase C model using different kind of integration methods; explicit and implicit Euler-Maruyama and Milstein methods. We simulate the behavior of protein kinase C pathway and all four integration methods are found to produce same results. Furthermore, we show that the stochastic responses provide more realistic representations than deterministic responses. After implementing stochastic models, we are able to use powerful stochastic parameter estimation methods. In future, stochastic signal transduction models can be integrated with the excitability models to understand neuronal information processing.

64

Spike-latency coding of topological feature homogeneity

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Spiking neurons can code stimulation strength in firing latency. In a recent publication, we described neural mechanisms for putting ensembles of spiking neurons into consistent internal states. Such ensembles then use a common time frame for latency coding. The visual system can employ this fast and accurate time-based code for the processing of spatial homogeneity. In a network simulation, we demonstrate the fast detection of spatially homogeneous luminance. We show, how homogeneity constraints can be dynamically adjusted through shaping of synaptic potentials. Homogeneity (``surface'') detection has been suggested to support stimulus processing in primate visual cortex.

65

Frequency sensitivity in the cricket cercal sensory system

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The cercal system is a mechanosensory system where filiform hairs of varying lengths respond selectively to near-field air-currents and initiate an increase or decrease in the firing rates of associated afferent neurons. These receptor neurons synapse onto primary sensory interneurons in the terminal ganglion of the cricket. Understanding the biophysical mechanisms used by interneurons to gather, process, and relay information about the dynamics of air current stimuli is crucial to our understanding of this model sensory system. In this work we develop, simulate, and analyze biophysically-based, mathematical models that incorporate five different ion channel types known to exist in these interneurons. We also incorporate realistic synaptic input where the spike timing is based on experimental recordings from afferent neurons in response to sinusoidal air-current stimuli. The use of reduced models allows for an analysis of channel kinetics and a better understanding of how membrane properties contribute to interneuron processing of dynamic sensory stimuli. We find that the frequency preferences of our model neuron depend on the resonant characteristics of the membrane. We also demonstrate the effects of various phase differences in synaptic inputs on the response properties of model interneurons for different parameter regimes corresponding to different frequency filtering properties.

66

A Model of Proximity Measurement by the Teleost Nucleus Isthmi

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Nucleus isthmi is a visually responsive structure found in nonmammalian vertebrates. The exact function of NI is unknown. However, in sunfish, recent research has provided evidence for NI working as a proximity detector for approaching stimuli. A model was constructed to mimic the response of sunfish NI to motion in the visual field. The key parts of the model include versions of optic tectum, nucleus pretectalis (NP) and NI. The model was constructed of linear summing units arranged in 5 topographically connected layers. Looming and retreating balls of varying speed and size were simulated and presented to the model. The model discriminated between looming and retreating stimuli. During trials involving retreating objects, the model NI responded with a single large burst of integrated activity that quickly subsided to baseline. Approaching stimuli evoked a linear rise in the activity of the model NI. The slope of this rise was linearly related to the speed of the object. The response was independent of stimulus size. Therefore, the data suggest that the model NI can provide a proximity measurement for a looming stimulus.

68

Stability of spike timing dependent plasticity in perturbed spiking neural networks

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Memory can be very stable. This is particularly striking because synaptic weights undergo continuous changes. First, constitutive cycling of AMPA recepetors in and out of the membrane in timescales of hours could presumably cause fluctuations in the synaptic weight. Secondly, random coincedences of pre and postsynaptic activity could lead to weight fluctuations. Here we consider the stability of memory in the context of single cells and network models with spike timing dependent plasticity. We examine the implications of a weight dependent learning rule for the stability of such a network in the face of synaptic perturbations, using either a hard-bound or a soft-bound learning rule. We find that in networks without lateral interaction hard bound models are more robust to synaptic fluctuations than softbound models. However, in networks with plastic lateral interactions the stability of the softbound models is restored. The implications for the receptive fields of each neuron in larger networks are being explored.

69

How slow inhibition leads to fast oscillations in the olfactory bulb

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Mitral cells in olfactory bulb (OB) are inhibitory connected via granule cell interneurons. This inhibition is necessary to generate OB intrinsic oscillations in the gamma frequency range (40-90Hz). However the long lasting lateral inhibition between mitral cells (rise time about 30ms and decay about 300ms) cannot account for the OB fast oscillations. We propose a new mechanism, stochastic synchrony, where mitral cells synchronization and local field potential oscillations are induced by spatially correlated fast inhibitory events superimposed to the slow dynamics of lateral and recurrent inhibition. We investigate this hypothesis both theoretically and experimentally. We show that neuron synchronization increases linearly with input correlations and may be responsible for global network oscillations. The oscillation frequency of type I neuron network is close to the single-neuron average firing rate. We show that type II membrane dynamics (similar to OB mitral cells) allows frequency oscillation in a shorter range (gamma range only) and synchronizes better than type I membrane dynamics in this frequency range.

70

Prenatal development of ocular dominance and orientation maps in a self-organizing model of V1

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What drives the development of ocular dominance and orientation maps in the primary visual cortex prenatally, i.e. prior to visual experience? Both molecular cues and spontaneous activity have been suggested as possible factors, but it is unclear how each one contributes. Simulations with the LISSOM model presented in this paper suggest that previsual spontaneous activity in the visual pathway alone is sufficient for realistic interactions between ocular dominance and orientation maps to form. Whether the activity patterns are correlated between the eyes (originating in the brain stem or the visual cortex) or uncorrelated (such as retinal waves) is important: while the maps form robustly with different proportions of the two kinds of patterns, their balance affects how the maps interact. Further, spontaneous activity lasting only for a short period of time can have lasting effects on organization. Future experimental studies should therefore focus on interactions between maps, and care should be taken when interpreting studies that disrupt only a portion of the spontaneous activity reaching V1.

71

Bistable network behavior of layer I interneurons in auditory cortex

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GABAergic interneurons in many areas of neocortex are mutually connected via chemical and electrical synapses. Previous computational studies have explored how these coupling parameters influence the firing patterns of interneuronal networks. Here, we investigated how connectivity parameters influence spike patterns in paired recordings from LI interneurons in brain slices from juvenile mice. Observed properties of chemical and electrical synapses were used to simulate connections between uncoupled cells via dynamic clamp. In uncoupled pairs, action potentials induced by constant depolarizing currents had randomly distributed phase differences between the two cells. When coupled with simulated chemical (inhibitory) synapses, however, these pairs exhibited bistable network behavior, tending to fire either in synchrony (near zero phase lag) or in antisynchrony (phase lag near one half of the inter-spike interval). Combining electrical with chemical synapses, prolonging decay time of inhibitory connections, or increasing the network's firing rate all resulted in enhanced stability of the synchronous state. Thus, electrical and inhibitory synaptic coupling constrain the relative timing of spikes in a two-cell network to at most two stable states, the stability and precision of which depend on the exact parameters of coupling.

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Methods for Finding and Validating Neural Spike Patterns

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Recent experimental and theoretical results have suggested the possibility that cortical neurons may fire in a small number of distinct spiking patterns when stimulated repeatedly by the same signal. Such firing patterns invalidate the assumption that cortical responses are Poisson and suggest the possibility of novel cortical information processing strategies. Unfortunately, methods for extracting and quantifying spike patterns from experimental data are still immature. We present a quantitative definition of spike patterns, a principled procedure for their extraction, and two methods, the Pattern Strength and Pattern Significance, for validating and quantifying the presence of spike patterns in neuronal data. Using the Pattern Strength and Pattern Significance, a simple, statistical model of the response of a neuron can be constructed which retains information about spike patterns which would be averaged out by procedures which use raw by trial averaging, such as in the creation of the standard PSTH. These procedures form part of the necessary basis for investigation of the role of spike patterns in the cortex.

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Dual Matching as the Problem that Neurons Solve

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This paper summarizes a dual theory of information and control and provides an example of this theory in its control venue to single-neuron computation. Single-neuron computation is perhaps one of the simplest conceivable engineering examples of this theory and wherein an analytic solution can be found to what is called the dual-matching problem. In information theory, the dual-matching problem corresponds to the dynamic matching of the source and the channel so as to optimize system transmission throughput rate. Within the control theory dual, a system executes a dual-matching program to maximize the rate it solves an internally defined problem through the balancing of the decisions it makes to the rate it acquires information. The proposed neural model falls into the latter category of "system" provides a very simple example of dynamic dual-matching using an "online" algorithm. The fundamental theory underlying the commonality of information and control lies in the respective quantification of what it means to both ask and answer a question.

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Robust persistent activity in neural fields with asymmetric connectivity

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Many models of stimulus-selective persistent activity in the brain are based on recurrent networks with 'continuous attractors'. The connectivity in these models supports the existence of self-stabilized activity profiles to represent any value along a continuous physical dimension such as direction or position. However, the continuity of the attractor states requires a perfect spatial symmetry in the connection profile. Already small deviations cause a drift in the spatial position of the activity pattern. To serve as a biologically plausible model for short term memory, the network must be sufficiently robust to perturbations in the symmetry. On the other hand, it has been suggested in the context of head direction cells in rats that the drift mechanism may be actively used for an updating of spatial representations during self-motion. Here we analyze persistent activity patterns in a neural field model composed of bistable neurons. We show that these patterns remain close to the actual cue position over time in spite of a substantial asymmetry in the connection profile. Using approximation techniques we derive an analytical expression for a threshold value. It describes the transition to a traveling activity profile as a function of the network parameters.

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Symmetry studies of oculo-motor systems

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In the viewing of a visual scene, the eyes move all the time so that eye movements play a characteristic role in visual perception. The kinematics of eye rotations can be used to understand the oculomotor control system. The mathematical basis underlying the representations of three dimensional eye movements involves rotation matrices, rotation vectors and can be easily described in terms of quaternion algebras. Analysis of eye movements would result data indexed by the SO(3) group. The SO(3) is intrinsically related to the sensorimotor systems. For example, in the labyrinth of the inner ear, rotatory movements of the head result in flow patterns in the three almost orthogonal semicircular canals, which are transduced as head angular velocity. SO(3) also appears in the configuration space of our limbs and in the kinematics of the eye. It is plausible that analysis of experimentally obtained oculomotor movements using the mathematical techniques presented in this report will lead to new means of analysis and explanation of the neurodynamics of multi-dimensional sensorimotor systems. This approach, described in the present report in terms of the symmetries of the dihedral groups, is based on the notion of symmetry studies for structured data, also reviewed in the report.

77

Evolutionary Computational Mechanisms for Embedding Physiological Responses into Genetic Reflexes

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Physiological reflexes are automated responses hardwired in the neural circuitry that provides an animal with appropriate response without needing to go through the learning phase each time. This paper investigates the theoretical mechanisms under which the transfer from the plastic learning circuitry to permanent hardwired circuitry may occur. Biological Hebbian associative learning rule with a reinforcer is used to simulate the self-guided learning neural network in this model to invoke the stretch reflex in equilibrium balancing. To consolidate the temporary learning into permanent circuitry in subsequent generations, the learning model is iterated through multiple generations such that the invariants between generations are consolidated. It can be shown that the stretch reflex circuitry can be solidified based on this invariance between generations.

78

Interacting processes within the Aplysia siphon-withdrawal circuit:

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The duration of the siphon withdrawal reflex (SWR) is reduced during exposure to water turbulence, an environment Aplysia frequently encounter. This behavioral effect is accompanied by two forms of neural plasticity in the SWR circuit: 1) sensory adaptation in the siphon mechanorecptors that transduce turbulence and 2) short-term enhancement (STE) at the inhibitory synapses of the L30 interneurons. To understand how these processes function during environmental change, we added them to an existing model of the SWR circuit (Lieb & Frost, 1997). The model consisted of sensory axons; L29, L34, and L30 interneurons, and a representative LFS motor neuron. Neurons were simulated with a hybrid integrate-and-fire schema that incorporates some realistic currents. Adaptation and STE functions were developed from physiological data. The completed model reproduced 1) the levels and pattern of turbulence-evoked activity throughout the circuit, 2) the rise and decay of L30 STE during turbulence, and 3) the peak and steady-state level of behavioral change during turbulence. The model failed to capture some L30 synaptic dynamics and the steady-state time of environmental regulation. The model can serve as a framework for exploring how the SWR integrates different forms of neural plasticity during behavioral change.

79

Temporally displaced STDP: Synaptic Competition and Stability

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Synaptic modification based on relative timing of pre and post-synaptic action potentials (STDP) has been showed in many regions of the nervous system in recent years. In theoretical studies, STDP has been modeled either as an additive or multiplicative process. In additive STDP rules, a computationally favorable competition occurs among the synapses, but the distribution of synaptic weights has an inherent instability. On the other hand, multiplicative STDP yields a stable weight distribution but the synaptic competition is lost. Here, by means of numerical simulations of an Integrate-and-Fire neuron receiving Poissonian excitatory and inhibitory spike trains, we show that an additive STDP rule with a slightly displaced time window results in both a stable weight distribution and a synaptic competition. The competition between the synapses takes place if a correlation between a subset of synaptic inputs is introduced. This results in a bimodal distribution with the synapses receiving correlated spikes being the winners.

80

The Propagation Mechanism of Spreading Acidification and Depression in the Cerbellar Cortex

Popa, Laurentiu; Chen, Gang; Gao, Wangcai; Reinert, Kenneth; Ebner, Timothy
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Electrical stimulation of the parallel fibers (PFs) can evoke spreading acidification and depression (SAD) in the cerebellar cortex. SAD is characterized by a high speed of propagation (~ 1 mm/s) perpendicular to the PFs orientation and a transient depression of the molecular layer circuitry. Glutamatergic synaptic transmission is involved. However, the mechanism of propagation remains obscure. Diffusion is too slow to account for the speed, and the geometry of propagation cannot be explained by neuronal projections. Newer findings regarding the presence of extra-synaptic, ionotropic glutamate receptors on PFs led us to hypothesize that the propagation of SAD involves glutamate spillover to activate neighboring PFs. A computational model was developed including realistic PF-Purkinje cell synaptic distribution and glutamate diffusion conditions to test this hypothesis. The model reproduced the propagation geometry and speed of SAD. The model also successfully predicted that local injections of glutamate can evoke SAD and the dependence of SAD activation threshold on the frequency of PF stimulation. Microinjections with glutamate confirmed the model hypothesis of direct PFs activation. Also, the glutamate concentration computed by the model is comparable to known experimental values. Supported in part by NSF-DGE9870633 and NIH-P01NS31318.

81

Deterministic Multiplicative Gain Control From Active Dendrites

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Multiplicative gain control is a vital component of many theoretical analyses of neural computations, conferring the ability to scale neuronal firing rate in response to synaptic inputs. Theories of gain control have involved network dynamics or the use of precisely balanced noisy inputs in the single cell. We demonstrate a novel, deterministic method for the control of gain in which a depolarizing afterpotential (DAP) arising from active dendritic spike backpropagation, leads to a multiplicative increase in gain. Reduction of DAP amplitude by dendritic, but not somatic, inhibition reduces the multiplicative effect, allowing for divisive scaling of the firing rate. In contrast, somatic inhibition acts in a subtractive manner, allowing spatially distinct inhibitory inputs to perform distinct computations. The simplicity of this mechanism, and the ubiquity of its elementary components, suggests many cell types have the potential to display a dendritic division of neuronal output.

82

Membrane currents underlying subthreshold oscillations in isolated olfactory bulb mitral cells

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We describe an efficient, network-ready compartmental model of an olfactory bulb mitral cell that exhibits subthreshold oscillations in accordance with the electrophysiological data of Desmaisons, Vincent, and Lledo (1999). Based on the network-optimized mitral cell model of Davison, Feng, and Brown (2000, 2003), with additional current mechanisms, the model exhibits subthreshold oscillations that are appropriately reset with inhibitory inputs and exhibit a frequency that depends on membrane potential. This cellular model is designed for integration into network models of the olfactory bulb for purposes of studying the multiple intrinsic and synaptically-based oscillatory mechanisms that are coordinated within this circuit during olfactory investigation and sensation.

83

Stimulus specificity of cortico-cortical connections optimizes information transmission

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A typical neuron in visual cortex receives most of its inputs from other visual cortical neurons which have similar stimulus selectivity. The structure and spread of the stimulus specificity of cortico-cortical connections have received a lot of attention because of its importance for understanding the mechanisms of generation of orientation tuning. However, little is yet known on whether this structure of inputs allows efficient transmission of sensory information across cortico-cortical synapses. Here we address this issue by using a computational model to quantify the information about the external stimuli that a typical cortical target neuron receives through its cortico-cortical synapses. By quantifying how the information available to the target neuron varies with the spread of the stimulus selectivity of cortico-cortical synapses, we demonstrate that the wiring of these synapses allows efficient transmission of sensory information.

84

Computational and neural mechanisms of task-switching

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Rapidly switching between two tasks that overlap in perceptual and response characteristics is assumed to rely upon the function of prefrontal cortex (PFC). One mechanism that PFC is hypothesized to subserve in such situations is the active maintenance of task sets. However, one potential problem for this account is that these active maintenance processes appear to be non-optimal: studies of human task switching performance demonstrate the presence of "residual switch costs," even when sufficient preparation time is given for a new task. This finding suggests that task-switching performance reflects a complex interplay between the updating of task-set information maintained in PFC and the lasting effects of previous stimuli, which are likely subserved by associative learning (e.g. priming effects). We describe a computational model of task switching in which this interaction is made explicit and linked to the dynamics of PFC. Simulation results indicate that the model provides an account of activity dynamics in PFC observed in human neuroimaging, as well as detailed aspects of behavioral performance phenomena, including the relationship between residual switch costs and the shape of reaction time distributions on switch trials.

85

Altered Sensory Filtering and Coding Properties by Synaptic Dynamics

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Short term synaptic plasticity of both facilitation and depression types are commonly seen and are known to involve a variety of biophysical mechanisms. We present results about the effect of short term synaptic plasticity on coding and filtering of time varying signals. We used the primary afferent fibers of the weakly electric fish, Apteronotus leptorynchus to motivate our computational analysis. These fish is able to detect electric field modulations over a wide range of frequencies (5-250 Hz). These signals are transmitted through the synapse between the afferents and the sensory pyramidal cells in the electrosensory lateral lobe. Our strategy was to constrain our model, based on in vitro data from electric fish. We then qualitatively and quantitatively varied the phenomenological synaptic plasticity rules to determine what dynamics could support the frequency filtering seen in vivo. We present results on coding properties in different parameter regimes, using coherence and mutual information per spike measures. This model predicts quantitatively the possible filtering and coding consequences of the in vitro observed short term synaptic plasticity. We also show the effects of these phenomenological synaptic dynamics on the high frequency transient detection abilities, which is a naturalistic communication signal for these fish.

86

Plasticity in a seizure model

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The interplay between excitatory and inhibitory neurons observed in spontaneous seizures in slices with added 4-aminopyridine manifest themselves in oriens lacunosum moleculare (OLM) cells as periodic occurrences of depolarization block. We model the behavior within using synaptic plasticity. A pyramidal cell and an OLM neuron are modeled using conductance based equations. The OLM to pyramidal cell synapse is a standard (non-dynamic) inhibitory input. The synaptic coupling from the pyramidal cell to the OLM cell is modeled via a dynamic synapse model displaying both facilitation and depression with differing time constants. Initially, facilitation is dominant, and the OLM cell receives increasingly stronger input. Eventually the synaptic input becomes sufficiently large that the sodium current of the OLM cell is no longer able to inactivate, and the cell stops firing though it stays depolarized. The pyramidal cell receives no inhibitory input, resulting in a markedly increased frequency. Eventually, synaptic depression dominates facilitation, and the OLM cell comes out of depolarization block. The cell's channel dynamics dictates that the firing begins to build gradually with low amplitude, slowly building to classical action potentials. That is, the OLM cell undergoes a supercritical Hopf bifurcation at the onset of depolarization block.

87

Multistability in a Two-Cell Inhibitory Network with Short-Term Facilitation

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Here we examine the dynamics of a model network of two Morris-Lecar neurons, reciprocally coupled by inhibitory synapses endowed with short-term facilitation. Each of the two model cells includes a post-inhibitory rebound conductance mimicking the T-type calcium current, enabling each neuron to fire a burst of spikes in response to a hyperpolarizing current pulse. We show that the interplay between the dynamics of the T-current and the dynamics of facilitation leads to a co-existence of several qualitatively different activity states, for the same model parameter values. In the first of these states, one of the cells spikes periodically at low frequency, suppressing the activity of the second cell. The level of facilitation is low in this case, and the T-current is inactivated in both cells. However, if one of the cells is transiently hyperpolarized, the resulting rebound burst leads to a build-up of facilitation, which in turn hyperpolarizes the second cell sufficiently to trigger a second rebound burst, and the network locks into a periodic anti-phase burst mode. Finally, we show that the network supports an additional metastable mixed-mode state lying near a chaotic attractor, where the cells fire irregularly and both the T-current and facilitation are only partially activated.

88

Competitive Dynamics in Cortical Responses to Visual Stimuli

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Neurons in the visual cortex of the macaque monkey exhibit a variety of competitive behaviors, including normalization and oscillation, when presented with multiple visual stimuli. Here we argue that a biophysically plausible cortical circuit with opponent inhibition, spike frequency adaptation and synaptic depression can account for the full range of behaviors. The governing parameter is the strength of inhibition between competing neuronal pools. As the strength of inhibition is increased, the pattern of network behavior shifts from normalization mode to oscillatory mode, with oscillations occurring at progressively lower frequency until, at the extreme, winner-take-all behavior appears.

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Fokker-Planck analyses of feedforward networks using neural noise colored by the refractoriness

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Stochastic differential equations and corresponding Fokker-Planck (FP) equations are frequently used to study stochastic behaviors of neuronal populations. For simplicity, the FP formulations assume that the neurons' firing follow Poissonian statistics. However, neurons exhibit refractoriness and have afterhyperpolarizations so that the autocorrelation of firing times is not a delta function (as would be the case for Poissonian processes) but has a negative component. Here we show that the Poissonian assumption leads to errors in the calculated firing behavior of feedforward networks. To more accurately model the network behavior, we provide a minimal extension of the conventional Fokker-Planck, by accounting for the non-Poissonian nature of neural firings up to a first order approximation. The new equation turns out to provide a substantially more accurate description of the population firing. This new equation may uncover properties that may have been overlooked in previous studies using the conventional stochastic and Fokker-Planck equations.

91

Optimal Electrosensory Prey Detection by Elasmobranchs

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The Dorsal Octavolateral Nucleus (DON) is a cerebellar-like structure that is the first central processing area for the electric sense in elasmobranchs (sharks, skates and rays). Secondary electrosensory neurons, called Ascending Efferent Neurons (AENs), are the principle neurons of the DON. These neurons are acutely sensitive to weak electric field sources in the environment. This paper shows how an AEN can be thought of as representing a hypothesis about the presence of prey in its receptive field, which fires when it has accumulated sufficient evidence that the hypothesis is true. Simulations show that this model, based on a fundamental theoretical assumption, reproduces the behavior of real AENs without any assumptions about neural implementation. The model is testable because it implies that parallel fiber activity affects the gain or sensitivity of AEN responses to afferent input, rather than contributing additively to AEN responses as assumed in previous models of DON.

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Computational Constraints on Cortical Development of Human Face Recognition

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A theory of visual perception of regularities in images lies at the heart of any comprehensive theory of human perceptual organization, and in particular, objects recognition [2][3][5]. It is not, therefore, surprising that in biological and computational vision, models of perception and description of geometric attributes of surfaces in natural scenes have received a great deal of attention [2][6]. In this article, we study the most basic constraints on the neuronal networks of the visual cortex that play the key role in perception of the class of images that exhibit a certain level of structural and statistical regularity. The paper provides an exposition of the geometric methods applied to coarse-grained classification of facial surfaces, starting from low resolution (newborn vision) and proceeding to progressively incorporate more details. We show how invariant representations for regular versus irregular images influence the coarse layout of neuronal networks. Finally, we comment on a collection of research problems for future investigation.

93

A Nonlinear Approach to Uptake of Neurotransmitters and Generalization of the Michaelis-Menten Equat

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An analytical challenge in studying the brain function is the development of a priori, biologically realistic, mathematical representations of the synaptic neurotransmission events. The Michaelis-Menten rate law and its generalizations are among the most useful descriptions of neurotransmitter uptake, yet they are fundamentally based on biologically ill-justified simplifications (e.g., the quasi-steady-state assumption). In the following, we study a dynamical system that is generated by measurements of neurotransmitter release and uptake, and illustrate the theory for the case of altered dopamine kinetics following neurotoxin-induced lesion of the nigrostriatal DA pathways in animals (an model of Parkinson's Disease). We formulate a variant of information-theoretic redundancy-reduction (a.k.a. sparse representation) in the context of dynamical systems theory. The main goal is to capture physiologically significant features of the kinetics from the stream of real-time neurotransmitter level measurements from sensors situated in the brain. Our main contribution is a theory and new algorithms that provide the multiple steps for derivation of the putative model from neuronal measurements. Unlike most other approaches, our framework promotes modeling the dynamics based on direct extraction of statistical features of the (e.g. dopaminergic) system from voltammetric measurements or other neuronal data with high temporal resolution.

94

A Geometric Method to Estimate Oscillatory Dynamics from the Time-Series of Single Electrode Neurona

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Empiric data support the notion that the basal ganglia (BG), cerebral cortex (Ctx), and thalamus (Th) operate as non-linear oscillators at high frequencies. This notion is the foundation of the theory that dynamically coupled, high frequency reentrant non-linear oscillators embedded in large networks are the fundamental mechanisms in the BG-Th-Ctx network and perhaps in many other regions of the brain. These reentrant oscillators form and sustain the dynamos that drive physiological function. Further, the unique characteristics of these oscillators govern the interactions between their oscillations. These characteristics then form local rules that govern the behavior of large, scale-free networks made up of interconnected oscillators. The resulting properties of the large networks then determine function. This paper provides a geometric-probabilistic framework for analysis of neuronal data as a preliminary step towards exploring the above-mentioned theory and formulating new hypotheses regarding neurodynamics of such oscillatory networks.

95

Pattern Recognition in Magnetoencephalography (MEG) Data

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MEG provides an excellent temporal resolution for non-invasive measurement of neuronal activity. MEG data analysis deals with large volumes of data, requiring high-performance computing. In this research, a new set of algorithms provides a model for real-time automatic pattern recognition from MEG data. We compare the predictions of our model with results from recently developed algorithms for analysis of average and single trial MEG data, such as ICA, PCA and SVM by implementing and testing them on MEG data collected with stimuli that are images of faces and houses. To examine whether the activation due to faces was face-specific, we have developed a relative version of the algorithm for MEG feature extraction from blind sets of data in experiments involving both faces and houses, and certain levels of noise added to faces. Our results suggest that a variety of cortical oscillations play important roles in providing a hierarchical dynamic organization in the integrated activities of neuronal circuits. Further, a fairly small number of channels suffice for pattern recognition from MEG signals, but the location of such specific channels varies from subject to subject.

96

The Properties of propagating Ca2+ wave throughout the astrocytes.

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We arrayed the hippocampal astrocytic Ca2+ model in one or two dimension and the properties of propagating Ca2+ wave throughout the astrocytes were studied. When you stimulated an astrocyte with glutamate, [Ca2+]i increases in the cell. The results are as follows. In a pair-pulse experiment, an astrocyte in an array was stimulated with glutamate twice with the different intervals. With shorter intervals, the second response of [Ca2+]i was inhibited. Longer the interval was, less the inhibition was. Thus the astrocytes have the refractory period of [Ca2+]i response. When an astrocyte is stimulated with the different frequencies, the velocity of the wave was different depending on the frequency. When you stimulated the two astrocytes with the different frequency and make the two propagating waves encountered at the middle of the astrocytes at first. The waves interacted each other and at last the wave with higher frequency remained. The results suggest that some astrocytes at the back of the Ca2+ wavefront, are in a refractory period, the two wave collides and they diminish. The wave occurring more frequently can expand its propagating region and finally it can propagate throughout all the astrocytes. The role of this phenomenon is discussed.

97

A new mode beyond the inverted-U region of the dopaminergic modulation of the prefrontal cortex

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It is well known that dopamine (DA) modulates, via D1 receptors, the activity of the dorsolateral prefrontal cortex (DLPFC) for working memory in monkey with an inverted-U shape profile. We studied the circuit dynamics of the DLPFC for wider variation of the cortical extracellular DA concentration than usually considered. The model we used for the analysis and simulation has simple network architecture, consisting of a pyramidal cell unit and an inhibitory interneuron unit that are reciprocally connected. Nevertheless, the network dynamics shows an unpredictable behavior in the hyperdopaminergic region. In this region, the simulation shows an emergence of a new mode of the activity, which is a hyperactive and hyperdopaminergic mode (we term this the ‘H mode’). This mode is along with the hypoactive and hypodopaminergic mode (we term this the ‘L mode’), which is predicted by the inverted-U shape characteristics. These modes depend on the strength of the input. We characterize, in this study, these novel dynamics and argue the relevance of these new modes to stimulant-induced psychotics.

98

Phase Analysis of Single-trial EEGs: Phase Resetting of Alpha and Theta Rhythms

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We perform phase analysis of the single-trial EEGs, especially the alpha (8-13Hz) and theta (4-7Hz) rhythmic components, which comprise the most dominant contribution to the event related potential(ERP). As the amplitude of sustained alpha rhythm decreases with visual stimulus onset, the theta component amplitude gradually increases starting from very weak amplitude. At about 100-200ms after visual stimulus presentation the phase distribution of the ensembles of EEGs deviates from a uniform distribution, the phase resetting, for both two components. Because of the phase resetting, prominent activities corresponding to the P1, N1, and P2 peaks are generated in the ERP pattern. The phase distribution of the alpha component is shown to be strongly correlated with the phase velocity modulation, while that of the theta component is anti-correlated with the phase velocity modulation. The mutual correlation between the alpha and theta components is measured by the coherence of phase difference of the two components. Over broad areas prominent coherency is observed, which implies a strong interaction between two components. From this we conjecture that the strong interaction between the sustained alpha rhythm and the evoked theta rhythm might be one of reasons leading to the phase resetting of the single-trial EEGs.

99

The Impact Of the Distribution of Isoforms on CaMKII Activation

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Calcium/Calmodulin-dependent kinase type II, CaMKII, has four types of isoforms; alpha, beta, gamma and delta with different calmodulin affinities and autophosphorylation rates. In the brain, CaMKII holoenzymes are mainly composed of the alpha and beta isoforms, which are typically present in the same holoenzyme. The ratio alpha:beta differs between parts of the brain. One of the key features of CaMKII is the neighbour-dependent phosphorylation. As the requirement for initiation of phosphorylation is that two neighbouring subunits have bound calmodulin at the same time, different calmodulin affinities are going to influence the rate and probability of phosphorylation. To investigate the impact of distribution of isoforms, both within a single holoenzyme and within a biochemical network important for synaptic plasticity, we model CaMKII activation using different alpha-to-beta isoform ratios and distributions within a holoenzyme. The mathematical model is developed in Matlab, with a deterministic biochemical network coupled to stochastic activation of CaMKII and five different CaMKII activity states for each subunit. This approach allows us to study the neighbour subunit interactions in detail.

100

A functional role of multiple resolution maps in categorization of visual stimuli

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The ability to group visual stimuli into meaningful categories is a fundamental cognitive process. To investigate its neural mechanism, we present a functional model of visual system in which the main function of categorization is generated based on three resolution maps of V1 and V4 areas, broad, middle, and fine resolution maps. The broad resolution map is used to categorize object made using the coarse image on the map. The middle resolution map is used for more detailed categorizations and for focusing attention on a part of the object form. The fine resolution map is used to compare the feedforward image of the parts sent from the lower system with the image predicted by higher visual area. Using the model, we show that the information of the three resolution maps is used to represent a common feature of visual object, required for categorization, in inferior temporal cortex. We also show that working memory of prefrontal cortex binds dynamically the memory of the object parts and increases the sensitivity of the neurons responding to the common feature.

101

Smoothing and thresholding in neuronal spike detection

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CCCN

This paper describes and compares different computationally efficient template and non-template based spike detection techniques intended for multi-electrode array applications. The highlight is the normalised cumulative energy difference (NCED) function technique which makes automatic threshold setting possible. We compare the NCED technique with simple amplitude thresholding and other smoothing techniques. The results show that NCED is superior to all the other methods described. This method is attractive because the detection is essentially independent of spike shape and polarity and it can be implemented in digital hardware for real time processing.

102

Simulation of D1 and D2 receptor effects on working memory.

Ebi, Hiroaki; Yamashita, Koki; Tanaka, Shoji
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In spite of the relative paucity of D2 receptors in the prefrontal cortex (PFC), they would have roles in cognitive functions. A neurophysiological study in monkey recently reported that D2 receptors in the PFC modulate saccade-related activity in an oculomotor delayed-response task. The actions of D2 receptors on individual neurons are inhibitory. However, the neurophysiological result shows that the neuronal response in the response period increases with the activation of D2 receptors. Therefore, how this property emerges from the inhibitory actions of D2 receptors comes into question. We addressed this issue by constructing a firing rate model of the PFC. The neurons consist of two populations of a set of excitatory and inhibitory neurons; one population has mainly D2 receptors, while the other has mainly D1 receptors. Because of the local inhibition, which is suppressed by D2 receptor activation, this model successfully reproduce the dependency of the saccade-related activity on the D2 receptor activation and inactivation by the application of D2 receptor agonist and antagonist. Next, we investigated the overall network properties of the interaction between the D2 effects and the D1 effects. We describe how these receptors contribute to different processes of working memory.

103

Population coding of electrosensory stimulus in receptor network

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To investigate the mechanism of sensory cording of spatiotemporally-varying stimuli, we study the population coding of receptor network in electrosensory system. Weakly electric fish use an amplitude modulations of their self-generated electric organ discharge(EOD AM) to detect distance and size of an object such as prey. We developed a model of fish by which we calculate numerically the spatiotemporal patterns of electric field around the fish body, and made a model of electroreceptor network. We showed in the previous paper that the information of object distance and size were represented by a combination of two characteristic features of EOD AM, the maximum amplitude and the half-maximum width of EOD AM. We show here that the information of object distance and its size are encoded as a dynamic activity of receptor network, leading to a reliable encoding of the two features of EOD AM through the integration of the receptor outputs based on ON center-OFF surrounding connection of the receptive field. We further show that the optimal ranges in the distribution of receptor sensitivity and the size of receptive field enable the receptor network to transmit reliably the information of the two EOD AM features into a target pyramidal neurons.

104

Disambiguation in spatial navigation with theta phase coding

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It is an open question how the hippocampal cognitive map is used for navigation in the environment with multiple destinations. In previous theoretical studies, directional connections in a hippocampal associative memory were considered to give a vector field guiding toward a single goal. It cannot be applicable to navigation with mutiple and/or changing goals. It is necessary to explore how a cognitive map without any specific goal is used in multiple behaviors. Our recent theoretical studies demonstrated that the associative connections in the hippocampus can represent the geometry of the environment, the cognitive map, through the sequence encoding by theta phase precession. A localized activity generated on the map represents not only where I am but also where I go. It also suggested the possibility of phase coding of multiple information in the hippocampal associative network.   Here we elucidated memory-guided locomotor behaviors by extending our hippocampal model. We hypothesized that current sensory input, memory retrieval and motion selection are concurrently coded in phase of every theta cycle and synthetically give a possible motion direction. Computer experiments demonstrated that the hippocampal-locomotor system with theta phase coding can generate context-dependent behavioral information without sustained activities in cortices representing desired destinations.

105

Dendritic Morphology Influences Burst Firing

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Burst firing, i.e., the occurrence of clusters of spikes with short interspike intervals, is a specific and important mode of neuronal signaling. Bursts can improve the signal-to-noise ratio of neuronal responses, while the fine structure of bursts may convey stimulus-related information and can influence short- and long-term synaptic plasticity. Given the importance of bursts, it is crucial to understand how bursts are generated and what factors influence their occurrence and fine structure. Here we study in a systematic way how dendritic morphology influences the cell's propensity for burst firing. We distinguish between the effects of dendritic topology and dendritic length, and use both somatic and dendritic stimulation. We show that both the total length of the dendritic tree and its topology markedly influence the degree of bursting. Both under somatic and dendritic stimulation, burst firing can occur only for a particular range of tree lengths. Interestingly, this range depends on topology: asymmetric trees start and stop bursting at a lower total dendritic length than symmetric trees. This implies that a small change in the topology of a dendritic tree can change the firing pattern from bursting to non-bursting or vice versa.

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Tools for integrating 3D single cell and population neuroanatomy data.

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Having a detailed wiring diagram of brain circuits and substantial numbers of 3D reconstructions of neurons would help immensely with modeling their operation - but surprisingly few of the reconstructions of populations and cells which have been done by neuroanatomy labs are available electronically. And even where they are, the data from different labs and brain regions are hard to compare and combine, with cells floating in free space and not tethered to 3D landmarks. This abstract describes tools we have developed as part of the www.ratbrain.org project, a collaboration between a number of neuroanatomy and neuroinformatics labs led by Dr Zaborsky, Rutgers University to develop software and databases to help improve data collection and sharing of neurolucida reconstructions of cells and populations in different areas of the rat brain.

107

The synchronization properties of fast rhythmic bursting neuron

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The fast rhythmic bursting (FRB) neurons in the neocortex show stimulus-depended synchronized gamma-frequency (20-70 Hz) activity which is thought to play a significant role in higher cognitive functions. The ionic mechanism underlying FRB firing, however, remains controversial. In the previous papers, we have investigated the synchronization properties of FRB neuron using two type models. The one-compartment model which includes calcium activated nonspecific cation channel shows significant transition from asynchronized to synchronized firing when the number of active potentials par burst increase. However the two-compartments model which includes persistent sodium channel show similar transition only when the synaptic connection is located on somatic compartment. Here, we investigated the effects of synaptic location by using the multi-compartment model based on the cation current model. Networks of the model neurons show transition between synchronized and asynchronized activities regardless of the synapse location. In addition, it is found that the network of cation channel model neurons are more rapidly synchronized or desynchronized than the network of persitent sodium channel model.

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A model of CA1 place field formation with CA3 lesioned

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When CA3 is lesioned, the direct entothinal input to CA1 is sufficient to form place fields that are normal in terms of size and position information, and that support spatial recognition memory (Brun et al., 2002; Science, 296(5576):2243-6.). However, when the entorhinal afferents to CA1 are stimulated in slice preparations, almost exclusively inhibitory somatic responses are observed. This paper provides a model of place field formation in the cortical input pathway to CA1that can also account for the inhibitory somatic response to slice stimulation. The entorhinal-CA1 network is modelled as a feedforward network of leaky integrate-and-fire neurons. The entorhinal inputs are modelled on recent recordings of superficial entorhinal cells, including their multiple place fields. CA1 Place fields are formed in the network through a combination of feedforward inhibition and Hebbian learning. It has recently been established that there is a large NMDA component at the entorhinal-CA1 pyramidal cell synapses. When this NMDA component is included in the model, place field formation in not affected. However, the somatic response to synchronous entorhinal activity is largely inhibitory, as the time scale of the EPSP is longer than that of the IPSP.

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Systematic reduction of compartmental neuronal models

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Detailed multicompartmental models can accurately describe the behavior of a single neuron, but are too complex to be used in large scale network models. On the other hand, the abstract neuronal models customarily used in network simulations often lack the distinctive characteristics of individual cell types. To date, most simplified models of specific neurons were developed using entirely ad hoc procedures, which probably result in suboptimal reduced models. Therefore, we attempted to develop a systematic procedure for finding simplified models which provide an optimal approximation of the behavior of complex compartmental model neurons. A 455-compartment active model of a CA1 pyramidal cell served as the target for simplified models. Model selection and optimization proceeded in two stages. First, a clustering algorithm was run on the response patterns of compartments in the original model in order to determine which compartments are functionally similar to each other and could therefore be combined to form the compartments of the reduced model. Next, the passive and active parameters of the resulting simple compartmental model were optimized using one of several nonlinear optimization algorithms. The behavior of the final reduced model closely matched that of the full model, demonstrating the viability of our approach.

110

Optimal spike-timing dependent learning rule that maximizes information transmission

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Maximization of information transmission by a spiking neuron model predicts changes of synaptic connections that depend on timing of pre- and postsynaptic spikes as well as on the postsynaptic membrane potential. Under the assumption of Poisson firing statistics, the synaptic update rule exhibits all the features of the Bienenstock-Cooper-Munro (BCM) rule, in particular regimes of synaptic potentiation and depression separated by a sliding threshold. Moreover, the new learning rule is also applicable to the more realistic case of neuron models with refractoriness and is sensitive to correlations between input spikes, even in the absence of presynaptic rate modulation. The learning rule is found by maximizing the mutual information between presynaptic and postsynaptic spike trains under the constraint that the postsynaptic firing rate stays close to some target firing rate. An interpretation of the synaptic update rule in terms of homeostatic synaptic processes and Spike-Timing Dependent Plasticity is discussed.

111

Adaptive sensory processing for efficient place coding

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This work presents a model of self-localization implemented on a simulated mobile robot with a realistic two-dimensional visual input. Internal representation of space is built incrementally from interactions with the environment and consists of a large number of place-sensitive units with overlapping receptive fields in accordance with experimental data on rodents. In contrast to all existing similar models the neurons in the sensory layer automatically adjust their transfer function using a simple local online algorithm that maximizes information transfer between the sensory input and the ouput firing rate resulting in the localized receptive fields of the downstream layer of place-sensitive units independently of the environment statistics.

112

Test of optimal component placement in Macaque and C. elegans neural networks

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Neural networks, such as ganglia in C. elegans as well as cortical connectivity in the macaque monkey, have been reported to show optimal component placement. This means that changing the position of neurons or cortical areas while keeping connectivity patterns unchanged would lead to an increase of total wiring length. It was suggested that the optimal placement of nodes resulted from evolutionary optimization. Here we investigated wiring organization of neural networks in metric space, analyzing 3D positions of cortical areas in the macaque and 2D projections of positions of individual neurons in C. elegans. Interestingly, at these levels of organization no optimal component placement was found. In contrast, rearrangements of macaque cortical areas or C. elegans rostral ganglia neurons could reduce total wiring length by 30% and 46%, respectively. Total wiring length could be reduced even when macaque cortical area sizes were taken into account when swapping area positions. For C. elegans, a reduction of total wiring length was possible both at the level of local short-distance connectivity as well as at the global level of the complete network. We discuss what alternative design constraints might apply to cortical and neural wiring.

113

Collective Plasticity and Individual Stability in Cultured Neuronal Networks

Raichman, Nadav; Volman, Vladislav; Ben-Jacob, Eshel
Raichman Nadav

The spontaneous activity of cultured neuronal networks is marked by the formation of synchronized bursting events (SBEs). Each neuron in the SBE has its own temporal fingerprint. It has been suggested that the SBEs could serve as a template of memory or for a network computing mechanism. To fit into this perception, the activity has to be persistent over an extended period of time and yet have a diverse repertoire of patterns. Both stipulations have been shown to fulfill: SBEs appear repetitively over hours, and networks can exhibit several sub-groups of SBEs. In this work we set out to examine the source of the differences between the sub-groups of SBEs. The motivation is to search for the hierarchical organizational motifs that afford the cultured networks with both plasticity and reproducibility. We found new motifs of individual stability and of collective regulation: First, each neuron maintains its temporal self-identity in the different types of SBEs. Second, each SBE has its own characteristic phases between the different neurons. These findings shift the attention in network computation from the single neuron to the collective network activity and in particular supports the notion of computation in the space of inter-neuron correlations.

114

Modelling Complex Cells with Generalized Independent Subspace Analysis of Natural Images

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The first two processing stages in primary visual cortex can be modelled as a linear filtering and a pooling stage. The filtering stage, with Gabor type filters which are localized, oriented and bandpass is well modelled by Independent Component Analysis (ICA) of natural images. The pooling can be modelled with Independent Subspace Analysis (ISA), which is an extension to ICA that groups the features into subspaces, inside which dependencies are allowed, and minimizes dependencies between the subspaces. This produces outputs similar to those of complex cells, when features with similar size and location but different phase are pooled together. However, some authors have objected that this is not valid, reasoning that there is no justification for the forced pooling. The present paper discusses how ISA can be extended to learn the optimal subspace size from the data by directly comparing the likelihood of ICA and ISA image models. The new ISA model is a proper two layer model which does not simply square the simple cell outputs but has a flexible nonlinerarity. It makes it possible to learn complex cell properties from natural images without any a priori assumptions on the pooling.

115

Transient Microcircuit Dynamics for the Neocortex

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The neocortex shows a stereotypical connectivity pattern between pyramidal cells and interneurons. In our group we study these feedback circuits in the prefrontal cortex using paired recordings on mutually connected cells. Earlier studies have shown that the direction of short term synaptic plasticity (depressing or facilitating) of excitatory connections from pyramidal cell to interneuron in the somatosensory cortex depends on the interneuron type. Based on the structural similarities between different neocortex areas we expect to find a similar functional differentiation in the prefrontal cortex. To determine prefrontal cortex microcircuit function we will electro-physiologically characterize pyramidal cells and interneurons from mouse prefrontal cortex and model these in the NEURON simulation package. Subsequently, we will electro-physiologically characterize and model the short term plasticity in this microcircuit. Then we will use the model to probe the consequences of variations in short term plasticity, the kinetics of postsynaptic current timescales and connectivity on microcircuit input processing.

116

Modelling the variation in dendritic outgrowth between different neuronal types.

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Dendritic morphology is now recognised as being highly significant for the signal processing of neurons. Different neuronal types have quite distinct dendritic morphologies. To aid our understanding of dendritic functionality, we seek to create a model of neurite outgrowth that can explain the differences in growth between neuronal types. To date, most models of neuronal outgrowth have used statistical techniques which ignore the true underlying biophysical mechanisms. Understanding which biological mechanisms take place during growth has been studied experimentally but few models have been created, and those that have are extremely simple. This paper details a model of neurite growth that incorporates many elements of current neuroscience theory. The result is a relatively complex model of interaction between three chemicals identified as proponents of dendritic growth: tubulin, MAP-2 and calcium. The model is able to produce a range of different dendritic morphologies. The large parameter space makes precise matching of the model to experimental data difficult, so a GA is being developed to automate the parameter searching procedure.

117

Comparison of automated parameter estimation methods for neuronal signaling networks

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This work is a suitability study of the different optimization methods for automated parameter estimation (fitting) in the context of neuronal signaling networks. The protein kinase C pathway, an important neuronal signal transduction pathway, was chosen to be used in the parameter estimation tests. The Gepasi simulation software was used in this study since it provides a relatively good variety of optimization methods. All the methods that are included in Gepasi: (1) deterministic, local methods: Hooke and Jeeves, L-BFGS-B, Levenberg-Marquardt, Nelder and Mead, Praxis, Steepest Descent, and Truncated Newton; (2) stochastic, global methods: Evolutionary Programming, Genetic Algorithm, Multistart, Random Search, and Simulated Annealing, were used in this study. These methods were used to estimate the reaction rate coefficients of the protein kinase C pathway. The results show that stochastic optimization methods perform well. It is also shown that under specific circumstances the computationally more lightweight deterministic methods can perform at least equally well as the stochastic methods. Based on the results of this work, we conclude that the so-called hybrid methods should be developed and implemented in the future.

118

Analyzing the robustness of redundant population codes in sensory and feature extraction systems

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Sensorineural systems often use groups of redundant neurons to represent stimulus information both during transduction and population coding of features. This redundancy makes the system more robust to corruption in the representation. We approximate neural coding as a projection of the stimulus onto a set of vectors, with the result encoded by spike trains. We use the formalism of frame theory to quantify the inherent noise reduction properties of such population codes. Additionally, computing features from the stimulus signal can also be thought of as projecting the coefficients of a sensory representation onto another set of vectors specific to the feature of interest. The conditions under which a combination of different features form a complete representation for the stimulus signal can be found through a recent extension to frame theory called "frames of subspaces". We extend the frame of subspaces theory to quantify the noise reduction properties of a collection of redundant feature spaces.

119

The fidelity of thalamic relay and implications for Parkinson's disease and deep brain stimulation

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The internal segment of the basal ganglia (GPi) inhibits thalamocortical relay (TC) cells, which normally function to relay excitatory signals. In this work, we perform a computational study of model TC cell relay under various GPi input conditions. We consider both computationally generated and experimentally recorded GPi firing patterns as sources of GPi inputs. The former allows for systematic variation of the correlation structure and burstiness of GPi firing, while the latter allows for direct comparison of model responses to data from both parkinsonian and deep brain stimulation (DBS) conditions. Our results show that in the parkinsonian case, characterized by oscillatory, correlated GPi activity, thalamocortical relay is compromised, relative to its normal high fidelity. Further, the high-frequency, highly correlated but regularized GPi firing that occurs under DBS is found here to provide significant restoration of thalamocortical relay fidelity. These findings suggest a possible mechanism by which Parkinson's disease may lead to compromised motor performance and by which DBS may restore motor processing in victims of Parkinson's disease.

120

Estimating the number of postsynaptic NMDA receptors in each spine

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Calcium levels in spines play a significant role in determining the sign and magnitude of synaptic plasticity. The magnitude of calcium transients in spines is highly dependent on the number of postsynaptic NMDA receptors in each spine. We have previously shown how the number of postsynaptic NMDA receptors determines the mean and variance of calcium transients in the postsynaptic density, and how this alters the shape of plasticity curves. However, the number of postsynaptic NMDA receptors in the postsynaptic density is not well known. Several attempts to estimate the number of postsynaptic AMPA receptors and NMDA receptors have relied on physiological techniques; however it is difficult to experimentally verify the validity of these techniques. In this paper we will use simulations and analysis using Markov models of NMDA receptors in order to test the validity of various estimation techniques, and possibly provide improved estimates. We find that the current approach to failure analysis is likely to underestimate the true number of postsynaptic NMDA receptors, due to simplifying approximations about stochastic antagonist binding and large number limits. We also show that nonstationary fluctuation analysis can yield misleading results when complex multi-state processes and measuring techniques are taken into account.

122

Discrete Approximation of Continuous K-Set Population Model

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K-sets, developed by Walter J. Freeman, model the dynamics of the mean field (e.g. average) amplitude of a neural population. They are described by a second order, ordinary differential equation. Hierarchies of K-sets have been used to model the aperiodic, chaotic like dynamics observed in perceptual and cortical areas of the brain. In this paper we develop a discrete simplification of the K-set neurodynamical population model. Our motivation is to develop a discrete model that replicates the dynamics of the K-sets, but in a simpler, more tractable form. The discrete simplification is useful in many areas, including the development of neural controllers for robotic agents, to explore the importance of mesoscopic (e.g. population level) neural dynamics in producing behavior. We present our development of the discrete approximation and then show that the model is capable of replicating the types of chaotic dynamics observed in biological brains.

123

Predicting gap junction location and density in electrically coupled hippocampal oriens interneurons

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Interneuronal networks are important for shaping population field rhythms in the hippocampus. Network connections include electrical synapses known as gap junctions, which allow direct transmission of electrical signals between connected cells. Recently, weak electrical coupling has been found between oriens interneurons in the CA1 region of the hippocampus. Action potentials in one cell produced spikelets in the connected cell of amplitudes ranging from 0.6-1.1 mV and time delays ranging from 3-5 ms. We use a previously developed multi-compartment model of an oriens interneuron to create a two cell homogeneous network connected by a dendritic gap junction. We explore the possible location and strength of the gap junction in order to match the experimentally measured spikelet amplitude and delay. The location of the gap junction is predicted to be between 150-200 microns from the soma with a gap junctional conductance between 500-800 pS.

124

Odour localisation in rats

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In order to successfully navigate using olfactory cues, an animal has to localise the odour source in addition to identifying the odour. Rats, being nocturnal creatures, use olfactory cues for navigation. We have trained rats to localise the source of an odour as coming from either the left or the right. Rats performed at above 80% accuracy in every session with median odour sampling times ranging from 200 to 250ms. When either of the nostrils was stitched shut, the rats were unable to perform at maximum accuracy. Rats performing odour discrimination tasks continued to perform at maximum accuracy with unilateral odour sampling. In order to mimic real world conditions, we have also trained rats to identify the odour, in addition to localising its source. As compared to rats performing only localisation of a single odour, rats performing simultaneous localisation and discrimination required an additional 30 to 50ms of odour sampling time. In summary, our experiments indicate that the olfactory system might localise the source of an odour by comparing stimuli between two nostrils. In addition, olfactory processing is fast and processing time increases with increase in the complexity of the task.

125

The Impact of Subthreshold Action Potential Threshold Adaptation on Neural Coding

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We study the computational consequences of subthreshold adaptation in a new phenomenological neuron model. Based on the analysis of in-vivo intracellular recordings from cat visual cortex we assume a time-dependent action potential threshold, which depends on the mean membrane potential (MP) preceeding an (AP). We show that this adaptation mechanism is genuinely different from previously studied adaptation mechanisms based on adaptation currents driven by AP activity. Using a novel representation of the stochastic neuronal dynamics we explicitly calculate the average firing-rate of a neuronal ensemble in response to arbitrary time-dependent stimuli. We then show that the studied adaptation mechanism is instrumental in reducing the firing rate response to slowly varying stimuli, while the response to transient stimuli is preserved.

126

High threshold K+ current increases gain by offsetting a frequency-dependent increase in low thresho

Fernandez, Fernando; Mehaffey, William; Molineux, Michael L.; Turner, Ray W.
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The kinetics of high threshold K+ currents (IKHT) from the Kv3 subfamily has led to the proposal that these channels offset cumulative Na+ current inactivation and stabilize tonic high frequency firing. All high frequency firing neurons examined to date, however, also express low threshold K+ currents (IKLT) that have slower kinetics and play an important role in setting the subthreshold and filtering properties of the neuron. IKLT has also been shown to dampen excitability and is therefore likely to oppose high frequency firing. In this study we examined the role of IKHT in pyramidal cells of the electrosensory lobe of weakly electric fish, which are characterized by high frequency firing and high levels of IKHT. We examined the mechanisms that allow IKHT to set the gain of the F-I relation by interacting with another low threshold K+ current. We found that IKHT increases the gain of the F-I relation and influences spike waveform almost exclusively in the high frequency firing range. The frequency-dependence arises from IKHT influencing both the IKLT and Na+ currents. IKHT plays a significant role in stabilizing high frequency firing by preventing a steady state accumulation of IKLT that is as important as preventing Na+ current inactivation.

127

Properties and roles of BKCa channels in cultured cerebellar granule neuron:

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We studied the properties and roles of single large-conductance calcium-sensitive potassium channels (BKCa) in cultured rat cerebellar granule neurons. In intact cells these channels had chord conductances of 130 to 200 pS, depending on the age of the cultured cells. The channel always needed depolarization for its activation and had the tendency to switch between normal and flickering modes during prolonged membrane depolarizations. The threshold for channel activation and the active voltage range depended on the time in culture. Voltage-dependent changes in channel open time and opening probabilities were obvious in both cell-attached and inside-out patches, but also depended on the solutions used and the age of the cells. In the simulation studies, using the previously developed compartmental model of the cerebellar granule neuron, the elimination of the BKCa channels decreases the width of action potentials and causes marked reduction in hyperpolarization. The observed alterations in the behavior of the BKCa channel may directly be linked to the complexity of granule neuron excitability during maturation and provide new insight into modeling the developmental changes induced by channels in small central nervous system neurons.

128

How connectivity and delays affect intrinsic dynamical states in cortical networks

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We study the role of connectivity and delays in neuronal interactions in generating intrinsic dynamical states in large networks of spiking neurons. We first explore the interplay of locally modulated connectivity and delay analytically in a reduced firing-rate model. The results from the rate model allow us to predict the spatio-temporal patterns which emerge in simulations of large networks of Hogkin-Huxley-type models. We then investigate the role of long-range, patch-like excitation on the generation of bump states and discuss the implications for orientation selectivity in visual cortex and working memory in prefrontal cortex.

129

MODELLING ECT EFFECTS BY CONNECTIVITY CHANGES IN CORTICAL NEURAL NETWORKS

Gu, Yuqiao; Halnes, Geir; Liljenström, Hans; von Rosen, Dietrich; Wahlund, Björn; Liang, Hualou
Hans Liljenström

We use biomathematical methods to investigate how cortical neurodynamics depend on network connectivity. In particular, we study changes in EEG pattern of depressed patients, following ECT (electroconvulsive therapy). The aim is to gain a better understanding of the neural mechanisms responsible for these changes, which include clear phase shifts in the EEG dynamics. This understanding is intended to provide clinical guidance, predicting ECT dose and response in depressed patients.

130

A method for decoding neurophysiological responses to arbitrary spike trains

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Many physiological responses elicited by neuronal spikes—intracellular calcium transients, synaptic potentials, muscle contractions—are built up of discrete, elementary responses to each spike. However, the spikes are fired in trains of arbitrary temporal complexity, and each elementary response not only sums with previous ones, but can itself be modified by the previous history of the activity. To completely characterize the spike-response transfer function, we wish to derive a small number of functions—the elementary response kernel and additional functions that describe the dependence on previous history—that will predict the response to any arbitrary spike train. We have developed a method to do this. Given the spike times in a train and the observed overall response, we use least-squares minimization to construct an estimated response that best approximates the observed response. In the process we derive three functions that completely define the response. We avoid the need for any initial assumptions about these functions by using techniques of mathematical analysis such as the calculus of variations. Furthermore, although the nonlinear problem is broken into several linear ones that must still be solved iteratively, few iterations are required. Each iteration itself finds the solution in one step, without search.

131

Neural model of decision making

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We have built a neuronal model of decision making implemented by a competition between groups of neurons that model a column in the LIP area of the brain. We use populations of Integrate-and-Fire neurons. Our model has three parts. First, the Direction Detectors. They are made of populations of Integrate and Fire neurons that produce imperfect discrimination between highly mixed stimuli. The second part is a visual column in area LIP that uses the output of the Direction Detectors and receives background noise from the brain. The internal recursive loops generate a competition between subgroups of this column. Specific results of this competition generate an eye movement that expresses the decision. We study how the dynamics of the decision making change as a function of the first and second order statistics of the background noise. By studying its influence on Reaction Time and Error Rate, we show that increasing the background noise reduces the Reaction Time whilst increasing Error Rate. We can compare such a model to the performance of living beings during psychophysical experiments, and assess the plausibility of the hypothesis that decisions are controlled by the statistical signature of the low level background activity of the brain.

132

Fitting experimental data to models that use morphological data from public databases

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Ideally detailed models should make use of morphological and electrophysiological data from the same cell. However, this rarely happens. The assumption of the modeler is that the morphological data used is representative of the particular cell type and that experimental data comes from an equally representative cell. Here we seek to determine how different the parameter value fits to the same experimental data would be with the use of different morphological data. We model morphological data for 4 CA1 pyramidal cells obtained from 3 different databases. Experimental data was obtained from 19 CA1 pyramidal cells. The multiple run fitter in NEURON was used to fit parameters in each of the 4 morphological models to match the experimental data for each of the 19 cells. Excellent fits were obtained in almost all cases, but the fitted parameter values averaged over the 19 cells were very different among the 4 reconstructions. The widely different parameter values obtained with the different morphologies can be explained in part by highly different measurements of diameter, total length, membrane area, and volume among the reconstructions.

133

Sparse rank based representation of visual input

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Early sensory cortices are faced with representing sensory stimuli in a compact form. Generative models have been shown to produce receptive fields similar to what has been experimentally observed, but their output cannot be efficiently transmitted using a spike rate code. Rank based coding maintains only the relative order of code components, allowing for fast transmission using a small number of spikes. We demonstrate, using a network model optimized for producing compact codes, that sparse rank based coding based on a generative model is a strong candidate for stimulus representation in primary visual cortex.

134

A state-space model for neural spike train rate estimation

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Many neurophysiological experiments involve measurement of timing of neural spikes in response to external cues or stimuli. We present a state-space model for estimating the spike rate function. This state-space model takes the form of two equations: an observation equation relating the observations (i.e. spike counts) to the rate function and a state equation defined as a simple random walk. The rate function and state are related through a log link function. The single unknown parameter in the state equation is estimated using the Expectation-Maximization algorithm and results in a maximum likelihood estimate of the spike rate function and its confidence intervals. We apply this technique to spike data from the hippocampus of a monkey performing a location-scene association task. The state-space method is computationally efficient and comparable to the results found with the Bayesian adaptive regression splines technique (BARS). These results suggest a quick practical approach for estimating the spike rate function in neural experiments.

135

Attractor dynamics in a modular network model of the cerebral cortex

Rehn, Martin; Lundqvist, Mikael; Lansner, Anders
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Our top-down view of the cortical associative memory networks has been expressed in an abstract, connectionist type network model. It is based on a probabilistic perspective on learning and memory as statistical inference, and incorporates a Hebbian synaptic learning rule derived from Bayes rule. The units of such networks have been mapped, not to individual neurons but to minicolumn modules and a biophysically realistic model with a minicolumnar structure was previously studied. The abstract framework also naturally suggests a modularity corresponding to a hypercolumnar organization. Here we extend the previously studied biophysically detailed network model with a hypercolumnar structure. We study the neurodynamics and associative memory properties of this extended network model. We describe how the different neuronal types are modeled and their synaptic connections as well as the network architecture and the way the full-scale network has been subsampled in the final model. We demonstrate that the network supports attractor dynamics, pattern completion, and pattern rivalry and further that all of the reported features of local UP states experimentally observed in vitro are reproduced in the model.

136

Correlated ensemble activity increased when operating a brain machine interface

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Correlated activity across an ensemble of neurons may reflect common modulating factors that are represented in the activity. Here we investigate correlated neural activity in the primate brain during target pursuit experiments, in which an external actuator was controlled initially by hand movements and eventually by a brain machine interface (BMI). During the initial phase, the external actuator followed the position of a hand-held pole (pole control) and the recorded activity was used to train a linear model. During the operating phase, the actuator was directly controlled by the brain activity using the trained predictive model (brain control). In both phases, the correlated activity was carried by few principal components. The variance of the correlated activity, however, increased significantly upon switching to brain control and especially when the monkey stopped moving its arm. Despite this increase, the ensemble of neurons with correlated activity remained relatively invariant. Furthermore, the percent variance attributed to the velocity of the actuator dropped upon switching to brain control, suggesting that novel factors became significant in modulating the firing rates during brain control.

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External Activity and the Freedom to Recode

Levy, William; Wu, Xiangbao
University of Virginia

A particular theory of hippocampal function (Levy, 1989) depends on randomization to produce the appropriate cognitive performance on hippocampal-dependent tasks (Shon et al., 2002; Sullivan & Levy, 2004). However, chaotic activity fluctuations, the randomizing effects of quantal synaptic failures, and initial state randomization can, in principle, be overcome by strong external excitation, especially when total activity is regulated. On the other hand, if external activity is too low, the randomization effects will destroy the information that the inputs are transmitting. Here we quantify an optimal level of external excitation in this recurrent, CA3 hippocampal model. The optimal level is between 25 and 50% of the total activity, and it is necessary to reproduce the learned performance of a behavioral experiment.

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Decision functions that can support a hippocampal model

Levy, William; Wu, Xiangbao
University of Virginia

The hippocampus is needed to encode context-dependent declarative memories. Using a predetermined training schedule, we have previously shown that a hippocampal-like computational model reproduces the transverse patterning (TP) and transverse non-patterning (TNP) data of Rudy's lab, two problems that require context for solution. To extend the predictions produced by the model, an extra-hippocampal decision function is added. Such a decision function allows a simulation to choose among the training items. In this report, three decision functions are compared in terms of fitting the published experimental learning curves for the TP problem. All three decision functions reproduce the asymptotic performance of the behavioral experiments. Two of the decision functions reproduce the experimentally observed learning curves.

139

Effects of stimulus transformations on estimated functional properties of visual sensory neurons

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The functional properties of neural sensory cell or small ensembles are often characterized by analyzing response-conditioned stimulus ensembles. Many widely used analytical methods, like Wiener kernels or STRF, rely on simple statistics of those ensembles. They also tend to rely on simple noise models for the residuals of the conditional ensemble. However, in many cases the response-conditioned stimulus set has more complex structure. If not taken explicitly into account, it can bias the estimates of many simple statistics, and render them useless for describing the functionality of a neural sensory system.

140

RBF: Rule-based firing for network simulations

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Full compartment models have the advantage of biological detail, but are computationally intensive and therefore unsuitable for extremely large network simulation. Integrate and fire neurons are fast, but lack critical biological detail. We introduce a rule-based firing (RBF) model neuron that features a variety of biological detail including adaptation, bursting, depolarization blockade, Mg-sensitive NMDA conductance, anode-break depolarization, and others. The model is entirely event-driven, with no integration overhead. RBF model neurons can also be run in hybrid networks with full compartment models that utilize independent integrators. The model is optimized for computational efficiency, using table look-ups in lieu of run-time calculation. It is fully parameterized so as to allow different neuron types to be constructed by varying, for example, presence or absence of rebound bursting. Parameters can be fit to compartmental models or electrophysiological data, which can be built-in as response wave-forms. Future efforts will involve encapsulating the input/output transform from dendritic inputs either by including dendrites as separate models or by use of multi-dimensional look-up tables.

141

Gamma Oscillations in a Minimal CA3 Model

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A minimal model of the CA3 region of the hippocampus demonstrates oscillations in a range of frequencies associated with gamma that is observed in the CA3-CA1 regions of the rat hippocampus. Using a fast-Fourier transform we measured these gamma oscillations across a broad range of conditions, including whether external input is provided or not, whether or not quantal synaptic failures exist, and a range of average firing rates. The center frequency of the gamma oscillations remained fairly robust to a variety of changes, but power depends on activity in a surprising fashion.

142

Analyzing epileptic patients ECoG recordings using the Functional Holography method

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A functional holography (FH) approach is introduced for analyzing the complex activity of ECoG recordings in the space of functional correlations. Although the activity is often recorded from part of the nodes only, the goal is to decipher the activity of the whole network. This is why the analysis is guided by the "whole in every part" nature of a holograms – a small part of a hologram will generate the whole picture but with lower resolution. The analysis is started by constructing the space of functional correlations from the similarities between the activities of the network components by a special collective normalization. Using dimension reduction algorithms (PCA), a connectivity diagram is generated in the 3-dimensional space of the leading eigenvectors of the algorithm. The network components are connected with colored lines that represent the similarities. Temporal information is superimposed by coloring the node's locations according to the temporal ordering of their activities. By this analysis, the existence of hidden manifolds with simple yet characteristic geometrical and topological features in the complex network activity was discovered. These findings could be a consequence of the analysis being consistent with a new holographic principle by which biological networks regulate their complex activity.

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A Self-Organizing Map with Homeostatic Synaptic Scaling

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Various forms of self-organizing maps (SOM) have been proposed as models of cortical development. Typically, Hebbian learning is used to strengthen associations between stimuli and winning neurons. However, the most straight-forward implementations of Hebbian learning lead to unconstrained weight growth. To counteract this problem, typical SOM algorithms use weight normalization: after each learning iteration all the weights are divided by the sum of the magnitude of the weights coming into each neuron. A more plausible mechanism for controlling the Hebbian process has recently emerged. It has been shown that neurons in the cortex actively maintain an average firing rate by scaling their incoming weights. This project explores the use of homeostatic weight scaling within an SOM model. It is shown to be capable of keeping Hebbian learning in check, thus leading to competition between the neurons. Self-organization takes place just as in the weight normalization case. In addition, the relationship between the rate of Hebbian learning and the rate of homeostatic learning is explored.

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Temporal Processing in the Exponential Integrate-and-Fire Model is Nonlinear

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The exponential integrate-and-fire (EIF) model was introduced by Fourcaud-Trocme et al. (2003) as an extension of the standard leaky integrate-and-fire model that more accurately represents voltage dynamics near spike threshold. Using a linear filter analysis based on sinusoidal inputs, the model was shown to act as a low-pass filter with the cutoff frequency weakly dependent on model parameters. Here, the nonlinearity in the EIF model's temporal response to step transients is investigated using square-wave inputs. A linear systems analysis was also performed for these inputs, with gain and phase calculated for each Fourier component of the square-wave. At higher frequencies, these diverged from the gain and phase calculated using sinusoidal inputs, with the gain calculated from square-wave inputs being approximately 20% less near 100 Hz. The time course of onset and offset responses to square-wave inputs were also compared. These have a different time course, with offset responses having a steeper initial slope, but a slower approach to equilibrium. These results demonstrate that nonlinearities contribute significantly to the temporal response of the EIF.

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Spike-frequency adaptation and the collective dynamics of neurons

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We investigate some implications of spike-frequency adaptation (SFA) on the transmission properties of spiking neurons. In noisy regimes amenable to a stochastic description of the dynamics, we first investigate the role of SFA in determining the phase lag of a neuron's response to oscillatory inputs. The zero-lag frequency can be computed in terms of the single neuron's parameters, and the approximate theory is confirmed by simulations in an interesting parameters region. We then analyze the role of SFA at the network level for an excitatory network,using a population density approach; the resulting theory allows to predict collective oscillations previously reported as related to SFA. We then characterize the phase-space of the network and the frontiers of the stability regions: i) for spontaneous activity the interval of synaptic couplings for which the network is stable increases with increasing SFA; ii) for given strength of SFA, the frequency of the calcium-related resonance changes, suggesting an observable correlate of synaptic changes in spontaneous activity; iii) it is also seen that SFA has a significant impact on the ``learning'' scenario encompassing simultaneously stable spontaneous and persistent activity. Increasing SFA the region of coexistence of both states is reduced.

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Evolving functional complexity in neuronal networks' behavior:

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The emergence of the functioning brain or even its basic unit, the neuronal network, from a collection of individual neurons is one of the most profound open questions in science. This question translates to investigation of the self-organization process of the neuronal network emergent from the collective interactions between its component neurons. In the current study we utilize our recently developed in-vitro experimental system, advanced theoretical notions and novel analysis tools for understanding general rules governing the development of networks' complex, collective, behavior from the individual neurons' activity patterns. Dissociated insect ganglion cells were cultured on multi-electrode arrays enabling long term, non-invasive, monitoring of electrical activity from several neurons simultaneously. We show prominent changes in the temporal patterns of neurons' electrical activity throughout the network evolvement process. Sporadic spontaneous firing of the single neurons changed into network activity with extremely complex temporal ordering: neural bursting events organized in rich temporal sequences, and inter-neuronal synchronizations. The described dynamics of neural activity patterns were analyzed to demonstrate evolving non-arbitrary, self-regulated functional complexity together with optimal regularity imparting tolerance and robustness to the network function.

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A realistic model of rod photoreceptor for use in a retina network model

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USP (Universidade de São Paulo)

We are developing a biologically accurate model of the mammalian retina in NEURON and we report here the first results relative to simulations of the rod photoreceptor . The rod model was adapted from a model by Kamiyama et al. (Kamiyama, Y., Ogura, T. and Usui, S., Ionic current model of the vertebrate rod photoreceptor, Vision Res., 36:4059-4068, 1996). It contains the following ionic currents placed at its inner segment: hyperpolarization activated current (Ih), delayed rectifying potassium current (IKv), potassium current (IKx) and calcium current (ICa). The effect of light transduction was simulated by a photocurrent applied directly into the inner segment. Although this approach does not model the biophysical processes involved in phototransduction it produced a hyperpolarizing response in the rod photoreceptor in agreement with experimental results (Baylor, D. A, G. Matthews, and B.J. Nunn. Location and function of voltage-sensitive conductances in retinal rods of the salamander, Ambystoma tigrinum.J. Physiol. 354:203-223, 1984).

149

Influence of spike sorting errors on spike correlation

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Neuroinformtics, Inst. Biology (Neurobiology)

The aim of spike sorting is to reconstruct single unit signals from multi-unit recordings. Failure in the identification of a spike or assignment of a spike to a wrong unit are typical examples of sorting errors (false negative and false positive errors, respectively). Their influence on cross-correlation measures has been addressed and it has been shown that correlations of multi-unit signals lead to incorrect interpretations. Our work focuses on the consequences of sorting errors on the evaluation of spike synchronization by the unitary event analysis. We formulated a model to study the influence of sorting errors on the significance of spike synchronization, and thus were able to study if and how it changes in case of imperfect sorting. Interestingly, we find after sorting a decrease of significance, even in the case in which wrongly assigned spikes are inserted, but no spikes deleted, i.e. the case of false positive errors only. Our results suggest low conservative sorting strategies to limit the influence of sorting errors on spike correlation analysis.

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Synchronization effects using a piecewise linear map-based spiking-bursting neuron mode

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Models of neurons based on iterative maps allows the simulation of big networks of coupled neurons without loss of biophysical properties such as spiking, bursting or tonic bursting and with an affordable computational effort. These models are built over a phenomenological basis and are mainly implemented by the use of iterative two--dimensional maps that can present similar neuro--computational properties that the usual differential models. A piecewise linear two dimensional map with one fast and one slow coupled variables is used to model spiking--bursting neural behavior. This map shows oscillations similar to other phenomenological models based on maps that require a higher computational effort. The dynamics of coupled neurons is studied for different coupling strengths.

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Parametric analysis of cerebellar LTD in eyelid conditioning

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Experimental data regarding eyelid conditioning converge on the important role played by the cerebellum in processing the conditioned and unconditioned stimuli and in sending the motor command for producing the conditioned response (CR). The temporal properties of eyelid conditioning can offer insight about the temporal dynamics of the plasticity induced in the cerebellum during learning. In this paper, we use a detailed model of the cerebellum to predict the eligibility delay and the duration of LTD at the granule to purkinje synapses, assumed to be involved in the acquisition of the conditioned response. The results indicate that there is an abrupt change in conditioning for eligibility delays varying between 100 and 200 ms. Moreover, the results predict that an eligibility delay of 125ms and a LTD duration of 100 ms show no conditioning for a 50 ms interstimulus interval. Although the existence of the eligibility delay has not been shown experimentally, this prediction is in agreement with suggestions provided by studies related to adaptation in the vestibular-ocular reflex.

152

A Biophysical Model of Frequency-Sweep Selectivity in Primary Auditory Cortex

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Physics and Astronomy

In vivo recordings indicate that certain cells in primary auditory cortex respond preferably to frequency sweeps of a certain rate and direction. In a model by Fishbach et al (2003) direction selective cells were constructed from thalamic inputs that were not direction selective themselves. In this model, thalamic inputs to the auditory cortex were modelled as time varying firing rates without explicit spikes. Simulations of this model accounted for a number of previously reported experimental measurements. Here we investigate what are the biophysical constraints for the emergence of direction selectivity using a model comprised of spiking thalamic neurons. In addition, we study the effects of recurrent cortical circuitry on direction selectivity. It is found that directional selectivity can still be achieved for a broad range of parameter values using an architecture similar to that proposed previously for visual cortex models. Furthermore, evidence is presented that recurrent connections could improve the directional selectivity of neurons in AI.

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Recurrent linear threshold network integrates sequence selectivity and Multiplicative Gain Modulatio

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Selectivity for temporal sequences is important for several visual functions. Sequence or direction selectivity can be explained either by feed-forward mechanisms that combine signals with different temporal delays, or by recurrent neural networks with asymmetric lateral connections. A second important computational function is multiplicative gain modulation, which is important for the implementation of coordinate transformations (using gain fields) and attentional control (e.g. areas V4 and MT) in the visual cortex. Gain modulation can be accomplished by multiplicative mechanisms that are inherent to individual neurons, like shunting inhibition, or by recurrent neural networks without multiplicative neural elements(Salinas & Abbott, 1996). By quantitative simulations we show that a simple recurrent linear threshold network with asymmetric connections is highly speed-selective, and accomplishes almost perfect multiplicative gain modulation controlled by an additive biasing input. We present also a mathematical solution of the nonlinear network dynamics that proves the existence of a stimulus-locked traveling pulse solution, which is stable within a limited regime of stimulus speeds that depends only weakly on the biasing input. The amplitude of this solution changes almost linearly with the biasing input, realizing an approximation of multiplicative gain control.

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ICA forms place cells, Hebbian learning forms replaying recurrent collaterals in robotic simulations

Takacs, Balint; Andras, Lorincz
Eotvos Lorand University

It has been argued that the processing of sensory information in the loop of the hippocampus and the entorhinal cortex involves independent component analysis (ICA) on temporally concatenated inputs. We demonstrate that ICA applied to a realistic Khepera robot simulation can form receptive fields found in vivo in rat experiments. Novel and simple Hebbian form emerges for CA3 collaterals, which learn to predict. We have found that this `add-on' learning spares receptive field properties. We conjecture that the entorhinal afferents of the CA1 subfield learn to denoise and also provide supervisory information for the Schaffer collaterals, thus keeping the CA1 representation steady during the slower formation of the bottom-up ICA and the predictive collateral connection system of the CA3 subfield. This model accounts for recent findings on the CA3 and CA1 place cells.

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Towards understanding synchrony coding

Itskov, Vladimir
Center for Molecular and Behavioral Neuroscie

In this talk we shall report on a new mathematical framework and computational algorithm for describing population activity and establishing patterns of synchrony in the neocortex. By synchrony we mean correlations in neuronal firing of small groups of neurons *beyond* what can be attributed to the structure of the stimulus or global cortical oscillations. These techniques are currently been tuned for experiments designed to explore synchrony coding in the auditory cortex.

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Cycle-to-cycle variability as an optimal behavioral strategy

Brezina, Vladimir; Proekt, Alex; Weiss, Klaudiusz
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Aplysia consummatory feeding behavior has traditionally been thought of as stereotyped. We have found, however, that essentially all aspects of this cyclical, rhythmic behavior—cycling of the feeding central pattern generator (CPG), motor neuron firing, muscle contractions, and finally the behavioral movements themselves—are highly variable from cycle to cycle. In some cycles, when the variability causes a mismatch between the animal's movements and the requirements of the feeding task in that cycle, the variability clearly makes the behavior unsuccessful. We propose that the variability is nevertheless permitted to exist, and may even be actively generated by the CPG, because it serves a higher-order functional purpose. When the animal is faced with a new and only imperfectly known feeding task in each cycle, the variability implements a trial-and-error search through the space of possible feeding movements, a strategy that clearly will not be successful in every individual cycle, but on average, over many cycles, may in fact be the animal's optimal strategy in an uncertain and changing feeding environment.

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Role of action potential shape and parameter constraints in optimization of compartment models

Weaver, Christina; Wearne, Susan
Center for Computational Biology

Compartmental models typically have large numbers of free parameters, only loosely constrained within physiologically plausible ranges, which are difficult to optimize manually. Accordingly, the use of automated parameter search methods has become increasingly common. An important step in parameter fitting is selecting an objective function that accurately represents key differences between the model and the experimental data. Action potential (AP) shape has been shown to be a critical determinant of neuronal firing dynamics. We describe construction of an objective function that incorporates both time-aligned AP shape error and errors in the statistics of firing rate and regularity. Furthermore, applying physiological boundary constraints requires an automated parameter search method which operates intelligently within them. We implement a variant of simplex-based simulated annealing, a robust stochastic optimization method, and introduce a recentering algorithm to handle infeasible points outside the boundary constraints. NEURON's Multiple Run Fitter is used to evaluate the objective function and to implement the optimization method. We show how our choice of objective function allows the model to capture essential features of neuronal firing patterns, and why our boundary management technique is superior to previous approaches.

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The Mixture Modeling Theory of Hippocampal Place Cell Remapping

Fuhs, Mark; Touretzky, David
Carnegie Mellon University

Place cells throughout the rat hippocampus show location-specific firing fields that topologically reorganize, or "remap", when the rat moves to a different environment. In some cases, however, remapping occurs only after extensive exposure to one or both environments, indicating that it is experience-dependent and not purely sensory driven. We propose that this construction of a multi-map representation of the world can be understood as a mixture modeling process, where the degree of remapping between environments reflects the perceived statistical likelihood that the features observed are derived from distinct sources. We simulated the construction of mixture models for several different training paradigms where the environments differed (square vs. circular arenas, or different room locations, or different rooms), or the animals had different amounts of pretraining. We found that the observed time course of remapping could be explained by the degree of similarity between environments and the amount of experience the rat had in each one. Our computationally explicit mixture modeling theory can also be used to predict the time course of remapping in as-yet untested training paradigms.

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Receptive fields of simple cells from a taxonomic study of natural images and suppression of scale

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Much effort has been carried out to propose models of the early visual pathway based on the statistical analysis of natural images. These conventional frameworks lead to predictions on the RFs of simple cells which do not fit well their observed properties [1]. In order to overcome these difficulties, we have been carrying a research program to derive robust coding principles from the statistics of natural images [2,3]. Two principles emerging from our study of image statistics are: first, there exists scale redundancy and this can be eliminated from the code; secondly, images are constructed by a combination (partly linear and partly non-linear) of some simple patterns of contrast (edges, bars, and composites of these two). These two principles can be used to derive filters which explain observed properties of the RFs of simple cells and which compare quite well with the results reported by Ringach [3] and previous experimental work.
[1] D Ringach, J Neurophysiol 88: 455-463, 2002] [2] A Turiel, G Mato, N Parga and J-P Nadal, NIPS vol 10: 836-842, 1997 [3] A Turiel, JM Delgado and N Parga, Neurocomputing 58-60: 915-921, 2004

162

Dendritic cable with active spines: a modeling study in the spike-diffuse-spike framework

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Heriot-Watt University

The spike-diffuse-spike (SDS) model describes a passive dendritic tree with active dendritic spines. Spine head dynamics is modeled with a simple integrate-and-fire process, whilst communication between spines is mediated by the cable equation. Here we develop a computational framework that allows the study of multiple spiking events in a network of such spines embedded on a simple one-dimensional cable. In the first instance this system is shown to support saltatory waves with the same qualitative features as those observed in a model with Hodgkin-Huxley kinetics in the spine head. Moreover, there is excellent agreement with the analytically calculated speed for a solitary saltatory pulse. Upon driving the system with time-varying external input we find that the distribution of spines can play a crucial role in determining spatio-temporal filtering properties. In particular, the SDS model in response to periodic pulse train shows a positive correlation between spine density and low-pass temporal filtering that is consistent with the experimental results of Rose and Fortune (JEB, (1999), Vol. 202). Finally we test the robustness of observed wave properties to natural sources of noise that arise both in the cable and the spine-head, and highlight the possibility of purely noise induced waves and coherent oscillations.

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Role of channel density variability in controlling neuronal dynamics:

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The intrinsic electrophysiological properties of neurons show a high degree of variability, even among neurons of the same type that have similar dynamical behaviors. This variability is due in part to differences in ion channel densities and distributions, indicating that members of the same neuronal population arrive at different ways of achieving the same overall dynamical behavior. However, the detailed biophysical differences that underlie within-population variability, and the broader significance of this variability to the function of neural circuits, are poorly understood. In the present study, we combined slice electrophysiology with computer modeling to study the sources and consequences of ion channel variability in neurons from the rat globus pallidus (GP). Beginning from a hand-tuned, 585 compartment GP neuron model, we generated a database containing 19,683 different variations of the original model's ion channel density parameters, and compared the models in this database to brain slice recordings from 80 GP neurons. We found that the simulation database represented a broad range of physiological behaviors, that multiple solutions existed for any given physiological behavior, and that individual neurons from the slice recordings matched different models from the database, illustrating that there is no single 'best' model of a neuron type.

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The role of correlations in coincidence detection and information transmission in visual cortex

Schultz, Simon; Montani, Fernando; Kohn, Adam
Imperial College London

It has been known for many years that nearby cortical neurons tend to fire spikes that are correlated in time. This has lead some to propose that neurons may act as coincidence detectors, in addition to or rather than their well-studied role as spike integrators. We recorded from pairs of single neurons in the primary visual cortex of the anaesthetised macaque monkey. Procedures were taken to minimise pain and discomfort in accordance with local and US national guidelines. We then used information theory to evaluate the effect of correlations between V1 spike trains on the information that could be extracted from them by downstream neurons employing integration or coincidence detection strategies. Preliminary results (6 pairs of cells) indicate that correlations can influence coincidence detectors either synergistically or redundantly, but that their effect on a multinomial code (integrating spikes but preserving neuron identity) is shifted in comparison towards independence or redundancy. Pooling spikes across cells leads to a drop in information - downstream decoders benefit substantially from knowledge of cell identity. Our results suggest that while correlations may not have much effect on information transmission in the cortex, they may play a significant role in information processing tasks involving coincidence detection.

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Reconstructing subpopulation connectivity within neuronal networks

Nykamp, Duane
University of Minnesota

To understand the function of neuronal networks, one would like to characterize the underlying connectivity patterns. Since one can simultaneously measure only a tiny fraction of neurons, the vast numbers of unmeasured neurons confounds attempts to determine the subnetwork connecting the measured neurons. I present a mathematical framework for analyzing connections among measured neurons. Through analyzing a simple probabilistic model of neural response, I demonstrate how to account for the presence of unmeasured neurons. One can determine connectivity patterns in terms of certain neural subpopulations, which are groups of neurons with a similar response to a stimulus.

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Attentional Modulation of Firing Rate and Synchrony in a Cortical Model for V2 and V4

Buia, Calin; Tiesinga, Paul
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Selective attention can modulate the response of a cortical neuron to a visual stimulus by increasing its firing rate or by increasing the coherence of its spikes with the local field potential. These effects were reproduced in a model neuron under the hypothesis that selective attention increases the synchrony of the inhibitory component of the input. Here we further investigate this hypothesis in a V4 network of pyramidal cells that receive feed-forward input from a V2 cortical column consisting of fast spiking inhibitory interneurons and regular spiking pyramidal neurons. The V2 column received a driving current representing attentional modulation. The pyramidal cells in the V4 network were driven excitatory inputs from the V2 column. We could dynamically switch the state of the V2 column from asynchronous to synchronous by short depolarizing or hyperpolarizing pulses in the driving current. The degree of synchrony and the firing rate of the V2 pyramidal neurons modulated the gain and the sensitivity of the V4 neuron's firing rate in response to stimulation. The results show that a canonical circuit of excitatory and inhibitory neurons can be used as a fast and powerful modulator of cortical information transmission.

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Simulating Place Field Dynamics Using Spike Timing Dependent Plasticity.

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Firing rates of cells in the rat hippocampus correlate with the location of the animal; the response region of such cells is called the place field. Place fields can become asymmetric (skewed) and the center of mass (COM) of the place fields shifts backwards with experience. Mehta et al. (2000) presented a feed-forward, rate-based model, motivated by spike timing dependent plasticity (STDP), that simulated the backward COM shift and the development of negative skewness of place fields. Here we simulate this place field plasticity, using spiking neurons and a spike-timing based learning rule, in order to investigate potential mechanisms and conditions under which place fields become negatively skewed, and to determine whether the mechanisms employed by Mehta et al. (2000) would generalize to simulations with stochastic, spiking neurons. We show that it is possible to obtain a COM shift as well as negative skewness of the weight vectors of place cells in these simulations. However, skewness and COM shift of place fields may not necessarily reflect the underlying plasticity changes between place cells and their inputs. Furthermore, we show that the variability of the COM shifts is related to the width of the inputs to the place cell.

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An Information-Theoretic Approach to Human Reach Path Analysis

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Human movement trajectories can exhibit subtle but important variations in path and timing in response to changes in task demands and initial states. Finding these variations automatically is challenging due to the high dimensionality of movement data. In this paper, we introduce an Information-theoretic method that can automatically extract the most important changes in movement kinematics that occur in response to changes in task demands. In particular, we analyze the relationship between visual uncertainty and reach path trajectory to the location of a target object using the Information Bottleneck method (IB). The virtues of the approach lie in the fact that it is automatic and data-driven and suitable for high-dimensional data. The method constructs a new variable T that encodes soft partitions of trajectories maximally informative about a task-relevant variable Y. The results show that reach behavior systemically becomes more conservative in the presence of target uncertainty, exhibiting a complex set of changes in reach trajectories that are difficult to relate to traditional summary measures.

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Model of auditory prediction in the dorsal cochlear nucleus via spike-timing dependent plasticity

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This study investigates the learning dynamics of cartwheel cells in the dorsal cochlear nucleus (DCN). Cartwheel cells are excited by parallel fibers that carry information from various sources, such as auditory stimuli, proprioception and recurrent inputs from higher-order auditory processing. Cartwheel cells are shown to respond well to auditory stimuli in the mouse DCN. A model of the DCN is presented that predicts how the auditory response of cartwheel cells adapts to predictable patterns of auditory stimuli. The spike-timing dependent learning rule at the synapse from parallel fibers onto cartwheel is shown to explain predictive learning in the response of cartwheel cells to auditory stimuli.

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Optimal Contour Integration: When Additive Algorithms Fail

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Contour integration is a fundamental computation during the segmentation of visual scenes into their distinct parts. Psychophysical evidence shows that contour integration in the brain is performed with a high degree of precision in widely differing situations. Therefore, the brain requires a reliable algorithm for extracting contours from a stimulus. While from a statistical point of view, contour integration is optimal for one specific problem when using a multiplicative algorithm, realistic neural networks employ additive operations to compute the saliency of a contour in a variety of stimuli. In this paper, we discuss in detail the potential flaws and drawbacks of both approaches. In particular, it turns out that additive models require a subtle balance of lateral and afferent input, which depends on the stimulus configuration, for a sound contour detection. But even if this balance is given, contour detection is still susceptible to neuronal noise. We therefore conclude that it is important to test experimentally whether contour integration in the brain relies on multiplicative, rather than on additive algorithms.

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Hippocampal sharp wave events increase during behavior with experience within session

Redish, A David; Jackson, Jadin C.; Johnson, Adam
Department of Neuroscience

Hippocampal local field potentials are punctuated by transient (200 ms) sharp wave events, which can be identified by 200 Hz ripples in recordings taken from the pyramidal layer. Sharp waves have been well-studied in slow-wave sleep after behavior. However, sharp waves also occur during periods of rest and immobility. Current theories suggest that the sharp wave arises from a noise-driven cascade across potentiated synapses. These theories predict that sharp waves should increase with experience within a session. We report that, on two different tasks (a linear track and a Multiple-T maze), time spent in sharp waves increases with experience on the tracks.

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Latent Learning requires multiple value functions within TDRL

Redish, A David; Johnson, Adam; Jensen, Steve; Jackson, Jadin C.
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In latent learning, rewards are shown to an animal without motivation, and when motivation is subsequently provided, the animal makes the appropriate decision to accomodate that motivation. In the classic example, rats are faced with a Y maze, with food available on one arm, and water on the other. Animals who are neither hungry nor thirsty are allowed to explore the environment. When placed back in the maze, hungry animals immediately run to the food, and thirsty animals to the water. In order to select an action, the set of possible decisions must be projected onto a single currency. In most temporal-difference reinforcement learning models, this question is side-stepped by having all rewards be members of the set of real numbers R. However, the rewards in the latent learning experiment cannot be directly compared until memory retrieval. This implies that the value function stored within memory cannot be a single unidimensional currency and must be stored in a diverse manner. In this paper, we present a simple TDRL model that includes separately motivated value functions and is capable of handling latent learning.

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Hippocampal replay contributes to within session learning in a TDRL model

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Department of Neuroscience

Temporal difference reinforcement learning (TDRL) algorithms, hypothesized to partially explain basal ganglia functionality, learn more slowly than real animals. Modified TDRL algorithms (e.g. the Dyna-Q family) learn faster than standard TDRL by practicing experienced sequences offline. We suggest that the replay phenomenon, in which ensembles of hippocampal neurons replay previously experienced firing sequences during subsequent rest and sleep, may provide practice sequences to improve the speed of TDRL learning, even within a single session. We test the plausibility of this hypothesis in a computational model of a multiple-T choice task. In experimental studies, rats show two learning rates on this task: a fast decrease in errors and a slow development of a stereotyped path. Adding developing replay to the model accelerates learning the correct path, but slows down the stereotyping of that path. These models provide testable predictions relating the effects of hippocampal inactivation as well as hippocampal replay on this task: (1) Hippocampal replay should develop with experience, (2) hippocampal replay should develop with the same time course as place field expansion and (3) inactivation of hippocampus should slow the decrease in errors and accelerate development of a stereotyped path.

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Bistabilility analysis of the NMDA receptor

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We analyzed bistability properties in a single NMDA synapse. We find there exists a parameter regime relating NMDA current, GABA current and membrane potential in which the synapse exhibits bistability. Within this regime, small changes in the membrane voltage such as might occur in the dendritic tree following a backpropagating action potential, give rise to an enhanced voltage at the synapse. Such a mechanism might be important in dendritic processing and plasticity.

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Effects of correlated input and electrical coupling on synchrony in fast-spiking cell networks

Schneider, Abraham; Lewis, Tim; Rinzel, John
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In layer IV of the somatosensory cortex both fast-spiking and regular-spiking cells receive direct thalamocortical input. The FS cells provide feed-forward inhibition onto the regular-spiking cells and thus participate in the initial cortical information processing. Synchronous activity between the FS cells has been observed within single cortical barrels and can affect the efficacy of the inhibition. Two factors that contribute to this synchrony are TC convergence/divergence onto FS cells and electrical coupling between the FS cells. We study the influences of these factors in models of the electrically coupled FS cell network. A synergistic effect between these two features is observed in a 400 FS cell network model. This synergistic effect is also seen in a reduced two-FS-cell model. We use the two-cell model to examine the underlying mechanisms that cause the observed super-linearity. By taking a spike-triggered average on a cell and examining which currents cause the cell to fire, we find that electrical coupling only facilitates spiking when there is already sufficient correlation due to the TC convergence/divergence.

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Place Field Dissociation and Multiple Maps in Hippocampus

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The attractor model of hippocampal place cells explains the robustness of firing fields when visual cues are removed. But this account conflicts with another set of observations. Discordant motion of local vs. distal cues in a double cue rotation experiment causes place fields to dissociate. Some fields rotate with the local cues, some with the distal, some show split fields, and some remap (Tanila et al., 1997; Knierim, 2002). The simplest explanation for the dissociation, that the attractor is weak and individual cells are tuned to only a few visual landmarks each, is contradicted by the robustness of firing fields after cue deletion. We propose an architecture with many overlapped "maplets" that are essentially independent. Place cells receive input from a broad array of landmarks, but when cues are rotated into a discordant configuration, strong attractor dynamics amplifies any disparity in local vs. distal cue input, causing each maplet to choose one set of cues to follow. When two overlaid maplets make different choices, their place fields dissociate, and if a maplet switches repeatedly from local to distal cues, split place fields will be observed. The model also accounts for the "barrier cells" observed by Rivard et al. (2004).

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Neural Model of the Transformation from Allo-centric to Ego-centric Representation of Motions

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In this work, we aim at exploring the mechanisms underlying simple forms of imitation such as mimicry. Specifically, we focus on the problem of how to map an allocentric representation of motions performed by others onto an egocentric representation of self-generated motions. To this end, we propose here a biologically plausible model of how such transformation might be performed by the brain, and more specifically in the superior temporal sulcus (STS). Finally, our model was applied on a mini-humanoid robot that is then capable of mimicking hand gestures performed by a human demonstrator.

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Short-term Synaptic Plasticity and the Detection of Weak Signals in Correlated Spike Trains

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We study a particular, hypothetical, form of fast synaptic plasticity as part of a model of early electrosensory signal detection. The proposed form of synaptic plasticity would enable a sensory neuron to actively exploit inter-spike-interval (ISI) correlations in its pre-synaptic afferent input, thus enhancing its sensitivity to weak stimuli. Our model captures fundamental aspects of the feedforward pathway at the first stage of electrosensory processing, the electrosensory lateral line lobe (ELL), which receives electrosensory afferent input. To assess the theoretical performance limits of an individual ELL-neuron (not considering feedback) for different input spike train statistics, we apply the framework of statistical detection theory and derive sequential likelihood ratio detector models for afferents with Poisson statistics as well as with realistic, negatively correlated ISIs. The proposed correlation-sensitive detector is motivated by an analysis of the afferent spike generator model and relies heavily on the properties of the dynamical system transforming its adaptive firing threshold. A stability analysis in terms of the Liapunov exponent reveals that threshold sequences form stable orbits, due to the particular form of refractoriness in our afferent model. Therefore, dynamic synaptic weights can synchronize with the threshold fluctuations and accurately track the firing probability, thus improving detection performance.

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MODELING THE DYNAMIC EVOLUTION OF NEURONAL INTERACTIONS DURING SEIZURES

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Recent experiments have demonstrated that 4-aminopyridine-induced seizures in the rat hippocampus take the form of interleaved activity between inhibitory and excitatory neurons. In an attempt to explore the mechanisms responsible for these spontaneously generated seizures we have constructed simple conductance based network models that include extracellular potassium dynamics. Stimulation by both extracellular potassium and synaptic inputs can qualitatively reproduce experimental findings. The potassium dynamics also tend to destabilize asynchronous network states, producing large fluctuation in excitatory activity, and thus making the networks more susceptible to runaway excitation and seizures. We will discuss further experiments and additional modeling that will help determine which of these mechanisms are responsible for the observed phenomena in vitro.

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Background gamma rhythmicity and attention in cortical local circuits

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We describe a simple computational model, based on generic features of cortical local circuits, which links cholinergic neuromodulation, gamma rhythmicity, and attentional selection. The model posits that cholinergic modulation, by reducing adaptation currents in principal cells, induces a transition from asynchronous spontaneous activity to a "background" gamma rhythm (resembling the persistent gamma rhythms evoked in vitro by cholinergic agonists) in which individual principal cells participate infrequently and irregularly. We suggest that such rhythms accompany states of preparatory attention or vigilance, and report simulations demonstrating that they can amplify stimulus-specific input and enhance stimulus competition within a local circuit.

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Locomotive Network Modeling based on Identified Neurons in Zebrafish

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CIRCS/Physics

The larval zebrafish (Danio rerio) generates a discrete set of movements, each with a distinctive bending pattern, like the J-turn, which is uniquely associated with the visual tracking of prey (Borla and O'Malley, 2002, 2005). While various hypotheses at the neuronal and network levels have been proposed to account for continuous undulatory swimming, there are currently no explanations of how the diverse locomotive patterns exhibited by larval zebrafish are generated. Our approach has been to combine anatomical, physiological and behavioral data with neuronal models, which has produced a more detailed and biologically realistic model of the larval locomotor control system. Our initial modeling efforts (Hill et al., 2004, 2005) showed that we could simulate major elements of the larva's locomotor repertoire with a relatively simple segmental model, in which 30 segments were connected in series to represent the larval spinal cord. We report here on several ways in which we have extended the initial model so as to: (1) incorporate new information about spinal interneuron anatomy and neurotransmitter phenotype, (2) integrate features pertaining to intersegmental coordination demands that are unique to the larval zebrafish locomotive repertoire, and (3) incorporate anatomically more realistic descending controls.

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Dynamic Regulation of Spike-timing Dependent Plasticity in Electrosensory Processing

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This study investigates the control of spike-timing dependent plasticity (STDP) by regulation of the dendritic spike threshold of the postsynaptic neuron. The control of synaptic plasticity may be implemented in the electrosensory system of mormyrid electric fish by feedback control. Dendritic spikes constitute the timing signal of the STDP learning rule that controls the output on the initial electrosensory processing structure, and the threshold of these spikes appears to be regulated by recurrent inputs from an external nucleus. This recurrent input may help to maintain a fixed output range. However, the control dynamics must be shown to be stable, and the conditions for stability would constrain potential models of synaptic regulation. The stability conditions for the control of STDP are investigated using control dynamical theory.

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Predicting salient features of the environment from central nervous system dynamics

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The nervous system cannot generate adaptive behavior unilaterally, but only as part of a larger, coupled dynamical system encompassing also the environment. If so, we may expect the dynamics that we observe in behavior-generating circuits within the nervous system to be adapted to the structure of the environment in which the animal has evolved. Indeed the dynamics of the nervous system may be understood as an internal model of the environment, and it should be possible, given the observed dynamics of the nervous system, to predict the features of the environment to which they are adapted. Here we describe experiments in the feeding system of Aplysia and a model of the results with which we are attempting such a prediction. We focus on the slow dynamics that govern the motor output of the feeding CPG. Extrapolating from previous history, these dynamics predict what will be the next appropriate action. To be adaptive, these predictions have to reflect the salient properties of the environment. To discover which properties these are, we run a model embodying the dynamics of the feeding CPG in various simulated environments to find the environmental features that maximize the performance of the model.

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Technique for eliminating nonessential components in the refinement of a model of dopamine neurons

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The relevance of calcium-mediated inactivation of L- and T-type currents in a mathematical model of the midbrain dopamine neuron tested for two firing patterns was exhibited by these cells in vitro. We found that calcium-mediated inactivation of L- and T-type currents could be removed without causing significant changes in both the ``slow oscillatory potential'' (SOP) and the apamin-induced square-wave patterns.

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TEMPORAL DYNAMICS OF SIGNAL TRANSMISSION THROUGH A POPULATION OF NOISY LIF NEURONS

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The synaptic input to a neuron is often thought of as a mean current and a constant background noise component such as white noise. The impact of the noise component on neuronal responses, in particular its effect on the temporal dynamics of neuronal firing rates in response to a time-varying mean current, has been well studied. Recent work has suggested that the noise component may also comprise a separate information channel to neurons. In particular, Silberberg et al (2004) have proposed that rapidly varying signals are more faithfully transmitted when encoded in the noise rather than when encoded in the mean. Here we use analytical and computational methods to continue this examination of synaptic noise as a possible information conduit to a neuron. We compare the effects of synaptic dynamics on how faithfully the mean current and the noise channel can transmit a rapidly varying signal to a neuron. Through analysis of these effects, it may be possible to predict synaptic time constants in vivo based on the measured temporal dynamics of neuronal responses.

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Reward-biased probabilistic decision making: mean field predictions and spiking simulations.

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In this work we study the basic competitive and cooperative mechanisms that underlie the neural activity correlated with the decision making process in primates. In particular, we focus on the dependence of neural activity on the expectation of reward associated to the eye-movement response performed by the monkey. In the simulations we have used the protocol followed by Platt and Glimcher (1999), in which the subject had to choose between two alternative eye-movement responses. Subjects were rewarded for choosing either of the two options, but the gain associated to each was different. The frequency with which the animal chose each response was used as a readout of the subjective value of each option. We explicitly model the processes occurring at the level of AMPA, NMDA and GABA synapses using an implementation of integrate-and-fire neurons to produce realistic spiking dynamics. A detailed analysis of the dynamical capabilities of the system is performed by exploring the stationary attractors in the parameter space with a mean field approximation consistent with the underlying synaptic and spiking dynamics. The non-stationary dynamical behavior, as measured in neuronal recording experiments, is studied using the full spiking network simulation. The results obtained fit well the experimental psychophysical data.

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Modeling Nonlinear Responses of Primary Visual Cortex Neurons

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Responses of neurons in primary visual cortex (V1) display a number of nonlinearities. One such example is contrast-dependent response saturation, where the response of the neuron ceases to increase with increasing stimulus contrast (essentially a measure of signal strength). This effect is known to be a network property rather than a biophysical limitation of a neuron. The normalization model is a descriptive model in which local activity within V1 is pooled and then acts divisively on neuronal responses within the network. This configuration effectively causes the gain of neurons within the network to depend on overall input to the network. The biological mechanism underlying this divisive normalization signal, however, is unknown. We consider three mechanisms of inhibition: a shunt conductance, balanced excitatory and inhibitory synaptic activity, and inhibitory current, all of which depend on signal contrast. Through computational studies, we determine which of these forms of inhibition best reproduces normalization effects observed in V1. By comparing our simulation results with data and by examining which functions of contrast-dependence can be supported by V1 circuitry, we will clarify which forms of inhibition can underlie normalization signals in V1 and other areas of the brain.

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Modeling brain dynamics to infer underlying

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University of Wisconsin

Functional imaging modalities detect activation levels in the brain; however the goal of most research is to understand the functional structure of the brain and identify the responsible sources for changing the brain dynamics during across conditions. Data from source localized EEG or MEG data can be used to train a model of the brain that uses backpropogation on an error surface that imposes anatomical limitations to a neural network in order to emulate the brains behavior realistically.

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Information retrieval by a network of neurons with multiple hysteretic compartments

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Neurophysiological findings of graded persistent activity in the prefrontal cortex of the monkey performing a vibrotactile discrimination task or in the goldfish oculomotor system during intermittent saccades suggest that memory retrieval in the brain is described by dynamical systems with continuous attractors. It has recently been shown that, in the layer V of the rat entorhinal cortex in vitro, robust graded persistent activity can emerge at a single-cell level. Multiple levels of stable activity of a single cell can be replicated by a model neuron with multiple hysteretic compartments. Here we propose a framework to simply calculate the network level of behaviour of an ensemble of multi-stable neurons. To demonstrate the functional advantage of the neural-network system with multi-stable neurons, we examined its application to a document retrieval task. In citation networks of ~100,000 neuroscience articles, a multi-stable neuron is assigned to each article. A query is represented by an initial state of the network activation pattern. A continuous attractor led by activation propagation in these networks defines search results. The performance of the system well illustrated in this technological application suggests that the neural-network system with multi-stable neurons describes essential features of information processing in the real brain.

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Consistency of Extracellular and Intracellular Classification of Simple and Complex Cells

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Using a rectification model and an experimentally measured distribution of the extracellular modulation ratio (F1/F0), we investigate the consistency between extracellular and intracellular modulation metrics for classifying cells in primary visual cortex (V1). We demonstrate that the shape of the distribution of the intracellular metric χ is sensitive to the specific form of the bimodality observed in F1/F0. When the mapping between F1/F0 and χ is applied to the experimentally measured F1/F0 data, χ is weakly bimodal. We then use a two-class mixture model to estimate intracellular physiological response parameters, given the F1/F0 distribution, and show that a weak bimodality is present in χ. Finally, using the estimated parameters we show that simple and complex cell class assignment in F1/F0 is more-or-less preserved in a heavy-tailed f1/f0 distribution, with complex cells being in the core of the f1/f0 distribution and simple cells in the tail (misclassification error in f1/f0 =19%). Class assignment in f1/f0 is likewise consistent (misclassification error in F1/F0 =15%). Our results provide computational support for the conclusion that extracellular and intracellular metrics are relatively consistent measures for classifying cells in V1 as either simple or complex.

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Creation of Long-term Mental Representations using the Dimension of Fractal dendrites

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This work explores the possibility of using a neuron's dendrite spatial dimension as primitives for creating representations of mental activity. Recent {\it in-vivo} experimental results show that: (a) spines are structurally unstable and (b) adult dendrites are not static. These results suggest that using the synapse alone to create mental representations is insufficient. Using diffusional type equations, as models for the voltage fluctuations at a neuron's soma due to massive synaptic activity, two experiments were performed: (a) the autocorrelation function of the cable equation with fractal boundary conditions was determined and compared to those of the Ornstein-Uhlenbeck and Tuckwell-Walsh random processes and (b) these autocorrelation functions remained unchanged in spite of drastic regression of its branches. These results hint at a remarkably stable possible form of ``information'' storage.

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A Segmentation Algorithm for Zebra Finch Song at the Note Level

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University of Maryland

Songbirds have been widely used as a model for studying neuronal circuits that relate to vocal learning and production. An important component of this research relies on quantitative methods for characterizing song acoustics. Song in zebra finches - the most commonly studied songbird species - consists of a sequence of notes, defined as acoustically distinct segments in the song spectrogram. Here we present an algorithm that exploits the correspondence between note boundaries and rapid changes in overall sound energy to perform an initial automated segmentation of song. The algorithm uses linear fits to short segments of the amplitude envelope to detect sudden changes in song signal amplitude. A variable detection threshold based on average power greatly improves the performance of the algorithm. Automated boundaries and those picked by human observers agree to within 5 msec for ~80 percent of boundaries. Further refinements of this algorithm are currently under development.

198

A Statistical Basis for Visual Field Anisotropies

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There exist numerous psychophysical paradigms for which performance varies with location of stimulus presentation within the visual field. The following considers potential bases for visual anisotropies, considering the possibility of a statistical basis for such effects in cases where basic sensory asymmetries are present. An argument is put forth establishing a dichotomy between early sensory anisotropies arising from the influence of scene statistics on the underlying neural hardware, and asymmetries resulting from the manner in which the output of early sensory channels is processed by higher visual areas. Finally, an argument is put forth concerning the apparent radial organization of the visual system, with the suggestion that geometric perspective may give rise to the statistical bias responsible for this effect.

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Dynamical Evolution of Neuronal Patterns

Schiff, Steven; Sauer, Tim; Kumar, Rohit; Weinstein, Steven
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We often seek to quantify the complex spatiotemporal patterns that neuronal systems create. Unfortunately, computational neuroscience frequently relies on qualitative visual inspection to delineate when such spatiotemporal patterns transition into new forms. To address this we developed a novel approach to canonical discrimination of Fisher (1936). We redefined the geometry that underlay Fisher's conjecture, and used this to replace the original technique with a more modern matrix algebra solution. This solution is now numerically stable when used on data sets typical of neuronal experiments. Our approach is broadly applicable to a wide variety of neuronal data sets in neuroscience. Using this technique we applied the first discrimination analysis to sequential measures of seizure dynamics. We sought to quantify the long held conjecture that seizures have unique initial and termination phases, to better understand how seizures start and stop. Twelve scalp and intracranial seizure records from 9 children were examined for all possible partitions into beginnings, middles, and ends. Discrimination into 3 groups was possible for 21 of 24 seizures, with significance by chi-square (p

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Modulation of gamma oscillations in the rat olfactory bulb during performance consolidation

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Gamma oscillations in the olfactory bulb (OB) have historically been characterized as odor-induced, or stimulus-driven. Recent evidence suggests that the presence of such oscillations may be more reliant on context than previously thought. This study proposes that gamma oscillations are modulated by expectations derived from previous experience and level of expertise within a particular sensorimotor context. Local field potentials were recorded from rat OB during performance of an olfactory discrimination task using well-trained and novel odor sets. Signals reflect the coherent activity of a large population of neurons within the OB, and gamma-band (40-100 Hz) power is used as an index of underlying oscillatory synchrony. During odor sampling of the well-trained odor set, the high-gamma frequency range (65-100 Hz) was marked by an increase in power over the course of a single 200-trial behavioral session. This distinction was not seen when rats were required to couple the same motor responses to novel sets of odors but reappeared when task performance reached criterion level. The increase in high-gamma oscillatory synchrony could correspond to the incorporation of the novel odor set into a broader context through the formation of neural cell assemblies that become more synchronized, larger or more reliable over time.

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Persistent neural activity in a bilateral neural integrator model

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Multilevel persistent neural activity has been identified as a neural correlate of short-term memory in a wide variety of systems. Here we model the mechanisms underlying persistent neural activity in a well-characterized model system, the goldfish oculomotor neural integrator. This is a bilateral brainstem region that converts velocity-encoded eye movement command inputs into signals that encode for the eye position. In the absence of command inputs, oculomotor neurons maintain persistent neural activity at firing rates that are threshold linearly related to the eye position. Experiments suggest that the neural integrator has excitation between neurons with the same position sensitivities and inhibition between neurons with opposite eye position sensitivities. Here, we model this bilateral arrangement and we derive conditions on synaptic connectivities between the excitatory and inhibitory neuron populations necessary to maintain multi-level persistent activity in the circuit. For the class of models satisfying these conditions, we compare model performance to the results of recent inactivation experiments probing the bilateral arrangement of this system. Our results are likely to reveal general principles of neural integration in systems exhibiting a push-pull arrangement of inputs and nonlinearities due to variable neuronal firing rate thresholds.

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A Spike Sorting Framework Using Nonparametric Detection and Incremental Clustering

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This paper introduces an efficient computational method for spike sorting, which is the process of detecting spikes from recorded extracellular signals and assigning each to a neuron. Spike sorting assists researchers in studying brain functions. Major challenges of automatic spike sorting include strong background noises, interfering spikes from surrounding neurons, and variations in spike shape and amplitude of the same neuron. Since neurons usually generate action potentials with a strong impulse, many spike sorting methods use threshold to obtain spike signals. Such methods can not obtain acceptable isolation when the background noise is strong. Our method is a two-step probability density based spike sorting method. In the first step, we produce signal vectors containing spikes using grid quantization. In the second step, we design an efficient incremental clustering algorithm based on the expectation maximization algorithm and a cluster merging strategy by multivariate statistical tests for equality of covariance and mean to group the spikes from the first step. Experiments on simulated and real spike signals show that our method can detect and cluster spike signals more efficiently in both time and space than traditional methods.

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Deficiencies in Traditional Measures of in vitro Hippocampal Rhythms

Gillis, Jesse; Zhang, Liang; Skinner, Frances
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Characterizing hippocampal electrical rhythmic activities requires a broadly applicable methodology which does not omit significant and potentially physiologically relevant detail. In a thick slice hippocampal preparation, spontaneous rhythmic field potentials are exhibited in the 3-4 Hz range. We analyze this in vitro hippocampal activity exhibiting spontaneous rhythms using common techniques appropriate for simple rhythms, as well as more complete time-frequency methods. Using time-frequency analyses, such as distributions from Cohen's class, wavelets, and others, the different tradeoffs between frequency resolution, interference, and biological relevance are examined with reference to the suitability of each for use in analyzing the hippocampal rhythm. Common measures for the analyzing character of a rhythm, such as phase relationships, frequency and coherence are calculated for each rhythm. These measures are then used to determine the population of time-frequency behaviour exhibited for a given frequency or coherence, thus determining the time-frequency variability which those characteristics elide.

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Employing Neural Potentiation Mechanisms Within Brain-Machine Interface System

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We developed a research paradigm for studying neural plasticity mechanisms within a brain-machine interface system that consists of the brainstem of a lamprey interconnected with a dynamical system simulated in real time. This BMI setup provides the bi-directional exchange of information between the neural preparation and the external system. In these experiments, one extracellular stimulating electrode and one extracellular recording electrode were used. We placed the stimulating electrode among the axons of the octavomotor nucleus (nOMP). We recorded extracellularly from axons of the the contra-lateral rhombencephalic reticular nucleus. To assess long-term changes in neural behavior caused by applying the tetanic stimulation, we conducted series of control trials, when no tetanic stimulation is delivered regardless of performance. For each trial, we have measured an average deviation of the robot orientation from the fixed target orientation. The performance in control trials is much better after training than before. The average errors for the pre- and post-training sets of control trials are significantly different with a confidence of 99%. This study provides encouraging results for controlled increasing of the neural output that brings desired behavior changes in the bi-directional brain-machine interface system.

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Associative Memory of Connectivity Patterns

Zhu, Junmei; von der Malsburg, Christoph

The goal of the visual correspondence problem is to establish a connectivity pattern, also called a mapping, between two images such that features projected from the same scene point are connected. Dynamic Link Matching (DLM) is a self-organizing dynamical system to establish such connectivity patterns for object recognition. With rather naturally given simple interactions between pattern elements, DLM can create mappings robustly against deformations, but its self-organizing process is too slow compared to the recognition time in adults. In order to improve the speed we propose to stabilize (store) established mappings so that they can be recovered efficiently and reliably in the future. This is implemented by modifying the underlying system of interactions using the established mappings as learning examples, where the Hebbian rule makes the adapted interactions between pattern elements proportional to the weights of an associative memory of these mappings. It is shown in simulation that the adapted interactions lead to faster DLM.

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Out of Sync: Asymmetric Bilateral Whisking Patterns in Freely Behaving Rats

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Rats are nocturnal animals with poor vision, and rely strongly on tactile information from their vibrissae (whiskers) to explore the environment. During exploratory behaviors, the rat typically "whisks" at frequencies between 5-15 Hz, and it is traditionally held that the vibrissae move with strict bilateral symmetry. Bilateral symmetry could pose a problem, however, during head rotations. Since the whiskers move with the head, whiskers ipsilateral to the direction of head rotation would "speed up" in proportion to the angular head velocity, while contralateral whiskers would "slow down" by the same amount. In the present studies we used high-speed video to record whisking movements and investigate the hypothesis that whisking includes compensation for head rotation. Results show that during head rotation whisking patterns are bilaterally asymmetric and that the associated timing differences depend on head velocity. We investigate two possible exploratory strategies that may underlie the asymmetries, and conclude that at least one function of the asymmetric whisking is to allow the rat to "look ahead" with its whiskers on the side towards which its head is turning. We discuss the implications of these results for models of central pattern generation (CPGs) in the rat vibrissal system.

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Onset Kinetics of Edge Definition and Border Ownership Assignment by Neurons in

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Previous studies have shown that part of the orientation-selective neurons of macaque area V2 signal border ownership, responding with different firing rates, depending on whether the border in the receptive field is a contour of a figure on one side or the other. For an unbiased and accurate estimation of the onset of the border-ownership signal, we have developed a method which combines two-phase linear regression with the bootstrap technique. Single-unit activity was recorded in area V2 of behaving macaques and responses to edges of contrast-defined and disparity-defined squares were analyzed. We found latencies for the population signal of 69 ms and 42 ms, respectively. The former emerged early (well before the peak of responses), but 27 ms later than the stereoscopic border ownership signal. For comparison, we also analyzed neurons signaling the edge contrast polarity for the same stimuli. The latency of this signal was 44 ms, again significantly shorter than the context-dependent border ownership signal. Thus, the assignment of border ownership in V2 --- presumably the neuronal bases of figure-ground segregation --- is performed rapidly, suggesting mechanisms that do not depend on form recognition processes that might occur in inferotemporal cortex.

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A Simple Model of Spike Processing

Lazar, Aurel
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Can stimuli be mapped into a spike train, processed in the time domain and converted back to control a biological process? We investigate this question and answer it in the affirmative. We demonstrate how to construct a linear operator that maps an arbitrary bandlimited stimulus into a desired signal using integrate-and-fire neurons, simple integrators and one-to-many axon/dendritic tree connectivity.

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Generation of Unitary Field Potentials in the Glomerular Layer of the Olfactory Bulb.

Kurnikova, Maria; Sergei, Karnup
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A novel type of spontaneous field potential fluctuations in the interface slices of the main olfactory bulb (MOB) is described. Extracellularly recorded spontaneous glomerular field potentials (sGFPs) were found to occur in normal conditions in the glomerular layer (GL). These sGFP are intrinsic to the GL and have comparable magnitudes, durations and frequencies both in standard horizontal slices where all layers are present, and in the isolated GL. Since the characteristics of sGFPs were not impaired in the isolated GL, we propose that their main generators are juxtaglomerular (JG) neurons with cell bodies located within GL. The impact of mitral (M) and deep/medium tufted (T) cells to sGFPs seems to be much lower than that of JG cells. Electrostatic fields generated by various populations of cells were calculated using a simplified model of a GL. Our model demonstrates details of field potential generation in the complex module comprising the glomerulus proper and a subset of M/T cells. Obtained results provide a better insight to organization of neuronal ensembles in the MOB and suggest an active role of the glomerular layer as a subsystem in processing of olfactory information.

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A Stochastic Population Approach to the Problem of Stable Propagation of Synchronized Spike Volleys

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A recruitment learning method has been proposed that models knowledge acquisition in cortical networks (Feldman, 1982; Valiant, 1994, 2000). In this model, a token of information is transmitted by a synchronized spike volley. Propagating spikes have a large projection, but only synchronized spikes that converge to the same neuron cause recruitment. Recruitment learning is prone to instability when a chain of concepts is recruited in cascade. We propose a biologically inspired model which exhibits stable recruitment over a multistage cascade. The model uses the noisy transmission delays inherent in cortical networks and also lateral inhibitory effects between principal neurons as negative feedback. In this model, the initially synchronized spike volley intended to cause recruitment is assumed to be subject to varying delays in the individual spikes. The varying delays in the spike arrival times cause the destination neurons to be recruited in a temporally dispersed sequence. During this process, we propose using the local lateral inhibition as a mechanism that saturates to fully inhibiting the localized area after enough neurons are recruited. We formally show that our model converges to a stable solution when repeated. Our numerical analysis results verify the stability of the model.

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Phospholipase C beta 4 selectively modulate cholinergic hippocampal theta oscillations

Shin, Jonghan; Shin, Hee-Sup
Korea Institute of Science and Technology

Phosphoinositide specific phospholipase C (PLC) hydrolyses phosphatidylinositol 4,5 bisphosphate and produces a pair of second messengers, diacylglycerol and inositol 1,4,5 trisphosphate (IP3). Interestingly, PLC beta 4 of the PLC family is predominantly expressed in the medial septum which is known to be critically involved in generation of hippocampal theta oscillations. Here, we assessed the isotype-specific role of PLC beta 4 in the generation of hippocampal EEG by using PLC beta 4 knockout (KO) mice. In PLC beta 4 KO mice, large irregular activity (LIA) recorded during resting states did not significantly differ between PLC beta 4 KO mice and wild littermates. Furthermore, theta rhythms recorded during walking also did not differ between PLC beta 4 KO mice and wild littermates. However, PLC beta 4 KO mice under urethane anesthesia, which has been known to induce isolated cholinergic theta rhythms, showed ~40 % reduced theta power in power spectral analysis compared to wild littermates. We suggest that PLC beta 4 expressed in the medial septum is involved in modulating cholinergic release in the medial septum cholinergic neurons, which can explain why PLC beta 4 KO mice showed reduced cholinergic hippocampal theta rhythms during urethane anesthesia.

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Influence of the neural network topology on the learning dynamics

Emmert-Streib, Frank
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We study the influence of the topology of a neural network on its learning dynamics. The network topology can be controlled by one parameter p_{rw} to convert the topology from regular to random in a continuous way \cite{WattsStro_1998}. As test problem, which requires a recurrent network, we choose the problem of timing to be learned by the network, that means to connect a predefined input neuron with a output neuron in exactly T_f time steps. We analyze the learning dynamics for different parameters numerically by counting the number of paths within the network which are available for solving the problem. Our results show, that there are parameter values for which either a regular, small world or random network give the best performance depending strongly on the choice for the predefined input and output neurons.

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Brain mechanisms for interleaving routine and creative action

Bond, Alan
California Institute of Technology

In our system-level approach to brain modeling, we define creative action as that originating in the basic knowledge elaboration activity of the cortex. We argue that cortical areas, particularly frontal areas, will be involved in the selection and control of routine action which originates in the basal ganglia. They initiate routine action, and monitor and terminate it. We explain the anatomical connectivity of the basal ganglia which place them in loops from various source areas of the cortex and back to frontal areas. We model routine action via the basal ganglia, which learn association connections among source areas and frontal areas. Routine action is often but not always initiated by goals, some of which may be set by frontal areas. Normally, there will be an interleaving of creative cortical action and routine action. We argue that the connections among the basal ganglia, thalamus and cortex provide a basis for real time control and monitoring of a stream of routine actions generated by the basal ganglia. We outline examples of routinization and interleaving for the Tower of Hanoi problem, for routinization of motor control, of problem solving action, and of eye movement.

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Unsupervised Extraction of Multi-Frame Features from Lip Motion Video

Lee, Soo-Young; Lee, Michelle Jeungeun; Lee, Kyungsuk David
KAIST

The features of human lip motion from video clips are extracted by three unsupervised learning algorithms, i.e., Principle Component Analysis (PCA), Independent Component Analysis (ICA), and Non-negative Matrix Factorization (NMF). Since the human perception of facial motion goes through two different pathways, i.e., the lateral fusifom gyrus for the invariant aspects and the superior temporal sulcus for the changeable aspects of faces, we extracted the dynamic video features from multiple consecutive frames for the latter while others had worked on static features from single-frame static images only. The number of features and sparseness are almost independent to the number of frames, and the multiple-frame features require less number of coefficients for the videos with the same frame length.

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A Computational Model of Anterior Intraparietal (AIP) Neurons

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JST-ICORP Computational Brain Project

The monkey parietal area AIP (anterior intraparietal area) has been shown to contain neurons that extract object features relevant for grasping such as the width and the height. AIP is strongly interconnected with the ventral premotor area F5 that is involved in grasp planning and execution. In our earlier simulation studies we have shown that grasp learning without delicate visual analysis is possible, and presented evidence from infant developmental literature1 supporting our hypotheses and simulation results. In this study we shift our attention to the formation (emergence) of AIP neurons during grasp development. In particular we propose a neural network structure and adaptation rule which is driven by the successful grasping during grasp learning. The simulations with the proposed network lead to emergence of units that have similar response properties as the AIP neurons. The results may have certain implications for the function of AIP neurons and thus should stimulate new experiments that can verify/falsify our model.

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Populations of Hodking-Huxley neurons in the high-conductance state

Morrissey, Edward; Moreno-Bote, Ruben; Parga, Nestor

We show how to predict the population response of Hodking-Huxley neurons in the high conductance state. The prediction is obtained by a generalization of a technique previously derived for leaky integrate-and-fire neurons bombarded by background noise and with synapses described either as simple filters [1] or in terms of conductances and driving forces [2]. The main technical difficulty comes from the fact that the response of Hodking-Huxley neurons depends not only on the value of the current but also on how this value has been reached. This difficulty is solved and the predicted population rate agrees quite well with numerical simulations. The Wang-Buzsaki model can be dealt with in a similar fashion. We believe that this solution for the population rate of these model neurons can be used to solve mean field models of networks. [1] R. Moreno-Bote and N. Parga, Phys Rev Lett 92(2) 028102, 2004 [2]R. Moreno-Bote and N. Parga, Phys Rev Lett, in press, 2005

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Self-Organization of Hierarchical Visual Maps with Feedback Connections

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Department of Computer Sciences

Most computational studies on the visual system have concentrated on the feedforward pathway from retina through the LGN to the different maps of the visual cortex. However, there are least as many feedback connections as feedforward ones in the primate visual system. What patterns of feedback connections exist, how they develop, and what their role is in visual processing is not well understood. In this summary, a computational experiment with the LISSOM model is described where feedback connections from V2 to V1 are learned through the same normalized Hebbian self-organizing mechanism as the feedforward and lateral connections in V1 and V2. The V1 and V2 maps form a hierarchical representation of the input, with feedback connections linking relevant cells at the two levels, suggesting that they can play a role in perceptual grouping phenomena.

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Fast inhibition in the olfactory bulb can lead to odor-evoked gamma burst and possibly phase coding.

David, François; Hughes, Etienne; Buonviso, Nathalie
Neurosciences et Systèmes sensoriels

The mammal olfactory bulb (MOB) exhibits an odor-evoked gamma burst during inspiration. Several experiments have indicated the fundamental role played by fast GABAa receptors mediated inhibition of mitral/tufted cells (M/TCs) by granule cells (GCs), the pharmacological blocking of these receptors abolishing the oscillation. We propose a scale-reduced model of the MOB reproducing many features of the dynamics observed. As a result of sufficient inhibition, we suggest that a set of stimulus-dependent M/TCs could have preferred firing phases which could encode the odor, as was similarly found in other species. The network properties indicate that, despite heterogeneous activity of the GCs, neighboring M/TCs can receive similar inhibitory synaptic currents, a result supported by experiments.

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Hilbert transform optimization to detect phase transitions on cortex in beta-gamma band

Demirer, Rustu Murat; Kozma, Robert; Freeman, Walter; Myers, Mark
University of Memphis

The aim of this study is to concentrate on a new robust filter design method applied to the rabbit and human cortex EEG data, with emphasis on the robustness of the results despite changing the digitizing interval, with further demonstration of the effects of changing the pass band filter characteristics when we apply Hilbert Transform to EEGs to detect the phase transitions on the cortex. A key problem with the band pass filtered gamma activity is low frequency bias that results in missing zero crossings. We state that simply finding the missing zero crossings and removing the spikes in the standard deviation of the spatial phase differences can not solve the problem. An unknown proportion of those events are, in fact, real, so throwing them out may not be correct. Instead we apply a factorized combination of two different type linear phase FIR filters based on pseudo spectrum of the multiple channel EEG using MUSIC algorithm and reconstruct the band pass filtered EEG with blocking the appearance of pseudo-phase transitions called as phase slips.

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Perception, Interoception and Self-Report of Pain

Assadi, Amir; Backonja, Misha; Chapman, C. Richard
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Self-report of pain is behavioral observable of the complex system underlying pain. The process of encoding and decoding of communication of pain requires numerous frames of reference, initiating with introspection in an internal (subjective) frame of reference of the patient and concluding in the external observer's one. Thus, self-report of pain requires a new approach to Shannon's information theory that requires a re-examination and mathematical treatment of most elements of the theory communication. A contribution of this paper is to delineate the underlying mathematical structure in the clinical context, and to use biological learning as a paradigm, and computational learning as the actual implementation of the theory using clinical behavioral data. Extracting mathematical precision from uncertainties of subjective self reports by patients on the one hand, and heuristic assessments and observations by health professionals on the other, is a formidable challenge. The present paper contributes to meeting this challenge, and proposes the outline of the informatics of pain, design and implementation of intelligent databases for improved diagnosis, better decision-making by physicians, and lowering the cost of health care by prioritizing the most significant factors with highest likelihood of a successful conclusion.

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Patterns of Dynamics in the Human Auditory Evoked Response

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An animal's auditory system experience massive numbers of diverse stimuli impressed upon the cochlea, thus creating neuronal spike trains that reach the cortex. Much of such stimuli arrive without any obvious relationship to our routine function in our environment. Only a small percentage of the sounds are significant to us, and accordingly, our brain must distinguish them and allocate extra amounts of the available functional and metabolic resources. How does the auditory cortex handle this impressive flow of spike trains, and extract the patterns that carry significant information? In this article we study the evoked potential of the local neuronal circuits of the left temporal lobe surrounding the auditory cortex in response to two types of simple auditory stimuli. The experimental setting called the odd-ball paradigm is used and intracranial electrophysiological recordings using an 8x8 grid collect the evoked response potentials that are then analyzed information-theoretically according to a generalized form of the theory developed earlier by the first author. These computations are then applied to test the role of gamma oscillations in elucidating cortical substrates of "auditory attention".

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Networks with fewer and stronger connections may store more information in neuronal avalanches

Beggs, John; Chen, Wei; Haldeman, Clayton; Hobbs, Jon; Tang, Aonan; Wang, Shaojie

A central task in cortical physiology is to determine how local cortical networks store memories. The synaptic hypothesis states that information can be retained in the connection strengths, or weights, between neurons, yet details of this scheme are incompletely understood. It is unclear whether a network can store more information if its units have many nearly equal weights (homogeneous distribution) or a few strong weights (biased distribution). To address this issue, we used 60 channel microelectrode data from cortical slice networks and a parsimonious model that captures central features of the data. Previous work showed that cortical slice networks spontaneously produce neural activity patterns that are statistically similar to avalanches seen in critical sand pile models. These neuronal avalanches may serve as a substrate for information storage since they occur in patterns that are temporally precise and repeatable for over 10 hrs. By varying connection weights in the model, we found that the biased distribution not only best fit the data, but also produced the largest number of repeatable avalanche patterns. These findings suggest that a few strong connections dominate in local cortical networks and that this connection scheme yields the largest memory capacity.

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Learning-induced oscillatory activities correlated to odor recognition: a network activity

Martin, Claire; Gervais, Rémi; Ravel, Nadine
University of Chicago

Previous data showed that in olfactory bulb (OB) and piriform cortex (PC) of awake rats engaged in an olfactory learning, odor presentation induced a power decrease of gamma oscillations (60-90 Hz) followed by a power increase in beta range (15-40 Hz). Both phenomena were strongly amplified after training. The aim of this work was to further characterize under which conditions this oscillatory activity could emerge. Local field potentials (LFPs) were recorded through chronically implanted electrodes in the OB and PC of freely moving rats performing an olfactory discrimination. Two methods were used to investigated the possible role of the OB-PC feed-back loop in the expression of beta activity following learning. In one group of animals, unilateral section of the olfactory peduncle was made before training, and LFPs were symmetrically recorded in OBs along the acquisition of the learning task. On the other hand, animals chronically implanted with intracerebral cannula were trained in the same task. LFPs were recorded under unilateral inactivation of the peduncle (lidocaine infusion) in experts animals. Data showed that deprivation of centrifugal feed-back led to an increase of spontaneous gamma activity, and abolished the typical beta activity observed in response to learned odors.

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Single neuron and neuronal ensemble contributions to neuronal population codes

Laubach, Mark; Narayanan, Nandakumar; Kimchi, Eyal
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How do ensembles of neurons interact to encode information? To address this issue, we examined the ability of neuronal ensembles from rat motor cortex to predict how well rats perform a simple reaction time task. Ensembles of ~15-30 neurons were recorded in the rat motor cortex. Statistical classifiers, such as learning vector quantization, support vector machines, and mixture discriminant analysis, were used to quantify how well the neuronal firing patterns discriminated between single trials with correct or errant task performance. Information contained in the neural data was estimated by applying information theory to confusion matrices obtained with each classifier. A major result was that the importance of single neurons for encoding behavioral events depends on whether the neurons are tested alone or as part of an ensemble. This effect was quantified using a framework developed by Schneidman et al. (2003). We found that redundancy was a dominant factor for the encoding of reaction time performance in ensembles of 8 or more neurons. These results were subsequently replicated using simulations of simple linear signals and also using simulated neuronal circuits generated using NEURON. Together, these results suggest that redundancy may be an important organizing principle for information processing in neuronal ensembles.

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A two-dimensional population density approach to modeling the dLGN/PGN network

Marco Huertas, Gregory Smith
Department of Applied Science, College of William and Mary

The interaction between two populations of integrate-and-fire-or-burst neurons representing thalamocortical cells from the dorsal lateral genicualate nucleus (dLGN) and reticular cells from the perigeniculate nucleus (PG) is studied here using a population density approach. Each population of neurons is described by a two-dimensional probability density function that evolves according to a time-dependent advection-reaction equation with appropriate boundary conditions. The state variables of each population are the neuron's membrane potential v and the inactivation gating variable h of the low-threshold current It. The interaction between populations as well as external excitatory drive representing optic tract stimulation is modeled by instantaneous jumps in the membrane potential of postsynaptic neurons. The computational efficiency and limitations of the population density approach is investigated in the context of dLGN/PGN network modeling. Parameter studies are performed that quantifies the input/output responses of the network to optic tract stimulation protocols with different amplitude, duty cycle and frequency. Effects of changes in cellular parameters and the sparsity of the network connectivity are also investigated.

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Opposing predictions of dominance time vs. contrast in two binocular rivalry models

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We consider two reduced population firing rate models to describe oscillation dynamics during binocular rivalry. These models, by Laing and Chow (2002) and by Wilson (2003), differ in their architecture, in the form of their gain functions, as well as how they implement the adaptation process that underlies alternating dominance. Here we focus on examining the effect of the strength of the inputs to the two populations on the rate (and existence) of oscillations. This is a test of Levelt's Proposition I (1968), which states that dominance durations decrease with increasing stimulus strength (e.g, constrast), and which has been confirmed since then in many psychophysics experiments. We show that Laing and Chow's model does not satisfy Levelt's Proposition I, while Wilson's model does. The presence of the separate inhibitory population and the absence of the recurrent excitation do not change our conclusion about the models' validation of Levelt's Proposition I. We suggest that the difference in the behavior can be attributed to the different shapes of the gain functions, as well as to the different treatments of the adaptation process in these models.

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Using one-dimensional maps for analyzing neuronal dynamics

Georgi Medvedev
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We use qualitative methods for singularly perturbed systems of differential equations and the principle of averaging to develop a method of reducing a class of differential equation models of neural cells to one-dimensional maps. We use this approach to describe some general traits of the bifurcation structures of two problems: a class of models of bursting neurons and a two-compartment model of a dopamine neuron. Both (classes of) models exhibit a variety of spiking, bursting, and mixed-mode firing patterns, which can be selected by small variations of parameters. The mechanisms for generating firing patterns in these two problems are qualitatively different. These differences are reflected in the corresponding families of the one-dimensional maps. In both cases, calcium dynamics plays a critical role in the mechanisms for generating firing patterns. Our analyses explain the mechanisms by which calcium (dependent) currents control the modes of activity in these models. We show that small variations of the parameters describing calcium (dependent) currents result in significant variability in the form and frequency of spiking and bursting regimes and explain the mechanisms underlying this variability.

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Modelling Complex Cells with Generalized Independent Subspace Analysis of Natural Images

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Previously we presented simulation results and analysis of spatially and temporally local rule that implements spike-timing-dependent plasticity (STDP). Here we investigate the properties of this rule with four types of gating in the setting that replicates the experiments with triplets of spikes. Similar to experimental data, the post-pre-post triplet leads to synaptic potentiation in most cases. The reaction of the model on pre-post-pre triplet is much more sensitive to parameter values and spike timings. The model suggests that the data of Bi and Wang (2002) for such a triplet are representing only one outcome out of several possible results.

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Relationship of Extracellular Potential to Biophysical Distribution of Membrane Currents

Kenneth Eaton, Craig Henriquez
Duke University

The state-dependent variation in firing activity of a neuron is a function of both the afferent synaptic input as well as the intrinsic spatial distributions of membrane currents in specific regions of the somatodendritic surface. The interactions of heterogeneous current activity can give rise to particular spiking patterns, such as tonic or burst firing, in response to different combinations of excitatory and inhibitory inputs. These patterns are often recorded using extracellular electrodes. In the present study, a biophysically-accurate thalamic reticular neuron model with a full dendritic morphology and spatially-distributed membrane and synapse currents is used to identify which characteristics of the extracellular potential relate to particular spatial patterns of membrane and synaptic current activity. Simulations show shifts in the baseline extracellular potential near distal dendrites associated with calcium currents during bursting activity. The localization of sodium currents in the soma leads to extracellular spikes whose amplitude falls off with distance from the neuron as expected from a point source of current, while more diffusely distributed synaptic currents exhibit slower rates of radial fall-off. Ultimately, this modeling approach may help to glean information about biophysical parameters from extracellular recordings.

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Basal-forebrain dependent versus independent networks for successful resolution of proactive interference

Jeremy Caplan, Eve de Rosa, Anthony R. McIntosh
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Proactive interference (PI) is a memory phenomenon wherein previous learning impairs the acquisition of new related information. Efficient resolution of PI relies on a network involving cholinergic modulation from the basal forebrain (BF) in rats. Application of a seed/behaviour partial least squares analysis to human fMRI data revealed that the BF network was also active during PI resolution in healthy control subjects. In patients with compromised BF function, a different network was associated with successful PI resolution. Critically, the BF-dependent network correlated with PI performance for Controls but the alternate network was not strongly coupled to patient behaviour. Thus, a functional network embedded within an rat anatomical networks was extended to human fMRI data, shown to relate to similar behaviour and contrasted with an alternate functional network.

Madison Restaurants

Restaurants

Admiralty Room, 666 Wisconsin Ave. (in the Edgewater Hotel)
Great view of Lake Mendota; continental cuisine. Extensive wine list.

Amy's Cafe, 414 W. Gilman St
Salads and sandwiches are the stars. Daily Mediterranean specials
.
Ancora Coffee-King Street, 112 King St.
More than just good coffee: breads, pastries and soup. Senior discounts.

Angelic Brewing, 322 W. Johnson
Everything from pasta to sandwiches, plus tap beers brewed on-site. Live music.

Argus Food and Spirits,123 E. Main St
Sandwiches, soups, salads and daily home-style lunch specials.

Atlanta Bread Company-University Ave, 3256 University Ave.
Sandwiches, salads and soups, plus bread, muffins, pastries, cookies and croissants.

Babcock Hall Dairy Store, 1605 Linden Dr
Babcock Hall ice cream by scoop or gallon, cheese, sundaes, malts, plus sandwich specials, taco salad, hot dogs.

Badgerland Bar & Grill, 525 W. Johnson St. (in the Howard Johnson Plaza Hotel)
Casual dining is complemented by Midwest fare.

Bahn Thai, 944 Williamson St
Delicately prepared Thai cuisine with excellent fish dishes and very spicy sauces. Try the tom ka gai soup. Delivery available 5-9 pm.

Baker's Too, 12 University Square
Soups, sandwiches, wraps, muffins and specials.

Bandung, 600 Williamson St
Madison's only Indonesian restaurant serves up excellent sate-ayam (chicken), sate-kambing (lamb) and sambalgoreng udang (shrimp). Monthly rice rijsttafel and Indonesian dance performances. Reasonably priced, friendly, and authentic.

Barriques, 1831 Monroe St
Tapas and wine by the glass.

Beijing Restaurant,40 University Square
Chinese restaurant specializing in Beijing-style entrees, including house seafood specials like the outstanding seafood wonton noodle. Delivery 4:30-9 pm Mon.-Sat.

Bellini's Lounge, 401 E. Washington
Traditional Italian-American dishes and traditional pizza from Biago Gargano, as well as spinach salad, Bistecca alla Pizzaiola, Pollo ala Pietro and Rigtoni Bolognese.

Big Ten Pub, 1330 Regent St
Appetizers, sandwiches, pizza, burgers,and daily lunch and dinner specials. Blue gill fish fry on Fridays.

Blue Marlin, 101 N. Hamilton St
Fresh seafood with inventive sauces. Choose from swordfish, tuna, salmon, soft-shelled crab, lobster and yes, marlin. Killer hash browns on the side.

Blue Moon Bar & Grill, 2535 University Ave
American grill specializing in soups and specials made from scratch. Friday's Manhattan seafood and New England clam chowder can't be beat.

Bluephie's, 2701 Monroe St
Contempo comfort food with a vegetarian tilt.

Bon Appetit Cafe, 805 Williamson St.
Small, intimate atmosphere. Mediterranean and international cuisine.

Brass Ring, The, 701 E. Washington Ave.
More than a pool hall with sandwiches, though it is that. Load up on appetizers, including the "Irish nachos," or chow down on a buffalo burger.

Brocach Irish Pub, 7 W. Main St.
homey Gaelic soul and some good, cheap food too; best of the bunch is a gravy-smothered roast chicken and the bang-up bangers and mash.

Brothers, 704 University Ave
Right in the middle of student territory, serving a full appetizer menu. No entrees.

Buffalo Wild Wings, 529 State St
Buffalo wings are the mainstays of this campus hangout, but the sandwiches and salads are crowd-pleasers, too.

Buraka, 543 State St.
The popular food cart has expanded to a cafe, serving African cuisine with an emphasis on Ethiopian dishes. Try the Misirwot, lentils and potatoes in a spicy sauce on injera, African flat bread. Available for private parties Sunday.

Burger Joint, The, 309. N. Henry St
Little place, big ideas -- like 1/3-lb. burgers made from never-frozen chuck, prime rib chowder, crab rangoon, an apple burger and a burger with egg, ham, cheese, avocado and bacon.

Butler Cafe, 15 N. Butler St
Sandwiches, salads, small bites, pizza, coffee.

Cafe Continental, 108 King St
Italian, Greek and French food, cooked over an open flame. Private room available for up to 12. Extensive wine list.

Café Montmartre, 127 E. Mifflin
Come for the atmosphere. Stay for the soups, salads, sandwiches, patés and cheeses--not to mention the many wines available by the glass, the international selection of tap and bottled beers, and that certain je ne sais quoi. Live music some evenings.

Campus Biryani and Kebab, 1437 Regent St
Low-key cafe offering some of the best bargain dining around. Order any of the biryani dishes--fluffy rice with choice of mutton, chicken or mixed vegetables--and you'll fill up for next to nothing. May be a tight squeeze for wheelchairs.

Capitol Chophouse, 9 E. Wilson St
Attached to the Monona Terrace Hilton. Steaks, seafood, and goat-cheese-stuffed Portobello mushrooms for the vegetarians.

Casa Bianca-N. Bassett, 333 N. Bassett
New York-style pizza by the slice or by the pie, chicken, seven different calzones, subs, 20 pasta dishes.

Casa de Lara-State Street, 341 State St
Authentic Mexican food and drink prepared in the family tradition and served in an elegant south-of-the-border dining room. Daily lunch specials and the best selection of tequila in the state.

Casbah, 119 E. Main
A cool Mediterranean oasis, this three-story restaurant and lounge offers the downtown crowd the world's smoothest hummus, swell falafel, as well as kebabs, fish, couscous, and an extensive array of salads. Come and enjoy a hookah.

Caspian Cafe, 17 University Square
Persian cuisine; hummus, shish kebabs with lamb, chicken and sirloin, baklava, Persian ice cream. Vegetarian & vegan choices. Catering.

Catacombs Coffee House, 731 State St.
Lower level of the Pres House. Vegetarian breakfasts and lunches. Open for music but not food on weekends.

Chang Jiang, 984 W. Main
Takeout Chinese.

Charley's Steakery, 644 State St
Grilled subs and salads, fries and lemonade.

Chautara, 334 State St
Features Himalayan and Nepalese food, with some Indian dishes.

Chin's Asia Fresh, 422 State St
Made-to-order Asian fusion stir frys and noodle bowls, with mix-and-match sauces in a postmodern atmosphere. 9 sauces including Thai peanut and Indo Coconut Curry, and a surprisingly good hot and sour soup.

Chocolate Shoppe, 468 State St
Ice cream featured on The Food Network for its farm-fresh dairy ingredients. 110 flavors (though not all are available at once); seasonal treats like Door County Cherry, s'mores, eggnog and pumpkin. Family-owned in Madison since 1962.

Cleveland's Diner, 410 E. Wilson St
An old favorite with a bright look; the menu features good-sized breakfasts served all day, sandwiches and homemade soups.

ColdStone Creamery, 427 State St
Premium ice-creams with mix-ins,a stunning array of candies, cakes, fruits and nuts. Ice cream is fresh daily and the mixing is done on a frozen granite stone.

Come Back In, 508 E. Wilson
Opened by the owners of Essen Haus; features 26 imported tap beers, hearty sandwiches and weekend prime rib specials.

Concourse Hotel Bar, 1 W. Dayton
Pizza, appetizers and other bar food faves.

Cool Beans Coffee Cafe, 1748 Eagan Rd.
Ancora coffee, smoothies, salads, wraps, sandwiches and desserts.

Coreana Korean Cuisine Restaurant, 35 University Square
Home-cooked Korean food. Look for the pork and ribeye steak bulgogi and classic bibimbap.

Crave Restaurant and Lounge, 201 W. Gorham
New-wave tapas bar with burgers and sandwiches as well. Try the black 'n' blue bacon burger, a juicy, meaty classic, or the 201 Club, a huge club sandwich.

Curry n' Hurry, 6 University Square Mall
North, South Indian and Indian-style Chinese food, served fast.

Curve, 653 S. Park St
Pancakes and American fries for breakfast; hearty sandwiches.

Dancing Grounds Coffee-W. Gorham Street, 315 W. Gorham St

Dardanelles, 1851 Monroe St.
Specialties from all over the Mediterranean, casual atmosphere, excellent food, nightly specials.

Dayton Street Cafe (in the Madison Concourse Hotel), 1 W. Dayton St
Features homemade pastries and bread, a 20-foot salad bar and an award-winning brunch including omelets made to order, chef-carved prime rib, fresh fruit, fresh-baked breads, pastries and desserts.

Dean's Downtown Delicatessen, 116 W. Mifflin St
Sandwiches made to order, soups, chili and salads. The meatball sandwich is a winner. Catering available for any occasion. New indoor seating area.

Dotty Dumpling's Dowry, 317 N. Frances St
They're ba-a-ack! The Overture-displaced dowry has returned to a Kohl-convenient location, with bigger burgers and the same malts, chilis and homemade soups.

Dunn Brothers Coffee, 517 N. Lake
Coffee shop out of the Twin Cities that roasts fresh daily. Pastries, muffins, breakfast and lunch sandwiches, soups.

Echo Tap & Grill, 554 W. Main St
Char-broiled sandwiches and other tavern fare. 5 tacos for $3.25 Thursdays. 19 beers on tap, pool, darts.

Einstein Bros. Bagels, 652 State St
Bagels in traditional and exotic flavors, along with sandwiches, soups, salads, coffee and cookies.

Eldorado Grill, 744 Williamson St.
Western setting, Mexican and Southwestern dishes.

Electric Earth Café, 546 W. Washington
A coffee house serving soups and sandwiches, early morning bakery and late night snacks. Many veggie selections.

Espresso Royale Caffe, 208 State St.
Coffee drinks and pastries plus sandwiches, soups, and salads.

Espresso Royale, 650 State St..
Coffee drinks, pastries, and sandwiches.

Essen Haus, 514 E. Wilson St
German food to satisfy the largest appetites. Over 280 imported beers. Live oompah music every night.

Extreme Pita, 527 State St
Imagine pita as a pizza or a salad, or opt for classic or gourmet versions. With a Smoothie King in the same stand.

Fair Trade Coffee House, 418 State St
Locally roasted beans from Just Coffee and Johnson Brothers, and Equal Exchange roasts, too. Among the edibles: cheesecakes, cookies, bagels, baguettes, bars, fitters, filled croissants and sandwiches.

Firefly, 2701 University Ave.
Pan-asian, with options like potstickers, chicken satay and curry, Chinese barbecue and a beef filet.

Flatiron Tavern, 102 King St
Eclectic pub fare includes chicken tingas, smoked trout sandwich, avocado club sandwich and an excellent clam chowdah.

Fraboni's Italian Specialties and Delicatessen, 822 Regent St
Porketta roasts, fresh Italian sausage and sauces, imported meats and cheeses, soups and homemade sandwiches.

Francie's Casual Cafe, 2424 University Ave. (in the InnTowner)
Breakfast, lunch specials, soups, sandwiches and pasta.

Frida Mexican Grill, 117 State St
Broad menu of contempo Mexican cuisine. Head for the taco locos, carnitas uruapan (slow roasted pork with tomatoes), or the camarones al mojo de ajo, or the tempting desserts.

Fyfe's Corner Bistro, 1344 E. Washington Ave
Pasta, certified Angus steaks and seafood in a casually elegant setting. Variety of wines by the glass. Banquet facility with seating for 30 to 150.

Gaston's, 2105 Sherman Ave
A Cajun and Creole cafe with wondeful gumbo, alligator bits and oyster po' boys. Also on the menu: catfish, shrimp Creole, roast chicken and a creamy cheesecake with bourbon sauce.

Gino's, 540 State St.
Famous for its stuffed pizza. All the Italian favorites, plus burgers. Delivery until 12:30 am.

Ginza of Tokyo, 122 State St
Fine sushi (Cancun roll, dragon roll, unagi) and tempura with other Japanese standards.

Glass Nickel Pizza-Atwood Avenue, 2916 Atwood Ave.
Well known for their specialty pizzas including the Sacre Bleu, Cardiac Arrest, Fetalicious, Santa Fe, and the Vegan Delight. Also pasta, calzones, salads, subs, chicken and fish. New eat-in dining room, two bars (one non-smoking).

Good Day Coffee Shop, 101 S. Webster St
This coffee shop in the GEF 2 building offers tasty bargains like the crispy clam basket, a Monday meatloaf special and Friday's special wraps. Breakfast until 10:15 am; lunch starts at 10:30 am.

Great Dane-Downtown, 123 E. Doty St
Pub fare deluxe: Sandwiches and grilled specialties, plus chicken pot pie and veggie favorites everyone can love, like the "Inner warmth peanut stew." Or fill up on the crazy chicken fingers and pub chips. Up to 14 handcrafted beers on tap.

Greenbush Bakery, 1305 Regent St
Old fashioned homemade doughnut shop with lots of variety -- and kosher, too!

Greenbush Bar, 914 Regent St
Intimate appetizer/wine bar. Italian-style pasta and pizzas are the fare. Scotch and microbrews a specialty.

Grid Iron, 1509 Monroe St
Upscale bar food, try the famous 1/2lb Grid Burger or the buffalo wings.

Guantanamera, 41 S. Butler St
Hearty, filling, dazzling Cuban food, including rice and beans. Fabulous stewed beef, fried plantains. Ladle on the hot sauce. Daily specials and catering available.

Gumby's Pizza, 2825 University Ave
Pizza, Buffalo wings, salads, Pokey sticks and pepperoni rolls. Free delivery.

GumSeng, 1314 W. Johnson St
Soups and Viet specialties. Excellent fried rice, soothing soups.

Harvest, 21 N. Pinckney St
Fancy "slow food" overlooking the Capitol. Maple laquered wild salmon, Black Angus Tenderloin and dramatic desserts. Menu changes seasonally.

Hawk's Bar, 425 State St
Salads, soups, sandwiches, and specials.

Himal Chuli, 318 State St
Excellent Nepalese food, including special vegetarian dishes and lentil soup. Try the lassi, a yogurt drink.

Hong Kong Cafe, 2 S. Mills St
Excellent Cantonese food featuring dim sum Saturday and Sunday mornings. Try the Snow Peas with Triple Mushrooms for a vegetarian treat. Free delivery with $10 minimum order.

House of Wisconsin Cheese, 107 State St
Sandwiches, cheese and UW Babcock Hall ice cream.

Husnu's, 547 State St
Turkish dishes and Italian specialties with fresh fish and daily specials.

Ian's Pizza, 319 N. Frances St
Slices with wildly inventive toppings from mac 'n' cheese to a steak dinner on a textbook-perfect crust.

Jamba Juice, 401 State St.
Fresh fruit smoothies, with yogurts and sorbets. Bread, pretzels and soups.

Jamerica Caribbean Restaurant, 1236 Williamson St
Tiny, homey grocery/restaurant hybrid with spicy jerk chicken that's fall-off-the-bone tender. Curried goat, jerk catfish and a variety of Jamaican sodas and beers. Catering.

Jamie's Cookie Company, 545 State St
Cookies and other home baked goods.

Jimmy John's, 527 State St
Subs from basic to giant gourmet, on whole wheat or French bread.

JJ's, 22 S. Carroll St. (in the Inn on the Park)
American favorites.

Jo's Tazzina, 45 S. Bassett St
Sandwiches, soups, salads, espresso bar, milkshakes, pastries.

Johnny Delmonico's, 130 S. Pinckney St
New York-style steak house with a '30s club feel. Steaks are cut in-house and well-aged. Seafood's great too.

Johnny O's, 620 University Ave
Steaks, martinis and more.

Jolly Bob's, 1210 Williamson St.
Specializing in spicy Caribbean fare, including dishes with Jamaican, Puerto Rican, Trinidadian and Cuban influences. Jerk pork, jerk chicken and grilled fish. Innovative appetizers. Choose from among over 50 rums, 20 top-shelf tequilas and 20 wines. Patio seating, just like the islands.

Kabul Restaurant, 541 State St.
Middle Eastern seafood, lamb, vegetarian and chicken dishes. Summer outdoor seating.

Kennedy Manor Dining Room & Bar, 1 Langdon St
Changing seasonal full menu. Specialties include "Manor Kir," house-cured salmon, risotto, oven-roasted beef tenderloin, osso bucco, chocolate steamed pudding, French wines. Live jazz Thurs. & Fri. nights.

Kimia Lounge, 14 W. Mifflin St.
Rooms from martini lounge to folk club to cigar bar, live music and dancing. Specialty drinks and wine, opulent eats: Lobster, beef shish kebab, quail, rainbow trout.

King of Falafel, 453 W. Gilman St
Very fresh Middle Eastern food, with good salads, falafel and tabouleh. Lamb shwarma, kefta kabob, and the maza veggie sampler platter for two are all enough to make the heart beat faster.

Kitchen Hearth, 114 E. Main St
Popular lunch takeout place, with several soup specials daily (look for the Reuben, and the African Chicken), salads, sandwiches, hot entrees, and an array of hard-to-pass-up pastries and desserts. Catering.

Kollege Klub, 529 N. Lake St
Hearty breakfasts, lunches and dinners served to a mostly campus crowd.

L'Etoile, 25 N. Pinckney St
Nationally recognized restaurant, featuring locally grown ingredients. A first-rate dining experience with a view of the Capitol.

L'Etoile Market Cafe, 25 N. Pinckney St
A cafe featuring coffee, croissants that melt on the tongue, including a standout apple version and pain au chocolat, gougeres and farm eggs. Come early for best selection.

La Hacienda, 515 S. Park
An authentic Mexican restaurant serving everything from tripe soup to pozole, sopas and tacos too. Outdoor patio.

Lakefront on Langdon Restaurant, UW Memorial Union, 800 Langdon St
Pizza, casseroles, chicken, fish, and of course fudge bottom pie.

Lava Lounge, 461 W. Gilman
Different lunch specials every day.

Le Chardonnay, 320 W. Johnson St
New lunch menu with sandwiches (including Croque Monsieur), five pastas and eight tempting salads. Dinners feature fish, chicken, boeuf bourguignon, New Zealand lamb and duck ravioli.

LMNO'Pies, 817 E. Johnson St
More like mmmmmmm' pies. Fruit pies, meat pies, pasties, cookies, cheesecake, brownies, muffins, all made from scratch, dine in or take home. Astounding array of possibilities on the menu, from a Rhuberry and Peppery Sweet Potato to a Sausage & Hashbrown Breakfast Pie.

Lombardino's Restaurant, 2500 University Ave
Upscale Italian takes over a Madison favorite. Menu changes seasonally.

LuLu's Deli and Restaurant, 2524 University Ave
Madison's oldest Middle Eastern restaurant. Authentic Arabic lamb, chicken and beef dishes; appetizers including hummus, tabouli and babaganoush; couscous, kabob, moussaka and spinach pie are daily specials.

Madison's, 119 King St.
Hamburgers, sandwiches, plus fish and steak dinners.

Main Depot, 627 W. Main St
Bar food, burgers, fried curds, steak sandwich.

Marigold Kitchen, 118 S. Pinckney St
Personal touches abound at this busy breakfast/lunch bistro. Twists on breakfast and lunch, with chili-poached eggs, French toast drizzled with pastry cream and fresh berries, hearty sandwiches, salads and soups.

Mediterranean Cafe, 625 State St
One of lower-State Street's undiscovered treasures. Emphasis on Middle Eastern and Mediterranean specialties.

Mekong, 600 Williamson St
Vietnamese and Thai cusine, with standout options like kung namdeng and beef larb.

Memorial Union Daily Scoop Deli, 800 Langdon St
Grab-and-go cold sandwiches, soup, chili, salads, snacks, fresh bakery, gourmet coffee and famous Babcock ice cream! Plus Daily Deli Deals.

Memorial Union-Brat Stand, 800 Langdon St
"Cool at the Union" means The Terrace. Wisconsin favorites including bratwurst, burgers, and corn on the cob hot off the grill! Wide selection of cold beverages including soda, lemonade, beer & locally brewed Rathskeller Ale (University ID or WI Union Membership & proof of age required). Live music and incredible lake view.

Mercury Cafe, 117 E. Mifflin
Pastries in the morning, followed by sandwiches like ham, muenster and kraut on multigrain and prosciutto on a baguette. Plus soups, salads and deli items.

Michelangelo's Coffee Shop, 114 State St.
Coffee, sandwiches, deserts, pastries and comfy reading corners. The veggie wrap, with lentils, rice, and hummus, is a keeper, and a rock-bottom bargain to boot.

Mickies Dairy Bar, 1511 Monroe St
A Madison must, a classic you usually only find in small towns. Pancakes, homemade coffeecakes and pies, cheeseburgers and real malts.

Milio's, 504 University Ave
Great sandwiches and subs for vegetarians and meat-eaters alike. Skinnys, roll-ups, and party subs.

Nadia's, 508 State St.
Traditional French Provencal menu. Coq au vin, bouillabaisse, veal chops Normande, chicken Amaretto and roasted lamb. Desserts made daily in-house.

Nam's Noodle, 1336 Regent St
Diner specializing in Vietnamese noodle soup called pho, which the adventurous among us can order made with fatty flank, tendon, or tripe. Or stick with the excellent vermicelli bowls.

Natt Spil, 211 King St
New dishes every week, but you might find thin-crust pizza, a must-eat pork sandwich, or an exceptional hoagie.

New Orleans Take-Out, 1517 Monroe St
Eat mo' bettah! Tasty Creole cuisine to bring home and enjoy. Barbecued shrimp, shrimp etouffee, fried oysters and catfish. Finish with a heavenly slice of sweet potato pecan pie.

Nick's Restaurant, 226 State St
Longtime downtown favorite with something for everyone, featuring Greek specials such as spinach pie and vegetarian gyros.

Nitty Gritty Restaurant and Bar-Frances St., 223 N. Frances St
The burgers, with legendary Gritty Sauce, are huge. So are the sandwiches. The place to celebrate birthdays. Outdoor patio seating.

Noodles & Co., 232 State St
A noodle deli, featuring hot and cold dishes from Japanese pan-fried to mac 'n' cheese.

Oakcrest Tavern, Regent Street, 1421 Regent St.
A real American menu: hamburgers, deli sandwiches, BLTs and salads. Full dinner menu includes grilled chicken, steak and seafood specials. Fish fry on Wed. and Fri.

Ocean Grill, 117 Martin Luther King Jr. Blvd
High octane wine list and a wide range of seafood entrees. Standouts: Salad Nicoise, sea bass, jambalaya.

Opus Lounge, 116 King St
The menu at this hip lounge features a transglobal smorgasbord of small dishes. Also serving fine wines, and a variety of champagne and desserts.

Orpheum Theatre's Grand Lobby, 216 State St
Grand movie palace atmosphere, inventive cuisine. Brunch includes French toast, made-to-order omelets, and eggs Benedict. Friday fish fry is blue gill.

Ovations, 1 W. Dayton St.
Features contemporary Midwestern cuisine and seasonal ingredients. Tempters include pumpkin-gorgonzola ravioli, walleye, ahi tuna, and an elk striploin, plus pork tenderloin and filet mignon.

Paisan's, 80 University Square
Italian dishes featuring the classic Garibaldi sandwich, homemade pasta and thin-crust pizza.

Papa John's Pizza, 515 University Ave
Pizza, bread sticks and cheese sticks. Free delivery.

Papa Phil's, 2611 Monroe St
An Italian neighborhood restaurant with old-world charm and standout meatball sandwich, calimari, seafood pasta dishes and build-your-own pastas.

Paradise Lounge, 119 W. Main St
Burgers, sandwiches, brats and fries. Noon-hour specials for the lunch crowd include meat loaf, enchiladas, and Friday fish fry.

Parkway Family Restaurant, 1221 Ann St
Breakfast all day, sandwiches, fish fry, desserts.

Parthenon Gyros, 316 State St
Variety of Greek dishes, heaping portions. Open-air dining, weather permitting, on the second floor.

Pasqual's Southwestern Deli, 2534 Monroe St
Burritos, quesadillas, tacos, enchiladas, tamales, blue corn bread, fresh guacamole and salsa every day.

Pavlov's Pizza, 1511 Williamson St
Mouth-watering pizza. Carryout only.

Pelmeni, 505 State St
Dumplings, just dumplings. Specifically small, round Russian dumplings filled with potato or sirloin, served with sour cream or a spicy red curry sauce. What the place lacks in menu choice it makes up for in yummmmm.

Peppino's Restaurant, 111 S. Hamilton St
Elegant Italian dining; try the veal florentine or the seductive lobster special. Extensive wine list.

Pizza Di Roma, 313 State St
Specialty pizzas including the spinach or the capricciso.

Pizza Extreme, 605 E. Washington Ave
Great stuffed pizza, fresh salads, gumbo, sandwiches and pasta. Try the jumbo-sized cheese-filled ravioli with pesto sauce. Free delivery with minimum order.

Pizzeria Uno, Gorham Street, 222 W. Gorham St
Good variety of Chicago-style deep-dish pizzas, "express" lunch specials, fresh salads, pasta dishes, delish burgers and even baby back ribs and steaks. Carryout and limited delivery available.

PJ Muellers, 1200 Main St.
Highly recommended Friday fish fry (haddock), pork schnitzel, corned beef and cabbage, and prime rib. Good food, large portions and modest prices.

Plaza Tavern & Grill, 319 N. Henry St
Home of the famous Plaza Burger and famous secret sauce. Grilled sandwiches, fries and malts.

Porta Bella, 425 N. Frances St
A famed romantic spot with Italian cuisine, pizza and ice cream drinks, plus a wine bar serving hors d'oeuvres.

Portal Music Cafe, 310 S. Brearly St
Live Music Venue/Sicilian restaurant. 100 person live music venue with food served 5:30 until 12:30 Monday through Saturday.

Potbelly Sandwich Works, 564 State St.
Yummy hot subs. You'll be back.

Public House, 680 W. Washington Ave
All-American cuisine, big salad bar, outdoor dining, 16 beers on tap.

Qdoba, 548 State St
A multitude of unusual options for Mexican: tacos and burritos with mix-and-match salsas. Veggie options include a spicy grilled vegetable burrito.

Quizno's Subs-Pinckney Street, 5 N. Pinckney St
A varied selection of oven-baked subs, as well as soups, salads and desserts.

Real Chili, 449 State St
Milwaukee venerable chili haven opens an outpost in Madison. Dry, chili-intense meat is mixed with your choice of spaghetti, beans, or spaghetti and beans, with onions, cheese and sour cream available as add-ons. Also available: veggie chili, chili dogs, tacos and fries.

Regent Street Retreat, 1206 Regent St
Burgers and fries, fried curds, onion rings, fish sandwich, French dip, brats, BLT, and Buffalo wings; eat 'em all in the flickering glow of the 150" projection TV.

Relish Deli, 1923 Monroe St
Out-of-the-ordinary sandwiches and salads, as well as imported and domestic meats and cheeses.

Restarante Mexicano, 2524 E. Washington Ave
Real Mexican -- tamales, enchiladas, burritos and even barbecued lamb.

Restaurant Magnus, 120 E. Wilson
A dramatic, vaulted dining room in warm, rich colors enhances this South American-flavored fine-dining restaurant. Music stage with Latin jazz and jazz. Live music 7 days a week. Extensive wine list, including wines from Argentina and Chile.

Restaurant Muramoto, 106 King St
Sushi and sake in a minimalist pan-Asian bistro. Excellent rolls, Asian lamb stew, salads and even desserts. All lunches $9.

Rising Sons Deli, 7 University Square
A small Laotian/Thai restaurant, with some ready-to-go options lending it the "deli" moniker. Interesting menu, with the Lao soup Kao Poun, laab with tripe, keng phet and Pa Priau Vaan, a deep-fried catfish in spicy sauce. Plus sticky rice, steamed buns and rolls, and a larger-than-usual slate of Asian desserts.

Rory's Casual Cuisine, 101 E. Main St.
International fine dining in restored historic, 19th century hotel. Features Continental, French, Italian, with an extensive beer and wine selection.

Sa-Bai Thong-University Avenue, 2840 University Ave
Thai food, featuring curries, noodle dishes and stir-fries. Try the seafood Poy Sien Song Krung.

Saz, 58 State St
Kebabs, hummus, salads, pizza and Mexican dishes.

Scott's Pastry Shoppe-Main St., 17 W. Main
Full-servuce bakery with cakes, pies,, donuts, pastries, cookies, tortes, eclairs, and breads, also serving lunch -- cold sandwiches, hot panini, three daily soups and chili.

Shamrock Bar, 117 W. Main St
Chicken and fish sandwiches as well as burgers, plus lunch specials

Simply Soup Co., 116 Martin Luther King Jr. Blvd
12 soups available daily. Experiment with the BLT, dill pickle, or stick with hearty herbed chicken & lentil or Door County beer and cheese.

Smoky's Club, 3005 University Ave.
A Madison tradition, serving outstading steaks in a bustling atmosphere. Limited reservations.

Starbucks-State Street, 661 State St.
A wee bit of Seattle right here in Mad Town.

State Bar and Grill, 18 State St
A lively bar with good soups, burgers, sandwiches and beer. Daily specials.

State Street Brats, 603 State St
Second floor with view of State Street. Satellite sports and a huge menu selection for the entire family; full bar with a microbrew selection.

Steep & Brew-State Street, 544 State St.
The aroma of coffee and freshly baked pastries gets your attention. Dessert coffees, pastries and fruit juices.

Stillwaters, 250 State St
Appetizers, sandwiches and salads. Nightly dinner specials.

Subway, 462 State St
Subs at great prices.

SukhoThai Restaurant and Deli, 1441 Regent St
Gourmet Thai cuisine with some spicy-hot specials as well as mild dishes. Vegetarian menu available. Also offers catering and cooking classes.

Sunprint on the Square, 1 S. Pinckney St
Breakfast features omlettes made with fresh eggs and a hearty huevos rancheros. For lunch, sit-down or grab-n-go sandwiches, soups and salads and excellent homemade baked goods and pastries. Don't miss the cinnamon buns and pecan rolls.

Sunroom Cafe, 638 State St
Cozy upstairs cafe serving well-made sandwiches, salads, soups and tempting pastries. Full dinner menu of fresh pasta and ethnic dishes from around the world. Also vegetarian dishes.

Takara, 315 State
Fine miso soup, tempura, and sushi.

Tokyo Express, 617 State St
Fast Japanese food.

Tornado Club, 116 S. Hamilton
Classic supper club atmosphere with a contemporary twist featuring top-notch steaks, also specialties such as pork tenderloin, venison and seafood. Chicken dinner on Sunday.

Tropic-A-Juno, 239 E. Main St
Jamaican comes to Sun Prairie, with midwestern touches like walleye along with standard jerk and curry dishes.

Tutto Pasta Cucina Italiana, 107 King St.
Spin-off of State Street's Tutto Pasta features a mind-boggling array of pasta in the old Clay Market space. A "sidewalk cafe" in the King Street atrium allows sidewalk dining even in the dead of winter.

Tutto Pasta Trattoria, 305 State St.
This is the place for pasta, with 40 varieties including conchiglie, penne, capellini, fettuccine, fusilli, rigatoni, with an excellent linguine alle vongole verace. Dinner is served into the wee hours of the night.

UW Memorial Union Rathskeller, 800 Langdon St.
A campus tradition with German murals of student life. Featuring quick-serve grilled specialties, Paul Bunyan burgers, Mexican entrees, soups, salads, sandwiches, and the Union's famous fudge-bottom pie.

Vientiane Palace, 151 W. Gorham St
Great Laotian and Thai food.

Vintage Bar & Grill, 529 University Ave
Fun food for the bar crowd. Sandwiches, salads, pastas, burgers, chili in a bread bowl, even tuna casserole. After 10 pm, snack menu only: deep-fried onion rings, catfish tenders, Southwestern olives, nachos.

Wando's, 602 University Ave.
Soups, sandwiches, gigantic burgers and chicken sandwiches, and a Friday fish fry.

Wasabi Japanese Restaurant and Sushi Bar, 449 State St
Over 40 kinds of sushi along with tempura, udon and teriyaki.

White Horse Inn, 202 N. Henry St
A popular downtown gathering place with a well-stocked Sunday brunch. Bistro menu for lighter entrees and the regular White Horse menu featuring fresh fish and steaks. Happy hour 4-7 pm Mon.-Fri with 10-cent shrimp and drink specials.

Willalby's Cafe, 1351 Williamson St
Diverse menu, from omelets to burgers, plus many vegetarian dishes.

Willy Street Co-op, 1221 Williamson St.
Hot entrees like the tasty chicken mole burrito, fresh organic salads, grab-and-go dips, sandwich and juice bar.

Yummy Buffet, 411 W. Gilman St
An all-you-can-eat Chinese buffet for $5! You can afford fall semester after all

Map of Madison – Campus Area

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