Report on the
IInd ESF Summer Symposium
“Neuronal Plasticity and Dynamics”

September 2-4, 2000
Trieste ITALY

Compiled by [1]Mathew E. Diamond, [2]Misha Tsodyks (symposium organizing committee)
& [3]Rodney Douglas (network coordinator)
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INTRODUCTION

For the second consecutive year, the ESF Summer Symposium on Neural Computation and Neuroinformatics was held on the Miramare campus of the International Centre for Theoretical Physics, overlooking a quiet harbor of the Gulf of Trieste. A total of 40 neuroscientists registered for the symposium (23 invited speakers and 17 junior participants), although the real number in attendance totaled approximately 60. Others who participated, although not registered, included (a) neuroscience faculty members, postdocs, and PhD students from the adjacent International School for Advanced Studies (*ISAS*), (b) students from the European School of Computational Neuroscience who elected to remain at the symposium rather than take a weekend vacation, and (c) faculty members and tutors of the above Computational Neuroscience School.

This report concerns mainly the scientific program of the symposium; significant delays in accounting by the administration prevent us from presenting the full financial accounting of the meeting at this time.

Background and Goals of the Symposium

The ESF Network on Computational Neurosciences and Neuroinformatics was established to promote the education of young scientists and to facilitate the interaction and collaboration of senior scientists, predominately in Europe. The Network aims to bring together scientists with different approaches to neural computation.

The Organizers would argue that many of these aims have been met by the first two installments of the Symposium. Young neuroscientists, most but not all of them European, were sought out as participants. These are referred to here as “junior participants,” and they numbered 17. Of these, 15 (88%) were from Europe. The “training environment” was enriched by the presence of 23 more experienced and established computational neuroscientists, who participated as either lecturers or discussion leaders. Of these, 17 (74%) were based at European research institutions.

Beyond satisfying, by and large, the geographic objectives, the symposium seemed to present an appropriate blending of neuroscientific approaches. Computational neuroscience and neuroinformatics are hybrid fields. Those trained purely in physics and informatics on one side, or systems neurophysiology on the other side, can be expected to become competent *computational neuroscientists* only when they have engaged, within their own research, the opposite side of the spectrum. Thus, the symposium organizers believe that European training in computational neuroscience and neuroinformatics will be best advanced by facilitating an interaction among the “pure” fields which are components of the mixture. Putting this into practice, the meeting hosted neuroscientists of systems neurophysiological extraction who demonstrated how biological research can be based upon the incorporation of computational methods (an example is Moshe Abeles’ attempt to detect firing patterns related to behavioral events), as well as neuroscientists of informatics extraction who demonstrated how state-of-the-art computational methods can be readily applied to biological problems (an example is Tali Tishby’s development of sophisticated and fast informational analysis methods).

Conversations with the junior participants indicated that presentation of the spectrum of neurocomputation and neuroinformatics had a beneficial effect, inasmuch as they returned to their home laboratories with a better understanding of how to carry out research in computational neuroscience and neuroinformatics. For instance, one postdoc described a new insight into the application of information analysis to visual receptive field structure. Another postdoc mentioned that he had a new understanding of the constraints that must be applied to neural network hardware to make it biologically realistic.

Organizers

The program of the meeting was organized by Mathew E. Diamond of the Cognitive Neuroscience Sector at the International School for Advanced Studies and Misha Tsodyks of the Neurobiology Department at the Weizmann Institute. Henry Markram (Weizmann Institute) withdrew from the organizational process early on. The development of the program was overseen by Rodney Douglas and Alessandro Treves, Network members. Although both organizers gave opinions concerning the full range of the symposium, they tended to concentrate on areas closest to their own research: M.E.D. was particularly involved in the systems and large-scale neurocomputation aspects of the symposium, while M.T. was particularly active in planning the cellular-synaptic and theoretical neurocomputation aspects.

Selection of speakers & recruitment of junior participants

As mentioned above, the selection of lecturers was intended to represent current advances in the computational investigation of neuronal plasticity and dynamics. Three principle problems were identified and the leading investigators in those areas were sought: (i) Neuronal basis of dynamics and plasticity in brain *(S.Fusi; K.Pawelzik; T.Sejnowski; S.Rotter; M.Rabinovich*); (ii) Population dynamics at the level of localized networks (*M.Carandini; Y.Freqnac; H.Sompolinsky; M.Abeles; M.Tsodyks; T.Tishby*); (iii) Large-scale processing (*S.Ullman; A.Villa; T.Kenet; S.Thorpe; D.Kleinfeld; M.E.Diamond; R.Romo*). These broadly defined areas then became the subtitles of the three sessions of the symposium, but the borders between the sessions of the symposium were not rigid.

Of those originally contacted, only four of those invited as lecturers declined to attend.

A few of the lecturers (e.g. T.Sejnowski, H.Sompolinsky) were selected among the faculty members of the ongoing School of Computational Neuroscience because their current research was seen as harmonious with the main focus of the symposium. Other senior participants provided their own financial support to attend the symposium (i.e. E.Rolls, R.Kessner, and S.Mizumori).

“Junior participants” were also sought for the symposium – their contribution is, in fact, the very justification of the symposium. Potential junior participants were contacted (a) through the website of the Summer Institute of Computational Neuroscience (hosted by ISAS), (b) through computational neuroscience internet newsletters, (c) through announcements at computational neuroscience meetings, such as the springtime Seville meeting, and (d) through “word of mouth” networks of computational neuroscientists. We recognize that a more systematic approach to reaching younger researchers will be of benefit to future symposia.

Those selected as junior participants for the symposium generally were researchers early in their careers, commonly 30-35 years old, who expressed to the organizers a strong and rational motivation for their participation. Others included cellular neurophysiologists (e.g. G.Kemenes) or quantitative neuroanatomists (e.g. R.Kotter) who indicated that they could realize a substantial gain from being exposed to new neurocomputational approaches. The specific roles of the junior participants were (1) to participate actively in discussion sections and (2) to present a poster.

Format of the meeting

Every symposium faces the choice between offering a larger number of short presentations or else a shorter number of full-length presentations. The organizers chose the second type of format, allotting 50 min for each presentation (lecture + discussion); this was judged to be the most effective way of communicating with the younger computational neuroscientists.

The symposium began at 10.00 Saturday morning, September 2nd. Rodney Douglas gave brief introductory remarks concerning the goal of the ESF Network on Computational Neurosciences and Neuroinformatics. Session 1 (*Neuronal basis of dynamics and plasticity in brain*) began immediately thereafter and continued through about 16.30 in the afternoon. A general discussion took place until 17.00, followed by an informal poster session that carried on until around dinnertime (posters remained on display throughout the symposium). Session 2 (*Population dynamics at the level of localized networks*) began at 9.00 on Sunday morning, and continued through 16.30 in the afternoon. Again, a half-hour general discussion was held until about 17.00, and this was followed by a second poster presentation period. Session 3 (*Large-scale processing*) was held from 9.00 Monday morning until 17.20 in the afternoon, and was followed by a general discussion until about 18.00.

PARTICIPANTS

List of <u>speakers</u>, <u>senior participants</u> and <u>junior participants</u> and their coordinates

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University of Utah

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Oxford, UK

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México,

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Institut de Physiologie
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Lausanne, Switzerland,

Geographic breakdown

Speakers and Senior Participants (23)

EC (7)
[1]Mathew E. Diamond (Italy)
Yves Fregnac (France)
Wolfgang Maass (Austria)
Klaus Pawelzik (Germany)
√Edmund Rolls (UK)
Simon Thorpe (France)
√Alessandro Treves (Italy)

Rest of Europe (10)
Moshe Abeles (Israel)
Matteo Carandini (Switzerland)
Rodney Douglas (Switzerland)
Stefano Fusi (Switzerland)
Tal Kenet (Israel)
Haim Sompolinsky (Israel)
Naftali Tishby (Israel)
Misha Tsodyks (Israel)
Shimon Ullman (Israel)
Alessandro Villa (Switzerland)

USA (5)
√Ray Kessner (Salt Lake City, UT)
David Kleinfeld (La Jolla, CA)
√Sheri Mizumori (Salt Lake City, UT)
Misha Rabinovich (San Diego, CA)
Terry Sejnowski (La Jolla, CA)

Other (1)
Ranulfo Romo (Mexico)

√ No costs incurred to ESF

Geographic breakdown (continued)

Junior Participants **(17)**

EC (11)

- Matthias Bethge (Germany)
- Simone Cardoso de Oliveira (Germany)
- [√]Valeria Del Prete (Italy)
- Michele Giugliano (Italy)
- Georges Kemenes (UK)
- Irina Kopysova (France)
- Rolf Kotter (Germany)
- Stefan Leutgeb (Germany)
- Jenny Read (UK)
- Inès Samengo (Italy)
- Simon Stringer (UK)

Rest of Europe (4)

- Lubica Benuskova (Slovakia)
- Galit Furhmann (Israel)
- Anna Gribova (Israel)
- Rony Paz (Israel)

USA (1)

- Alex Guazzelli (Seattle, WA)

Other (1)

- Thomas Trappenberg (Japan)

[√] No costs incurred to ESF

THE SCIENTIFIC SESSIONS:

Summaries and discussions of selected presentations, garnered from the notes of the junior participants

Session 1: Neuronal basis of dynamics and plasticity in brain

Stefano Fusi presented an analysis of a hardware device which is intended to shed light on the limitations and efficiency of memory storage in a network. He argued that learning must be stochastic and controlled by an internal synaptic threshold. The threshold is required to "protect" against the effects of spontaneous activity, which can dominate a network in the intervals interposed between stimuli. Stochastic processes imply that synaptic efficacies, on long time scales, must be discrete. Stochasticity was argued as a mechanism to slow down learning, allowing for a better redistribution of the memory resources across the synapses. Experiments in association cortex were pointed to as evidence that learning is particularly slow, which implies small transition probabilities for synaptic transitions. (Though discussants found it difficult to compare learning rates in the real brain with those in hardware models – the timescales are not self-evident.) Such small transition probabilities can be achieved by exploiting the variability in interspike intervals, an outcome of the collective dynamics of the network. The statistics of pre and post synaptic activity thus control learning and forgetting rates without requiring any change in the inherent time constant of the synaptic device.

Misha Rabinovich discussed the role of the nonlinear dynamics of neurons and synapses for information transmission in the following basic neural network: sensory input-synapse-neuron1–synapse-neuron2-output. Using both the methods of nonlinear dynamics and classical information theory (where the parameters depend on average mutual information) Rabinovich showed that: (1) The information transmission depends on encoding and synaptic dynamics; different neurons or/and different encoding need different kinds of dynamical synapses which are able to maximize information transmission; (2) Spiking-bursting neurons and dynamical synapses are able to recover information which can be hidden at the first step of information transmission; (3) Information recovery depends on synaptic strength, which is able to change the cooperative neural dynamics qualitatively and, in particular, produce neuronal synchrony. Synchrony of neuronal discharge completely blocks the recovery of hidden information.

In the General Discussion section, K. Pawelzik asked whether there is any role of neural dynamics in predicting behavior. He worried that in fact, only a few people take time into account. M.Abeles stressed that, in fact, when you find the correlation coefficient between, let us say, the neuronal response and execution of movement to be 0.87, what does it really say? E.Vaadia said that from the time course of the responses being built up in the premotor cortex, he can predict when the execution of movement will actually happen. He can make this prediction already at the beginning when this activity starts to build up. Asked whether there is any adaptation of time and speed during learning of the task, M.Tsodyks pointed out that we can study dynamical attractors which allow us to make predictions. But the crucial question is then how the attractors themselves adapt during learning the task.

Meanwhile stimulated perhaps by S.Rotter's and K.Pawelzik's argument for the importance of spike timing, A.Treves opened up a debate by wondering whether that people are taking time *too much* into account. Selecting just one function hypothesized to depend crucially on spike timing, Treves focused his critical gaze on synaptic modification. He referred to the experimental data which some investigators, most notably L. Abbott, take as proof that different time windows between pre- and postsynaptic spikes in cerebral cortex determine the sign of synaptic potentiation – either LTD and LTP. For instance, H.Markram et al. showed that when the postsynaptic spike occur 10 ms after the EPSP, then the LTP follows, whereas when the postsynaptic spikes precede the EPSP by 10 ms, then LTD is the outcome. Treves questioned whether one-spike-pairing-with-EPSP data may be at all relevant. Many processes are occurring at synapses with different timescales. The modification at a single synapse may be related to the timing between the EPSP-induced Ca2+ influx and the Ca2+ influx induced by the back-propagating postsynaptic spike(s). The timing may be important for this process, but the question remains whether one spike can make a difference. An additional note of cynicism was raised regarding the relevance of all *in vitro* slice data to synaptic modifications, since these preparations lack all the neuromodulators present *in vivo.* S.Thorpe took a more "system-like" approach, with less emphasis given to single synapses. For instance, in a system that oscillates at 40 Hz, a set of neurons that leads it postsynaptic neurons may be a "winner."

Session 2. Population dynamics at the level of localized networks

M.Carandini discussed the dynamical representation of contrast in primary visual cortex. Cells in the primary visual cortex are of two types, simple and complex. The subject of this talk was the quantitative models of simple and complex visual responses. For simple cells, models of the visual responses are quite successful. Such models derive from the linear model developed in the late 70s, and from the divisive gain control model developed in the early 90s. A divisive gain control model gives rise to an equation that is very accurate in describing visual responses, but at the moment lacks a firm biophysical explanation. (The discussants queried how such models deal with the diversity of specific response properties present in real neurons). Proposed biophysical explanations rely on one of two mechanisms. The first mechanism results from intracortical feedback, and is based on shunting inhibition. The second mechanism is feedforward, and relies on synaptic depression. Carindini argued that both mechanisms could be at work, but shunting inhibition is more consistent with the available real neuronal data. On the other hand, for complex cells, the classical model is largely inadequate to describe the visual responses.

M.Abeles then presented experiments concerning the timing accuracy of cortical neurons. His laboratory has examined the time accuracy of cortical activity by jittering the spike trains and examining the effect on the statistics of neuronal firing. The activity of several single units was recorded in parallel from motor areas of behaving monkeys while they were scribbling freely in 2D. The motion was parsed into strokes and those were classified into 12 categories. (Incidentally, many members of the symposium were impressed by what had been accomplished simply by the parsing algorithm). Recording time was divided into epochs around each of these strokes. All the data from each type of epoch was analyzed together by constructing three fold correlations among triplets of single units. These correlations were constructed as histograms comprising 100x100 bins of 1, 2, or 3 ms each. For each bin the probability of seeing a given number of counts in the bin, given the counts in its neighboring bins, was computed. Two statistics were extracted from these correlations: (1) The density of these probabilities as derived from the correlations of all the available data in each state; (2) The probability of the least likely event in each correlation histogram. For both types of statistics Abeles got values which are far beyond what is expected by chance. Validation of the significance of these statistics was confirmed by the method of Bienenstock, Date, and Geman. According to their approach, the null hypothesis to be tested is that the spike trains do not have any accuracy beyond some value W. If so, then jittering each spike within a window of W ms should not affect the statistic derived from the spike trains. The data is then jittered 100 times and a histogram of the derived statistic is constructed. If the statistic of the real data is well outside this histogram then the null hypothesis may be rejected. According to this test, the accuracy of cortical firing was well below 2 ms. How can such accuracy be generated in the noisy cortical mesh of weak connections? There is no clear answer to this question, but Abeles would like the answer to be that synfire chains are responsible for the accuracy.

Session 3. Large-scale processing

T.Kenet presented interesting results concerning single neurons and the dynamics of population activity in cat visual cortex. Real-time optical imaging using voltage-sensitive dyes was combined with simultaneous recordings of single unit activity in area 18 of the visual cortex of anesthetized cats, to answer three main questions. First, knowing that spontaneous activity is of the same order of magnitude as, and has a strong effect on, evoked response, the investigators wondered what drives a neuron to fire spontaneously. It turns out that the probability for a neuron to fire spontaneously at any instant can be predicted by the corresponding state of the population activity in a large area surrounding the neuron. This state, in turn, corresponds to the functional map obtained using the neuron's optimally oriented stimulus. This finding then raised several other questions. If intrinsic states of activity are indeed present in spontaneous activity, what are the dynamics governing these states, how often do they occur, how they arise, etc. Analysis of the data revealed that a state that corresponds to orientation selectivity may occur about 20% of the time. A state often rises in full (namely, when patches corresponding to this state are visible over most of the imaged area, of 3-5 by 3-5 mm), and may remain for around 100 ms, or may alternatively switch to the state which corresponds to the adjacent orientation. Finally, the influence of the interaction between feedforward and recurrent inputs on the response of a neuron driven by a visual stimulus, is another intriguing question. Looking at the evoked response of single neurons versus the evoked response of the population, Kenet’s lab found that, on average, the first spike in response to optimal visual stimuli occurs before the orientation map emerges. Were there strong recurrent connection at play at this time we would expect to see the map. Yet, the first spike is well tuned for orientation. Hence, it is most likely that the early spikes are mostly the result of feedforward connections. Later spikes, when the orientation map is already present, could result from both feedforward and recurrent connections.

Turning from the visual to the tactile modality, D. Kleinfeld addressed coherent signaling along the vibrissa sensorimotor loop in rats during exploratory whisking. The vibrissa sensorimotor system consists of nested feedback loops. Kleinfeld discussed the nature of neural flow along these loops, with a focus on signals that are required for the animal to determine the absolute position of the vibrissae upon contact with an object. Data were obtained from animals trained to whisk in air in search of a food reward. In this task, animals whisk for bouts that are 2 to 4 s in length. The whisking frequency is relatively constant within a bout, with peak occurrences at 7 and 10 Hz, but varies in frequency between bouts. To assess the global coherence of signaling, the spatially coherent activity was measured along three pathways, the vibrissa area of cerebellum (hindbrain loop), the primary vibrissa area of sensory neocortex (forebrain loop), and the hippocampus (limbic loop). Kleinfeld observed broadband oscillations (5 to 10 Hz and 15 to 20 Hz) in the motion of the vibrissae, as detected via the mystatial electromyogram (EMG), that were phase locked with the cortical and cerebellar differentially recorded local field potentials (∇LFP), and the hippocampus theta-rhythm. The vibrissa input modulated only a small faction of the cortical and cerebellar activity in the alert animal, 6 to 10 %, but the internal activity between vibrissa areas of neocortex and cerebellum, and the hippocampus, were highly phase-locked. To assess the nature of a reference signal of vibrissa position, Kleinfeld measured the correlation between the single unit signal in primary vibrissa (S1) cortex and the EMG. On average, 10 % of the spiking output by a neuron was modulated by rhythmic movement of the vibrissae. Critically, for some units the extent of modulation was sufficiently deep and the overall spike rate was sufficiently high so that the position of the vibrissae could be accurately predicted on a single trial basis. To assess the nature of sensory flow into motor areas at the level of cortex, the laboratory measured single unit activity in primary motor (M1) cortex of awake but restrained animals. In response to rhythmic sensory input between 1 and 20 Hz, the spike rate was modulated at the ~ 10 % level, largely independent of frequency. This result shows that the rapid change in vibrissa position is transmitted to motor areas for possible motor control of vibrissa position. To assess the ability of M1 cortex to control the vibrissae, periodic, microinjected currents were delivered to M1 cortex, and the resulting vibrissa movement was measured. In alert animals, stimulation led to motion at normal whisking frequencies. In contrast, this effect is blocked with animals in the sessile or anesthetized state. To assess the nature of signaling at the level of the lateral facial motor nucleus (FN), whose output directly drives the mystatial musculature, Kleinfeld measured the electrical filtering in single neurons in a slice preparation. Neurons in the FN integrate input from cortical, collicular, and trigeminal centers. These cells exhibited an electrical resonance near 10 Hz, close to the natural whisking frequency. This results shows that the motor pathway rejects internal signals that lie outside the range of normal whisking. In conclusion, the cortical sensorimotor loops have reliable information on vibrissa position and can reliably control vibrissa position. The transformation of sensory input to motor control of the vibrissa, and behavior choice by the animal in response to stimuli, remain open issues.

Remaining in the tactile modality, R.Romo asked the fundamental question: are the cortical neuronal responses associated to the stimuli causally related to perception? He investigated this in monkeys trained in a discrimination task. Two vibratory stimuli of 500 ms were sequentially delivered, separated by a variable interstimulus interval; the monkeys had to indicate, by pressing one of two push-buttons, whether the frequency of the second stimulus was higher or lower than the frequency of the first stimulus. Extracellular recordings were made from primary somatosensory cortex (S1) during performance of the task. Neurons with quickly adapting (QA) properties were significantly phase-locked to the mechanical stimulus wave form. These responses typically showed moderate increases in their mean firing rates for increasing stimulus frequencies. These results suggest that, for a population of S1 neurons, stimulus frequency can be read-out or extracted from either the timing of the action potentials, due to the phase-locking, or from the mean firing rate at which these are produced for different stimulus frequencies. Romo tested the possibility that these neurons are directly involved in the perception of the mechanical vibrations by computing neurometric functions using both the periodicity and the firing rate, and then determining which of these two measures is associated with the psychophysical performance. It turns out that neurometric thresholds based on the firing rate are very similar to the animal's psychometric thresholds whereas neurometric thresholds based on periodicity are far lower than those thresholds. These results indicate that an observer could solve this task with a precision similar to that of the monkey, based only on the firing rate produced during the stimulus periods. The next set of neurons inserted microelectrodes into clusters of QA neurons of S1, and the first or both stimuli were then substituted with trains of current pulses during the discrimination task. Psychophysical performance with artificial stimulus frequencies was almost identical to that measured with the natural stimulus frequencies. The results indicate that microstimulation can be used to elicit a discriminable analog range of percepts, and shows that activation of the QA circuit of S1 is sufficient to initiate all subsequent neural processes associated with vibrotactile discrimination.

In General Discussion, E.Rolls first referred to the talk of M. Tsodyks, who theoretically demonstrated that the sustained neuronal rates in cortex require synaptic depression. For instance, other models without it, possess jumps in the mean rates. The comment has been made that all these models do not incorporate the role of neuromodulators like, for instance, ACH which is known to reduce LTD. The second point made by E.Rolls was related to the finding that the neural code (whatever it is) can be read in about 20 ms for instance at one stage of the visual system. A.Treves and others using the information theory showed that in short time windows there is more information in the spike train than in longer time windows. However, in populations of cells the probability distributions may be more difficult to estimate because of the dimensionality of space. The third point raised by Rolls was related to the second point: a cortical area can operate in a short time of about 20 ms. However, Rolls reminded us that although 20 ms are enough for categorization, the percepts are not very conscious, that is, people feel like they were guessing. In spite of the fast computation, the reverberant activity lasts. Then what it is good for? The last point of discussion stressed that the more neurons we take into the consideration, the more information we can get and obtain the more precise prediction. Information in the rates of simultaneously recorded neurons is high, then how much extra is there in (i) spike order (ii) spike timing and (iii) spike synchronization?

APPENDIX 1. *PROGRAM OF THE SYMPOSIUM*

Computational Neuroscience and Neuroinformatics

Neuronal Plasticity and Dynamics

Adriatico Hotel, Trieste
2-4 September, 2000


15th century Trieste

EUROPEAN SCIENCE FOUNDATION

the

abdus salam
international centre for theoretical

IInd Symposium in
Computational Neuroscience and Neuroinformatics

Neuronal Plasticity and Dynamics

Adriatico Guesthouse, Grignano, Trieste
2-4 September, 2000

Saturday, September 2

10.00 - 10.15	R. Douglas	Introductory remarks

SESSION 1. Neuronal basis of dynamics and plasticity in brain

10.15 - 11.05	S. Fusi	General considerations on long term synaptic plasticity in material devices

11.05-11.25	COFFEE BREAK	
11.25 - 12.15	K. Pawelzik	Signaling by noise in neocortical neuronal ensembles
12.15 - 13.05	T. Sejnowski	Large-scale coherence in brain dynamics
13.05-14.30	LUNCH	
14.30-15.25	S. Rotter	Variability and reliability of neuronal responses in the motor cortex
15.25-16.15	M. Rabinovich	Information transmission and recovery in neural communications
16.15-16.35	COFFEE BREAK	
16.35-17.00	DISCUSSION How important is spike timing?	
17.00-18.00	POSTER SESSION	

Sunday, September 3

SESSION 2. Population dynamics at the level of localized networks

9.00-9.50	M. Carandini	Dynamical representation of stimulus contrast in the primary visual cortex
9.50-10.40	Y. Fregnac	Dynamics of interaction between feedforward, recurrent and lateral synaptic inputs during visual processing by primary visual cortical neurons
10.40-11.00	COFFEE BREAK	
11.00-11.50	H. Sompolinsky	The equilibrium properties of networks with temporally asymmetric Hebbian plasticity
11.50-13.40	LUNCH	
13.40-14.30	M. Abeles	The accuracy of spiking time in the cortex
14.30-15.20	M. Tsodyks	Modeling the activity of neocortical circuits with dynamic synapses
15.20-15.40	COFFEE BREAK	
15.40-16.30	T. Tishby	Neural codes and the information

		bottleneck method
16.30-17.00	DISCUSSION	
17.00-18.00	POSTER SESSION	

Monday, September 4

SESSION 3. Large-scale processing

9.00-9.50	S. Ullman	Computational aspects of object classification by the visual cortex
9.50-10.40	A. Villa	Spatiotemporal firing patterns related to higher brain functions
10.40-11.00	COFFEE BREAK	
11.00-11.50	T. Kenet	Single neurons and the dynamics of spontaneous population activity in cat visual cortex
11.50-12.40	S. Thorpe	Learning to categorize natural images: Experiments and models
12.40-14.30	LUNCH	
14.30-15.20	D. Kleinfeld	Coherence and coding among the nested feedback loops in the vibrissa somatosensory system
15.20-16.10	M.E. Diamond	Learning in a topographic framework
16.10-16.30	COFFEE BREAK	
16.30-17.20	R. Romo	Exploring the cortical evidence of a sensory discrimination
17.20-18.00	DISCUSSION	

Symposium participants

Although a list of participants was included in the original Program, to conserve space, we have deleted this from the Report; please see p.6.