Application for a Tenure Track Faculty Position in Computational Neuroscience at the Brown University Providence, RI, USA

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April 27, 2012

To
The faculty search committee chair
Brown University, Providence, RI, USA

Subject: Application for the Tenure Track Faculty position in the Brown University Providence, RI, USA.

Dear Search Committee Chair,

I hereby would like to apply for the Tenure Track Faculty position at the Brown University Providence, RI, USA.

Currently, I am a junior group leader in the group of Prof. Ad Aertsen in the University of Freiburg, Germany. My current research focusses on both theoretical as well as applied aspects of neuroscience. On the theoretical side I am interested in understanding

- the rules that govern the communication between two similar or dissimilar networks of spiking neurons,
- the implications of network connectivity for the analysis of task related neural activity.

On the applied side I am interested in developing computational models of brain disorders and different intervention strategies. To this end, currently, I am developing network models of different brain disorders such as the **Parkinson's disease**, **post-traumatic stress disorder**, and **epilepsy**.

In my ongoing work using computational models of modular biological networks I have isolated several parameters of both network activity and network structure that influence the transmission of spiking activity. In my future work I will extend my current research to develop a theory to describe the transmission of spiking activity between two arbitrary network with a long term aim to understand information processing in biologically realistic networks.

This apparently theoretical interest, in fact, quite naturally extends towards development of brain disorders. Several brain disorders (e.g. **Parkinson's disease**, **post-traumatic stress disorder**, and **epilepsy**) can be described as disorders of brain dynamics and involve altered interactions between multiple networks.

Thus, a systematic investigation of how neuronal networks communicate and transformation of inputs not only will help us develop a computational theory of brain function but also provide crucial insights about brain disorders and stimulation protocols to intervene with the aberrant brain dynamics associated with different brain disorders. Indeed, we have successfully extended our theoretical insights to understand neural mechanisms underlying some aspects of Parkinson's disease[1] and formation of fear memories [2].

[1] Kumar et al. 2011, Frontiers in Sys. Neurosci.
[2] Vlachos et al. 2011, PLoS Comp. Biol.

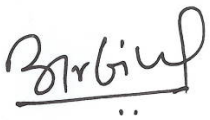
As a post-doctoral researcher I have had first hand experience of the rich and diverse neuroscience community at the Brown University that addresses neuroscientific questions at virtually every scale – from molecule to systems and behavior. That is why I consider Brown University as one of the most suitable places to pursue my research goals.

I think with my expertise in neuronal network dynamics and modeling of brain disorders, I will add new dimensions to the pre-existing diversity of neuroscience, while making close collaborations with several research groups (e. g. Barry Connors, John Donoghue, Michael Frank, Stephanie Jones, Christopher Moore, and David Sheinberg).

My curriculum vitae, and summary of current, proposed research and a list of three referees are appended with this letter.

Please feel free to contact me should you need further information.

Sincerely,



Arvind Kumar

Referees:

Prof. Dr. Ad Aertsen Bernstein Center Freiburg Neurobiology & Biophysics Faculty of Biology University of Freiburg, Germany Email: aertsen@biologie.uni-freiburg.de Ph. No.: +49-761-203-2718	**Prof. Dr. Stefan Rotter** Bernstein Center Freiburg Computational Neuroscience Faculty of Biology University of Freiburg, Germany Email: stefan.rotter@bcf.uni-freiburg.de Ph. No.: +49-761-2039550
Prof. Dr. Ulrich Egert Bernstein Center Freiburg Biomicrotechnology, Faculty of Engineering Dept. of Microsystems Engineering Freiburg, Germany Email: ulrich.egert@imtek.uni-freiburg.de Ph. No.: +49 (0)761-203-7524	**Prof. Dr. Markus Diesmann** Inst. of Neuroscience and Medicine (INM-6) Computational and Systems Neuroscience Research Center Juelich Juelich, Germany Email: diesmann@fz-juelich.de Ph. No.: +49-2461-61-4748

Curriculum Vitae

Name:	Arvind Kumar
Date of Birth:	19.10.1976
Place of Birth:	Murthal (Haryana), India
Nationality:	Indian
Family Status:	Married
Languages:	English (Fluent) Hindi (Mother tongue) German (conversational)
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Research Positions

08/2008 - present	Junior Group Leader (in the group of Prof. Dr. Ad Aertsen), Faculty of Biology, University of Freiburg, Germany.
08/2006 - 07/2008	Post doctoral researcher (in the group of Prof. Dr. Mayank Mehta), Dept. of Neuroscience, Brown University, Providence. RI, USA.
04/2002 - 07/2006	Research assistant, Neurobiology and Biophysics, University of Freiburg, Germany.
01/2000 - 04/2002	Senior Research Fellow at Indian Institute of Technology, Delhi, India.

Academic Background

04/2002 - 06/2006	Doctoral studies at University of Freiburg, Germany. PhD (magna cum laude) attained June 2006 Thesis: Dynamics of Cortical Networks-Conductance-based Synapses and the Synfire Activity. (Supervisors: Prof. Dr. Ad Aertsen, P.D. Stefan Rotter)
12/1997 - 12/1999	Studies towards Masters in Engineering (Non-linear systems) at Birla Institute of Technology and Science, Pilani, India. Masters Thesis: Stability and control of the dynamics of the Double Inverted Pendulum (PEDU-BOT). (Supervisor: Prof. Dr. L. Behera – now at IIT Kanpur, India)
07/1993 - 06/1997	Studies towards Bachelor in Engineering (Electronics and Communications) at CR State College of Engineering, Murthal, Haryana, India.

Other Scientific Activities

- Associate Faculty Member, F1000 (Since 2010).
- Guest Editor, Frontiers Special topics issue in Computational Neuroscience: Structure, dynamics and function of brains: exploring relations and constraints.

- Reviewer for J. Computational Neuroscience, Neural Computation, Frontiers in Neurosci., J. Neurophysiology, PLoS Comp. Biology, Brain Research, Chaos, Neural Computation.
- Co-organizer, workshop on Basal Ganglia: Dynamics, Function and Learning, 20th Annual Computational Neuroscience Meeting: CNS 2011, Stockholm Sweden.
- Coordinator of the nuSPIC: the Neural System Prediction and Identification Challenge. An online tool to test the viability of two fundamental beliefs in the field of neuroscience using simple networks of spiking neurons. [more info: http://nuspic.g-node.org]

Teaching and Training

2004 - present	Supervision of MSc and PhD students. **Current Students** (co-supervision) Ajith Padmanabhan (PhD Uni. Freiburg) Jyotika Bahuguna (PhD Uni. Freiburg) Simachew Abebe (PhD Uni. Freiburg) Alejandro Bujan (PhD Uni. Freiburg) **Former students** Ioannis Vlachos (PhD Uni. Freiburg) Man Yi Yim (PhD Uni. Freiburg) Jens Kremkow (MSc Uni. Freiburg) Sven Schrader (MSc Uni. Freiburg)
2012	Coordinator, Quantitative Methods in Biology. MSc. course at the Faculty of Biology, University of Freiburg
2012	Faculty, System Neurobiology Spring School, Kyoto, Japan
2011	Co-Lecturer, Signals and Systems. MSc. course at the Faculty of Biology, University of Freiburg
2009 - 2010	Co-Lecturer, Computational Neuroscience I: Models of Neurons and Networks. MSc. course at the Bernstein Center Freiburg, University of Freiburg
2006 - 2007	Tutor, EU Advanced Course on Computational Neuroscience, Aarcachon, France.
2002 -2004	Tutor, Signals and Systems. MSc. course at the Faculty of Biology, University of Freiburg
12/1997 - 12/1998	Teaching assistant (Control Systems Engineering for four semesters) and Lecturer (Microprocessor Based System Design) Dept. of Electrical and Electronics Engg., Birla Institute of Technology and Science, Pilani, India.

Funding

2010 - 2014	Principal Investigator: EuroSpin - European Study Programme in Neuroinformatics. (EU Erasmus Mundus 159661-1-2009-1-SE-EMJD)
2009 - 2013	Principle investigator: Marie Curie Initial Training Network 'From Neuroscience to Neuro-Inspired Computing' (PITN-GA-2009-237955)

International Collaboration

- **Prof. Jose Manuel Alonso**, SUNY College of Optometry New York NYm USA.
  Study of LFP and spike relationship in awake primates in vivo.
- **Prof. Hagai Bergman**, Hebrew University, Jerusalem, Israel.
  Dynamics and models of Parkinson's Disease related activity..
- **Prof. Rui Costa**, Champalimaud Neuroscience Programme Lisboa, Portugal.
  Dynamics and models of Parkinson's Disease related activity..
- **Prof. Jeanette Hellgren-Kotaleski**, Royal Institute of Technology, Stockholm, Sweden.
  Study of activity dynamics and network interaction in the basal ganglia.
- **Prof. Ilan Lampl**, Department of Neurobiology, Weizmann Institute of Science, Rehovot, Israel.
  Study of LFP and spike relationship in anesthetized animals in vivo.
- **Prof. Andreas Lüthi**, FMI, University of Basal, Switzerland.
  Study of neural mechanisms underlying fear conditioning and extinction.

Publications

13 Froriep UP, **Kumar A**, Haeussler U, Cosandier-Rimele D, Haas CA & Egert U (2011) Theta coupling shifts within the hippocampal formation in temporal lobe epilepsy. *to appear in Epilepsia*.

12 Vlachos I, Aertsen A, **Kumar A** (2012) Implications of network structure on neural activity: Beyond statistical significance. *PLoS computational Biology* doi: 10.1371/journal.pcbi.1002311.

11 Yim MY, Aertsen A, & **Kumar A** (2011) Significance of input correlations in striatal function. *PLoS Computational Biology* 7(11): e1002254 doi:10.1371/journal.pcbi.1002254.

10 **Kumar A**, Cardanobile S, Rotter S & Aertsen A (2011) Role of inhibition in generating and controlling Parkinson's disease related oscillations in the basal ganglia. *Frontiers in Systems Neuroscience* 5:86. doi: 10.3389/fnsys.2011.00086.

9 **Kumar A** & Mehta M (2011) A biophysical model predicts novel rate and timing dependence of synaptic plasticity. *Frontiers in Neuroscience* 5:38. doi: 10.3389/fncom.2011.00038.

8 Vlachos I, Herry C, Lüthi A, Aertsen A & **Kumar A** (2011) Context dependent encoding of fear and extinction memories in a large-scale network model of the basal amygdala. *PLoS Computational Biology* 7(3): e1001104. doi:10.1371/journal.pcbi.1001104.

7 Kremkow J, Aertsen A, & **Kumar A** (2010) Gating of signal propagation in spiking neural networks by balanced and correlated excitation and inhibition. *J Neurosci* 30: 15760-15768.

6 **Kumar A**, Rotter S & Aertsen A (2010) Spiking activity propagation in neuronal networks: reconciling different perspectives on neural coding. *Nature Reviews Neurosci* 11 : 615-627.

5 **Kumar A**, Rotter S, & Aertsen A(2008) Conditions for Propagating Synchronous Spiking and Asynchronous Firing Rates in a Cortical Network Model. *J Neurosci* 28(20):5268-5280.

4 **Kumar A**, Schrader, S, Rotter S, & Aertsen A (2008) The high conductance state of cortical networks, *Neural Computation* 20(1): 1-43. *Mentioned in F1000 Biology*.

3 Ahmed OJ, McFarland JM, & **Kumar A** (2008) Reactivation in ventral striatum during hippocampal ripples: evidence for the binding of reward and spatial memories? *J Neurosci* 28: 9895-9897.

2 Kremkow, J, **Kumar A**, Rotter S, & Aertsen A (2007) Emergence of population synchrony in a layered network of the cat visual cortex. *Neurocomputing*, 70 20692073.

1 Meier R, **Kumar A**, Schulze-Bonhage A, & Aertsen A (2007) Comparison of dynamical states of random networks with human EEG. *Neurocomputing*, 70 1843-1847.

Forthcoming publications: currently under review/revision

1. Kremkow J, Aertsen A, & **Kumar A** (2012) Role of correlated excitation and inhibition in neural information processing, *invited review Trends in Neuroscience*

2. **Kumar A**, Vlachos I, Aertsen A, & Boucsein C (2012) The challenges of understanding brain function by specific manipulation of neuronal sub-populations. *submitted*

Non-Neuroscience Publications

1. **Kumar A** & Singh HP (2011) Information homeostasis as a fundamental principle governing the cell division and death. *Medical Hypotheses* 77(3):318-22. *Impact factor: 1.389*
2. Kumar R & **Kumar A** (2010) Design and simulation of D-latch and multiplexer using numos. Proc. 27th Int. Conf. on Microelectronics Nis, Serbia.

Abstracts (since 2010)

1. Bujan AF, Aertsen A & Kumar A (2012) . Structure of stimulus induced correlations in random networks with distance dependent connectivity. COSYNE 2012 *poster II.17*, Salt Lake City, Utah, USA.
2. Vlachos I, Aertsen A & Kumar A (2011) Implications of network structure on neural activity: Beyond statistical signicance. 41th Annual Meeting of Soc. Neurosci. Washington DC, USA.
3. Padmanabhan A, Vlachos I, Aertsen A & Kumar A Invariance of network dynamics to biophysical properties. 41th Annual Meeting of Soc. Neurosci. Washington DC, USA.
4. Kremkow J, Kumar A, Aertsen A & Boucsein C (2011) Effect of correlated excitation/inhibition and network structure on spiking activity propagation in neuronal networks *in vitro*. 41th Annual Meeting of Soc. Neurosci. Washington DC, USA.
5. Vlachos I, Herry C, Lüthi A, Aertsen A & Kumar A (2010) How do distinct neuronal subpopulations in the central amygdala shape the fear response? - A computational model. 40th Annual Meeting of Soc. Neurosci. San Diego CL, USA.
6. Kremkow J, Aertsen A & Kumar A (2010) Consequences of delayed correlation between excitation and inhibition for signal propagation in spiking neural networks. 40th Annual Meeting of Soc. Neurosci. San Diego CL, USA.
7. Kumar A, Aertsen A, Rotter S & Cardanobile S (2010) Dual role of inhibition in unleashing and quenching oscillatory activity in the dopamine-depleted basal ganglia. 40th Annual Meeting of Soc. Neurosci. San Diego CL, USA.
8. Froriep UP, Kumar A, Haeussler U, Cosandier-Rimele D, Haas CA & Egert U (2010) The relation of entorhinal cortex and dentate gyrus in a model of temporal lobe epilepsy. FENS Abstr. vol 5, 015.14
9. Rotter S, Kumar A, Feige B, Schueltke E, Amtage F, Pinsker M, Aertsen A & Cardanobile S (2010) Task related phase locking of spikes in the STN of humans with Parkinson's disease. FENS Abstr. vol 5, 018.6
10. Vlachos I, Herry C, Lüthi A, Aertsen A & Kumar A (2010) How do distinct neuronal subpopulations in the central amygdala shape the fear response? - A computational model. FENS Abstr. vol 5, 192.58
11. Yim MY, Kumar A & Aertsen A (2010) Weak input correlations enhances the signal-to-noise ratio in striatum network model. FENS Abstr. vol 5, 200.6
12. Kremkow J, Aertsen A & Kumar A (2010) Temporal gating of signal propagation in spiking neural networks by delayed correlation between excitation and inhibition. FENS Abstr. vol 5, 192.29

Invited Talks (since 2009)

- 03/2012 - *Dynamics and functional consequences of some inhibitory sub-cortical networks.* Systems Neurobiology Spring School, Kyoto, Japan.
- 03/2012 - *Dynamics of spiking activity in the striatum and its role in Parkinson's disease related oscillations in the basal ganglia.* RIKEN Brain Science Institute, Wako-shi, Japan.
- 03/2012 - *Role of striatal activity in Parkinson's disease related oscillations in the basal ganglia.* Okinawa Institute of Science and Technology, Okinawa, Japan.
- 10/2011 - *Mechanism of generation and suppression of oscillations in the basal ganglia.* VI Bernstein Conference, Freiburg, Germany 2011.
- 09/2011 - *Neural mechanisms underlying the functioning of deep brain stimulation*. Bio Medical Technology Conference, Freiburg 2011.
- 01/2011 - *Propagation of spiking activity in neural networks: implications for the neural code.* Institute Colloquium, Max Planck Institute for Biocybernetics, Tübingen, Germany.
- 01/2011 - *Propagation of spiking activity in neural networks: implications for the neural code.* Institute Colloquium, Max Planck Institute for Biocybernetics, Tübingen, Germany.
- 11/2010 - *Implication of network structure for the neural code.* Brain Corp. La Jolla,CL, USA.
- 06/2010 - *Propagation of spiking activity in cortical networks.* 10th Neurex Annual meeting 2010 Organizational principles in nervous system: compartments and ensemble.
- 07/2009 - *On the propagation of synchrony and firing rates in a cortical network model.* Joint BCCN Freiburg-Graduate School, Ulm Workshop: Structure and dynamics of networks.

Summary of current research

In the last decade networks have emerged as a powerful tool that can bridge the bottom-up and top-down approaches to understand brain function. Already, since my doctoral studies I have used networks as a framework to develop a theory of brain function and have addressed following theoretical and applied topics in neuroscience.

• Theoretical Neuroscience

1. Self-sustained activity in recurrent networks

In my doctoral research, for the first time I showed that random recurrent networks with *conductance based synapses* can exhibit self-sustained (without external input and pacemaker neurons) asynchronous-irregular (AI) activity (**Kumar et al. 2008a**), which most closely resembles the ongoing activity in the neocortex. Notably, previous theoretical work suggested that self-sustained activity cannot be of AI type (Latham et al. 2000[3]), and now such self-sustianed activity has become a popular model of ongoing activity in the brain.

2. Conditions for propagation of spiking activity between two networks

Because brain is a modular system it important that spikes can be transmitted from one network to another. In fact, transmission of spiking activity is a key property of neural codeSince my doctoral research I have used simple network models to isolate at least four key properties that influence the propagation of spiking activity:

i. Ongoing network activity (**Kumar et al., 2008b**).
ii. Network structure (**Kumar et al., 2010**).
iii. Correlation between excitation and inhibition (**Kremkow et al., 2010, 2012**).
iv. Structure of input projections (**Yim et al., 2011**).

3. Implications of network structure on neural data analysis

In a typical behavioral experiment the task-related neural activity is tested for its statistical significance. If the activity is found significant against an appropriate null hypothesis, it is implicitly assumed that this activity is *indeed* responsible for the task. However, we showed that if the network from which the data is being recorded is a non-classical random network, statistical significance is a *necessary* but not *sufficient* condition. In fact, we *also* need to define *'structural significance'* of the activity which can be determined from the impact of a neuron's activity on the network (*embeddedness*). Thus, for the first time, we outlined the importance of network structure to better analyze the data (**Vlachos et al., 2012**). 'Embeddedness' is also crucial to resolves two critical limitations of the lesion-based approach (using optogenetics) to understand brain function (**Kumar et al., 2012, in review**) and development of therapeutic brain stimulation protocols.

4. Synaptic plasticity

Virtually every synapse in the brain shows short or long term changes in its strength depending on the spike timing or firing rates. Using a biophysical model of calcium dependent plasticity we showed that besides spike and rate, periodicity is an important determinant for the synaptic plasticity. Specifically, we showed that irregular spike trains induce less plasticity than the regular ones. Further, we found that while considering unsaturated synapses, even the spike count is an important determinant of plasticity and amount plasticity induced by short spike trains is a non-monotonic function of spike rate. Moreover, each synapses may have a specific frequency at which it maybe the most malleable. Finally, we showed that, when spike timing and rate dependent plasticity are combined, synapses are most malleable at frequencies around 10 Hz (**Kumar and Mehta, 2011**). These new insights about synaptic plasticity suggest novel mechanisms for storage and retrieval of memory in biological neural networks which are currently being investigated.

[3]Latham PE et al. (2000) Intrinsic dynamics in neuronal networks. I. Theory. *J. Neurophysiol.* 83: 808-827.

5. Neural system prediction and identification challenge: nuSPIC

To test the fundamental and implicit belief in neuroscience that we can understand the function of a network by knowing connectivity and task-related activity of all its neurons, we have launched a web-based challenge (http://nuspic.g-node.org). Through the nuSPIC we invite interested people to experiments with a small networks to extract the implemented function using the activity and connectivity of the neurons. In general nuSPIC is also a power educational tool to teach basic computational neuroscience and neural network dynamics.

• Applied Neuroscience: Models of brain disorders

Certain brain diseases such as Parkinson's disease, epilepsy, schizophrenia, post-traumatic stress disorder (PTSD) can be described as the disorders of brain dynamics. Recently, we have successfully described the neural mechanisms underlying some aspects of Parkinson's disease and PTSD based on our understanding of network interactions.

1. Parkinson's disease

To understand the origin of Parkinson's disease related beta band oscillations I investigated the dynamics of basal ganglia. This research was initiated when we observed that previous models of these oscillations were not consistent with recent experimental data. Consistent with the latest experimental data we showed how increased activity in the striatum could be the main cause of oscillations in Parkinson's disease. Based on this, we proposed a unified explanation of (1.) why in normal healthy state there are no oscillations in the basal ganglia (2.) why oscillations emerge in the dopamine depleted state, (3.) how deep brain stimulation of the the sub-thalamic nucleus could quench these oscillations (4.) why PD patients have problems in initiating movements and (5.) why after deep-brain-stimulation PD patients become impulsive (**Kumar et al. 2011**). More recently we have described how small changes in the correlations in the striatum could also initiate oscillations (**Kumar et al. in preparation**).

2. Post traumatic stress disorder

In collaboration with Prof. Andreas Luethi (FMI, Basel, Switzerland), I led a project to develop the first large-scale model of basal amygdala to study network level mechanisms involved in the emergence of fear and extinction of fear (**Vlachos et al., 2011**). This model is consistent with experimental evidence arguing that extinction of context-dependent fear is, in fact, masking of existing fear memories and not unlearning of fear. In addition to this insight about the fear extinction, the model made several testable prediction and made suggestions for possible intervention strategies to accelerate fear extinction.

3. Mesial temporal lobe epilepsy

In collaboration with Dr. Ulrich Egert (IMTEK, University of Freiburg, Germany) I am studying the dynamics of interactions between the entorhinal cortex and the hippocampus in a mouse model of epilepsy. Our experimental data indicates that in focal epilepsy the communication between the entorhinal cortex and the hippocampus is altered because of a loss of synchrony between the two brain regions in the epilepsy free ongoing activity (**Froriep et al., 2012**). A population model of entorhinal cortex and the hippocampus suggests that the asymmetry of connectivity between the two regions is the key factor in inducing the loss of synchrony.

My work has been published in reputed journals in the field of neuroscience and has been covered in popular press (http://www.bcf.uni-freiburg.de/news/), including two features in the biggest Greek newspaper BHMA, an interview on the German National Radio and a short movie for the Bernstein Network TV based on my work on Parkinson's disease.

Proposed research

Both anatomical and electrophysiological evidence suggest that the brain is a network of functionally specialized of networks. It is also becoming clear that brain function is not localized in one single network but rather it is the interactions among different networks at different spatial and temporal scales that govern the function and dysfunction. This suggests that we should consider the brain as a network of networks (NoNs). The also implies that that neural information processing should involve two distinct components: (1) Transmission of spiking activity between different specialized networks in order to integrate multi-modal sensory-motor and/or cognitive information. (2) Transformation of spiking activity by a network as defined by its connectivity and ongoing activity. In fact our recent works suggest that some computations could already be performed in 'transit' (Yim et al. 2011).

Based on this new conceptual shift in our view of neural information processing, we will investigate transmission and transformation of spiking activity in NoNs and identify control strategies to influence these two components in a desired manner.

Currently, while studying neural information processing, the concepts of transmission and transformation are not separated, largely due to the implicit (and wrong) assumption that neural activity does not change during transmission. However, our recent work suggests that the structure of the input projections strongly influences the properties of the propagating spiking activity and indeed some pre-processing of information may already take place in transit. How and which properties of the receiving network, input projections, and the input neural code determine the processing in 'transit' remains to be investigated. In fact, a general theory of how neuronal network communicate with spikes is essentially lacking.

Transformation of neural activity in a biological neural network (BNN) depends on the structure of the BNN, the dynamical state of the activity and neuron and synapse properties. Therefore, the anatomical and electrophysiological diversity among different networks in the brain raises several pertinent questions: How do these diverse networks differ in their network function? Do they have comparable computational properties? Are specific networks more suited to work with specific neural codes? To address these questions and understand the functional properties of BNNs, it is important to quantify the activity and structure dependent transformation of neural code in a network.

Finally, it is necessary to understand how transmission and transformation properties of a NoN can be controlled in a desirable manner so as to identify neural mechanisms underlying various brain disorders and control or correct disease related neural activity.

Thus, following the theoretical framework of 'network of networks', there are three broad themes of my future research i.e. *transmission*, *transformation* and *control*. Under each theme I have isolated few immediate goals that could be achieved in next five years:

I. Transmission of spiking activity in networks of networks

The specific aims under this theme are (expected to be achieved in next five years):

- What are the constraints that maximize the transfer of spiking activity between similar or dissimilar networks under biologically realistic conditions.
- How the neural activity is changed during transmission and characterize computations that may be performed in 'transit'.

II. Transformation of spiking activity in biological neural networks

The specific aims under this theme are (expected to be achieved in next five years):

- Compare different networks for their transformation properties
- Determine if different networks prefer specific neural codes to maximize their information processing capacity

- Determine how the ongoing activity states affect the network transformation given the specific connectivity of the network

III. Control of spiking activity dynamics in biological neural networks

The specific aims under this theme are (expected to be achieved in next five years):

- Identify key control variables in the network that can affect network function (transmission and transformation)
- Develop methods to estimate embeddedness of neurons in inhomogeneous networks
- Develop methods and protocols to intervene with the disease-related aberrant dynamics of networks in the brain.

Significance of the research program

One of the direct application of my theoretical research to develop computational models of brain disorders that are manifested at the level of activity dynamics (e.g. epilepsy, Parkinsons disease, anxiety and PTSD) based on our understanding of interactions between generic as well as brain specific networks (such as hippocampus, basal ganglia and amygdala). In addition, it will help us develop new strategies for intervention of disease related aberrant dynamics of one or more brain areas. In at least three of my recent publications (Kumar et al. 2011, Vlachos et al. 2011, Froriep et al. 2012) we have already demonstrated that indeed it is possible to exploit our understand of network interaction to reveal neural mechanism underlying brain disorders.

A theoretical understanding of the 'controllability of a neuronal network' will also be highly useful for the development of closed-loop brain machine interfaces. The idea of embeddedness of a neuron in a local network can be extended to a network of brain areas, which can be assessed through fMRI, MR-EEG or diffusion tensor imaging. Tools developed for estimating the embeddedness of a node could be very useful in the planning for surgical removal of brain tissue.

The new suggestion to separate neural information processing into transmission and transformation will reveal how and what types of computations can be performed while the activity is in 'transit'. Further, it promises to provide novel insights about the computational capacities of different specialized networks in the brain, such as the hippocampus and the basal ganglia as well as the neural code.

Together, the study of transmission and transformation will also help both, in better interpretation of the electrophysiological data and in designing better experimental design taking into account the network topology. Moreover, this work will pave the way for the development of data analysis tools that will take into account the topology of the underlying network. An understanding of how a network processes information goes beyond neuroscience and insights obtained from my research would be applicable to various other physical and biological systems where networks are used as a theoretical framework.

Collaborations with experimentalists

These three themes are clearly theoretical in their nature but require constant interactions with experimentalists. Thus, there will be ample opportunity to work in collaboration with experimentalists not only to obtain realistic network parameters and but to develop better data analysis methods and to test model predictions. I already have several ongoing collaborations with experimentalists who are investigating neural dynamics in various brain areas(cf. CV). Data from the ongoing projects of these collaborators will be available to my research group for developing biologically realistic network and neuron models for this project. Moreover I look forward to develop specific collaborations with other research labs in Brown University (e. g. Barry Connors, John Donoghue, Michael Frank, Stephanie Jones, Christopher Moore, and David Sheinberg).

Teaching philosophy

I very much enjoy teaching and find it a very enriching experience. Since my Masters degree, I have regularly participated in teaching in different capacities, from traditional class room (group) teaching to supervision of PhD students (cf. CV).

Currently, I am coordinating a graduate level course on 'Quantitative Methods in Biology' for the newly formed Masters program at the Faculty of Biology, University of Freiburg. Recently, I was also invited to lecture in the Systems Neurobiology Spring School, 2012, Kyoto, Japan.

Based on my experience, I find it very important to complete lectures with suitable tutorials and small projects, so as to maximize the learning process. Evidently, with tutorials and projects, we teach student how to learn to solve problems by themselves. This philosophy is reflected in my teaching thus far and I always complemented the theory lectures with appropriate tutorials. In fact, this is a system we have adopted in the 'Quantitative Methods in Biology' course for every lecture.

Beyond group teaching, I have been involved in the supervision of multiple undergraduate and Masters theses. I have also supervised multiple projects at the EU Advanced Summer School on Computational Neuroscience (ACCN at Arcachon, France, 2006, 2007). Given the multidisciplinary nature of neuroscience, not every research topic can be covered in a class room setting. So, I very much encourage students to take up small projects, which I prefer to design together with the student. In my experience, such focused training is very effective in training students to take up research. In fact, this is the best aspect of teaching for me, which allows me to be creative with the designing of appropriate student projects.

In addition, I have also co-ordinated advanced seminar topics. At the University of Freiburg, every semester a reading course is offered in which we choose recent and classical papers on a particular theme. These papers are presented in a group setting. In my opinion, this is one of the best forms of training to learn to quickly grasp and critically evaluate a research paper.

Because neuroscience is becoming ever more multidisciplinary, and it is unlikely that one teacher can cover all relevant ranges, it is important to involve experts from different fields to give lectures in neuroscience courses. For instance, I would like to develop the curriculum of the course on Computational Neuroscience involving faculty members from Neuroscience as well as from Mathematics, Physics, Electrical and Computer Engineering Departments. Finally, in my opinion every course in neuroscience should combine the group teaching with hands on tutorial and short projects.

Besides, I am interested in developing teaching aids and resources for neuroscience and especially computational neuroscience education. The web interface developed as a part of the Neural System Prediction and Identification Challenge (nuSPIC) project that I am coordinating, is a very good teaching tool. It can be already used to introduce neural networks to undergraduate and even high school students without much knowledge of programming languages.

What would I like to teach

I have a multidisciplinary education background. Before starting my research in Computational Neuroscience, I studied Electrical Engineering with a specialization in Communication Engineering and Control of Nonlinear Systems. This background allows me to provide different courses at the undergraduate and graduate levels. For instance, I can imagine participating in or offering the following courses at undergraduate and graduate levels:

- Introduction to Neurobiology
- Methods and models in computational neuroscience
- Neural data analysis
- Scientific computing using PYTHON and/or C++

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