



## PhD Thesis Proposal Form China Scholarship Council (CSC)

**FIELD open**

Thesis subject title:

**Computation and Coding in Neural and Cognitive Systems**

**Laboratory name :** Laboratoire de Physique Statistique, Ecole Normale Supérieure

**▪ PhD supervisor (contact person):**

- Name: Rava Azeredo da Silveira
- Position: CR CNRS
- E-mail: rava@ens.fr
- Phone number: 01 44 32 34 73

**▪ Thesis proposal (max 1500 words):**

This thesis offer is directed to students with a quantitative background (mathematics, physics, computer science, statistics, biology or psychology with solid technical foundations, engineering) and who are interested in theoretical/computational aspects of brain function. The work proposed will involve theory and modeling, but also data analysis and, possibly, collaboration with experimental groups on the design and implementation of neural and behavioral experiments.

The problems considered will pertain to the computations carried out by experimentally defined circuits of neurons, or to models of coding and representation of information in large populations of neurons and in cognition. These will include questions on the strategies used by large neural populations and smaller neural circuits to code for sensory information, as well as more behavioral and algorithmic questions on the representation of probabilistic information.

It is important to me that the student ‘own’ his/her project, and that he/she approach it with eagerness and enthusiasm. To this aim, the specific project will be identified with the student, in a series of initial discussions. The themes considered will include:

- dynamics and computation in circuits of neurons, in the contexts of vision, adaptation, and motion processing (data analyses and modeling);
- neural coding: population codes, noise, correlations, high-dimensional representations (data analyses and modeling);

- cognitive systems: inference processes and biases, perceptual and value-based decision making (data analyses and modeling, behavioral experiments).

As examples of projects, we provide hereafter a brief overview of two projects, on neural coding and cognitive decision making respectively.

### ***Sensory coding in populations of neurons***

What makes the problem of population coding in the brain so interesting – and difficult – is its high dimensionality: the joint activity of the neurons in a population yields an exponential explosion of the number of states. Historically, many models have used so-called ‘tuning curves’ to describe the response properties of individual neurons, inspired by responses in the sensory periphery. More recently, neurons such as the so-called ‘grid cells’ have opened the door to more involved forms of single-cell response. What are the implications of intricate single-cell properties for neural population coding? We plan to examine this question by exploring theoretical models, from which we can calculate the performance (accuracy, capacity) of neural codes as a function of single-cell and population properties. We also plan to analyze data of jointly measured cortical neurons from identified populations, with the aim of understanding (*i*) how single-cell properties relate to circuit architecture and (*ii*) the nature of sensory information representation in identified neural populations.

### ***Models of inference and decision making: noise, biases, and sub-optimality***

Inferring and deciding are core functions of the brain. Sensory modalities provide us with information based on which we construct ‘models of the world’ (models of the causes of the stimuli we perceive). In behaving, we take decisions based on our inferred models. However, even though inferring and deciding are viewed as rational faculties of the brain, human rationality is in fact severely limited: Wikipedia lists tens of biases and effects which limit or distort our rational reasoning. Biases represent ways in which behavior deviates from the predictions of optimal models. In this project, we propose to study quantitatively why and how inference and decision-making operate sub-optimally. On inference, we plan to develop models in which the mental cost of computation limits the accuracy of the inference. On perceptual and economic decision-making, we plan to generalize existing models to include intuitively important quantities, such as the sense of confidence in the face of a choice or the aversion to large fluctuations of gains and losses as a result of choice.

*The following three talks are illustrative of research themes in my group:*

- “Un Regard sur la Vision” (a pedagogical talk for a general audience, in French):  
<http://savoirsenmultimedia.ens.fr/expose.php?id=662>
- “The Orchestral Brain : High-Fidelity Coding with Correlated and Heterogeneous Neurons” (technical talk, in English):  
[http://www.youtube.com/watch?v=\\_BEbjwmGRXY](http://www.youtube.com/watch?v=_BEbjwmGRXY)
- “Various approaches to online inference — human behavior and theoretical models” (technical talk, in English):  
<https://www.youtube.com/watch?v=fOR1LDobZyE>

### **▪ Publications of the laboratory in the field (max 5):**

- R. Azeredo da Silveira, T. A. Münch, S. Siegert, T. James Viney, G. B. Awantramani, and B. Roska  
“Approach sensitivity in the retina processed by a multifunctional neural circuit”  
*Nature Neuroscience*, 12 (10), 1308–1316 (2009)
- R. Azeredo da Silveira and B. Roska  
“Cell Types, Circuits, and Computation”

*Current Opinion in Neuroscience*, 21 (5), 664–671 (2011)

- D. Clark, R. Benichou, M. Markus, and R. Azeredo da Silveira  
“Dynamical Adaptation in Photoreceptors”  
*PLoS Computational Biology*, 9 (11), e1003289 (2013)
- R. Azeredo da Silveira and M. J. Berry II  
“High-Fidelity Coding with Correlated Neurons”  
*PLoS Computational Biology*, 10 (11), e1003970 (2014)
- F. Franke, M. Fiscella, M. Sevelev, B. Roska, A. Hierlemann, and R. Azeredo da Silveira  
“Structures of Neural Correlation and How They Favor Coding”  
*Neuron*, 89 (2), 409–422 (2016)

- **Joint Phd (cotutelle) :** NO
- **Co-directed PhD :** NO

In case of a Co-directed or a Joint PhD, please detail:

- Partner University name
- Laboratory name and web site:
- PhD co-director (contact person):
  - Name:
  - Position:
  - E-mail:
  - Phone number:
- Provisional duration and timetable of the PhD student stays at the ENS Ulm:
- If previous collaborations with the Chinese co-director/university, please detail:
- Interest of the Joint Phd for the French co-director, for his/her laboratory, for ENS Ulm:

Date: 15 January 2017

Signature of the PhD director



Name and signature of the Laboratory director



M. Jorge KURCHAN, Directeur  
Laboratoire de Physique Statistique  
ECOLE NORMALE SUPERIEURE  
24, rue Lhomond  
75231 PARIS Cedex 05  
Tél. : 01 44 32 35 82