Proposal for a one-semester program (October-December 2011) at CIRM in theoretical, mathematical and computational neuroscience

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Neuroscience and its applications are greatly developing world-wide and Europe is one of the important contributors to the advancement of this discipline. Because of the variety of topics that it has to address, it is characterized by a very broad inter-disciplinarity and requires the cooperation of actors in several fields of knowledge, as well as the development of new ones.

In this context, the need for developing new theoretical and computational tools can be clearly identified and must be addressed. While methods from statistical physics, information theory, machine learning and various fields of mathematics such as the theory of dynamical systems, the stochastic calculus have been "tried" upon a variety of neuroscience problems, we are completely lacking, and this should not come as a surprise, a testable theory of, even parts, of neuroscience. There are at least five reasons for this.

First is the great difficulty, practical and ethical to perform experiments with living beings. This means that theories are hard to put to the test in neuroscience, unlike in Physics where it is somewhat easier.

Second is the fact that mathematicians are more inclined, probably for traditional reasons, to look for applications in the fields of Physics or, more recently, of Engineering or Computer Science, rather than in Biology and, of course, Neuroscience. However, there seems to be a trend towards biology, at least a considerable amount of interest exists in the mathematical community.

Third is the fact that in order to come to grip with a problem in neuroscience, and we believe this to be true for biology in general, you have to absorb a very significant amount of material and literature that is written in a very different style from the one which is used in the so-called "hard" sciences; this constitutes an intellectual and sociological obstacle to the development of theoretical research in neuroscience.

Fourth is the sheer complexity of the central neural system (CNS) in mammals and in particular in primates, which includes spatio-temporal scales spanning several orders of magnitudes as shown in Figures 1 and 2. This has deep implications on the types of theoretical tools that may be amenable to the study of the phenomena at hand. The kind of mathematics that are relevant, bifurcation theory, stochastic calculus, degree theory, partial differential equations are hardly taught in the Physics, Computer Science, Engineering, and of course Biology, courses; the implication of this is that the students who are trained in these domains and would like to do research in theoretical neuroscience are confronted with the extra challenge of having to become acquainted and familiar with quite difficult parts of contemporary mathematics.

Fifth, many tools of applied mathematics have been developed along applications in Physics or Engineering as mentioned above. However, biology poses different challenges to mathematics that are traditionally not encountered in non-living systems such as distributed time delays and multi-scale information processing to name a few. As a consequence, many "out of the box" tools in mathematics cannot be directly applied to neuroscience problems, but need to be refined and expanded, sometimes newly developed.

A fairly recent analysis of the French situation with regard to Neuroscience can be found in reference [1].

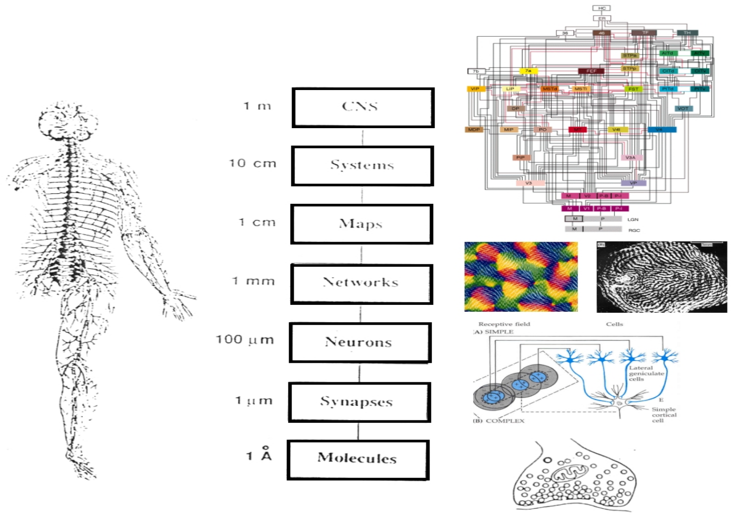

Figure 1: Schematic levels of spatial integration in the nervous system. The spatial scale at which anatomical organizations can be identified varies over many orders of magnitude. Icons to the right represent structures at distinct levels in a bottom-up fashion: (bottom) a chemical synapse, (middle-bottom) a network model of how thalamic afferent cells could be connected to simple cells in visual cortex, (middle-top) maps of orientation preference and ocular dominance in a primary visual area; (top) the subset of visual areas forming visual cortex and their interconnections (adapted from Churchland and Sejnowski, 1988).

All these remarks address the reasons why we think that organizing a semester on theoretical neuroscience would be timely and useful.

It would be timely because we think that the time has come for putting this new discipline on the French map. Some other European countries among which the United Kingdom and Germany play a prominent role have understood the importance of Neuroscience and decided to support inter-disciplinary research in this area at a very high level; examples of this commitment are the Gatsby research unit and the Wellcome Trust Centre for Neuroimaging, both at UCL, UK, and the Bernstein centers in Germany.

The here proposed semester program would be useful because it will make the community of theoretical neuroscientists, which is already quite rich in France as well as in Europe, more aware of its existence, its qualities and its problems. A series of conferences, Neurocomp, was started in 2006 at the French level by a group of dedicated individuals and has been quite successful at structuring mostly the French community. The last one was held in Bordeaux in 2009 and was well attended. It is clear that there is a strong demand from this community for more scientific action. Further the program would be useful by directing the attention of mathematicians to some very hard problems arising from neuroscience; vice versa it will bring the existence of relevant areas in mathematics to the attention of neuroscience researchers.

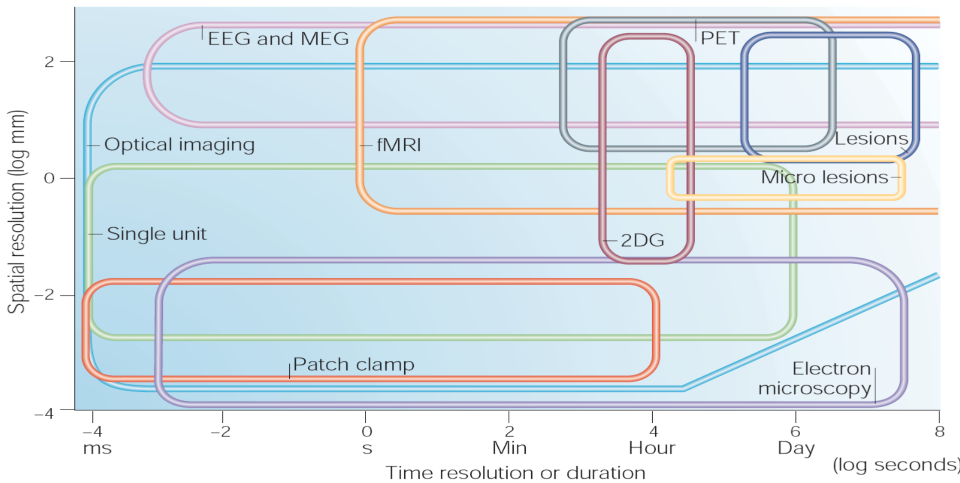

Figure 2 : Space and time-scale in brain activity measurements.

We are therefore proposing to hold a one-semester program at CIRM in 2011 entitled "theoretical, mathematical and computational neuroscience". This program will be driven by a few senior people (the pillars) with significant research and teaching experience in these domains. These pillars will reside at CIRM for long periods of time, at least one month, and organize such activities as short courses and workshops that will be attended by PhD students, Postdocs and researchers. The pillars should be endowed with a budget to allow them to invite other well-known and/or promising people, worldwide, to come to CIRM to make the attendees benefit from their experience.

Beside these workshops and short courses there will be short periods of time where no activities are formally planned but during which the people in residence at CIRM will form small subgroups with similar research and scientific interests and will attempt to start cooperative work.

Such an endeavor is very much in the spirit of the Newton Center in Cambridge where we have seen superb collaborations start and bear magnificent fruits.

The semester would feature four kinds of events:

- **Workshops:** on specific topics in mathematics that are relevant to neuroscience. We are planning on four one-week workshops on the following subjects:

    1. Mean-field methods and multiscale analysis of neuronal populations: co-organized by Nicolas Brunel (CNRS) and Olivier Faugeras (INRIA)3-7/10/2011
    2. Spatio-temporal evolution equations and neural fields: organized by Paul Bressloff (Oxford University, UK) and Stephen Coombes (Nottingham University, UK) 24-28/10/2011
    3. Learning and plasticity: organized by Wulfram Gerstner (EPFL, Lausanne) 7-10/11/2011
    4. Mathematical models of cognitive architectures: organized by Gustavo Deco and Viktor Jirsa (CNRS-ISM, Luminy) 5-9/12/2011

Their duration would be of the order of a week (5 days)

- They could be complemented by **Working groups** in which a small group of people with similar interests would work intensively together for some period of time in order to break new grounds in some well-defined area.
- **Seminars** will be given in general areas of mathematics, theoretical physics, neuroscience, and biology. One purpose of these seminars is to open as widely as possible the range of scientific domains that might be relevant to mathematics and theoretical neuroscience.
- **Courses** in specific areas of mathematics will be given by experts, e.g., large deviations and mean-fields (Gérard Ben Arous, Courant Institute), stochastic dynamic systems (Nils Berglund, Université d'Orléans), slow-fast systems (Jean-Pierre Françoise, Paris VI, and Martin Krupa, New Mexico State University), bifurcation theory (Pascal Chossat, CNRS), numerical methods for stochastic differential equations (Denis Talay, INRIA), stochastic networks and queues (François Baccelli,), machine learning (Francis Bach, INRIA/ENS Paris), multigrid techniques (Alain Dervieux, INRIA).

Some of the residents (people staying for a month or more) could be: Gérard Ben Arous (Courant Institute, large deviations), Bard Ermentrout (University of Pittsburgh, Dynamical Systems), Martin Golubitsky (Ohio State University, Bifurcation Theory), David Mumford (Brown University, Pattern Theory), Jean Petitot (Ecole Polytechnique, dynamical models in cognitive sciences).

Viktor Jirsa (CNRS-ISM, Luminy) would be the local organizer.

[1] Olivier Faugeras, Yves Frégnac, and Manuel Samuelides. A Future for Systems and Computational Neuroscience in France?, Journal of Physiology, Paris, 101/1-3, pages 1-8, 2007.