Opportunities for US-French Collaboration in Computational Neuroscience

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Introduction

Computational Neuroscience brings together the efforts of several scientific fields to provide a computational description of brain and behavior, across multiple spatio-temporal scales, species and development and at different levels of analysis (cellular, systems, cognitive and algorithmic). By encompassing domains such as biology, neuroscience, psychology, social sciences, computer science, physics, and mathematics, computational neuroscience benefits from a reciprocal exchange among new methods. Further, Computational Neuroscience has the potential to provide significant, influential breakthroughs in medicine, life sciences, and computer science among others, and, as such, constitutes an interdisciplinary grand challenge for contemporary science and engineering.

Within this context, the Agence Nationale de la Recherche (ANR) of France and the US National Science Foundation (NSF) convened a two-day workshop to address the key challenges as the field moves forward into the next decade, and to explore the possibility of creating international teams of researchers between the United States and France. Twenty expert scientists and engineers from both countries met to discuss and identify research areas for sustainable and complementary US-French collaborations in the area of Computational Neuroscience. The objectives of the panel discussions were: 1) to articulate the space of potential intellectual partnerships and the value added by bringing US and French researchers together; 2) to analyze the broader impacts of a partnership between US and France; 3) to identify the relevant practical considerations and specific needs for making US-French collaborative efforts scientifically and operationally successful. The full workshop agenda and participant list are included in the Appendix.

Scientific Opportunities

The goal of the workshop was to identify complementary areas of research in France and the United States as well as their technical and methodological strength in order to better articulate the breadth of potential intellectual partnerships and the value added by bringing US and French researchers together.

Any opinions, findings, and conclusions or recommendations expressed in this report are those of the workshop participants and do not necessarily reflect the views of the Agence Nationale de la Recherche (ANR) of France or the US National Science Foundation (NSF).

Computational neuroscience as a modern field of scientific investigation has changed enormously in a very short amount of time. The past decade has witnessed massive growth in the amount of data produced in neuroscience and made available to research and industrial laboratories, creating a need for new approaches to store and analyze massive amount of data. Modern experimental neuroscience now has unprecedented access to sophisticated genetic manipulations and high resolution imaging techniques that allow scientists to study cellular-level, systems-level, and cognitive levels of analyses, but will also produce massive amount of new data.

Within this context, the challenging questions that will arise regarding how the brain and the mind work require more than ever multiple groups to work in synergy. A bi-national community is much better poised to make a transformative impact given the high expertise and shared goals France and the United States have in computer science, neuroscience, and related fields.

For instance, domains such as the development of generic neural computational approaches, large-scale neural networks, model-based data analysis, multilevel mean-field descriptions of neural populations, and multi-scale measures of brain network dynamics would tremendously benefit from the expertise of the two countries. New formalisms that can explain plasticity and learning, from synapses to cortical regions, and model the neural computations of perceptual and cognitive behaviors are needed both for translational research in clinical sciences, medicine and engineering, and the development of neuromorphic, smart brain-machine and mind-machine interfaces. For instance, making progress in neurorehabilitation and implementing neurally integrated prosthetics requires having formal models that allow one to quantify and predict dynamic behaviors in noisy, realistic environments at the level of the synapse, neuron and brain regions. In this context, the development of brain-machine interfaces will strongly benefit from the natural French focus on physics and biophysics and the US focus on devices. The US emphasis on connectome and BigData initiatives would naturally fit with the French and European community emphasis on multiscale dynamics as well. Bringing neuroscience together with strong computing paradigms is another hallmark of synergistic collaboration between the two countries given their long-lasting, historical strengths in computer science and engineering (see Appendix for List of Potential Topics)

Importantly, collaborative proposals between France and the United States that would combine innovative modeling frameworks with modern neuroscience techniques would be ideally positioned to produce a converging picture of how the various types of computations collaborate to create intelligent behavior. Currently, we stand at the frontier of being able to develop and build prototypes neuro-prosthetics, sensory-substitution devices, and other brain-machine and mind-machine interfaces, as well as codifying a set of set of experimental protocols from motor neuro-rehabilitation to cognitive enhancement. A key milestone that must be reached, however, is to understand and model the neural mechanisms that are the target of any device or intervention. This international collaboration is in an excellent position to help accelerate progress in developing neural models capable of such accurate predictions.

Broader impacts of an International Partnership

Discussions at the workshop focused on the similarities and differences of the educational mission at the graduate and postdoctoral levels and importantly the role of international training experiences for this very multi-disciplinary field of research. The group discussed how to foster exchanges of students and investigators as well as the challenges arising in international research collaboration.

The workshop participants felt that international experiences can play a critical role in the training and development of scientists, encouraging creativity and independence by enabling them to think "outside the box" of their typical contexts, and exposing them to different approaches to collaboration and discourse. Moreover, the field of computational neuroscience, by its nature, requires combining knowledge across disciplines, which themselves are highly technical and involve expertise developed over time. The international program would be ideally suited to create high performing trans-disciplinary researchers, and foster new ideas to face the challenges of understanding the dynamics and connectivity architecture of the brain. Mechanisms could take the form of travels, summer of sabbatical visits across laboratories, as well as workshops and the sharing of databases. The creation of trans-disciplinary researchers with expertise from both the theoretical and the experimental neuroscience sides could have a transformative impact on solutions for brain machine interfaces and artificial systems that communicate with humans.

Important Considerations for Implementation

Participants agreed that the time is right for developing a fruitful international collaboration given the explosion of neuroscience data and the computational capabilities made available by internet and cloud systems. The computational neuroscience community already shares a common language of theoretical concepts and educational mission, but real opportunities like international exchanges of ideas, methods and people remain to be developed. Given the challenges ahead, the potential for developing flexible long term funding mechanisms to support innovation, infrastructure and projects of larger scales was seen as a bridge towards breakthroughs, supported by the fact that the training of trans-disciplinary researchers (including graduate students, postdocs, junior and senior investigators) towards mastery would take longer than the training of an individual within a discipline or method.

Other issues to take into account are that often research performed at multiple sites is complex (e.g. if a needed device or equipment is only at one site), requiring exchanges of individuals for longer periods of time. The patenting system also differs between the two countries, as well as the relations between academia and industry. Regarding student exchanges, institutional requirements for visitors, salary and tuition vary considerably between the two countries, as well as within the US universities. Additionally, some research laboratories in France are not necessarily affiliated with a teaching department, whereas research and education are more closely integrated in the US system. The cost of personnel and equipment may also largely vary between the countries and between experimental and theoretical work.

Conclusions and Recommendations

Rapid advances in empirical methods together with powerful computational techniques and an unprecedented ability to store and analyze large quantities of data, place computational neuroscience at the threshold of paradigm-shifting discoveries, with implications spanning multiple issues of critical international and national interests, such as education, medicine, health sciences, bioengineering, computer science, and economics. Computational neuroscience thrives from integrating expertise across multiple disciplines and, therefore, is well suited for funding mechanisms specifically designed to foster integrative research and international collaboration.

Both French and US participants recommend that a coordinated funding mechanism be established between the two countries to support joint research projects in the area of computational neuroscience and related disciplines, with a specific emphasis for the support of student exchange and career development. Given the interdisciplinary nature of the field, joint reviews by individuals from both countries would be appropriate, as well project evaluation mechanisms that are specifically tuned to identify the benefit of collaborative work, being multi-disciplinary or trans-disciplinary.

France and the United States are ideally posed for accelerating progress in emerging interdisciplinary topics of neuroscience, and realizing the opportunities posed specifically by computational neuroscience: the discovery of novel solutions for brain-machine and mind-machine interfaces and artificial systems that communicate with humans, and enhance human physical and cognitive abilities. The building of trans-disciplinary researchers and teams with mastery in several disciplines and methods is likely to have a long lasting implications in domains of critical national and international interest, such as education, medicine, health and well-being, bio-engineering, computer science, robotic, economic, and security.

APPENDICES

1- PARTICIPANTS

The workshop brought together investigators whose research exemplifies the emerging integration across disciplines and with experience in one or more levels of analysis of computational neuroscience, computer science and experimental neuroscience. The participants represented each country's research community in terms of disciplines, universities, regions and gender, including individuals with international experience.

Chairperson (US): Aude Oliva (MIT) is a Principal Research Scientist in the Computer Science and Artificial Intelligence Laboratory at MIT. Her work in Computational Perception and Cognition builds on the synergy between human and machine vision, and how it applies to solving high-level recognition problems. Her research expertise includes human behavioral, cognitive neuroscience and computer vision methods.

US Participants:

Larry Abbott (Columbia) is a Professor of Neuroscience, Physiology & Cellular Biophysics, Biological Sciences and co-director of the Center for Theoretical Neuroscience, Columbia. His research involves the computational modeling and mathematical analysis of neurons and neural networks.

Ralph Etienne Cummings (John Hopkins University) is a professor of Electrical and Computer Engineering. His research expertise includes mixed signal VLSI systems, computational sensors, computer vision, neuromorphic engineering, and neuroprosthetic devices.

Jack Gallant (Berkeley) is a Professor of Psychology. His research expertise includes Systems and Computational Neuroscience. His research program is dedicated to understanding the structure and function of the human visual system at a quantitative, computational level, and to building models that accurately predict how neural responses during natural vision.

Polina Golland (MIT) is an Associate Professor of Electrical Engineering and Computer Science. Her research interests span computer vision and machine learning. Her current work focuses on developing statistical analysis methods for the characterization of biological processes using images (from MRI to microscopy) as a source of information.

Yann LeCun (New York University) is a Professor of Computer Science and Neural Science. His research expertise includes machine learning, computer vision and computational neuroscience.

Markus Meister (Harvard) is a Professor of Molecular and Cellular Biology. His research focuses on understanding how large systems of nerve cells operate, what computation these neural circuits perform and how these functions are implemented by individual neurons and their connections.

Cynthia Moss (Maryland) is a Professor of Psychology, Neuroscience and Cognitive Science. Her research is directed at understanding auditory information processing and sensorimotor integration in vertebrates for developing integrative theories on brain-behavior relations in animal systems.

French participants:

Chairperson (France): Alain Destexhe, (CNRS-UNIC, Gif) is a CNRS senior researcher. His research program stands at the interface between biophysics, physics, computer science and neuroscience, from the microscopic (single neurons) to the macroscopic (networks or populations of neurons) aspects of the central nervous system function.

Nicolas Brunel (CNRS, Paris) is a CNRS senior researcher. His research program is at the interface between physics and neuroscience with the aim to understand the behavior of neural systems.

Olivier Faugeras (INRIA, Nice) is an INRIA senior researcher. His research expertise is in computational neuroscience, mathematics and the modeling of biological and machine visual perception.

Yves Fregnac (CNRS-UNIC, Gif) is a CNRS senior researcher and Professor in Cognitive Neuroscience at Ecole Polytechnique. His multidisciplinary research interests include functional intracellular and synaptic imaging of visual cortical receptive fields, optical imaging of cortical network dynamics, supervised models of Hebbian plasticity during development and adulthood.

Viktor Jirsa (CNRS, Marseille) is CNRS senior researcher. His research interests are in theoretical neuroscience and include principles of self-organization and spatiotemporal formation with a focus on biologically realistic neural networks and the influence of connectivity on network dynamics.

Jean-Pierre Nadal (CNRS, Paris) is a CNRS senior researcher. With a background in statistical physics, his research interests are in the fields of computational neuroscience (with focus on neural information processing), and of complex systems (biological and social networks).

Sylvie Renaud (Institut Polytechnique de Bordeaux and CNRS, Bordeaux) is a Professor in microelectronics. Her research interests are: analog and mixed neuromorphic VLSIs; memristor-based neuromorphic devices; real-time hardware simulation platforms of spiking neural networks; hybrid systems interfacing living and artificial neurons; analog ASICs for biological signal conditioning and events detection; active VLSI implants for neurodegenerative diseases and diabetes; closed-loop living-artificial systems.

Bertrand Thirion (INRIA, Saclay) is an INRIA senior researcher. His research interests include geometry and statistical modeling, for application to anatomical and functional brain mapping.

Simon Thorpe (CNRS, Toulouse) is a CNRS senior researcher. His research programs in computational neuroscience, neuroscience and psychophysics are centered on understanding the phenomenal processing speed achieved by the visual system.

2- GOVERNMENT OBSERVERS

Jean-Yves Berthou (Head of ICT department, ANR)
Jenifer Clark (Scientific coordinator of Health and Biology department, ANR)
Jean-Michel Heard (Head of Health and Biology department, ANR)
Nakita Vodjdani (Head of European and International cooperation, ANR)

William Barkis (NSF CISE)
Carmen Huber (Head, NSF Europe Office)
Yuan Liu (NIH NINDS, CRCNS program director)
Kenneth Whang (NSF CISE, CRCNS program director)

3- WORKSHOP SCHEDULE

Tuesday 29th November 2011

11:00 Welcome coffee

11:00	Welcome address by the ANR Deputy Director General, Philippe Freyssinet	
11:10-11:40	Introduction to ANR and to NSF/NIH CRCNSF	
11:40-11:50	Overview of workshop goals	
11:50-12:00	Introductory tour de table	
12:00-13:00	Lunch	
13:00-15:00	**<u>Session on Biophysical Models & Spike-based Coding</u>** **<u>Chair: Alain Destexhe</u>**	
13:00-13:20	Efficient models of neural computation in the retina	**M. Meister**
13:20-13:40	Biophysical models and dynamic-clamp experiments: connecting models with living neurons	**A. Destexhe**
13:40-14:00	From spike-based computing to bio-inspired hardware	**S. Thorpe**
14:00-14:20	From single neuron to network dynamics	**N. Brunel**
14:20-14:40	The bio-hardware front-end: extracellular-based interface	**S. Renaud**
14:40-15:20	Discussion / Synthesis led by M. Meister & A. Destexhe	
15:40-18:00	**<u>Session on Network Models, Neural fields and Dynamics Network</u>** **<u>Chair: Larry Abbott</u>**	
15:40-16:00	Large scale brain networks, from the connectome to dynamics	**V. Jirsa**
16:00-16:20	Bridging the gaps between micro/meso/macro levels	**O. Faugeras**
16:20-16:40	The variety of wiring patterns in neural circuits	**L. Abbott**
16:40-17:00	Silicon Systems that Speak the Same Language as the Nervous System	**R. Etienne-Cummings**
17:00-17:20	Biologically-inspired models of learning and visual perception that actually work	**Y. LeCun**
17:20-18:00	Discussion / Synthesis led by V. Jirsa & L. Abbot	

Wednesday 30th November 2011

09:00-12:20	**<u>Session on Models of Perception & Cognition</u>** **<u>Chair: Simon Thorpe</u>**	
09:00-09:20	Multiscale approaches and Complexity concepts in Low-level perception	**Y. Fregnac**
09:20-09:40	Neural Field models of some aspects of visual perception	**O. Faugeras**
09:40-10:00	Active sensing in complex environments	**C. Moss**
10:20-10:40	Statistical analysis methods for characterization of biological processes	**P. Golland**
10:40-11:00	Representation of semantic categories in natural movies and its modulation by attention.	**J. Gallant**
11:00-11:20	Recovering the brain regions that convey information about the subjects mental state in functional neuroimaging	**B. Thirion**
11:20-11:40	Neural coding of categories	**J.P. Nadal**
11:40-12:30	Discussion / Synthesis led by C. Moss & S. Thorpe	
13:30-14:30	**Panel discussion: Intellectual merit of an international partnership**	**A. Oliva / O. Faugeras**

14:45-15:45	**Panel discussion: Broader impacts of an international partnership**	**R. Etienne-Cummings**
16:00-17:00	**Panel discussion: Practical Issues of an international partnership**	**P. Golland / Y. LeCun / Y. Fregnac**
17:00-18:00	**Synthesis discussion for the report**	**A. Oliva**

4- LIST OF US-FRANCE TOPICS DISCUSSED AT THE MEETING

Several topics of synergistic collaboration between France and United States were discussed at the meeting. Whereas the list created at the discussion is by no means exhaustive, it illustrates some exciting challenges in Computational Neuroscience that both communities see coming ahead.

- Multiscale measures of brain dynamics, functional connectivity (effective/functional vs. structural connectivity), modelling brain signals and activation patterns (from intracellular to macroscopic signals such as EEG, MEG, fMRI, …) and bridging the gaps between scales (e.g. linking neural-based measures to metabolic or hemodynamic measures), mapping of the brain at multiple levels of analysis.

- Mathematical approaches, neurogeometry, topology, information-theoretic approach, data mining, mean-field and neural field approaches, stochastic dynamics, dynamical systems, bifurcations, propagation delays, etc

- Plasticity and learning: rules of plasticity (STDP etc), sign of plasticity (Hebbian, anti-Hebbian, etc), plasticity in mean-field, meta-plasticity, associative memory, sequence learning, homeostasis, perceptual filtering.

- Generic features and versatility of the neural code: population coding, spike-based and temporal coding, deterministic chaos vs. stochasticity.

- Generic neural computing architectures: canonical neural circuits, role and processing impact of layered structures, columns and sub-networks, role of recurrent, lateral and feedback networks,.

- Generic neural computations: interaction between ongoing (spontaneous) activity and externally-driven information, role of noise, state-dependent processing, oscillations, dynamic reorganization of circuits

- Defining new state variables for mesoscopic modeling (e.g the meta neuron, the metacolumn where mean field models would be justified, e.g state variable reflecting the functional expression of columns through haptic coupling, glial interactions, and field effects)

- Neural computations (including their emergence and representation) of perception and cognition in the context of natural environments, including social context, and behaviors (including movement, perception-action cycles, adaptation, learning, memory, language, decision making, etc. using behavioral, psychophysics, electrophysiology, imaging or modeling approaches, among others)

- Comparative study and modelling of perceptual, motor, cognitive and social systems and their neural correlates across species and across phylogenetic branches

- Neuromorphic, brain-machine and mind-machine interfaces for prosthetics, as well as interfaces for perceptual, cognitive and functional enhancement (e.g. embedded hybrid (bio-silicon) neural computation; dynamic-clamp; neuromorphic cognition; neuro-engineering, perceptual and cognitive technologies for non invasive human-device interfaces)

- Model-based data analysis, extracting knowledge from measurements of brain and neural activity, as well as from experimental data gathered from behavioral experiments (at the individual, group and social levels)

- Convergence of computing paradigms (computer science, computer vision - or other modalities -, machine learning, etc) with neuroscience and behavioral sciences.

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