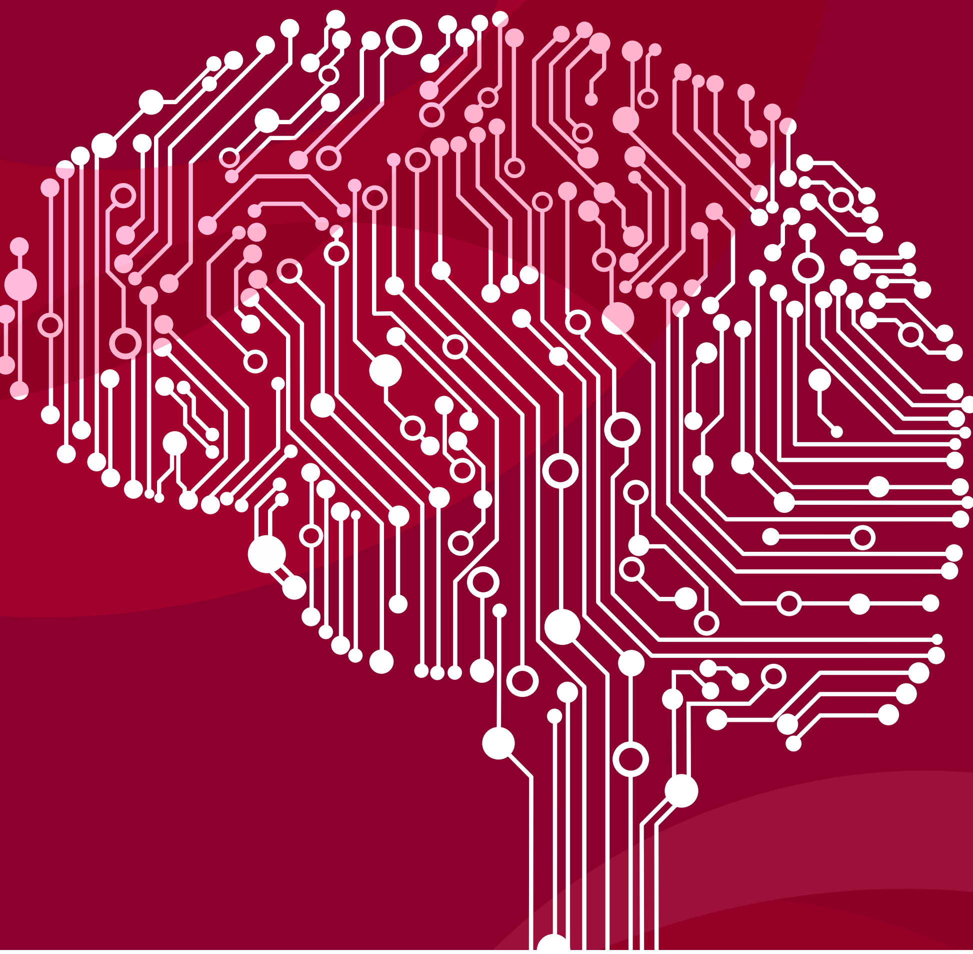
Research Interfaces between

# Brain Science and Computer Science



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## Brain Workshop Description

Computer science and brain science share deep intellectual roots. Today, understanding the structure and function of the human brain is one of the greatest scientific challenges of our generation. Decades of study and continued progress in our knowledge of neural function and brain architecture have led to important advances in brain science, but a comprehensive understanding of the brain still lies well beyond the horizon. How might computer science and brain science benefit from one another?

This two-day workshop, sponsored by the Computing Community Consortium (CCC) and National Science Foundation (NSF), brings together brain researchers and computer scientists for a scientific dialogue aimed at exposing new opportunities for joint research in the many exciting facets, established and new, of the interface between the two fields.

# Organizing Committee

**Polina Golland**
Professor, Computer Science and Artificial Intelligence Laboratory, Massachusetts Institute of Technology

**Gregory Hager**
Chair of the Computer Science Department, The Johns Hopkins University

**Christof Koch**
Chief Scientific Officer, Allen Institute for Brain Science

**Christos Papadimitriou** (Chair)
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**Tal Rabin**
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**Joshua Tenenbaum**
Professor, Brain and Cognitive Sciences, Massachusetts Institute of Technology

**Kenneth Whang**
Program Director, NSF

**Ross Whitaker**
Professor, School of Computing SCI Institute, University of Utah

**Ann Drobnis**
Director, Computing Community Consortium

# Agenda

## December 3

**5:30 PM** Welcome and Overview of the Workshop Panels
**6:30 PM** Dinner
**7:30 PM** Introductions

## December 4

**7:30 AM** Breakfast
**8:30 AM** Welcome
**8:40 AM** Plenary: *A Big Data Approach to Functional Characterization of The Mammalian Brain*
Jack Gallant

**9:30 AM** Panel: *Brain Mapping*
**11:00 AM** Break
**11:30 AM** Panel: *Brain / Mind / Body*
**1:00 PM** Working Lunch
**2:00 PM** Plenary: *Time, Space and Computation: Converging Human Neuroscience and Computer Science*
Aude Oliva

**2:45 PM** Panel: *Computing and the Brain*
**4:15 PM** Break
**4:30 PM** Breakout Sessions
**6:15 PM** Dinner
**7:30 PM** Plenary: *Can Models of Computation in Neuroscience be Experimentally Validated?*
Leslie Valiant

## December 5

**7:30 AM** Breakfast
**8:30 AM** Panel: *Creating Open-Science Platforms for Heterogeneous Brain Data*
**10:05 AM** Plenary: *Theory, Computation, Modeling and Statistics: Connecting the Dots from the BRAIN Initiative*
Terrence Sejnowski

**10:50 AM** Break
**11:05 AM** Breakout Sessions
**12:00 PM** Working Lunch
**1:00 PM** Breakout Reports
**2:00 PM** Workshop Concludes

# Plenary Speakers

## Jack Gallant, UC Berkeley

Dr. Jack Gallant received his PhD in Experimental Psychology from Yale. He is currently at the University of California, Berkeley in the Department of Psychology. The focus of his research is on understanding the structure and function of the visual system. The visual system is also tightly integrated with other sensory subsystems and systems for memory and language. Because of this interconnectivity, and because the brain is build on modular principles, vision research also has important implications for understanding other brain systems. The goal of the Gallant Lab is to understand the structure and function of the human visual system at a quantitative, computational level, and to build models that accurately predict how the brain will respond during natural vision.

## Aude Oliva, MIT

After a French baccalaureate in Physics and Mathematics and a B.Sc. in Psychology (minor in Philosophy), Aude Oliva received two M.Sc. degrees –in Experimental Psychology, and in Cognitive Science and a Ph.D from the Institut National Polytechnique of Grenoble, France. She joined the MIT faculty in the Department of Brain and Cognitive Sciences in 2004 and the MIT Computer Science and Artificial Intelligence Laboratory - CSAIL - in 2012. She is also affiliated with the Athinoula A. Martinos Imaging Center at the McGoven Institute for Brain Research, and with the MIT Big Data Initiative at CSAIL. Her research is cross-disciplinary, spanning human perception/cognition, computer vision, and cognitive neuroscience, focusing on research questions at the intersection of the three domains. She is the recipient of a National Science Foundation CAREER Award (2006) in Computational Neuroscience, an elected Fellow of the Association for Psychological Science (APA), and the recipient of the 2014 Guggenheim fellowship in Computer Science.

## Leslie Valiant, Harvard

Leslie Valiant was educated at King's College, Cambridge; Imperial College, London; and at Warwick University where he received his Ph.D. in computer science in 1974. He is currently T. Jefferson Coolidge Professor of Computer Science and Applied Mathematics in the School of Engineering and Applied Sciences at Harvard University, where he has taught since 1982. His work has ranged over several areas of theoretical computer science, particularly complexity theory, learning, and parallel computation. He also has interests in computational neuroscience, evolution and artificial intelligence and is the author of two books, Circuits of the Mind, and Probably Approximately Correct.

## Terrence Sejnowski, Salk Institute

Terrence Sejnowski received his PhD in physics from Princeton University and was a postdoctoral fellow at Harvard Medical School. He was on the faculty at the Johns Hopkins University and he now holds the Francis Crick Chair at The Salk Institute for Biological Studies and is also a Professor of Biology at the University of California, San Diego, where he is co-director of the Institute for Neural Computation and co-director of the NSF Temporal Dynamics of Learning Center. He is the President of the Neural Information Processing Systems (NIPS) Foundation, which organizes an annual conference attended by over 1000 researchers in machine learning and neural computation and is the founding editor-in-chief of Neural Computation published by the MIT Press.

# Plenary Talks

## A Big Data Approach to Functional Characterization of The Mammalian Brain

A full understanding of the computational principles of the mammalian brain will require that we obtain detailed information about brain function and brain structure. Any attempt at functional characterization is inevitably limited by technological limits on functional recording, and by the absence of computational theories rich enough to account for complex cognition. To surmount these problems my lab has focused on inductive approaches that have their roots in system identification. We gather large, high-quality data sets under naturalistic conditions, and we use statistical and machine learning methods to model the data. Our pipeline allows us to [1] characterize functional properties (i.e., tuning, response manifold) of local units; [2] cluster local units into functional maps; and [3] determine how functional maps are modulated by attention and learning. Another key problem is to understand how information flows between functional maps, but this is difficult to address with current technology. In the long term we anticipate that all of these problems can be addressed within a single statistical framework.

**Jack Gallant,** *UC Berkeley*

## Time, Space and Computation: Converging Human Neuroscience and Computer Science

Computer science is bringing the world to cognitive scales of time, space, and capacity. Already, cognitive activities such as holding a conversation, recalling facts, and recognizing objects can be facilitated by computing systems at nearly the same rates that the human brain itself accesses and processes information. However, to further develop and fully engage with artificial systems at human-cognitive levels, we must understand cognition itself, and how it is mediated by the brain. To this end, multimodal non-invasive human neuroimaging techniques can overcome spatial and temporal limitations in current technology. Further, relating the results with computational approaches offers a platform to test algorithmically explicit models of perceptual and cognitive neural representations at high temporal and spatial resolution. In this way, understanding the links between natural and artificial information processing will be essential not only to advance fundamental understanding of neural dynamics, but pave the way to fully realizing the benefits of an increasingly technologized society.

**Aude Oliva,** *MIT*

## Can Models of Computation in Neuroscience be Experimentally Validated?

We suggest that to achieve an understanding of how any particular computational mechanism works, a necessary step is to identify a model of computation that is useful in that context. Once one has such a model, one can start studying the interacting components of: representations, algorithms and functionality. We shall illustrate this argument in the context of memory and learning tasks for cortex. It appears that for any significant cortical task these interactions, among representations, algorithms, and functionality, raise complex issues and give rise to complex theories. The inevitable question for any such theory is whether there is somewhere to start to validate it. We shall suggest a positive answer, in the form of a concrete series of experiments for the case at hand.

**Leslie Valiant,** *Harvard*

## Theory, Computation, Modeling and Statistics: Connecting the Dots from the BRAIN Initiative

The era of big data has arrived in neuroscience, which joins physics, astronomy, genomics and other sciences.  The goal is to make these large databases available to anyone who wants to analyze them, but this will require a cultural shift from current practice.  The BRAIN 2025 Report that was released by the NIH last June highlights the increasingly important place that Theory, Modeling, Computation, and Statistics will have in achieving the goal of understanding the basic principles of brain function.

**Terrence Sejnowski,** *Howard Hughes Medical Institute, Salk Institute for Biological Studies, University of California, San Diego*

# Panels

## Brain Mapping

**Charles Fowlkes**
**James Haxby**
**Jeff Lichtman**
**Ragini Verma**
**Moderator: Polina Golland**
**Moderator: Hanspeter Pfister**

Scientists are recording the functions and mapping the connectivity of neuronal structures to help us understand how brains work. Computational analysis and modeling promises to extract relevant information from the tremendous amounts of measurement data. In this session we will explore the state of the art in brain measurement and reconstruction, in modeling the functional organization of the brain based on imaging data, and discuss current and future challenges.

## Brain / Mind / Body

**Matt Botvinick**
**Naomi Hannah Feldman**
**Konrad Koerding**
**Raj Rao**
**Moderator: Stefan Schaal**

In this panel, we discuss connections between brain science and topics of cognitive psychology, computational motor control, artificial intelligence (AI), machine learning (ML), and robotics. In some sense, we are addressing a classical claim by Richard Feynman in that "What I cannot create I do not understand". AI, ML, robotics are largely about synthesizing systems that accomplish some form of autonomy and competence in real world tasks. The information processing in these tasks if often based on similar information emitted from a physical environment as has to be processed by human and non-human animals. Action with a physical body becomes the evidence of successful behavior, and many components of physics in biological and physical systems are the same. Cognitive psychology, computational motor control, and related fields address the computational interface between synthetic and biological systems, maybe something that could be called the level of theory and algorithms in the spirit of David Marr. But often, it is hard to connect this more abstract computational thinking to the low levels of neuroscientific reality. What is the role of these more abstract theories of information processing in brain science? How can neural-level modeling and experimental work inform the building blocks of distinctively human cognitive capacities, such as language and higher-level thought? How can collaborative project be initiated, how can they be successful? This panel will take a fresh look at these topics with a variety of panelists and participants from related areas.

## Computing and the Brain

**Shafi Goldwasser**
**Yann Lecun**
**Pietro Perona**
**Leslie Valiant**
**Moderator: Sanjeev Arora**

The study of computing and the study of the brain interrelate in three ways, each suggesting a major research direction. First, if the brain is indeed implementing an algorithm (or collection of algorithms), then the study of efficient algorithms as well as experience with design of intelligent/autonomous systems ought to suggest possibilities/theories for the brain's architecture and function. Second, experimental study of brain architecture and function is a massive-data problem that necessitates advances in computing. Third, the remarkable efficiency (including energy efficiency) of the brain, once understood, may inspire radically new algorithmic or system organization approaches that could transform computing itself. This panel will vigorously discuss current state of understanding of these three directions, and the most productive avenues of research in the immediate future.

## Creating Open-Science Platforms for Heterogeneous Brain Data

**Greg Farber**
**Jeremy Freeman**
**Paul Thompson**
**Joshua Vogelstein**
**Moderator: Miyoung Chun**

Data generation in brain science has rapidly accelerated, drawing on research advances in genetic, molecular, cellular, imaging, and electrophysiological (and other) approaches. However, tools for systematically archiving, integrating, and disseminating data generated through divergent experimental techniques lag far behind. In this session, we will discuss potential strategies for and challenges to developing open-science platforms that enable large, heterogeneous data sets to be combined and exploited to develop increasingly detailed and comprehensive models of neural function.

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