Computational Neuroscience

2020

Final discussion

Odelia Schwartz

Computational neuroscience

http://ccneuro.org/ccn-blog/

How can we find out how the brain works? (2017)

Yoshua Bengio, U Montreal
Department of Computer Science and Operations Research

" If there is a compact description of the computational principles which explain how the brain manages to provide us with our intelligence, this is something I would consider the core explanation for how the brain works – a little bit like the laws of physics for our physical world. Note that this is very different from the structured observation of our world in all its encyclopedic detail, which provides a useful map of our world, but not a principled explanation. Just replace 'world' by 'brain'. My thesis is that those principles would also allow us to build intelligent machines and that at the heart of our intelligence is our ability to learn and make sense of the world, by observing it and interacting with it. That is why I believe in the importance of a continuous discussion between the brain researchers and AI researchers, especially those in machine learning – particularly deep learning and neural networks. This is likely to benefit AI research as well, as it has in the past."

Computational neuroscience

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How can we find out how the brain works? (2017)

Tom Griffiths, UC Berkeley

Department of Psychology and Cognitive Science

“ As a cognitive scientist I normally think about this question from the perspective of Marr’s levels of analysis. Understanding how the brain works is a question at what Marr called the “implementation” level, but I think a lot of insight can be gained by asking why the brain does what it does — a question at Marr’s “computational” level. Between those levels of analysis is the “algorithmic” level, which looks at the particular cognitive processes that are involved in solving a problem. Over the last few years a lot of progress has been made at both the implementation level and the computational level, but I think the algorithmic level gets neglected when we think about the brain. Understanding the algorithms that brains execute — and how brains learn to execute those algorithms — is going to be a critical part of finding out how the brain works.”

Computational neuroscience

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How can we find out how the brain works? (2017)

Alona Fyshe, University of Victoria, BC, Canada
Department of Computer Science

" We will need to continue to study the brain at multiple scales, both at the neuronal level, at the macro level (via brain imaging), and at the behavioral level. And we need to continue to bring these worlds together. We also need to start pushing brain imaging experiments in humans out into the real world. We can learn something about human language understanding by watching people read single words or single sentences, but we will miss out on the higher level comprehension areas that are required for larger scale understanding and reasoning. Similarly, viewing pictures or watching videos tells us something about vision, but interacting with objects in the real world will likely tell us more. There is tremendous value in tightly controlled experimental paradigms, but we also need some people doing the hard work that gets at the more holistic aspects of brain information processing."

Computational neuroscience

http://ccneuro.org/ccn-blog/

How can we find out how the brain works? (2017)

Michael Shadlen, Columbia University
Department of Neuroscience

- By testing neurobiological hypotheses that address the “how” question at a variety of levels. To me, “how the brain works” is a biological problem because I am less interested in mimicking the brain with a machine than I am in assessing what goes wrong when the brain doesn’t work, and how we might remedy the fault. To this end, functional equivalence (like airplanes to birds), which might interest the engineer, is not enough and possibly detrimental—a misguided diversion. To make progress on the “how” of cognitive function, my approach is to focus less on the representation of information and more on what the organism does with the information.”

Computational neuroscience

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How can we find out how the brain works? (2017)

Birte Forstmann, University of Amsterdam

Integrative model-based cognitive neuroscience research unit

" I believe that formal models that make simultaneous predictions about different modalities such as behavior and the brain are powerful tools. Such tools could help to gain a better mechanistic understanding of brain function."

Computational neuroscience

http://ccneuro.org/ccn-blog/

How can we find out how the brain works? (2017)

Nicole Rust, University of Pennsylvania
Department of Psychology

" It all begins with thoughtful descriptions of the computations that the brain solves, which are often directly reflected in behavior. Ultimately, a description of "how" is formalized by a model that provides a non-trivial account of data. Crucially, while many of us have been taught that the ultimate test of understanding something is to build it, recent work in our field highlights that you can build something without deeply understanding how it works. Model interpretability is one of the biggest challenges that we currently face."

Computational neuroscience

http://ccneuro.org/ccn-blog/

How can we find out how the brain works? (2017)

Odelia Schwartz, University of Miami
Department of Computer Science

" There is a continued need for computational frameworks that interplay with experimental design and analysis at multiple levels (e.g., neurons, circuits, cognition). I have been intrigued by how neural systems represent and learn about stimuli in the natural environment, resulting in complex inferences and behavior. My main focus has been building computational neural models that push towards a more principled understanding for natural stimuli such as visual scenes. With advances in machine learning and in understanding the statistics of natural stimuli, I believe there is potential for progress in designing and interpreting experiments with naturalistic environments and tasks."

Computational neuroscience

http://ccneuro.org/ccn-blog/

How can we find out how the brain works? (2017)

Wei Ji Ma, New York University
Center for Neural Science and Department of Psychology

" …At a more sociological level, I am old-fashioned and strongly believe in small, hypothesis-driven science. While some problems in neuroscience might be best addressed using big data, big simulations, or big collaborations, my sense is that those currently involve more hype than substance. Neuroscience and cognitive science have come far with a "letting a hundred flowers bloom" approach, and there is no evidence that this approach is bankrupt. More specifically in computational neuroscience, small science often amounts to a search for evolutionarily meaningful organizing principles, perhaps initially in a toy model – this is my favorite approach."

From the NIH web site: Committee report: Brain 2025: A Scientific Vision (from 2014)

#1. Discovering diversity: Identify and provide experimental access to the different brain cell types to determine their roles in health and disease. It is within reach to characterize all cell types in the nervous system, and to develop tools to record, mark, and manipulate these precisely defined neurons in the living brain. We envision an integrated, systematic census of neuronal and glial cell types, and new genetic and non-genetic tools to deliver genes, proteins, and chemicals to cells of interest in non-human animals and in humans.

From the NIH web site:
Committee report: Brain 2025: A Scientific Vision
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#2. Maps at multiple scales: Generate circuit diagrams that vary in resolution from synapses to the whole brain. It is increasingly possible to map connected neurons in local circuits and distributed brain systems, enabling an understanding of the relationship between neuronal structure and function. We envision improved technologies—faster, less expensive, scalable— for anatomic reconstruction of neural circuits at all scales, from non-invasive whole human brain imaging to dense reconstruction of synaptic inputs and outputs at the subcellular level.

From the NIH web site:
Committee report: Brain 2025: A Scientific Vision
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#3. The brain in action: Produce a dynamic picture of the functioning brain by developing and applying improved methods for large-scale monitoring of neural activity. We should seize the challenge of recording dynamic neuronal activity from complete neural networks, over long periods, in all areas of the brain. There are promising opportunities both for improving existing technologies and for developing entirely new technologies for neuronal recording, including methods based on electrodes, optics, molecular genetics, and nanoscience, and encompassing different facets of brain activity.

From the NIH web site:
Committee report: Brain 2025: A Scientific Vision
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#4. Demonstrating causality: Link brain activity to behavior with precise interventional tools that change neural circuit dynamics. By directly activating and inhibiting populations of neurons, neuroscience is progressing from observation to causation, and much more is possible. To enable the immense potential of circuit manipulation, a new generation of tools for optogenetics, chemogenetics, and biochemical and electromagnetic modulation should be developed for use in animals and eventually in human patients.

From the NIH web site:
Committee report: Brain 2025: A Scientific Vision
(from 2014)

#5. Identifying fundamental principles: Produce conceptual foundations for understanding the biological basis of mental processes through development of new theoretical and data analysis tools. Rigorous theory, modeling, and statistics are advancing our understanding of complex, nonlinear brain functions where human intuition fails. New kinds of data are accruing at increasing rates, mandating new methods of data analysis and interpretation. To enable progress in theory and data analysis, we must foster collaborations between experimentalists and scientists from statistics, physics, mathematics, engineering, and computer science.

From the NIH web site:
Committee report: Brain 2025: A Scientific Vision (from 2014)

#6. Advancing human neuroscience: Develop innovative technologies to understand the human brain and treat its disorders; create and support integrated human brain research networks. Consenting humans who are undergoing diagnostic brain monitoring, or receiving neurotechnology for clinical applications, provide an extraordinary opportunity for scientific research. This setting enables research on human brain function, the mechanisms of human brain disorders, the effect of therapy, and the value of diagnostics. Meeting this opportunity requires closely integrated research teams performing according to the highest ethical standards of clinical care and research. New mechanisms are needed to maximize the collection of this priceless information and ensure that it benefits people with brain disorders.

From the NIH web site:
Committee report: Brain 2025: A Scientific Vision (from 2014)

#7. From BRAIN Initiative to the brain: Integrate new technological and conceptual approaches produced in Goals #1-6 to discover how dynamic patterns of neural activity are transformed into cognition, emotion, perception, and action in health and disease. The most important outcome of the BRAIN Initiative will be a comprehensive, mechanistic understanding of mental function that emerges from synergistic application of the new technologies and conceptual structures developed under the BRAIN Initiative.

The overarching vision of the BRAIN Initiative is best captured by Goal #7—combining these approaches into a single, integrated science of cells, circuits, brain, and behavior.

From the NIH web site:
Committee report: Brain 2025: A Scientific Vision
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Cross boundaries in interdisciplinary collaborations. No single researcher or discovery will solve the brain's mysteries. The most exciting approaches will bridge fields, linking experiment to theory, biology to engineering, tool development to experimental application, human neuroscience to non-human models, and more, in innovative ways.

From the NIH web site:
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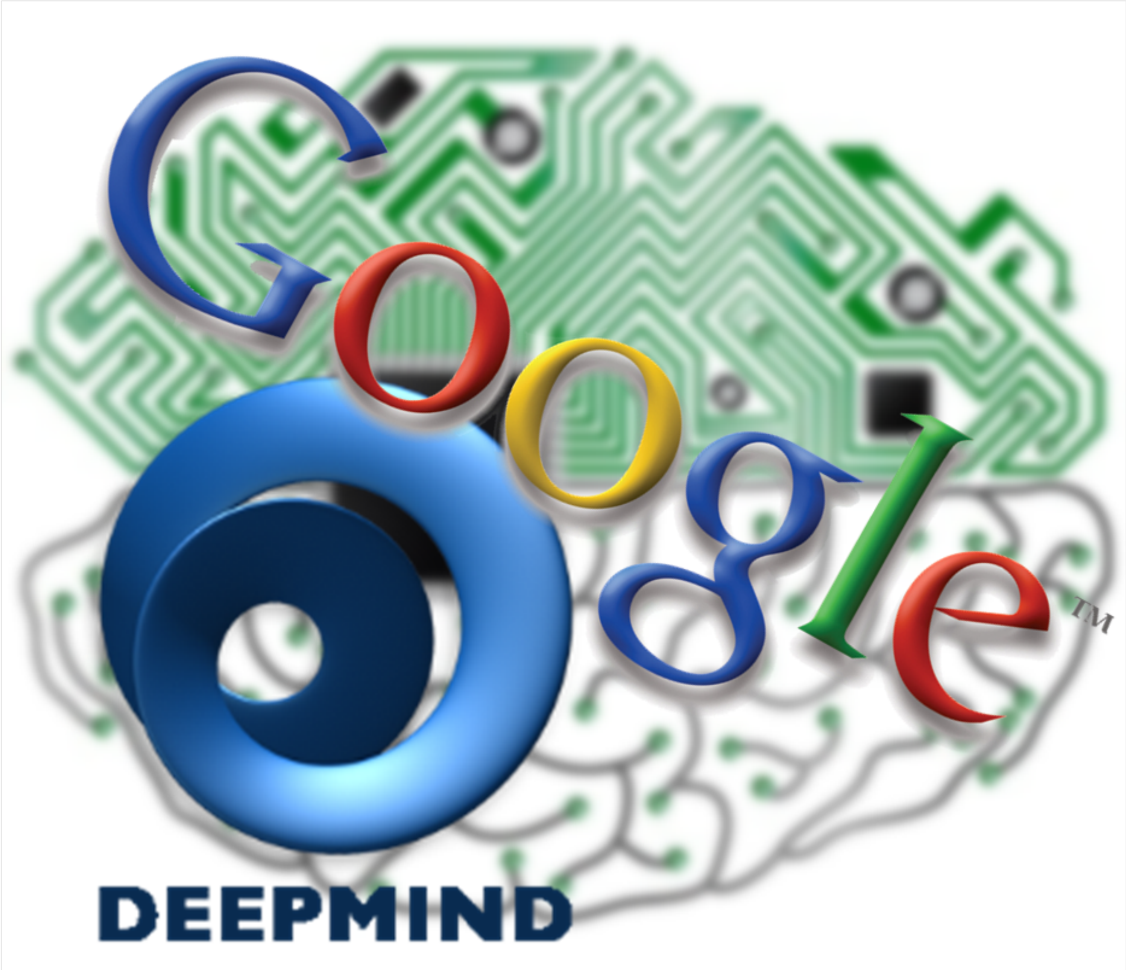
Theory, Modeling, and Statistics Will Be Essential to Understanding the Brain

Ideally, theorists and statisticians should be involved in experimental design and data acquisition, not just recruited at the step of data interpretation.

Lots of recent interest from industry



Google Brain

"We are a machine intelligence team focused on deep learning. We advance the state of the art in order to have a positive impact on the world. We achieve this goal by focusing on highly flexible models that learn their own features, end-to-end, and make efficient use of data and computation. This approach fits into the broader Deep Learning subfield of ML and ensures our work will ultimately make a difference for problems of practical importance."

Computational neuroscience

Deep Mind: solve intelligence.
Use it to make the world a better place

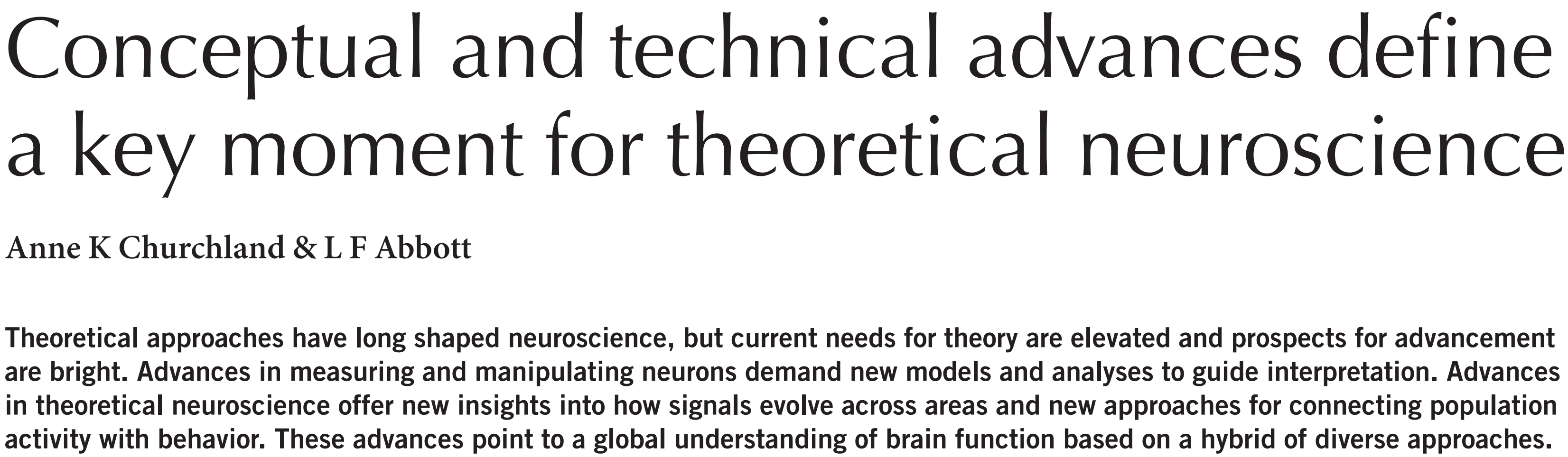
"We joined forces with Google in order to turbo-charge our mission. The algorithms we build are capable of learning for themselves directly from raw experience or data, and are general in that they can perform well across a wide variety of tasks straight out of the box. Our world-class team consists of many renowned experts in their respective fields, including but not limited to deep neural networks, reinforcement learning and systems neuroscience-inspired models."

Computational neuroscience

IBM Research: Cognitive computing:

"The Cognitive Era: By any measure, 2015 has been a landmark year for the discussion around artificial intelligence and its potential impact on business and society. Be part of the conversation as we explore a fascinating and diverse set of issues related to the powerful cognitive technologies that are emerging to augment human capacity and understanding."

Computational neuroscience


Conceptual and technical advances define a key moment for theoretical neuroscience

Anne K Churchland & L F Abbott

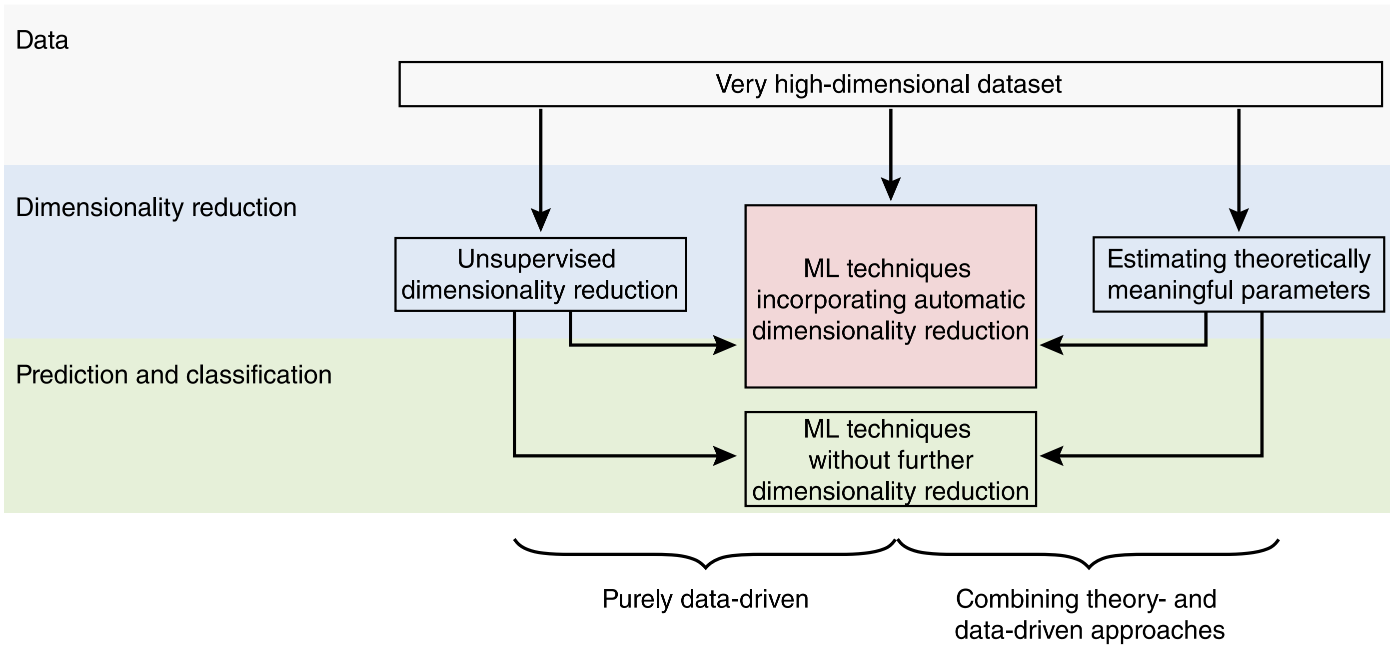
Theoretical approaches have long shaped neuroscience, but current needs for theory are elevated and prospects for advancement are bright. Advances in measuring and manipulating neurons demand new models and analyses to guide interpretation. Advances in theoretical neuroscience offer new insights into how signals evolve across areas and new approaches for connecting population activity with behavior. These advances point to a global understanding of brain function based on a hybrid of diverse approaches.

Churchland, A.K. and Abbott, L.F. (2016)

Computational neuroscience

"In the coming years, we will obtain enormous quantities of behavioral, recording (both electrical and optical), connectomic, gene expression and other forms of data. Obtaining deep understanding from this onslaught will require, in addition to the skillful and creative application of experimental technologies, substantial advances in data analysis methods and intense application of theoretic concepts and models."

Computational modeling of brain disorders



- Huys et al., Nature Neuroscience 2016: Computational psychiatry as a bridge from neuroscience to clinical applications (see also Montague, Dolan, Friston, Dayan, Trends in Cognitive Sciences 2012)
- Theoretically meaningful approaches can add value beyond purely data driven machine learning
- This approach is used in computational neuroscience for understanding normal brain functioning, and is of potential interest for understanding brain disorders

Computational modeling of brain disorders

- Computational perspective as complementary or on top of pure machine learning

Huys et al., Nature Neuroscience 2016: Computational psychiatry as a bridge from neuroscience to clinical applications; Montague, Dolan, Friston, Dayan, Trends in Cognitive Sciences 2012; Bennett, Silverstein, Niv: The Two Cultures of Computational Psychiatry 2019;
Hauser et al. 2019)

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Computational modeling of brain disorders

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- Consider cognitive task and related data

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- Fit model parameters to clinical patient data
- Consider model components in relation to mechanistic explanations, e.g., regarding neuromodulators

Huys et al., Nature Neuroscience 2016: Computational psychiatry as a bridge from neuroscience to clinical applications; Montague, Dolan, Friston, Dayan, Trends in Cognitive Sciences 2012; Bennett, Silverstein, Niv: The Two Cultures of Computational Psychiatry 2019; Hauser et al. 2019)

Fields evolving include …

- Computational Cognitive Neuroscience (new conference combining AI, Cognitive Science, Neuroscience)
- Decision making and reinforcement learning. "Perceptual Decision-Making: A Field in the Midst of a Transformation" (Najafi, Churchland 2018)
- Computational Psychiatry
- Vision and learning …
- New approaches and analyses for making sense of large scale data

Related research areas At UM

- Computational Neuroscience
- Neural Engineering and Brain machine Interfaces
- Machine learning
- Data science
- Large-scale fMRI
- Technology such as optogenetics
- Neuroscience / Biology
- Robotics