BIOGRAPHICAL SKETCH

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NAME: Olshausen, Bruno A.

eRA COMMONS USER NAME (credential, e.g., agency login): bolshausen

POSITION TITLE: Professor of Optometry and Neuroscience

EDUCATION/TRAINING *(Begin with baccalaureate or other initial professional education, such as nursing, include postdoctoral training and residency training if applicable. Add/delete rows as necessary.)*

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	Completion Date MM/YYYY	FIELD OF STUDY
Stanford University, Palo Alto, CA	B.S.	06/1986	Electrical Engineering
Stanford University, Palo Alto, CA	M.S.	06/1987	Electrical Engineering
California Institute of Technology, Pasadena, CA	Ph.D.	12/1994	Computation & Neural Systems

A. Personal Statement

A significant part of my career at both UC Davis and UC Berkeley has been dedicated to providing interdisciplinary training to graduate students and postdocs in neuroscience. At UC Davis I created a new course on *Information Processing Models in Neuroscience and Psychology* and at UC Berkeley I created a new course on *Neural Computation*, both of which have been attended by students and postdocs across multiple disciplines ranging from neuroscience and psychology to physics and engineering. I have supervised the Ph.D. theses of 15 students from neuroscience, vision science, computer science, electrical engineering, and biophysics, and I have mentored 10 postdocs. Those trained in my lab have gone on to faculty positions (University of Washington, Georgia Institute of Technology, University of Connecticut), engineering positions (Qualcomm, Nokia, Booz Allen Hamilton, Google), postdocs at other academic institutions (MIT, Stanford, UC Davis), or co-found startups (Nervana Systems, Bay Labs, IQ Engines). Beyond my own lab, I also serve as Director of the Redwood Center for Theoretical Neuroscience which comprises four PI labs and roughly 20 students and postdocs. I strive to create and open and inviting research environment that draws in students across multiple disciplines to address problems in computational neuroscience. My research focuses on understanding the information processing strategies employed by the visual system for tasks such as object recognition and scene analysis. Our approach is based on studying the response properties of neurons in the brain, and attempting to construct mathematical models that can describe what neurons are doing in terms of a functional theory of vision. The aim of this work is not only to advance our understanding of the brain, but also to devise new algorithms for image analysis and recognition based on how brains work.

1. Olshausen BA, Field DJ (1996). Emergence of simple-cell receptive field properties by learning a sparse code for natural images. **Nature, 381,** 607-609.
2. Rozell CJ, Johnson DH, Baraniuk RG, Olshausen BA (2008) Sparse coding via thresholding and local competition in neural circuits. **Neural Computation, 20**, 2526-2563.
3. Cadieu CF, Olshausen BA (2012) Learning Intermediate-Level Representations of Form and Motion from Natural Movies. **Neural Computation, 24**, 827-66.
4. Anderson AG, Ratnam K, Roorda A, Olshausen BA (2020) High-Acuity Vision from Retinal Image Motion. **Journal of Vision, 20(7)**, 34-34.

B. Positions and Honors

Positions

1987 – 1989	Research Associate, Research Institute for Advanced Computer Science, NASA Ames Research Center
1989 – 1992	Graduate Research Assistant, Division of Biology, California Institute of Technology
1992 – 1994	Graduate Research Assistant, Department of Anatomy and Neurobiology, Washington University School of Medicine
1994 – 1996	Postdoctoral Fellow, Department of Psychology, Cornell University
1996	Postdoctoral Fellow, Center for Biological and Computational Learning, Massachusetts Institute of Technology
1996 – 2001	Assistant Professor, Department of Psychology, and Center for Neuroscience, University of California, Davis
2001 – 2005	Associate Professor, Department of Psychology, Department of Neurobiology, Physiology & Behavior, and Center for Neuroscience, University of California, Davis
2002 – 2005	Senior Research Scientist, Redwood Neuroscience Institute, Menlo Park, California
2005 – 2010	Associate Professor, Helen Wills Neuroscience Institute and School of Optometry, University of California, Berkeley
2005 –	Director, Redwood Center for Theoretical Neuroscience, University of California, Berkeley
2010 –	Professor, Helen Wills Neuroscience Institute and School of Optometry, University of California, Berkeley

Other Experience and Professional Memberships

2002 –	Member, Society for Neuroscience
2000 – 2016	Action Editor, *Journal of Computational Neuroscience*
2005 – 2015	Editorial Board, *Vision Research*
2006 – 2013	Co-founder and Member of the Board, IQ Engines
2013 – 2017	Advisory Board, NIH COBRE, University Nevada, Reno
2012 – 2016	Advisory Board, Bernstein Center for Computational Neuroscience, Tübingen, Germany

Honors

2008 – 2019	Fellow, Canadian Institute for Advanced Research, Neural Computation and Adaptive Perception program
2009	Fellow, Wissenschaftskolleg zu Berlin, Berlin, Germany

C. Contribution to Science

1. **Sparse coding and natural scene statistics.** The images that fall on our retinae are not random collections of pixels, but rather they contain a certain statistical structure which reflects the structure of the natural world. It has been argued by Barlow and others that neural representations in the brain are adapted to this structure so as to form an efficient code of natural scenes. Over the past 25 years, a number of investigators have shown that one can account for sensory coding strategies at early stages of the visual (and auditory) system in terms of this principle. My main contribution to this area is in showing that the principle of sparse coding (also proposed by Barlow) can account for the response properties of neurons in visual cortex. This work thus provides a link between the response properties of cortical neurons and the statistics of images. Current work in my lab focuses on extending this principle to higher

cortical areas in order to make testable predictions about response properties that are currently unknown or poorly understood.

a. Olshausen BA, Field DJ (1997). Sparse coding with an overcomplete basis set: A strategy employed by V1? **Vision Research, 37**, 3311-3325.
b. Simoncelli EP, Olshausen BA (2001). Natural image statistics and neural representation. **Annual Reviews of Neuroscience, 24**, 1193-1215. PMID: 11520932
c. Olshausen BA (2013) Highly overcomplete sparse coding. In: **SPIE Proceedings vol. 8651: Human Vision and Electronic Imaging XVIII**, (B.E. Rogowitz, T.N. Pappas, H. de Ridder, Eds.), Feb. 4-7, 2013, San Francisco, California.
d. Chen Y, Paiton DM, Olshausen BA (2018) The Sparse Manifold Transform. In: **Advances in Neural Information Processing, 31.** arXiv:1806.08887

2. **Neurophysiological studies and analysis of data.** In addition to constructing theories and models, my lab also works together with experimental labs to gather data that can either test models or guide the formation of new models. Using fMRI we were able to find evidence of 'explaining away' in visual cortex, in which high-level areas interact with low-level areas to form a consistent explanation of a complex scene. Using EEG we showed that the timecourse of basic level object recognition is considerably slower than the animal vs. non-animal tasks that led many in the field to conclude that vision was a mostly bottom up process. Together with Charlie Gray's lab, we showed that the population activity within a column of cortex contains correlated ensembles, and we developed a statistical method for identifying these ensembles using a restricted Boltzmann machine (RBM). We have also conducted meta-analyses of neuroanatomical datasets in order to assimilate studies done across different labs to form a database of connections between visual cortex and pulvinar.
   a. Press WA, Olshausen BA, Van Essen DC (2001) A graphical anatomical database of neural connectivity. **Philosophical Transactions of the Royal Society, B, 356,** 1147-1157. PMID: 11545696.
   b. Murray SO, Kersten D, Olshausen BA, Schrater P, Woods DL (2002) Shape perception reduces activity in human primary visual cortex. **Proceedings of the National Academy of Sciences, USA, 99** (23): 15164-15169. PMID: 12417754
   c. Johnson JS, Olshausen BA (2003) Timecourse of neural signatures of object recognition. **Journal of Vision, 3**, 499-512. PMID: 14507255
   d. Köster U, Sohl-Dickstein J, Gray CM, Olshausen BA (2014) Modeling higher-order correlations within cortical microcolumns. **PLOS Computational Biology**, 10(7): e1003684.

3. **Perspectives, opinions and reviews.** A significant part of my scientific career has been spent challenging conventional views of visual cortex function and conveying a different perspective about how vision works. It is my view that the function of cortical circuits is so deeply mysterious that in many cases we are better served by taking a more exploratory, rather than hypothesis-driven, approach. I also believe that studying animal behavior and taking into account the demands of scene analysis in the natural environment are key to asking the right questions about how visual systems work.
   a. Olshausen BA, Field DJ (2005) How close are we to understanding V1? **Neural Computation**, **17**, 1665-1699. PMID: 15969914
   b. Olshausen BA (2013) 20 years of learning about vision: Questions answered, Questions unanswered, and Questions not yet asked. In: **20 Years of Computational Neuroscience**. (J. Bower, Ed.), Springer Series in Computational Neuroscience 9.
   c. Olshausen BA (2014) Perception as an inference problem. In: **The Cognitive Neurosciences, V**. (M. Gazzaniga, R. Mangun, Eds.), MIT Press.
   d. Lewicki MS, Olshausen BA, Surlykke A, Moss CF (2014) Scene analysis in the natural environment. **Frontiers in Psychology, 5**, article 199.

4. **Technology transfer.** As we learn more about principles of information processing in the brain, it will undoubtedly lead to the development of new technologies based on these principles. Sparse coding for example is now central to much of image and signal processing, and it has played an important role in the development of deep networks that are now widely employed for image recognition in the commercial sector. The electronics industry is also taking inspiration from neuroscience as they confront the end of Moore's law and the need to invent new modes of memory storage and computation that utilize nanoscale

devices in the low-power, analog regime where signals are imprecise. I have recently begun collaborating with a team of electrical engineers to bring ideas from neural computation to bear on this problem.

a. Rozell CJ, Olshausen BA, Baraniuk RG, Johnson DH, Ortman RL (2008) Analog System For Computing Sparse Codes. **U.S. Patent Application No: 12/035,424**
b. Wang CM, Sohl-Dickstein J, Tosic I, Olshausen BA (2011) Lie Group Transformation Models for Predictive Video Coding. In: **Data Compression Conference 2011 proceedings**.
c. Zarcone R, Paiton D, Anderson A, Engel J, Wong HP, & Olshausen BA (2018) Joint Source-Channel Coding with Neural Networks for Analog Data Compression and Storage. **Data Compression Conference 2018 Proceedings.**
d. Zheng X, Zarcone R, Paiton D, Sohn J, Wan W, Olshausen BA, Wong HSP (2018) Error-Resilient Analog Image Storage and Compression with Analog-Valued RRAM Arrays: An Adaptive Joint Source-Channel Coding Approach. **2018 IEEE International Electron Devices Meeting (IEDM).**

<u>Complete List of Published Work:</u>

https://scholar.google.com/citations?user=4aqK_74AAAAJ&hl=en&oi=ao

D. Research Support

<u>Ongoing Research Support</u>

DARPA J. Rabaey (PI), B.A. Olshausen (Co-PI) 9/1/19-3/31/21
Computing in Superposition with High-Dimensional Vectors
The goal of this project is to explore the use of High-Dimensional Computing for autonomous learning in open-ended environments.
Role: Co-PI

AFOSR B.A. Olshausen (PI), Pentti Kanerva (Co-PI) 7/1/19-6/30/21
Computing in Holographic Representation
The goal of this project is to build a database of Cerebellum anatomy to construct a model of its function based on high-dimensional computation and sparse-distributed memory.
Role: PI

NSF F. Sommer (PI), B.A. Olshausen (Co-PI) 9/1/17-8/31/20
Extracting and understanding sparse structure in spatiotemporal data
The goal of this project is to develop robust sparse coding models that are well-behaved in response to spatiotemporal data, and to explicitly encode topographic structure in a sparse representation.
Role: Co-PI

<u>Completed Research Support</u>

NSF/SRC S. Salahuddin (Lead PI), B.A. Olshausen (PI) 10/1/16-9/31/19
ENIGMA
The goal of this project is to develop a hyperdimensional computing architecture, drawing upon emerging memory technology, and explore its applications on image and language understanding tasks.
Role: PI

SRC Starnet N. Shanbag (Lead PI), B.A. Olshausen (PI) 11/1/12-10/31/17
Systems on Nanoscale Information Fabrics (SONIC)
The goal of this project is to develop new computing architectures based neural computation that can be implemented in in nanoscale devices.
Role: PI

DARPA 20151755 B.A. Olshausen (PI) 7/1/15-12/31/16

Perceptual Systems Based on Cortical Computation

The goal of this seedling project is to demonstrate how incorporating principles of cortical computation can improve machine learning algorithms.

NSF IIS-1111654 M.S. Lewicki (Lead PI), B.A. Olshausen (PI) 7/1/11-8/30/16

RI: Large: Collaborative Research: 3D structure and motion in dynamic natural scenes

The goal of this project is to develop mathematical models of the 3D structure of natural scenes, as well as computational models for how this structure may be inferred from images.

Role: PI

National Geospatial-Intelligence Agency HM1582-08-1-0007 B.A. Olshausen (PI) 8/1/08–7/31/16

Unsupervised Learning of Hierarchical Structure in Multi-Band Imagery

In this project we are develop unsupervised learning models to derive efficient representations of time-varying, multi-band images suitable for object recognition or tracking tasks.

Role: PI

NIH R01 EY019965 B.A. Olshausen (PI) 8/1/09-7/31/15

CRCNS: Neural Population Coding of Dynamic Natural Scenes

The goal of this project is to develop models to capture the population responses of cortical neurons in response to time-varying natural images.

Role: PI