Adam Shai – ACT 2019 School Application

Explanation of relevant background

I am a neuroscientist by training (and interest) and started learning category theory about 1.5 years ago after reading Misha Gromov's "Ergobrain." I devoured David Spivak's "Category Theory for the Sciences" and was happy to see that category theory was even more inspiring, and promising for application to neuroscience than what Gromov's writing had hinted at. Since that introduction to category theory, I have been reading about it nonstop, (silently) following the applied category theory community on the internet, and have been lucky to have many discussions with an incredible math graduate student at Stanford (Sophie Libkind, also applying). During my Ph.D. I did a mix of computational, theoretical, and experimental neuroscience. I generally feel comfortable with mathematics, though I am by no means a pure mathematician! Specifically with respect to David Spivak's topic, due to my current research project as a postdoc, I am quite well versed in Karl Friston's "Free energy principle," which heavily relies on the concept of a system persisting through time in a high entropy world to explain neural activity and its structure. In addition, I work daily with real neural data from rats performing a variety of cognitive tasks, which require new analysis tools to make sense of.

Ph.D completion date and one sentence summary of subject matter.

June 10, 2016 - My thesis work theoretically and experimentally studied the physiology of a prominent cell type in the neocortex, and how that physiology contributes to computation at the aggregate level of the cortical network.

Order of project preference

David Spivak's - Towards a mathematical foundation for autopoeisis.

To what extent can I commit to coming to Oxford

Because of the relevance of the autopeisis project, and because I will have to pay for this out of pocket, I can only commit if I am able to be in the autopoiesis group.

Brief statement on why I am interested in ACT 2019 School. How can this contribute to my goals? How can this school help in my research career?

It is my hope that the ACT 2019 School will help me acquire the tools to use category theory to make headway into my main academic interest - how cognition arises from neurons and their interactions. Category theory seems to be fundamentally concerned with many of the concepts that the neuroscience community implicitly feel are important (Yoneda-esque thinking, what structure means, etc.), but have not yet figured out how to deal with. I imagine a future where category theory serves as the go-to math for understanding the brain (much like linear algebra and dynamical systems are now); I hope to be part of that revolution.

Towards the end of a book chapter I co-authored ("Signals, Systems, and Psyche. (2016)") before I even knew that there was a branch of math called category theory, I wrote about the relational structure of cognition (cognitive objects are defined in terms of their relations to other cognitive objects, and form a "relational network"), how this relational idea should be applied to neural networks from which cognition emerges (the "meaning" of a neuron's activity should be understood in terms of the influence of that activity on other neurons), and how neuroscientists were in need of a way to include this type of relational understanding in their thinking. Neuroscience lacks a general language with which to describe such structure, both at the cognitive and neural level, making them hard to explore experimentally. Even more pressing, without a language capable of describing the structure of neural networks and cognition, it will be hard to understand their relationship.

Since that time, I have found a number of mathematical frameworks (e.g. Jim Crutchfield's "Calculus of Emergence" and a number of ideas stemming from dynamical systems theory) which contain this concept to differing degrees, but none so naturally as category theory. The margins of my copy of "Category Theory for the Sciences" are filled with exclamation points. David Spivak's recent work on mereology and operadic modules seem particularly relevant to the questions that have held my intellectual attention for at least a decade now. I am currently a postdoc, interested in how brains make internal models of their world. I do this by measuring the activity of thousands of neurons in the rat cortex as the animal performs a number of cognitive tasks (you can see an example of the type of thing I do here: https://bit.ly/2DgYmoq) in which I manipulate the task structure and look for corresponding structures in the neural activity of the rat. In the future I hope to continue my experimental and theoretical research, and see category theory as a potential foundational mathematics with which to understand the brain, not just for me, but for the field of neuroscience as a whole.

ADAM SHAI
ashai@stanford.edu

Department of Biology
Stanford University
1050 Arastradero Road, Building B
Palo Alto, CA 94304

RESEARCH EXPERIENCE

Schnitzer Laboratory, Stanford University **Feb 2016 – Present**
Postdoctoral Scholar
Studying how brains create internal models of their environments in the rat neocortex

Koch Laboratory, Caltech and Allen Institute for Brain Science **Aug 2010 – Jun 2016**
Graduate Student and Visiting Scientist
Theoretical and experimental projects concerning the biophysical properties of single neurons in the neocortex and how they contribute to computation by integrating feedforward and feedback long-range inputs

Larkum Laboratory, Humboldt University, Berlin **Nov 2011 – Dec 2012**
Graduate Student Whitaker Fellow
Experimental work on biophysics of dendritic computation in mouse visual cortex

Materials Process Design and Control Laboratory, Cornell University **Fall 2008 – Spring 2009**
Undergraduate Research Student
Ab-initio quantum mechanics for computation of the multi-dimensional potential of systems with many atoms

Molecular BioEngineering Laboratory, Cornell University **Spring 2006 – Spring 2009**
Undergraduate Research Student
Studied thermodynamic properties and 3D structure of engineered DNA machines

Institute of Bioengineering and Nanotechnology, Singapore **Summer 2008**
NSF Funded Undergraduate Attachment Student
Developed PEG-peptide hydrogel for chondrogenic differentiation of human mesenchemal stem cells

Smilow Research Center, New York University School of Medicine **Summers 2003-2007**
Summer Research Student
Designed *in vivo* optical system for imaging voltage and calcium propagation in mouse and pig hearts

ACADEMICS

California Institute of Technology, Department of Biological Engineering
- PhD in Bioengineering, Summer 2016
- Thesis: *The Physiology and Computation of Pyramidal Neurons*
- NSF Graduate Research Fellow and Whitaker International Fellow

Cornell University, Department of Biological and Environmental Engineering **GPA: 3.754**
- Honors BS in Biological Engineering, Spring 2009
- Concentration in Biomedical Engineering
- Honors Thesis Topic: *Thermodynamics and 3D Structural Properties of Engineered DNA Motifs*

PUBLICATIONS

Shai, A., & Larkum, M. E. (2017). Deep Learning: Branching into brains. *eLife*, *6*, e33066.

Hawrylycz, M., Anastassiou, ... & Mihalas, S. (2016). Inferring cortical function in the mouse visual system through large-scale systems neuroscience. *Proceedings of the National Academy of Sciences*, *113*(27), 7337-7344.

Anastassiou, C. A., & **Shai, A. S.** (2016). Psyche, Signals and Systems. In *Micro-, Meso-and Macro-Dynamics of the Brain* (pp. 107-156). Springer, Cham.

Shai, A. S. (2016). *The Physiology and Computation of Pyramidal Neurons* (Doctoral dissertation, California Institute of Technology).

Shai, A. S., Anastassiou, C. A., Larkum, M. E., & Koch, C. (2015). Physiology of layer 5 pyramidal neurons in mouse primary visual cortex: coincidence detection through bursting. *PLoS computational biology*, *11*(3), e1004090.

Shai, A. S., Koch, C., & Anastassiou, C. A. (2014). Spike-timing control by dendritic plateau potentials in the presence of synaptic barrages. *Frontiers in computational neuroscience*, *8*, 89.

Palmer, L. M**., Shai, A. S**., Reeve, J. E., Anderson, H. L., Paulsen, O., & Larkum, M. E. (2014). NMDA spikes enhance action potential generation during sensory input. *Nature neuroscience*, *17*(3), 383.

Lee, J. B., **Shai, A. S.,** Campolongo, M. J., Park, N., & Luo, D. (2010). Three-Dimensional Structure and Thermal Stability Studies of DNA Nanostructures by Energy Transfer Spectroscopy. *ChemPhysChem*, *11*(10), 2081-2084.

Rosner, G., Bullinga, J., **Shai A.**, Morley, G.E. (2007). Examination of t-wave alternans in wild type mice. *Probe: the publication of research on biomedical endeavors,* 1():34-34

POSTERS AND INVITED TALKS

- A Shai, C Anastassiou, M Larkum, C Koch. *The influence of long-range inputs on single-cell dendritic signaling.* Society for Neuroscience 2014 Conference abstract and poster. (Washington DC, November, 2014)
- A Shai, C Anastassiou, S Murphy, M Larkum, C Koch. *The neurophysiology of feedback: a mechanism for binding.* Association for the Scientific Study of Consciousness Conference 17 abstract and poster. (San Diego, July 2013)
- A Shai, C Anastassiou, C Koch. *Layer 5 V1 neurons of the mouse: From single cell to network.* Society for Neuroscience 2012 Conference abstract and poster. (New Orleans, October, 2012)
- A Shai, C Anastassiou, C Koch. *Single neuron computation during oscillatory barrages of synaptic input*. Society for Neuroscience 2011 Conference abstract and poster. (Washington DC, November, 2011)
- Third Annual Graduate Symposium on Quantum Mechanical Models of Materials talk: *Thermal Properties and Phonon Calculations of Metals Using the Small Displacement Method* (Cornell, Spring 2008)
- Institute of Biological Engineering Regional Conference talk – topic: *Thermodynamics and Structure of DNA Nanoarchitectures* (Cornell University, Fall 2008)
- Cornell University BioExpo 2008 poster: *Thermal and Structural Properties of Engineered DNA motifs*
- Guest Lecturer for AEM 4240: Management Strategy: *Applications of Multidimensional Calculus to Modified Bertrand Markets* (Cornell University, Spring 2008)

OUTREACH, AWARDS, EXTRACURRICULAR ACTIVITIES

- Stanford Brain Day, Volunteer Instructor. Guide local middle school classroom in an interactive neuroscience lesson (2018)
- Writer and Scientific Advisor for live action children's education show "Beakman on the Brain" (2012)
- Awarded NSF Graduate Research Fellowship (2011)
- Awarded Whitaker International Fellowship (2011)
- Teacher Assistant for CNS102a – Brains, Minds, and Society (Caltech, 2011)
- Volunteer Instructor for Iridescent Learning Family Science Night (2010)
- First Place Winner of Cornell University Arthur Lynn Andrews Annual Short Story Contest (2008)
- Executive Board Member of Cornell University Chapter of Institute of Biological Engineering (2007 – 2009)
- Editorial Board Member of Rainy Day Literary Magazine (Cornell University, 2005 – 2008)
- Teacher Assistant for MAE 715 – Graduate Atomistic Modeling (Cornell University, 2009)
- Awarded NSF funded research in Singapore's Institute of Bioengineering and Nanotechnology (2008)