EKATERINA A. KOULAKOVA

e.koulakova@nyu.edu | Huntington, NY

I seek to understand how the brain's biological constraints shape cognition. Neural systems don't merely observe the environment; they actively interpret it, constructing meaningful representations based on past experiences and structural biases to form coherent models of the world with which we interface. My goal is to understand how these systems and their architectures implement statistical processes underlying learning, memory, and decision making.

As a physics major, my drive to describe natural phenomena through quantitative organizing principles led me to join Dr. Kolmogorov's computational materials science lab. There, we applied neural networks to predict stable chemical compositions not yet synthesized experimentally. To support this project, I compiled datasets to train our neural network (NN) model. This required me to conduct a comprehensive literature review on the physical properties of alkali-tin compositions. Using experimentally derived properties, I trained our NN on these compositions to identify the lowest free-energy states or the most stable configurations. To enhance model accuracy, I helped derive a theoretical correction term for the free energy equation to simulate substitutional defects in crystalline solids, a crucial factor in assessing thermodynamic stability [1]. This analysis enabled us to evaluate whether potential compositions lay on the free-energy convex hull, indicating stability. Based on these findings, I proposed new structures for stability screening that had not yet been experimentally synthesized. Our evolutionary searches ultimately uncovered two previously unknown stable phases demonstrating the model's predictive strength [2]. This work introduced me to research fundamentals - data analysis and literature reviews - and allowed me to contribute to analytical derivations grounded in thermodynamic principles, essential for interpreting and validating our NN results.

Intrigued by the effectiveness of neural networks in extracting meaningful patterns from complex data, as an independent summer project, I designed a convolutional neural network (CNN) to examine how genomic constraints shape sensory perception. Although the CNN I developed and optimized ultimately fell short of predicting gene expression, this experience deepened my understanding of key neuroscience concepts. It also honed my skills in neural network optimization, coding in MATLAB, and data management.

To understand how the brain's architecture implements perception-related algorithms, I joined the labs of Dmitry Rinberg and Shy Shoham at the NYU Neuroscience Institute. My current project addresses the "figure-ground separation" problem in olfaction, investigating how signals are extracted amid dynamic background odors. I am focused on the single glomerulus, a fundamental unit of olfactory encoding, where olfactory receptor neurons excite mitral cells (MCs) that relay sensory information to higher brain regions. To explore the encoding mechanisms of this principal circuit motif, I employ optogenetics to selectively stimulate a single glomerulus while concurrently using two-photon (2P) imaging to monitor the activation of its associated MCs while mice are engaged in a stimulus detection task. Thus far, I have developed a paradigm that demonstrates mice can detect single glomerulus stimulation at various latencies within the sniff cycle. My next objective is to assess whether this detection remains stable when a background odorant is introduced. I hypothesize that once the mouse learns to detect this minimal stimulus, its detection rate will remain high despite the presence of a masking odorant. Overall, this project explores the limitations of current models of temporal olfactory encoding by determining whether stimulus detection is correlated with its MC activation or if additional pathways are recruited through feed-back and learning. Independently executing, managing, and refining our experiment has allowed me to gain skills in training mice, conducting cranial-window surgeries, data analysis with Python and MATLAB, and an in-depth understanding of 2P microscopy. Over the past two years in the lab, I have deepened my interest in systems neuroscience and learned to approach challenges with persistence and incremental progress, embracing the nonmonotonic yet rewarding nature of research.

During my graduate studies, I aim to explore how the brain's biological constraints shape learning, memory, and decision-making through an integrated computational and systems neuroscience approach. Cornell's Neurobiology and Behavior program stands out to me for its strong faculty expertise aligned with my research interests.

Dr. Weinan Sun's research on how the hippocampus learns a set of discrete states and transition rules aligns with my goal of uncovering deterministic principles that guide behavior. Implying a predictive relationship between the current state, a sensory input, and a subsequent state greatly appeals to me, especially in a naturalistic behavioral paradigm reducing constraints on behavioral output. Furthermore, his assessment that learned manifolds could be applied to novel conditions echo insights that I gained during my legal internship, as discussed in my personal statement.

Building on my experience with two-photon imaging, I am drawn to Dr. Ian Elwood's research on decision-making and working memory, especially the computational role of dopamine in the basal ganglia. I am particularly intrigued by the possibility of uncovering nuances in dopamine's function beyond reward prediction error, perhaps exploring its role in planning behaviors within the dorsomedial striatum. To this end, I appreciate the lab's use of virtual reality to bypass stringent behavioral tasks, enabling high-dimensional statistical analyses of behavioral outputs. Employing machine learning to analyze experimental results in unveiling relations between neural activity and behavior aligns with my core research goals.

Similarly, the work of Drs. Antonio Fernandez-Ruiz and Azahara Oliva on hippocampal memory coding in naturalistic behavioral paradigms deeply interests me. I am eager to investigate how biological neuronal networks generalize learning across domains, particularly the role of social memory traces in hippocampal-subcortical interactions during sleep and relevant wake states. Using closed-loop optogenetic manipulations to remotely modulate neural activity and test causal hypotheses would provide powerful insights into these processes.

Beyond its academic offerings, I am drawn to Ithaca for its small-town charm. During my undergraduate years at Binghamton University, I often visited to hike and study at local cafes - an environment I believe is perfectly suited for my graduate studies. Ultimately, I am eager to deepen my expertise in quantitative modeling and systems neuroscience through Cornell's Neurobiology and Behavior program, with the goal of establishing my own line of research one day.

[1] Daeumer et al., *Acta Materialia* (2022), `https://doi.org/10.1016/j.actamat.2022.117671`

[2] Kharabadze et al., *npj Computational Materials* (2022), `https://doi.org/10.1038/s41524-022-00825-4`