

My long-term research interest is to develop a mesoscale theory of neural circuits—identifying order parameters that integrate structure and function. To approach this goal, I will construct compact phenomenological descriptions of neural activity and connectivity that lie between microscopic biophysics and macroscopic behavior. I pursue a top-down approach between purely data-driven statistical/machine-learning methods and crude mean-field approximations, using phenomenological models with intuition from (non-equilibrium) statistical mechanics and information theory. I will also directly model entities like waves and ephaptic coupling, which may serve as existing mesoscopic computational units that integrate ultrastructure and neuronal spiking, complementing the approaches above.

Specific Research plan: Statistical Mechanics for Networks of Real Neurons

1. **Small-scale, high-precision activity.** I will analyze 2-photon holographic optogenetics data from mouse sensory cortex or zebrafish (~40 neurons) using maximum entropy models (or other phenomenological models) to study ensemble coding principles.
2. **Large-scale population activity.** I will analyze large-scale imaging data from mouse sensory cortex (e.g., light-beads microscopy of ~1 million neurons) or zebrafish (~100,000 neurons) using coarse-graining methods and above new ensemble coding principles, to extract low-dimensional descriptions and identify candidate mesoscale variables organizing these populations
3. **Electric field–based interactions.** I will analyze electric field data (ephaptic coupling) to probe possible characteristics of mesoscale computation units, exploring how field-based interactions can integrate and mediate spiking activities.

Beyond data analysis, at each step I will build simplified dynamical models and develop analytical understanding using mean-field methods from statistical mechanics. These models will guide further data analysis.

In conclusion, by combining compact phenomenological models, first principles, and direct modeling of electric fields, we will refine mesoscale descriptions of real neural circuits. Even if the brain doesn't operate exactly at this level, it would be valuable for encoding and decoding BCI applications.