Interrogating the Functional Logic of Drosophila Brain Circuits at Single-Synapse Scale

Aurel A. Lazar[1], Mehmet K. Turkcan[1,*], and Yiyin Zhou[1]

[1] *Department of Electrical Engineering, Columbia University, New York, NY 10027, USA*
[1] *The authors' names are listed in alphabetical order*
[*] *Presenting Author*

Abstract

The current paradigm of computational studies of neural circuit function largely focuses on characterizing neuron connectivity. A widely-used approach is to model neurons as nodes in a graph and their connections as edges. However, this neglects the myriad of differing functions that synapses may achieve. Based upon the visualization and analysis of the Hemibrain connectome/synaptome dataset of the fruit fly brain, we propose a new computing paradigm for discovering the functional logic of fly brain circuits that shifts the modeling emphasis from communicating neurons to the interactions between blocks of synapses.

Underlying the computing paradigm introduced here, there are two building blocks: the synaptic computing complex (SCC) and the synaptic processing unit (SPU). The SCC models an axon terminal, the synapses and neuromodulatory inputs impinging on the axon terminal, and the synapse lying across active zones of the axon terminal and postsynaptic densities. SCCs can be found throughout the fly brain. The ubiquitousness of SCCs suggests that in addition to the processing in the postsynaptic neurons, computation heavily takes place in the presynaptic terminals. The SPU models a synapse-rich volume such as a glomerulus in the antennal lobe (AL) and a compartment in the mushroom body (MB). An SPU consists of SCCs as atomic building blocks and defines the computation in the SPU. The compositions of SPUs take the form of communicating neurons interpreted here as wires that connect SPUs, governing the I/O of a local processing unit (LPU) modeling a neuropil [1].

To explore the functional logic of neural circuits, we model SCCs in the AL and MB at three levels of abstraction. The first level corresponds to the ground truth synaptome of the Hemibrain dataset, where each individual axon terminal interacts with a different set of input synapses. At the second level, all the inputs onto an axon are grouped to interact with all the axon terminals of the neuron. At the third level, we group all the inputs onto the axons of neurons of the same cell type. We provide circuit diagrams and a FlyBrainLab library to automatically map these three levels and compositions of SPUs into executable circuits by leveraging the Hemibrain dataset [2]. We quantitatively characterize the role of SCCs in shaping the response of the circuit. The I/Os of the three levels are then compared to identify the appropriate level for modeling the functional logic of each neuropil.

References

[1] Givon and Lazar, PloS one, doi: 10.1371/journal.pone.0146581, 2016.

[2] Lazar et al., eLife doi: 10.7554/eLife.62362, 2021.