Neural Circuits and Computations in the Octopus Visual System

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Our understanding of the neural basis of visual function is largely based on studies in vertebrates, motivated by their similarity to the human brain. Cephalopods, including octopuses, represent a completely independent evolution of intelligent behavior and a highly capable visual system, but with a fundamentally different brain organization and neural circuitry. Additionally, cephalopods possess unique visual capacities not present in vertebrates, such as the ability to match skin camouflage to the visual scene, and to detect objects based on the polarization of light. Remarkably, their brains continue to grow throughout their lifetime, incorporating new neurons into the neural circuitry. Understanding cephalopod vision would dramatically expand our knowledge of sensory processing and cognition and could lead to transformative solutions in brain-inspired computing, enhancement of sensory capabilities, and treatment of brain injury. However, the neural basis of vision in cephalopods is largely unknown.

In recent work, we performed the first recording of visual responses in the octopus brain, using in vivo imaging of neural activity. We also determined the "parts list" of the octopus visual system, by applying single-cell transcriptomics to identify cell types. These findings provide the necessary foundation for us to now determine how the neural circuits of the octopus brain implement visual computations. We will first determine how specific cell types and their connections compute fundamental features of the visual scene that support behavioral capabilities such as prey capture and camouflage. We will then extend this to a sensory capability that humans lack, polarization vision. Finally, we will examine the biological basis and computational implications of the continued neural expansion of the octopus brain over its lifetime. Much as studies in the vertebrate visual system inspired current approaches in machine vision and translational neuroscience, we expect that these findings will contribute to novel approaches based on the unique neural architecture of the octopus brain.