Benefits of pathway splitting in sensory coding

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Abstract:

In many sensory systems, the neural signal splits into multiple parallel pathways. For example, in the mammalian retina, ~20 types of retinal ganglion cells transmit information about the visual scene to the brain. The purpose of this profuse and early pathway splitting remains unknown. We examine a common instance of splitting into ON and OFF neurons excited by increments and decrements of light intensity in the visual scene, respectively. We test the hypothesis that pathway splitting enables more efficient encoding of sensory stimuli. Specifically, we compare a model system with an ON and an OFF neuron to one with two ON neurons. Surprisingly, the optimal ON-OFF system transmits the same information as the optimal ON-ON system, if one constrains the maximal firing rate of the neurons. However, the ON-OFF system uses fewer spikes on average to transmit this information. This superiority of the ON-OFF system is also observed when the two systems are optimized while constraining their mean firing rate. The efficiency gain for the ON-OFF split is comparable with that derived from decorrelation, a well known processing strategy of early sensory systems. The gain can be orders of magnitude larger when the ecologically important stimuli are rare but large events of either polarity. The ON-OFF system also provides a better code for extracting information by a linear downstream decoder. The results suggest that the evolution of ON-OFF diversification in sensory systems may be driven by the benefits of lowering average metabolic cost, especially in a world in which the relevant stimuli are sparse.

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