Temporal Coding in the Visual Cortex

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We are interested in what strategies the brain uses to encode images. In the early 1960s, Hubel and Wiesel discovered that single neurons in the primary visual cortex show a selectivity (increased firing rate) for local, oriented edges. But in the forty years of research since then, we still know relatively little about how populations of these neurons work together to encode images. In particular, what kind of coding strategy must the brain use in order to take the many local features of objects distributed across distant areas of cortex, and bind them together into a coherent and meaningful perception? In order to answer this question, one must study the behavior of large populations of individual neurons responding to known stimuli. Unfortunately, current experimental methods lack the ability to simultaneously monitor large numbers of individual neuronal reponses, so we must build models in an attempt to simulate their behavior.

In the neuroscience community, there has been a controversy over whether the brain encodes information by firing rates (rate coding), or whether there is a significant amount of information encoded in the spiking patterns of neurons (temporal coding). When one measures single neuronal reponses to the same stimulus over multiple trials, one sees that firing rates stay constant while spiking patterns vary. This has led many to assume that the brain uses only the firing rate to carry information. However, recent evidence from EEG, MEG, and multiple electrode recordings have shown that certain stimuli can create oscillatory activity in neuronal populations in the gamma frequencies (40-60 Hz). This has led to a theory that the brain is using a temporal code, in which different assemblies of neurons phase-lock with one another, according to the nature of the stimulus. It could be the strategy that the brain uses to solve the ”binding problem.” This has been controversial, as many proponents of the rate-code theory believe that such oscillatory activity is merely an epiphenomenon, and has little to do with neural coding. We are interested in building biologically inspired models of primary visual cortex (V1) that are based upon temporal coding theories. In particular, we would like to find models that reproduce these gamma oscillations, and show a direct correlation to the stimulus input.

This research could lead to valuable new insights and applications in the field of image analysis. While the human visual system has no trouble performing complex tasks such as object recognition, it has been incredibly difficult to get computers to accomplish anything but the most simple tasks. Some interesting parallels have already been drawn between wavelets and the human visual system. The work of David Field and Bruno Olshausen on sparse coding have highlighted some of these connections. Their analogy is based on the fact that the brain sparsely represents images in a relatively small set of active neurons, while wavelets have the ability to sparsely represent the same data in a small set of wavelet coefficients. They have also shown that network models based on sparse coding principles, when trained on sets of natural images, will develop localized, oriented, and bandpass receptive fields – the very same qualities posessed by the receptive fields of neurons in primary visual cortex. We are only at the beginning of understanding how the brain encodes information, and discoveries about how the human visual system works will likely to lead to more effective computational methods in image analysis. There are numerous potential benefits for a variety of data analysis tasks, including denoising, image segmentation, and object/face recognition.

References

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