Sparse and Distributed Codes of Neuronal Population in Primary Visual Cortex

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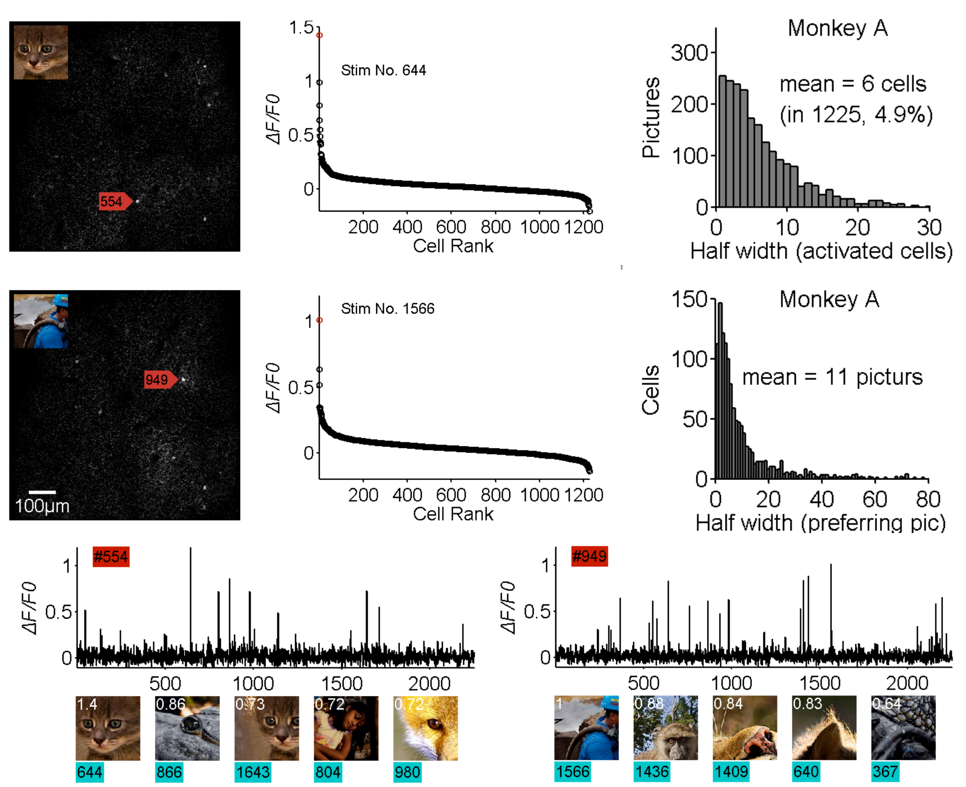
Z. LI[1], Y. ZHANG[1], M. LI[2,3], F. LIU[2,3], H. JIANG[2,3], T. LEE[1], S. TANG[2,3]

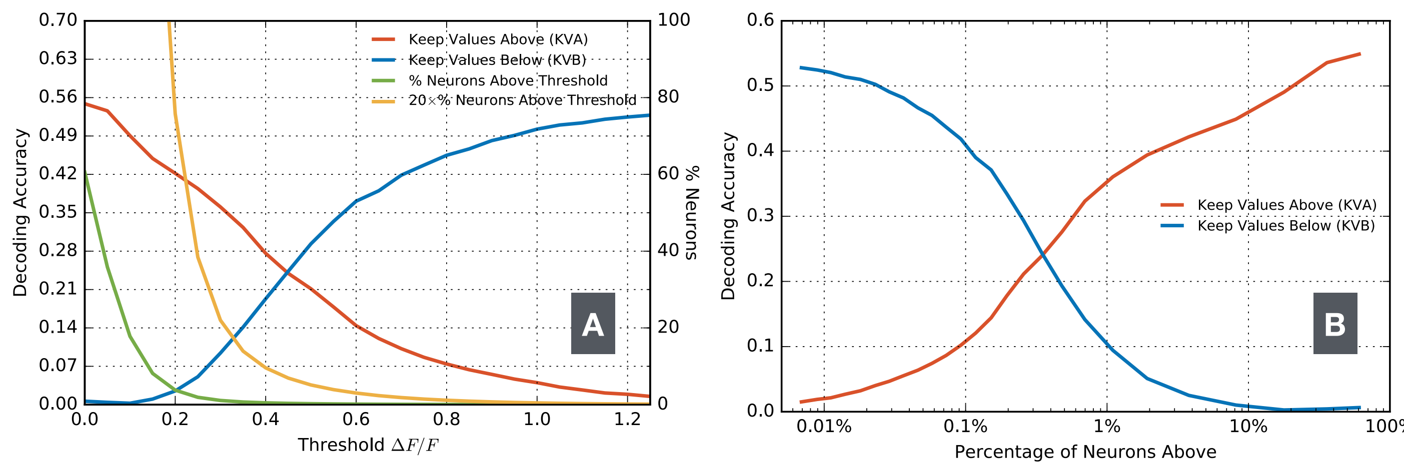
1. Ctr. for the Neural Basis of Cognition and Computer Sci. Dept., Carnegie Mellon Univ.
2. Sch. of Life Sci. and Peking-Tsinghua Ctr. for Life Sci., Peking Univ. 3. IDG/McGovern Inst. for Brain Res. at Peking Univ.

Neurophysiological studies of visual cortex have been limited by the number of neurons that can be monitored simultaneously and the number of stimuli that can be tested. Our team at Peking University established the feasibility of large-scale long term two-photon imaging of neurons with a genetically-encoded calcium indicator in the primary visual cortex (V1) of awake macaques, which allows us to simultaneously image thousands of neurons and systematically characterize their responses to 2,250 natural images. It was found that robust responses in neuronal population in the V1 superficial layer to any given natural image were highly sparse, with less than 0.5% of the neurons responding above half of their peak responses, and large portion of neurons exhibited significant preferences and specificity to complex patterns. In this study, we investigated how much information is encoded by the sparse rigorous responses of a few neurons and how much is encoded by the distributed responses of hundreds of mildly responding neurons in response to any given image. We performed decoding and visualization analysis using population responses below or above different response thresholds to evaluate systematically the information content in different neuronal population response regimes.

Sparse Population Responses of V1 Layer 2/3 Neurons



k-NN Decoding Analysis

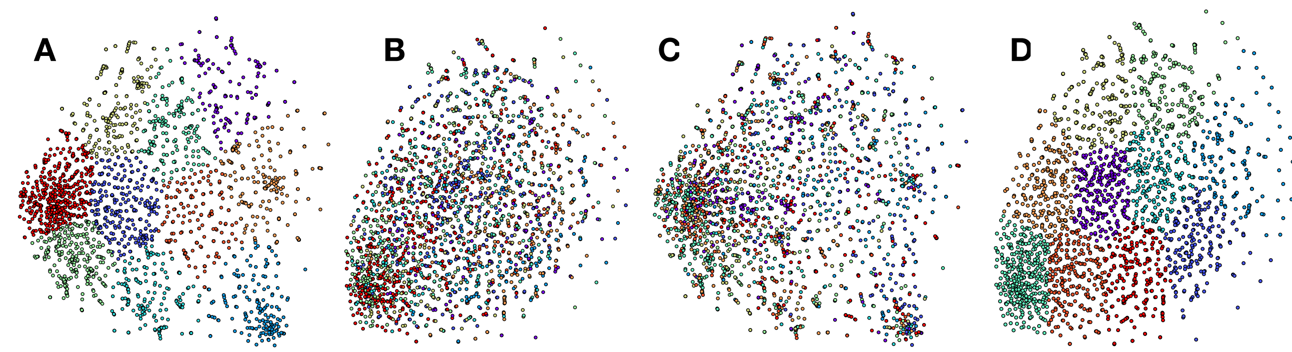


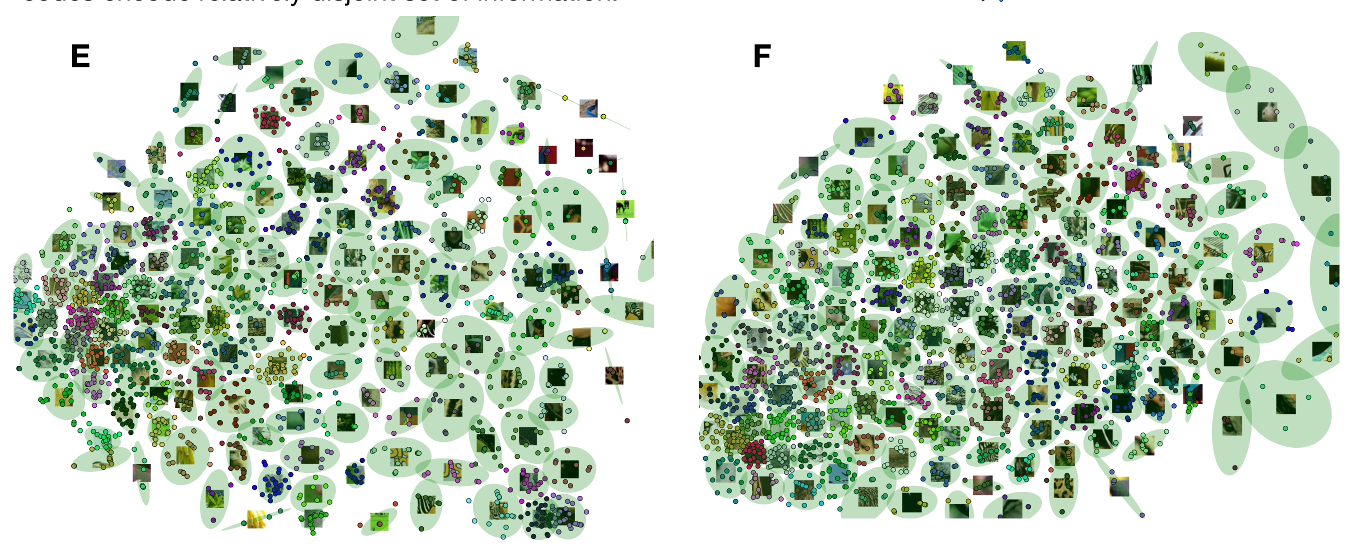
A: Decoding accuracy with responses above and below different response threshold. Only 0.5% of the neurons on the average responded ABOVE the threshold (sparse code), and yet achieved 50% of the achievable accuracy (red curve). The 99.5% of the neurons below the 0.4 threshold (distributed code) carried less than half of the accuracy (blue curve).

B: Show decoding accuracy as a function of the average percentage of neurons needed to encode each image.

Clustering

We used TSNE dimensional reduction technique to visualize the clusters of images in the low-dimensional manifolds defined by the neural responses below and above the 0.4 threshold. We found that image clusters (obtained by K-means) in the above-0.4-threshold sparse code manifold (**A**) become mixed together in the low-dimensional distributed code manifold (**B**), and vice versa (**C**, versus **D**), suggesting the sparse and distributed codes encode relatively disjoint set of information.





E & F: Visualization of finer clusters of images in sparse code manifold and distributed code manifold.

Conclusion

1. We found on the average that 0.5% of the neurons carry half of the information (based on decoding accuracy) for encoding a natural image using sparse rigorous response, and that 99.5% contribute to the other half using weak distributed responses.
2. The information carried by the sparse and the distributed codes live in relatively non-overlapping complementary manifolds.

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