Title: Real-Time Bayesian Optimization for Efficient Multidimensional Neural Tuning Characterization

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Summary: A fundamental goal in neuroscience is understanding the relationship between sensory stimuli and resultant neural responses. Characterizing neural responses across multiple dimensions of visual stimuli - such as direction of motion, size, and contrast - is essential for understanding complex sensory processing and tuning. As we move towards studying real-world conditions, a challenge arises from the large number of stimuli to present when forming all possible combinations of these parameters, along with time and financial constraints posed by *in vivo* experiments. There is thus a critical need for systems capable of efficiently capturing neural responses in real time and adaptively selecting a manageable subset of stimuli to display. These systems must also be flexible enough to learn and identify neural tuning curves across various experimental platforms, brain regions, behavioral conditions, and visual inputs. Here, we developed an efficient closed-loop system that integrates streaming modeling with experimental imaging to capture and analyze neural responses in high-dimensional stimuli environments *in vivo*. We employed Bayesian optimization with Gaussian Processes and custom multidimensional kernels to fit multivariate tuning curves and thereby identify stimuli that maximize neural responses. We applied our method to study the mouse primary visual cortex (V1), using two calcium indicators (GCaMP6s,6f) and five C57BL/6 mice. We successfully characterized multidimensional neural responses across a five-dimensional visual space, adaptively sampling fewer than 91 stimuli (about 3% of ~3k possibilities). Preliminary results revealed distinct functional types of neuron preferences. For example, the directional tuning of some V1 neurons is modulated simultaneously by stimulus size and contrast; interactions that would have been missed if such combinations of stimulus dimensions were not measured. With efficient real-time identification of neural tuning preference *in vivo*, we can also improve robustness to noise and dynamic changes in neural tuning through optimizing kernel selection and hyperparameter tuning throughout an experiment.