Dr. Pippo Pluto,

Editor,

November, 2021

Dear Dr. Pippo,

Please find enclosed a manuscript, titled “Random Compressed Coding with Neurons,” which we are submitting for consideration as an Article in Neuron.

A central question in neuroscience is how populations of neurons accurately represent information about stimuli or tasks in spite of the variability, or noise, which affects their responses. This question has been grounded in a firm theoretical footing through the ‘efficient coding hypothesis’ which proposes that neural responses are arranged as to achieve the most accurate code subject to constraint on the neural resources engaged. To date, most models of efficient coding have been formulated in terms of neurons exhibiting simple selectivity profiles, or tuning curves. Real neurons, however, can come with highly complex, sometimes irregular, tuning curves. Grid cells in enthorinal cortex, for example, exhibit multimodal and spatially periodic selectivity, and this supports a highly accurate code which cannot be achieved with simpler tuning curves.

In this manuscript, we ask whether such highly efficient codes result from fine-tuning of the neural responses, as in the case of grid cells, or can obtain more generally in neural populations exhibiting complex tuning curves. As a simple, benchmark mode, we consider a shallow neural network in which complex and irregular tuning curves in the output layer emerge purely because of randomness in the synaptic connectivity. While complexity in the neural responses enhance the accuracy of coding in some ways, it also leads to catastrophic, or global, coding errors. We show that, nevertheless, a population of neurons with complex, irregular tuning curves can reach an optimal tradeoff of local and global errors. In this efficient coding regime, information is compressed by the shallow network from a high-dimensional representation into a lower-dimensional representation which nonetheless suppresses coming errors exponentially. Thus, the kind of highly efficient coding that occurs in grid cells is an example of a broader class, which does not require fine-tuning of the neural response properties. While we provide detailed analytical calculations and numerical simulations to support out conclusions, the main ideas can be conveyed quite simply through a geometric picture of the population coding, which we discuss.

We complement our basic theoretical results by a re-analysis on monkey cortex data, where we propose that ‘efficient compressed population coding occurs’. We also extend them by considering generalization such as the coding of multi-dimensional stimuli, the impact of various types of neural noise, and the relation between our work and recent work on characterizing the dimensionality of neural population activity.

More broadly and beyond its technical details, our work comes to complement a lively and growing literature on both efficient coding and the geometry of neural population activity. While most earlier work focuses on the relation between stimuli and a single population of (peripheral) neurons, our works sets the efficient coding problem in the context of a network with more than one population, where the interaction between populations affect the structure of the efficient coding. Our work also addresses the current interest in ‘neural manifolds’—mappings between stimuli and high-dimensional neural population activity—from the point of view of efficient coding. More than 70 years ago, Shannon pointed out that a random code can be highly efficient. We build on this observation by considering a family of codes—from fully irregular (Shannon-like) to fully smooth (classical, simple tuning curves)—and we show that a non-trivial optimum exists in between these two limits, as a function of the neural noise.

Because of its connections with various current topics of interests in the study of high-dimensional neural activity and coding, we believe that the work summarized in the enclosed manuscript would be of interest to the readership of Neuron.

Suggested reviewers (Simone): Larry Abbott, Eero Simoncelli, Xue-Xin Wei, Julijana Gjorgjieva (?), Yonatan Aljadeff, Cengiz Pehlevan (?), Dmitri Chklovskii

Suggested reviewers (Rava): Eric Shea-Brown, Vijay Balasubramanian, Yasser Roudi, Nicolas Brunel, Kanaka Rajan (?)

Sincerely,