On the spatial and temporal scales of perceptual integration in the brain

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Over the last 20 years, experimental protocols have developed to study neural activities in awake animals performing perceptual decision-making tasks [1, 2, 3]. Typically, the animals must assess the value of a sensory stimulus and take a decision on the basis of their percept, while multiple electrodes record single neuron activities in the involved brain regions—thus opening unprecedented opportunities to understand the neural coding of sensory information. A "standard model" for these tasks has progressively emerged, whence the animal's percept and subsequent choice on each trial are obtained from a linear integration of the activity of sensory neurons [4, 5]. However, up to date, there has been no principled method to estimate the parameters of this model: mainly, the typical number of neurons K from the population involved in conveying the percept, and the typical time scale w during which these neurons' activities are integrated. In a recent article [6], we proposed a novel method to estimate these quantities from experimental data, and thus assess the validity of the standard model of percept formation.

Our first contribution is to clarify the predictions of the "standard" model, in the form of three characteristic equations describing the predicted covariance structure of neural activities and animal percept. These equations bind together all traditional experimental measures in these tasks (PSTHs, Joint-PSTHs, choice probability curves, and the animal's perceptual sensitivity), as a function of the model's spatial and temporal parameters of integration.

Our second contribution is a proposed solution to the inverse problem—the relevant one experimentally speaking—that consists in recovering the best-fitting model parameters on the basis of experimental data. This inverse problem is ill-posed, since only a small fraction of the relevant population's neurons are recorded. Our solution relies on the double hypothesis that the unknown neural ensemble conveying the percept (of size K) is (1) read out in an *optimal* fashion, (2) statistically similar to any *random* neural sample of size K from the population. From there we derive a straightforward method of inference, which allows to target the most plausible model parameters given the experimental data at hand. As an important limitation, this straightforward inference can only explore readout sizes K smaller than the number of neurons recordable simultaneously by the experimenter (say, N).

In this talk, I will first present these results. Then, I will discuss some mathematical questions which arise when one tries to extrapolate the results to neural ensembles of size K larger than N. The whole inference problem can be classically re-expressed as a function of the eigenmodes for the variance of population activity (a procedure known as PCA, or SVD decomposition). In this new basis, the random choice of K neurons for perceptual readout translates into a random matrix problem, related to the distribution of the eigenvectors of a random covariance matrix. I will present a conjecture in this regard, and how it could be used as a basis for future extrapolations on real data.

References

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