Accumulation versus propagation: coding dynamics in motion discrimination

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***Short Abstract* — We propose two temporal phases of collective computation in a visual motion direction discrimination task by analyzing recordings from 169 neural channels in the prefrontal cortex of macaque monkeys. Phase I is an "intensive" or incompressible phase in which uncertainty is substantially reduced by pooling information from many cells. Phase II is an "extensive" or compressible phase in which numerous single cells contain all the information present at the population level in Phase I. Intriguingly, the most informative cells in Phase I are least coupled to each other on short timescales, as measured by size distributions of synchronous events. We suggest that this dynamic of independent accumulation followed by cooperative propagation is a generic feature of robust collective computing systems related to consensus formation.**

***Keywords* — Neural coding, population coding, collective behavior, criticality**

I. Introduction

The nervous system is the paradigm of a distributed information processing system, with information present at multiple levels that span single cells, correlated modules, the hemispheres, and the whole brain. How these scales interact, how activity across scales becomes coordinated, and how adaptively significant information is encoded are among the primary concerns of cognitive neuroscience.

Here, we explore these issues with data from an experiment developed by Newsome and collaborators [1,2] that tracks neuronal processing in a visual discrimination task. Macaque monkeys are trained to discriminate directions of motion in a stochastic random dot display. In each trial, the stimulus is presented, and after a delay a "go" cue prompts the subject to indicate their decision about the dots' direction of motion using an eye movement. A multi-electrode array simultaneously measures times of action potentials in 169 neural units in prefrontal cortex. Neurons in this area are known to carry high-level signals specific to salient visual targets and eye movements [2].

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II. Population to Individual Coding

During the visual stimulus presentation (Phase I), a subset of cells becomes increasingly informative about the eventual decision. Just before the go cue, Linear Discriminant Analysis can use their rates of firing to predict the monkey's decision with ~85% accuracy. The information, however, is not stored in any individual unit—maximal performance requires integrating over the activity of >20 cells. After the go cue, when the decision is translated into an eye movement (Phase II), many more cells become predictive, and can predict the output with near perfect accuracy. Conversely, the number of units needed to attain maximal performance drops to 1–2. In this way, the decision process includes a switch from *accumulation* in a population code to *propagation* of information to individual rates. Implementing this switch has implications for the units' collective dynamical properties.

III. Criticality and Information Localization

Multiple other neuronal systems have behavior suggestive of tuning toward a specific point between complete independence and complete correlation, a phase transition that implies maximal sensitivity to perturbations (e.g. [3-5]). For the units in our study that carry negligible information about the decision, we also find evidence of this near-critical state in their distribution of sizes of synchronous events.

However, the cells whose firing rates contain the most information about the eventual decision are decidedly not critical, firing largely independently of one another, with an event size distribution similar to an independent null. This more generally suggests a robust method for collective decision making: localized accumulation of evidence by independent individuals followed by a consensus process that propagates a single decision to the global scale.

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