Journal Club

Editor's Note: These short, critical reviews of recent papers in the *Journal*, written exclusively by graduate students or postdoctoral fellows, are intended to summarize the important findings of the paper and provide additional insight and commentary. For more information on the format and purpose of the Journal Club, please see http://www.jneurosci.org/misc/ifa_features.shtml.

Some Spikes Are More Informative Than Others

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Review of Masse and Cook (http://www.jneurosci.org/cgi/content/full/28/6/1343)

What is the language of the brain when it links perception and behavior? Studies in the past have suggested that there are subsets of "most informative" neurons for perception and behavior (for review, see Parker and Newsome, 1998), and recent findings have revealed that perception and behavior can both be induced with the stimulation of only a small number of neurons (Houweling and Brecht, 2008; Huber et al., 2008). Well-known examples of selective subsets of neurons are found in the direction-, disparity-, and speed-tuning properties of cortical motion-sensitive neurons in middle temporal area (MT) of the monkey brain (for review, see Born and Bradley, 2005). As a popular cortical area to investigate the link between perception and action, neuronal activity in area MT has been studied using different analytic measures such as spike rates, local field potentials, oscillations, and response latencies, but the information density of the neuronal activity is usually analyzed between, rather than within, single neurons. The known dissociation between more and less informative neurons, however, raises the question whether the amount of information carried by the neural activity within a single neuron could also be nonuniformly distributed. A recent study by Masse and Cook (2008) published in *The Journal of Neuroscience* addresses this question and demonstrates that for a motion detection task, some spikes generated by neurons in MT are indeed more informative about the stimulus content than others. Importantly, the more informative spikes are also more closely related to the monkey's response behavior. These novel findings suggest a relationship between spikes, stimuli, and behavior that varies on a relatively short timescale within a single neuron.

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Masse and Cook (2008) used datasets from several studies in which the activity of single neurons in area MT was recorded while monkeys detected the onset of coherent motion in a dynamic random dot pattern. Importantly, the motion stimulus was updated relatively slowly (every 27 ms), causing the neurons to discharge in an oscillatory manner with a frequency that matched the stimulus updates. Based on this oscillatory firing pattern, the authors subdivided the neuronal responses based on whether they occurred during the rising or falling phase of the oscillation [Masse and Cook (2008), their Fig. 2 (http://www.jneurosci.org/cgi/content/full/28/6/1343/F2)]. Using spike-triggered averages (the average stimulus content preceding a spike), the authors demonstrated that spikes during one of the phases (often the rising phase) were more informative about the presence of motion in a neuron's preferred direction than spikes during the other phase. To link these findings to behavior, correlations were calculated between the spike-triggered average and two measures based on receiver-operant characteristics: neurometric value and detect probability. These measures indicate the extent to which an ideal observer would be able to distinguish coherent and random motion (neurometric value) or different behavioral responses (detect probability) based solely on the neuronal data.

Correlations between neurometric value and detect probability revealed that the spikes that were most informative about the presence of motion in the neuron's preferred direction were also more informative about the coherence of motion and more predictive of the monkey's behavioral response. Interestingly, the activity during the most informative encoding phase was correlated with the animal's correctly reporting the onset of coherent motion, whereas activity during the weaker encoding phase was correlated with the animal's failing to detect coherent motion onset [Masse and Cook (2008), their Fig. 6 (http://www.jneurosci.org/cgi/content/full/28/6/1343/F6)].

Models of perceptual decision making typically involve the accumulation of spike-rate-encoded sensory evidence toward a decision moment (for review, see Gold and Shadlen, 2007). This mechanism assumes that all spikes from a single neuron are similarly related to the stimulus content and the observer's behavioral response. It is unclear how the neural activity that is correlated with failed behavioral responses should be incorporated in such a mechanism. If the integration of sensory evidence toward a perceptual decision would occur upstream from MT, this issue could be resolved with a selection mechanism that processes both positively and negatively correlated spikes in an appropriate manner. Unfortunately, an equally problematic issue directly follows from this solution, because it remains unclear how such an upstream decision area would "know" whether spikes are positively or negatively correlated with the stimulus content. Searching for the answer to this question in the oscillations of activity might have been promising if the strong encoding phase was always either the rising or the falling phase of the oscillatory neuronal response, but this varies between cells [Masse and Cook (2008), their Fig. 5 (http://www.jneurosci.org/cgi/content/full/28/6/1343/F5)]. This interneuronal variation makes the selection mechanism for the most informative spikes even more complex, strongly suggesting that there must indeed be a later neural stage that combines information from multiple neurons.

The oscillatory neural response in the current study is a direct result of a slowly refreshed stimulus and thus to some extent artificial. Generally, the temporal precision of a neural code tremendously increases if spikes are phase-locked to some oscillatory process because it allows a continuous latency code (Butts et al., 2007), but these oscillatory processes do not necessarily have to be this artificial or even oscillatory. With more natural stimuli, spikes could just as well be phase-locked to the stimulus, to spikes from other neurons, or to internal oscillations of the local field potential (LFP). A relationship between the LFP and spikes further has the advantage of offering a direct relationship between the input (LFP) and output signals (spikes) of a cortical region.

The information carried in precise spike times is many times larger than that in spike rates, which are typically integrated and averaged over intervals of tens of milliseconds. The information content increases even more when spikes are part of a fixed pattern of relative spike times originating from several synchronized neurons (Tiesinga et al., 2008). Masse and Cook (2008) used classical spike counts in more or less arbitrarily chosen time intervals to conclude that some spikes are more informative than others. A more precise analysis of spike times from synchronously recorded neurons might provide insights into the mechanism by which the information asynchrony arises and tell us more about the brain's decision mechanisms. It is, however, very well possible that the brain has ways of selecting the most informative neurons and best encoding spikes (or spike patterns) that go beyond the detection mechanisms of our current analysis techniques.

Apart from the discussed problems with the current interpretation of Masse and Cook's results, the authors have convincingly demonstrated that even within a single neuron, some spikes are more informative than others, and apparently the brain relies mainly on these more informative spikes to shape behavior. Unfortunately, it remains unclear how this information asynchrony arises or how the brain integrates the information from multiple neurons. It is up to future research to unravel general rules regarding the context that gives spikes their information value and the neural mechanisms on which the brain bases perceptual decisions and behavior. Whereas our current understanding of the brain's language is sufficient to participate in interesting dialogues, there is clearly still a tremendous amount of neural grammar and semantics to be learned.

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