CCN Lab 1: from single cells to psychophysics

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1 Introduction

In seminal experiments, W. Newsome, K. Britten and colleagues [1, 5] were able to record the activity of neurons in the visual cortex of monkey while the animals were performing a motion discrimination task.

In the behavioral part, the monkey had to report the direction of motion of random dot images (varying the level of coherence[1] so that the task could be made easier or harder). During the same task, one neuron was recorded in area MT. Only two different possible directions of motion were used while a particular neuron was being recorded: the direction that produced the maximum response in that neuron, or the opposite direction. The monkey's task was to discriminate between these 2 directions. The aim of the study was to compare the ability of the animal with that of single cortical neurons in this task.

They found something very surprising: the performance of single neurons was very similar to the psychophysical sensitivity of the whole animal. The authors therefore suggested that under these conditions, psychophysical judgements could be based on the activity of a relatively small number of neurons. This idea is still debated.

Aim of this lab

The aim of this lab is to model their experiments, and learn about how to relate the activity of one neuron and psychophysical performance. The tool they used (also described in [2], chap 3) which they called the '*neurometric curve*' is now widely used in electrophysiological studies (for recent studies, see e.g.[4, 3]).

[1] percentage of dots moving together in the fixed direction. At 0% coherence, the dots move randomly. At 50% coherence half the dots move randomly and half together. At 100% coherence all the dots move together.

2 Lab 1

Setting up the model

We first model the activity of one neuron in MT. The activity $r(\theta)$ of this neuron as a function of the direction of the stimulus shown in the receptive field can be described using a gaussian tuning curve with preferred direction θ_+ =0 deg, standard deviation $\sigma = 60$ deg, amplitude R_{max}= 30 spk/s (we consider that the coherence level is fixed for now) and a baseline K (spontaneous activity) of 20 spk/s.

$$r(\theta) = R_{max} e^{-\frac{(\theta-\theta_+)^2}{2\sigma^2}} + K \tag{1}$$

The variability of the spike count is Poisson.

- Plot the tuning curve of the neuron as a function of the stimulus direction. The mean response of the neuron for a stimulus moving at 0 deg (thereafter denoted '+') is denoted μ_+ . The mean response for 90 deg ('$-$') is denoted μ_- .
- Compute the response of the neuron for 100 repetitions of stimulus + and stimulus $-$. Plot the histogram of the response of the neuron for these 2 stimulus directions.

Constructing the ROC curve

Next, we simulate the experiments of Britten et al (1992). In a series of trials, we present randomly either stimulus + or -, and record the activity r of the neuron. To decode, we (arbitrarily) choose a response level z between μ_+ and μ_-(e.g. halfway: $z = \frac{\mu_- + \mu_+}{2}$). If $r \geq z$ we report '+', if if $r \leq z$, we report '$-'$.

How good would be the performance of the animal if it was based on such a simple rule and one neuron?

- Based on 100 repetitions of each stimulus for 1 sec, compute the false alarm rate $P[r \geq z|-]$. This is also called the 'size' of the test, an denoted $\alpha(z)$. Compute also the hit rate $P[r \geq z|+]$. This is also called the 'power' of the test and denoted $\beta(z)$.
- Construction of the ROC curve. Compute $\alpha(z)$ and $\beta(z)$ for 20 values of z between 0 and 100 spk. For these 20 values of z, plot $\beta(z)$ (on the y-axis) against $\alpha(z)$ (on the x-axis). This is the ROC curve.
- Compute the area A under the ROC curve. A is used as a measure of performance for this task, describing the optimal performance that can be achieved in the discrimination task, based on the activity of one neuron (independent of the threshold that is used). This measure can be compared with the psychophysical performance (% correct in a 2 alternative forced choice design).

Constructing the Neurometric function

It is known that the amplitude of the response of the neuron varies with the level of coherence c of the stimulus. We assume that the relationship between the response and degree of coherence can be modelled assuming that R_{max} depends linearly on c. Modify your neuron's model to take this into account (R_{max}=30 spk/s corresponds to a coherence of 100%. For a coherence of 0 %, the neurons response at the baseline level).

- Choose 10 values of coherence c between 0% and 100% and compute $A(c)$. This is the neurometric function.
- How does it compare with the psychometric function reported by Britten et al ? (Fig 1) What are the model parameters that influence its shape?

Supplementary Questions :

- How do you have to change the parameters of the model so as to be able to account quantitatively for the results of Britten et al? (Fig. 1)
- Was there a simpler way to get the neurometric curve in this case?
- Do you think the comparison of the authors between the performance of one neuron and the whole animal makes sense? How could we reconcile their results with the fact that we have so many neurons in the brain? Could their reasoning be wrong?

References

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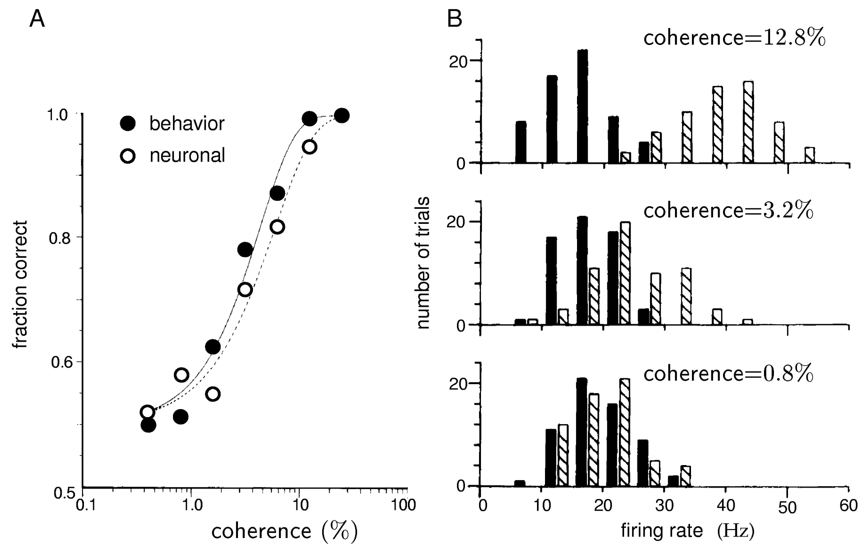

Figure 1: Behavioral and electrophysiological results from a random dot motion discrimination task. A) The filled circles show the fraction of correct discriminations made by the monkey as a function of the degree of coherence of the motion. The open circles show the discrimination accuracy that an ideal observer could achieve on the analogous two-alternative forced choice discrimination task given the neural responses. B) Firing rate histograms for three different levels of coherence. Hatched rectangles show the results for motion in the plus direction and solid rectangles for motion in the minus direction. The histograms have been thinned for clarity so that not all the bins are shown. (Adapted from Brittenetal., 1992.)