Rate neurons

In this short note we introduce the idea of rate-based neurons. In the previous section we considered McCulloch-Pitts neurons, these have an on-off behaviour, we know that neurons actually communicate using spikes, also called action potentials, discrete pulses of voltage. Of course, this is not necessarily inconsistient; it is possible, but unlikely, that neurons have a low and high firing rate and that we can effectively analyse that part of the behaviour of the brain that is relevant to computation by considering neurons only as on / off thresholding units. Howver, it is much more likely that this would only give a very partial account of neural computation, but that there are nonetheless useful insights to be gained in considering what algorithms could be supported by on-off neurons.

The next step in our consideration of neuronal models is to imagine that spikes are irrelevant but spike firing rates are important and that we can understand neural computation by describing computation based on neural firing rates. It is known that this picture does not apply to some specialised circuits such at the one used by owls to locate their prey. In the owl auditory system the precise temporal difference between sounds arriving at each of the owls ears is calculated by finding the point individual spikes from each ear arrive at the same point. However, it is not uncommon for people to believe that, in general, neuronal computation is based on the communication and transformation of firing rates; in fact, one very common point-of-view is that computation is rate based but that plasticity, that is learning through changes in synapse strengths, depends on spike times.

The idea of rate coding dates back to the earliest detailed measurements of the electrical activity of nervous system. Edgar Adrian was one of the great pioneers, he was a neurophysiologist, but, as is often the case, his success relied on innovation in equipment, coupled, of course, to careful experimentation. He pioneered the use of vaccuum tubes to amplify electical signals allowing him and his co-workers to record the activity in individual nerve fibres. He recorded from the sensory nerves carrying signals from muscles in frog, by attaching a silk thread to the muscle, passing it over a pulley and attaching a weight he was able to observe a linear relationship between the frequency of spikes along the nerve and the size of the weight. He also noted that the frequency decreased with time, see Fig. 1.

This graph has two curves, one labelled 3 grams, the other 0.5 grams. The y-axis is titled "frequency per second" and has marks spanning zero to 150, the x-axis is titled seconds after loading and runs for 20 seconds. It is indicated that the load is removed at 20 seconds. Both curves are smooth and decay gently, they are both surrounded by dots giving the acual data. The 3 gram curve is higher than the 0.5 gram, it starts near 150 and decays to about 90; the 0.5 gram starts at 70 and decays to about 30.

Figure 1: A figure from [1] showing the response to two different weights.

References

[1] Adrian, ED. and Zotterman Y (1926) The impulses produced by sensory nerve-endings: Part II. The response of a Single End-Organ. The Journal of Physiology, 61.2:151