Theoretical analysis of the cross-correlation between spike trains of two connected neurons

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How much does a single spike influence the firing of the neuron which receives it? This central question has attracted a lot of attention from both experimentalists and theoreticians. Here we address it quantitatively in a simplified theoretical setting and use the results to interpret in-vivo data.

We study analytically the statistical effect of an incoming spike train on the firing of a post-synaptic neuron subject to strong, in-vivo like, background synaptic inputs. We first consider a single-compartment integrate and fire model, and calculate perturbatively the cross-correlation between the incoming spikes and the output of the neuron. In particular, we compare the time-course of the cross-correlation with the time-course of the post-synaptic current, and show that they are related via the so-called firing-rate response function. We also quantify the influence of the arrival time of an incoming spike on the timing of the following post-synaptic spike. We show that the effect of the pre-synaptic spike is independent of its timing, if the pre-synaptic spike arrives with a sufficient delay after the previous post-synaptic spike. For in-vivo like background synaptic activity, the necessary delay is very short. Finally, we extend our results to a two compartment integrate and fire model, as well as the exponential integrate-and-fire model.

In the light of these findings, we examine experimental data from simultaneous in-vivo measurements of cerebellar Purkinje cells and molecular layer interneurons which project on them. In that case, the interneuron spike train corresponds to the input spike train, and the Purkinje cell to the post-synaptic neuron. The predictions of the two-compartment model are found to be in excellent agreement with experimental data.