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Spike sorting should be biased for optimal neural control prostheses

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The convergence of new techniques for electrode implantation, neural recording, signal processing, and mechanical design has spurred some startling advances in the study and design of neural prostheses [1,2]. In previous work, we showed how information theory can be used to characterize the ultimate limits of neural prosthesis performance [3]. By computing the information capacity of the neural prosthesis channel, we showed that neural stimulation prostheses such as cochlear and ocular implants are not fundamentally constrained by the stimulation technique. Theoretically, the same performance can be achieved using either a single electrode to stimulate an entire population of neurons or an array of electrodes to stimulate each individual neuron directly. In contrast, the best-case performance of neural control prostheses such as bionic limbs and brain-computer interfaces is severely limited by using gross recordings instead of isolating individual units. Multi-electrode recording techniques can mitigate this performance loss, but only to a limited extent. Consequently, spike sorting is essential to the success of neural control prostheses.

Here, we investigate how the quality of the spike sorter affects the optimal performance of a control prosthesis. We show that the capacity of the spike sorting neural prosthesis channel depends heavily on the type and frequency of errors that the sorter commits. False positives are the most crucial type of error, severely degrading the capacity, even when the error rate is extremely small. Missed spikes also degrade the capacity, but the effect is only linearly proportional to the error rate, and the reduction is only severe when the neurons are highly correlated. Mislabeling spikes only decreases capacity when the neurons all receive independent inputs; when the population receives a common stimulus, labeling errors cause no reduction in capacity.

From an information theoretic viewpoint, the best performance of a neural control prosthesis depends on how accurately the interface can extract information from neural recordings, and we have shown that optimizing this capability amounts to maximizing the capacity of the spike sorting channel. A surprising consequence of this strategy is that the resulting optimal spike sorter does not necessarily preserve the statistics of the original spike trains. Although accurate spike train reconstruction is important for experimental analysis, for neural control applications the optimal spike sorter should be intentionally biased to reduce the rate of false positives, thereby increasing the capacity and improving the best-case performance.

References

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