An Efficient Computation of Continuous-time Correlogram of Spike Trains

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Precise time delay in transmission of a spike in the neural system is considered to be one of the key features to allow efficient computation [1]. Cross correlogram is a powerful tool that is often used to quantify the delay of spike propagation and connection strength given a pair of spike trains. This includes the auto correlogram as a special case for analysis of periodicity in a spike train. An efficient algorithm for estimating these correlograms [2] involves histogram construction with time interval bins. This quantization of time introduces binning error and leads to coarse time resolution. Furthermore, the cross correlogram does not take advantage of the higher temporal resolution of the spike times provided by current recording methods. However, continuous-time analysis methods would naturally benefit from such improvements. We propose a novel method that provides continuous time resolution on correlogram, yet achieving efficient computation.

The continuous time resolution is achieved by computing at finite points where the continuous cross correlogram has local maxima. The algorithm takes advantage of the fact that the cross-correlation at time lag Δt of two smoothed spike trains (denoted as i and j) can be estimated from samples expressed with simple double summation as

$$\frac{1}{N_i N_j} \int_0^T \sum_{m=1}^{N_i} h(t - t_m^i - \Delta t) \sum_{n=1}^{N_j} h(t - t_n^j) dt = \frac{1}{N_i N_j} \sum_{n=1}^{N_j} \sum_{m=1}^{N_i} \kappa(t_m^i - t_n^j + \Delta t).$$

The number of time lags to compute the summation is $N_i N_j$ which results in the straight forward computation time complexity to be $O((N_i N_j)^2)$. However, by using computational tricks for a widely used kernel, $\kappa(t-s) = \exp(-\frac{|t-s|}{\tau})$, we can achieve $O(N_i N_j \log(N_i N_j))$. This kernel is a result of using a first order infinite impulse response low pass filter on the spike train, i.e. h is a causal exponential decay function. Furthermore we can reduce the cost by focusing on the time lags of interest which is less than 500 ms in most physiological contexts.

We demonstrate the result to estimate the effective delays in a neuronal network from synthetic data and recordings of dissociated cortical tissue.

Acknowledgments
This work was partially supported by NSF grant 0422718. The work of A. Paiva was supported by FCT under grant SFRH/BD/18217/2004.

References

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