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Higher-order correlations in non-stationary parallel spike trains: statistical modeling and inference

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Introduction

Understanding the cooperative dynamics of large neuronal groups is a major topic in current brain research. A particularly controversial issue has been the extent to which groups of neurons exhibit higher-order correlations in their firing patters [1]. Higher-order correlations are a signature of the temporal coordination of action potentials across neurons and are considered to be a powerful mechanism to cooperatively compute and transmit information in neuronal pools [2]. Currently available analysis tools, however, require vast sample sizes [3], rendering the analysis of massively parallel spike trains (N > 10) for higher-order correlations essentially impossible.

Background

We have recently presented a novel method for a cumulant-based inference of higher-order correlations (CuBIC) that avoids the need for extensive sample sizes [4,5]. This is achieved by: a) exploiting constraining relations among correlations of different orders and b) estimating correlations among spike trains by the cumulants of the superimposed and discretely sampled spiking activity of all recorded neurons (population spike counts). Combining these concepts, CuBIC infers the presence of higher-order correlations from only few lower-order cumulants, which drastically reduces the requirements with respect to sample size as compared to previous approaches.

CuBIC employs the Compound Poisson Process as a statistical model for the population spike counts, where correlations are induced by the insertion of additional coincident events in continuous time, i.e. before the binning is applied [6]. In its current form, CuBIC furthermore assumes all spike trains to be stationary, an assumption which is often violated in standard experimental protocols.

Results

Here, we present a non-stationary version of the compound Poisson process by decoupling the correlation structure from the intensity of the population. Using the "law of total cumulance", we incorporate common, population-wide non-stationarities into the computation of the cumulants of the population spike counts. These rate-adjusted cumulants are then utilized to adapt CuBIC to infer higher-order correlations even from non-stationary data stretches. The performance of the proposed adaptation is illustrated via numerical simulation.

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