Dimensionality Reduction in spatio-temporal MaxEnt models and analysis of Retinal Ganglion Cell Spiking Activity in experiments
Rubén Herzog, Maria-Jose Escobar, Adrian Palacios, Bruno Cessac

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Retinal spike response to stimulus is constrained, on one hand by short range correlations (receptive field overlap) and on the other hand by lateral connectivity (cells connectivity). This last effect is difficult to handle from statistics because it requires to consider spatio-temporal correlations with a time delay long enough to take into account the time of propagation along synapses. Although MaxEnt model are useful to fit optimal model (maximizing entropy) under the constraints of reproducing observed correlations, they do address spatio-temporal correlations in their classical form (Ising or higher order interactions but without time delay). Incribing in such models somewhat integrates propagation effects, but in an implicit form, decision of observing a neuron is a process of making a decision of the states of all other neurons in the network, but the states of the other neurons in the network are not necessarily affected by the state of the neuron under consideration. We propose here a method of dimension reduction, i.e. a projection on a relevant subset of parameters, relying on the so-called Susceptibility matrix closely related to the Fisher information. In contrast to standard methods in information geometry through, this matrix handle space and time correlations.

We have applied this method for retina data obtained in a diurnal rodent (Octodon degus, having 30% of cones photoreceptors) and a 252-MEA system. Three types of stimuli were used: spatio-temporal uniform light, white noise and a natural movie. We show the role played by time-delayed pairwise interactions in the neural response to stimuli both for close and distant cells. Our conclusion is that, to explain the population spiking statistics we need both short-distance interactions as well as long-distance interactions, meaning that the relevant functional correlations are mediated not only by common input (i.e. receptive field overlap, electrical coupling, spillover) but also by long range connectivities.

**Methods**

Recordings: Extracellular recording of the electrical activity of retinal ganglion cells in the retina of Octodon degus were performed as described in a previous study. The retina was stimulated with a checkerboard pattern (USB-MEA256 from Multichannel Systems, MCS GmbH).

Stimuli: (i) Photopic spontaneous activity (PSA). (ii) A uniform spatio-temporal invariant field (15 ms). (iii) White noise (WN): Bi-

The images were projected using a conventional DLP LED projector at 60fps and registered at 20kHz. Sorting was done using Offline Sorter (Cetyx Inc.) and the spatio-temporal receptive fields were computed using STA in WN stimulus.

Analysis: A binary raster $\omega$ of $N=50$ neurons with a bin size of 5ms was considered in $KL$ when $K>1$. The goal is to fit the empirical distribution of $\omega$ with a MaxEnt model (eq 2), which minimizes its corresponding Susceptibility matrix (eq 2):

$$S(k) = \sum_{l=1}^{K} \log \lambda_{l}$$

where $\lambda_{l}$ are the eigenvalues of the susceptibility matrix $S$. This relation tells us how much a change on one parameter $h_{l}$ changes the estimation of the observables probabilities $m_{l}$, $\gamma$ depends on stimulus, increasing their entries as the stimulus complexity increases.

**Spectral Properties Under Different Stimuli**

The effect on the estimation of slight changes in the $i$th parameter is computed as $S(i, k, \epsilon)$, where $v_{k}$ is the $k$th entry of the eigenvector $\lambda_{k}$ and $\lambda_{k}$ is the corresponding eigenvalue. The Change Index (eq. 1 on the right) is the ratio of the effect before ($K = L$) and after filtering ($K = 2$): $\gamma_{i} = \epsilon_{i}/\epsilon_{L}$, which modifies the effect of filtering on the direct influence of $h_{i}$ on $m_{l}$ estimation and all the indirect influences $\lambda_{i}$ acts on $m_{l}$ which modifies $\lambda_{l}$

(a) shows the distribution of C.I. values for the pairwise parameters, where PSA shows two modes, one close to 0 and other to 1. WN and NM show one big mode close to 1. Thus, static stimulus (PSA) shows much more than the other two.

(b) shows the % of the remaining pairwise spatial (solid) and temporal (dashed) parameters as the C.I. threshold increases. Temporal interactions are more abundant than spatial ones for all stimuli at all thresholds. PSA shows less remaining pairwise parameters than dynamic stimuli for spatial ones but not for temporal ones. Then, the number of spatio-temporal parameters required to optimally fit the empirical distribution increases with the stimuli high-order correlations.

(c) shows the Receptive Field (RF) Spacing (< 1 overlap = 1 adjacency, horizontal dashed line; > 1 no overlap) as the C.I. threshold increases for spatial (blue) and temporal (black) parameters. Lines are medium coverage of the interquartile range. We see the same behaviour for all cases: the RF spacing slightly decreases with C.I. threshold, showing that the optimal set of parameter includes both short-range (i.e. RF overlap) and long-range (no overlap) pairwise interactions for all stimuli.

**Conclusions**

(1) The $\chi$ spectrum contains mainly information about individual neurons firing rates, while the second cut-off contains information about spatio-temporal correlations. When $k = n$, there is no relevant information about spatio-temporal correlations on the data and it can be optimally explained by a model which takes into account only neuron firing rates.

(2) All tested stimuli require spatio-temporal interactions to optimally fit the recorded retinal population activity. So, as other works have shown on different species (salamander [23,35]; monkey [4]; guinea pig[3]), retinal population activity presents significant spatio-temporal interactions. Moreover, the stimulus high-order correlations increases as $k$ increases, but filtering with $k = 2$ limits to $k = 6$, reduces the C.I. of most of the spatio-temporal parameters at values ~ 0.2, while most firing rates parameters remain unchanged.

(3) The first N dimensions contains mainly information about firing rates, while the next $k_n$ contains information about spatio-temporal correlations. The number of optimal dimensions $k_n$, required to fit the empirical distribution increases with the stimulus high-order correlations.