Dimensionality Reduction in spatio-temporal MaxEnt models and analysis of Retinal Ganglion Cell Spiking Activity in experiments

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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 (firing or higher order interactions but without time delay). Binning in such models somewhat integrates propagation effects, but in an implicit form, decisions are based on a severely bias data [1]. To resolve this issue we have considered spatio-temporal MaxEnt model formerly developed e.g. by Vasquez et al. [2]. The price to pay, however is a huge set of parameters that must be fitted to experimental data to explain the observed spiking patterns statistics. There is no a priori knowledge of which parameters are relevant and which ones are contributing to overfitting. 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 though, 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, apoptosis) but also by long range connections.

## METHODS

### Recordings

Extraacellular recording of the electrical activity of retinal ganglion cells (RGC) in diurnal rodent Octodon degus were performed using a Multitecde Array (UMS-MEA256 from Multichannel System, MCS GmbH).

**Stimuli:** (i) Photopic spontaneous activity (PSA). A uniform spatio-temporal invariant field (15 mins), (ii) white noise (WN). Binaric checkerboard pattern (20 mins), and, (iii) Natural Movie (NM): recorded in the animal’s natural environment (30 mins, movie, 40 repetitions).

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

**Analysis:** A binary raster of size N = 56 neurons by a bin size of 5ms was obtained when the firing rate of a neuron is equal to 1. The goal is to fit the empirical distribution of a with a MaxEnt model (eq. (1)) and compute its corresponding Susceptibility matrix (eq. (2)).

\[
W(\omega) = \sum_{k=1}^{N} \lambda_k m_k(\omega) (1)
\]

where \(m_\omega\) are the observables, \(t_\omega\) the free parameters to fit, \(t_\omega\) the neuron label. 1 ranges from 0 to \(N-1\), where the integer \(N\) is called the range (i.e memory) of the potential. \(\lambda_k\) in this case, \(\lambda_2\) = 2.

The Susceptibility matrix (eq. (2)) tells us how much a change short time on one parameter (\(\lambda_k\)) changes the estimation of the observables probabilities (\(m_\omega\)) on stimuli, increasing their entries as the stimulus complexity increases.

**Results:**

The set of indistinguishable distributions around the optimal set of parameters is represented on the parameter space (see a) with a volume \(V(P)\) satisfying:

\[
\log V(P) = \sum_k \lambda_k - \log \sum_k \lambda_k
\]

where \(\lambda_k\) are decreasing \(\lambda\) eigenvalues. The Change Index (CI equation on) is the ratio of the effect of before (\(K = 0\)) and after filtering (\(K = \lambda_k\)). CI = 1 means no filtering effect and CI = 0 means full filtering effect. Thus, CI summarizes the effect of filtering on the direct influence of \(m_\omega\) on \(W(\omega)\) and all the indirect influences \(t_\omega\) acts on \(m_\omega\) which modifies \(\lambda_k\).

**a)** shows the distribution of CI values for the pairwise parameters, where PSA shows two modes, one close to 0 and other to 1. WN and NM shows one big mode close to 1. Thus, static stimulus (PSA) shows much more parameters are filtered by filtering than dynamic ones.

**b)** shows the % of the remaining pairwise spatial (solid) and temporal (dashed) parameters as the CI 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 different thresholds. Then, the number of spatio-temporal parameters required to optimally fit the empirical distribution increases with the stimulus high-order correlations.

**c)** shows the Receptive Field (RF) spacing (1 overlay = 1 adjacency, horizontal dashed line, > 1 no overlap) as the CI threshold increases for spatial (blue) and temporal (black) parameters. Lines are median of the range the interquartile range. We see the same behaviour for all cases: the RF spacing slightly decreases with CI 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.

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**REFERENCES**


**CONCLUSIONS**

The first cut-off of the \(\chi\) spectrum contains mainly information about individual neuron firing rates, while the second cut-off contains information about spatio-temporal correlations. If \(k_\omega\) is a neuron, 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.

All tested stimuli require spatio-temporal interactions to optimally fit the empirical distribution and retinal population activity. So, as other works have shown on different species (salamander [2,3,5]; monkey [4]; guinea pig[5]), retinal population activity presents significant spatio-temporal interactions. Moreover, the stimulus high-order correlations increases the number of relevant spatio-temporal interactions on the network.

The optimal set of pairwise parameters, which implies a pair of neurons, includes neurons with overlapped receptive fields as well as distant neurons for all tested stimuli, with small differences between stimuli. Short range correlations can be explained via stimulus correlation and receptive field overlap whereas long range more presumably reflect lateral connectivity effects.