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Method for analyzing the inhibition of cellular signals in the spike train format

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ABSTRACT

This method can be used to detect signs of inhibitory neurons among a set of cell activity data in the spike train format. It is known that inhibitory neurons prevent the activity of related neurons for some time. This method detects the absence of spikes in a given period of time. The result is the level of suppression from inhibitory neuron. This method also contains an example of sorting the suppression level matrix.

Keywords: interneuron, inhibition, spike train

1. INTRODUCTION

One of the ways to represent neuron activity is the spike train format, which is widely used. In this format, the spikes are considered as events. We want to consider the case when each individual spike train denotes signals from different neurons. Namely, we say that $n-$spike train corresponds to events $t_i^{(n)}, n = 1...N$ from the $n-$neuron, and $m-$spike train respectively describes the events $t_j^{(m)}, m = 1...M$ from the $m-$neuron. At the same time, we are looking for situations where the behavior of a pair of spike train data resembles the action of an interneuron and its target. We know how interneuron suppresses the activity of other neurons in the classic signal generator circuit. By the method, we try to find a signs of this suppression.

This method of event analysis was inspired by event synchronization[1] and SPIKE-order[2] methods. In these methods authors showed how to measure the value of synchronization of two neurons and how to indicate the order of spikes from them. We borrowed the idea of collecting the time profile and matrix of the studied characteristic. Pairwise sorting of matrices is also a modified version of sorting from the SPIKE-order method.

2. METHOD

2.1 Inhibition in spike trains

We assume that a fairly reliable sign of inhibition is a situation when, in response to an impulse from one neuron, the generation of impulses from another neuron stops for a certain period of time. See the Alg. 1 and Fig. 1. To do this, one needs to check whether the spikes of the follower-neuron have disappeared for some conditional time τ_a after the event $t_i^{(n)}$. The second condition is to check whether there were spikes from the follower-neuron before there was a spike of the putative inhibitory neuron. The time before the event $t_b = t_i^{(n)} - \tau_b$. Thus, to know the second condition, we check the time interval from t_b to $t_i^{(n)}$.

The neuron's role in a pair is rated as a suppressor if all inhibitory conditions are satisfied. The second one is, respectively, an oppressed neuron. If we consider not one pair of neurons but many, then we can assemble a matrix. Each row of the matrix can show the suppressor-to-oppressed level.

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2.2 Sorting

The matrix of inhibition itself does not show a distinctive structure of the neural network. But the sorting may reveal spots on matrices that generalize relations between some pairs of neurons.

The sorting of pairs in the matrix is happening in such a way as to maximize the value of the upper right corner of the matrix. Sorting is doing by a simulated annealing algorithm in order to move the pairs in an optimal way. The algorithm selects the initial conditional temperature from the largest value of the matrix cell. The target *coolest* conditional temperature is 0.001. The cooling factor is 0,999. By the end of sorting, the most suppressing neuron is on the 1st row of the matrix, and the least suppressing on the last.

3. RESULTS

The case study for this methods was the analysis of experimental recordings from the inferotemporal area of the monkey's brain. This area is known as the object-selective and face-selective area.[3] The experimental data contained the time-dependent electrophysiological activity of neurons of a 6-year-old monkey. The set of visual stimuli contained images of the faces of baby monkeys. The monkey's eyes were focused on at these faces. At the previous prepossessing stage, researchers picked the part of the signal when the monkey's attention was confirmed by camera. The control time was -300–0 ms before stimulus detection. Respectively, the experimenters showed the image for 300 ms. A detailed description of the experimental approach is in.[4]

We used current method and built the matrix of relative suppression level from 36 recorded neurons. The delays τ_b and τ_a were chosen to be 33 ms. See this matrix in Fig. 2. Then we sorted this matrix according to described sorting algorithm. See sorted matrix in Fig. 3.

As a result of sorting, we see that for this data set, neurons 26,29 and 25 were most often inhibitory, and neuron 9 almost did not suppress other neurons.

4. DISCUSSION

In future versions of this algorithm, the τ_a and τ_b intervals will be changing dynamically, since different interneurons can have different temporal characteristics. We should also try to normalize results according to the total number of spikes in the spike train. Otherwise, if the neurons themselves were frequently active, the probability of detection of inhibitory properties increases.

Detecting inhibition and spike train sorting gives us the capability to discriminate states of the network. This method may be implemented in the case of various studies whether its stimuli-dependent or long-term experiments.

5. ACKNOWLEDGMENTS

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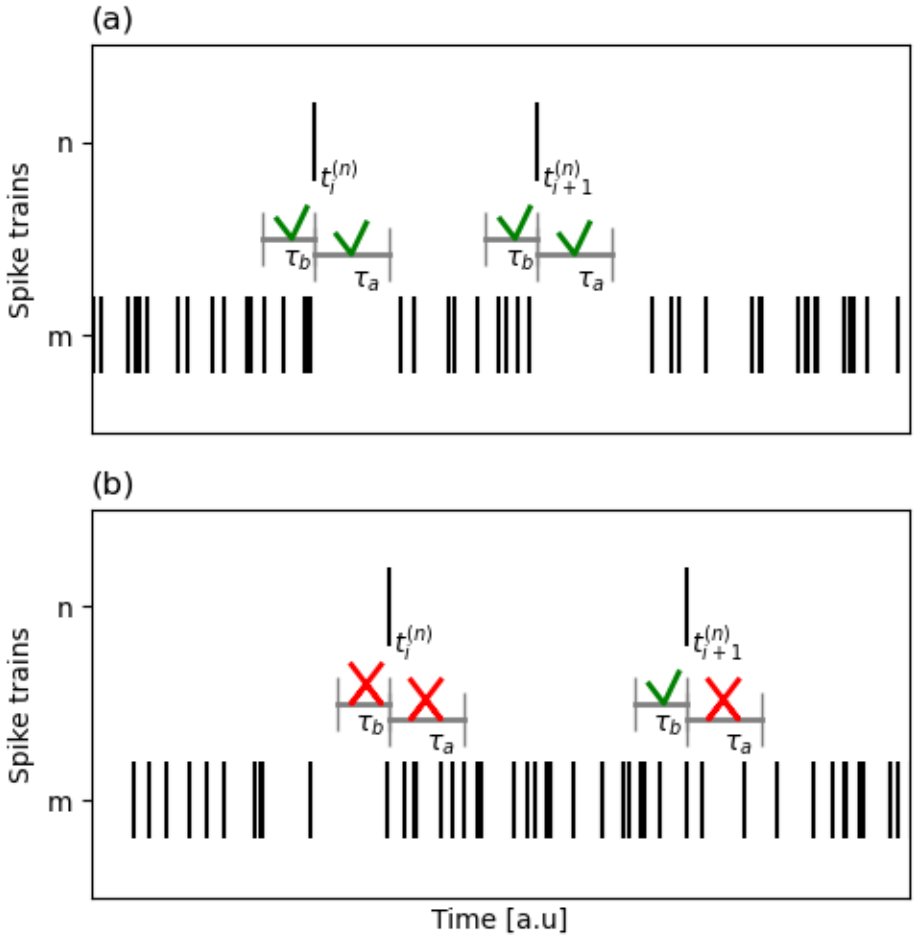

Figure 1. Inhibition test for n-spike trains and m-spike trains. There are $t_i^{(n)}$ - an event from n-spike train, time delays τ_b and τ_a before and after the event respectively. **a** – An example where all conditions are met (for some time there are m-spikes before the n-events and none after it). **b** – An example where the conditions are rarely met (there are spikes after n-events without any delays).

Algorithm 1: $n-$Spike-train vs $m-$spike-train inhibition test.

Result: the profile and the percentage of inhibition

$i = 0$; // index counter

while $i \leq N$ **do**

  $t_a = t_i^{(n)} + \tau_a$; // time after $t_i^{(n)}$

  $t_b = t_i^{(n)} - \tau_b$; // time before $t_i^{(n)}$

  c_1 = There is **no** $t_j^{(m)}$ between $t_i^{(n)}$ and t_a;

  c_2 = There is $t_j^{(m)}$ between t_b and $t_i^{(n)}$;

  $P_i = c_1 \ \& \ c_2$; // inhibition profile

  if $P_i = True$ **then**

    $p = p + 1$; // number of cases

  end

  i = i+1; // increment index counter

end

$I = \frac{p}{N}$; // percentage of inhibition

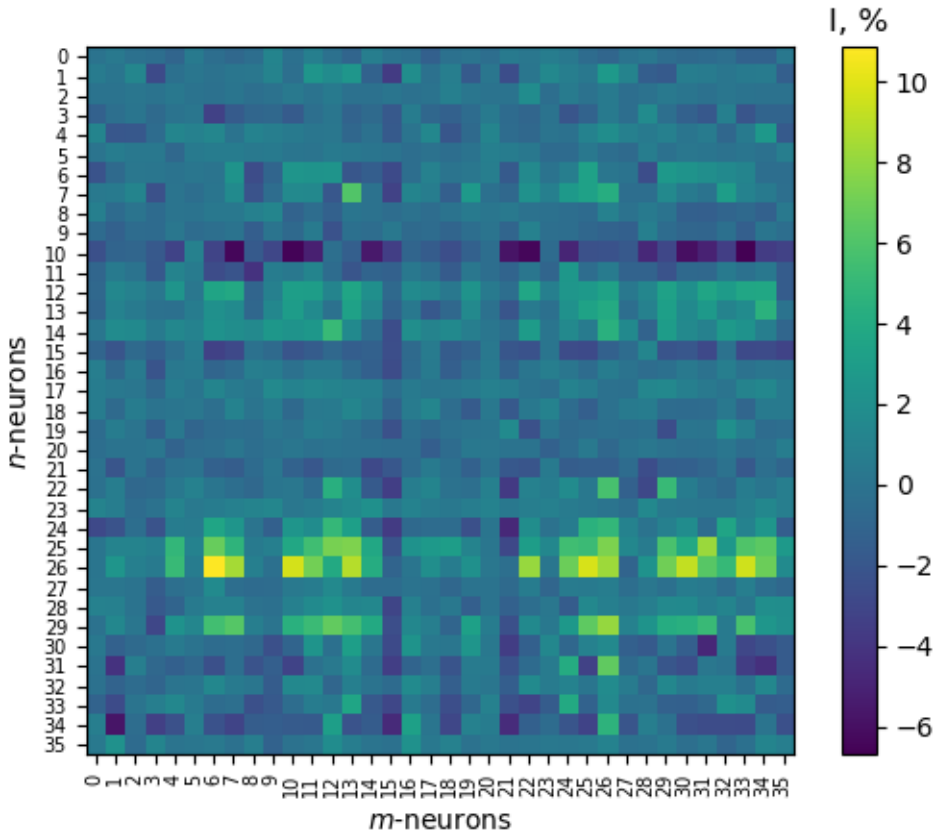

Figure 2. The matrix of suppression level. This matrix is assembled as a result of processing 300 spike trains from 36 neurons. These neurons were located in the temporal lobe of the monkey's brain. At the time of recording these spikes, the monkey was shown pictures with the faces of baby monkeys.

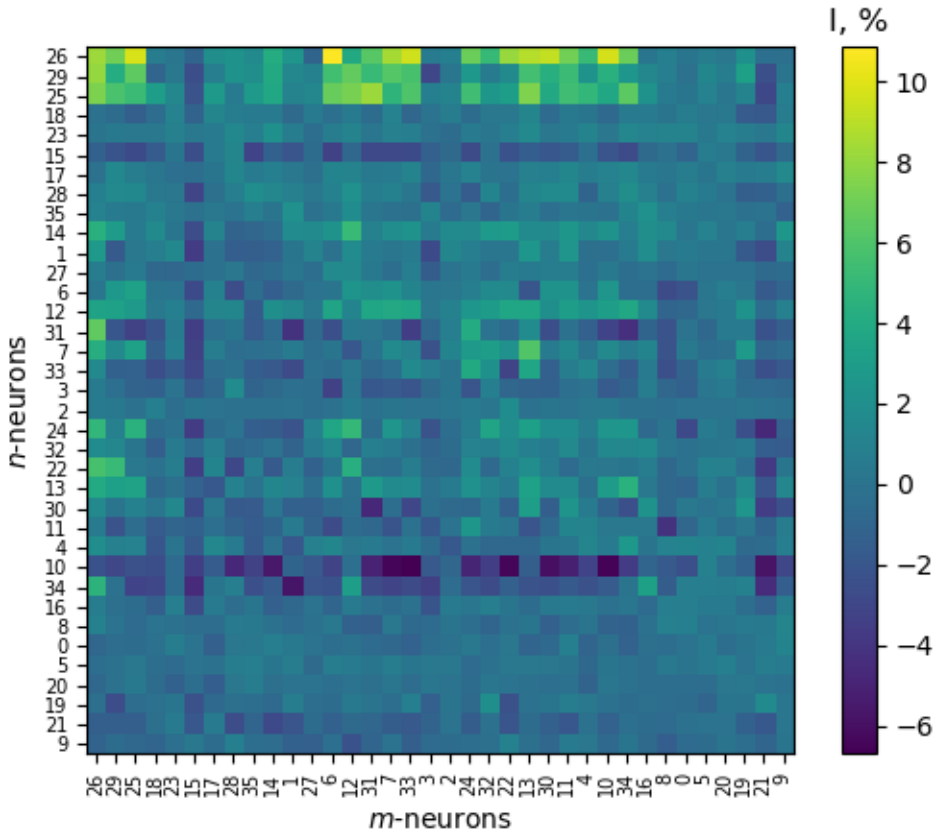

Figure 3. Sorted matrix of suppression level. As a result of sorting, we can see which neurons were most often inhibitory. Neurons that are located on the top line are the most inhibitory. Neurons that are in the bottom line are less than the rest showed inhibitory properties.