Stimulus-induced pairwise interaction can be revealed by information geometric approach

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Abstract. Understanding the interaction of neural activities is one of the most important themes in neuroscience. To resolve this question, cross-covariogram analysis of two neurons' activities is one of most extensively used techniques. This analysis is conducted mostly against the null hypothesis of independent firing. Here, we argue that an additional analysis is required to understand the role of correlation with respect to behaviourally relevant parameters such as visual stimulus. Specifically, we propose conducting this analysis against the null hypothesis of the activity in a control period. We show that information geometric approach can achieve this task. Furthermore, we demonstrate the validity of this method using data taken from the inferior temporal cortex. The results indicate the possible existence of a stimulus-modulated correlation.

1 Introduction

The multi-unit recordings of many neural activities have become widely available, and to make best of such massive data, methods of analysis need to be further developed. As an attempt to achieve this goal, we previously proposed information geometry (IG) approach to decipher interactions of neural firing [4]. In this paper, we illustrate this approach by focusing on the simplest case of analysis, namely an examination of cross-correlation between two neurons.

We previously noted [4] that, although cross-covariogram analysis usually examines correlated activity against the null hypothesis of no correlation, it is often more appropriate to evaluate such correlated activity against the activity in a control period. Section 2 clarifies this issue. The IG approach allows us to easily handle such a test, which is explained in Sect. 3. In Sect. 4 and 5, we demonstrate the method by using real data recorded from the inferior temporal (IT) cortex. The results suggest that a stimulus-modulated correlation exists. Finally, a short discussion is given in Section 6.

2 Preliminaries

2.1 Cross-covariogram analysis

Cross-covariogram analysis is most extensively used for analyzing the cross-correlation of a pair of two neurons. This analysis implicitly presumes wide-sense stationarity, so all of the arguments below, are made under this assumption. This analysis is mostly combined with the shuffled predictor, called the conventional cross-covariogram analysis in this paper. The shuffled predictor creates a distribution of the null hypothesis that retains the mean firing rate of each neuron but has no correlation between their firings, i.e. they are independent firings. Thus, such an analysis can only reveal whether neural firing is correlated or not within a period of interest in comparison to no correlation.

2.2 Analysis against the null hypotheses of control period

We now propose that an equally important test is to examine whether neural firing in a period is correlated in comparison with the firing in another period.

To understand why this is important, by way of example, let us consider a single-unit recording using control and test periods. In the control period, the experimental manipulation is usually kept to a minimum, so activity in this period is regarded as being in resting mode. In the test period, some manipulations are done, e.g. showing a visual stimulus, to examine how a neuron responds to the manipulation. The firing in the test period is tested against the firing in the control period. If significant, the firing in the test period is considered test-related. Note that we would not call the firing test-related if we performed the test against zero firing, even if significance was found by that test.

The same argument can be applied to the cross-covariogram analysis. To examine whether a test-related correlation exists, we should examine the correlation in the test period against that in the control period, i.e. against the null hypothesis of the correlation in the control period, but not as done by conventional cross-covariogram analysis. Obviously, this type of argument is generalized for examining the firing between any two periods of interest.

3 Information-geometric approach

Information geometry (IG) provides useful tools and concepts, including the orthogonality of coordinate parameters and the Pythagoras relation in the Kullback-Leibler divergence [1]. Using the IG approach, a novel method can be constructed to evaluate the interaction of neural firing in a systematic manner [3, 4]. The method allows us to decompose the interactions of neurons of various orders, e.g. pairwise, triplewise and higher order interactions [4]. It can also be applied to analyze and compare different models used for a spike train of single neurons [2]. This further allows us to construct, relatively easily, a hypothesis test under the framework of a log likelihood ratio test [4]. This generality allows us to examine a test of correlation against any null hypothesis [4].

For the cross-correlation (under wide-sense stationarity), we use the IG mixed coordinates $(\eta_1, \eta_2, \theta_3)$ (see [4] for more details). θ_3 is the term measuring the interaction. The Fisher information matrix induces a natural metric, by which we can verify the orthogonality between η and θ components. Such orthogonality cannot generally hold if we replace θ_3 by the interaction term used by the cross-covariogram analysis, denoted here by c. In fact, only when $c = 0$, i.e., there is no correlation, does the orthogonality hold between η and c, and this is why a cross-covariogram analysis is convenient only for a test of no correlation.

4 Experimental setting

Experimental details are published elsewhere [5, 6], so only a brief summary is provided here. We conducted simultaneous recording of multi-unit activity from the IT cortex of two anesthetized macaque monkeys. Both control and stimulus periods had 1 sec length, where a visual stimulus is presented in the stimulus period. Correlation is estimated by the IG mixed coordinates for each period, using a 5-ms bin size. In the following, we report the results of correlation at a time lag of zero, i.e. simultaneous coincident firing.

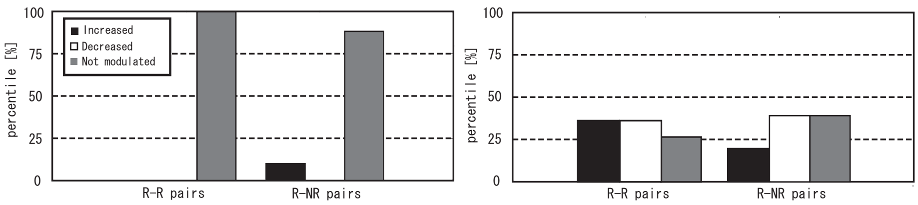

Fig. 1. Correlation in stimulus period is examined in comparison with that in control period, indirectly (left) or directly (right). See main text for details. Black, white, and hatched bars indicate the percentage of the number of pairs with correlation significantly increased, significantly decreased, or non-modulated, respectively.

5 Results

In this section, we report the results of 21 pairs of neurons, where each pair is categorized as either an R-R or R-NR pair. Here, R indicates that one neuron's firing is task-related (Wilcoxon test, $p < 0.05$), whereas NR indicates that one neuron's firing is not. We found 11 R-R pairs and 10 R-NR pairs.

First, we tried to perform a conventional cross-covariogram, for which we used the IG approach by setting the null hypothesis as $\theta_3 = 0$, since it is essentially equivalent. We found that *all* pairs had significant correlation, even in the control period, and further that almost all pairs (precisely, all except one R-NR pair) also had significant correlation in the test period. Thus, in this data, the conventional cross-covariogram is not informative for comparing the correlation between the two periods. However, if we still wanted to use this test to determine whether the correlation had changed from the control to the test period, one way might be to indicate whether the significance had changed between the above two results, i.e. Fig. 1 left; in this case, almost all pairs would be classified as unmodulated.

Now let us directly examine by the IG approach whether the correlation in the test period is significantly different from that in the control period (Fig. 1 right). We find that R-NR pairs have more decreased correlation whereas R-R pairs equally have both increased and decreased correlation. Clearly, this result is more informative in that it reveals either increased or decreased modulation for more number of pairs. It appears that the simultaneous correlation may be differentially modulated for R-R and R-NR pairs. More specifically, given the results of other analyses we performed [6], it will be particularly interesting if further analysis will lead to the observation that the correlation is increased for two neurons if both have task-related activity but decreased for two neurons if one of them does not have task-related activity. To confirm, though, we still need to examine with a greater number of samples.

6 Discussion

We presented one utility of the IG approach, specifically the flexible use of any null hypothesis, by using real data from the monkey IT cortex in a cross-correlation analysis. The results are promising for further investigations.

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References

1. Amari, S., Nagaoka, H.: Methods of Information Geometry. American Mathematical Society / Oxford Univ. Press, Providence (2000)
2. Nakahara, H., Amari, S., Richmond, B.J.: A comparison of descriptive models of a single spike train by information geometric measure. Neural Comput. **18** (2006) 545–568
3. Nakahara, H.: Comments on analysis of neural coding by information geometric measure. International Symposium on Nonlinear Theory and its Applications, NOLTA2004, Fukuoka, Japan, Nov 29–Dec 3, 2004, Proceedings. (2004) 31–34
4. Nakahara, H., Amari, S.: Information geometric measure for neural spikes. Neural Comput. **14** (2002) 2269–2316
5. Uchida, G., Fukuda, M., Tanifuji, M.: Correlated transition between two activity states of neurons. Phys. Rev. E **73** (2006) 031910
6. Uchida, G., Fukuda, M., Sato, T., Nakahara, H., Tanifuji M.: Stimulus-dependent modulation of synchronous activities of neurons in area TE of anesthetized macaque monkeys. (in preparation)