ANALYSIS OF MULTI-DIMENSIONAL SPIKE TRAINS USING VISA

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ABSTRACT

1. Introduction

In general, experts involved in research on neural coding agree that information in nervous system is encoded in the spatio-temporal patterns of spikes. However, there are two distinct opinions about the manner in which this encoding takes place. Some experts consider that temporal coding is based on the exact timing of spiking activity of a single neuron whilst others believe that this encoding is solely based on the firing rate of a single neuron [6]. The authors subscribe to the former opinion. Substantial quantities of simultaneously recorded spike train data exist, in addition to the numerous models developed for the generation of this data. However, current software systems to support the analysis and exploration of these large datasets are not adequate. The main focus of the research presented in this paper is the development of improved software systems to study the spatio-temporal patterns in these datasets.

Experimental data has shown that spatio-temporal patterns are variable within these datasets. Thus, when the same stimulus is presented to a subject twice, the resulting patterns can vary. However, when a larger neural population is studied, it is still possible to identify a sub-population, under variable conditions, that exhibits synchronous activity.
This paper describes several techniques based on Information Visualization that support the exploration of multidimensional spike train datasets and the identification of sub-populations of synchronously active neurons. Traditional measures of assessing synchrony, such as pair-wise cross correlation functions are becoming increasingly time-consuming and complicated when the number of simultaneously recorded spike train increases. Therefore, new, computer methods of dealing with these vast data sets are essential.

2. The VISA Visualisation Tool

In the previous workshop on Neural Coding, 2001, an initial prototype of the visualization tool was presented [8, 9]. This tool is called, VISA, Visualization of Inter-Spike Associations, and it supports the analysis of multidimensional spike train data. It supported the use of the gravity transformation algorithm [3, 4] and the display of its output data using parallel coordinates [5, 12]. Additionally, these parallel coordinates could be animated over time.

Much software development in the area of Information Visualization is now designed upon the much-cited "Information Seeking mantra" introduced by Shneiderman [7]. This mantra states the basic requirements of any useful information visualization system as "Overview first, zoom and filter, then details on demand". This mantra has been adopted as the fundamental premise upon which the VISA tool has been designed. The main aim of this tool is to enable users to view their data at different levels of detail, from abstract representations of the complete data set to specific representations that enable inspection of individual data items. The latest version of VISA includes additional numerical methods and visualization algorithms.

3. Additional functionality

Users require a wide variety of different ways to look at the same data set. This is largely due to the fact that representations accentuate some aspects of data sets but rarely do they expose all features of a data set. Additionally, the increasing size of data sets currently under investigation also means that multiple, and often synchronized, views of data are now required. To support this requirement for a range of representations of the same data set, additional functionality has been incorporated into VISA. This includes the addition of two new visualization tools: the "Correlation Grid"[10] and the "Tunnel"[11] representations.

The Correlation Grid is a technique used to represent the synchronous activity exhibited by clusters of spiking neurons. Let us consider a dataset of *n* spike trains. To quantify the similarity of spike trains, the cross correlation function of each pair of neurons is calculated. Subsequently, each of these functions are normalized using the Brillinger method [2]. This normalization is used to define the distance between two spike trains subsequently used for cluster analysis. The results of cluster analysis are represented using an $n*n$ grey-scale grid. The scale goes from white, representing no significant correlation between the two corresponding spike trains, to black, representing the most significant correlation within the current dataset. The Correlation Grid allows clearly visualize the clusters of synchronous spike trains.
The "Tunnel" also allows to find clusters of synchronous activity and this method uses 3D representation of information and immersion possibilities, such as those used in Virtual Reality, to locate neurons that are spiking synchronously. Multiple spike trains are represented as bands or strips that make up the walls of a long tunnel. This representation supports movement of the user through the Tunnel. Additionally, it support the reordering of spike trains, to aid the identification of trains that are synchronized. For example, the cross correlation based clustering method can be used to reorder the spike trains within the tunnel, so that trains that are most similar are adjacent to each other.

4. Results of synchronization analysis supported by visualization

In this section, a simplified case study is described. This case study illustrates how the use of visualization representations supports the investigation of synchrony in artificially simulated neural activity.

4.1 The neuronal assembly

In order to illustrate the new visualization techniques included in the VISA toolbox, a data set was generated, for 20000 msec with a time step of 1msec, using an enhanced integrate-and-fire generator [1]. This dataset was based on an assembly of ten neurons with the connection scheme shown in Figure 1.

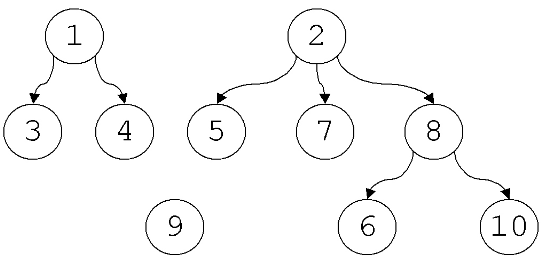

Figure 1: The neuronal assembly used to generate data depicted in Figures 2 and 3.

4.2 The Correlation Grid

The Correlation Grid is a representation that provides an overview of all of the individual cross correlograms for a given data set. An example of this representation for the generated data is shown in Figure 2.

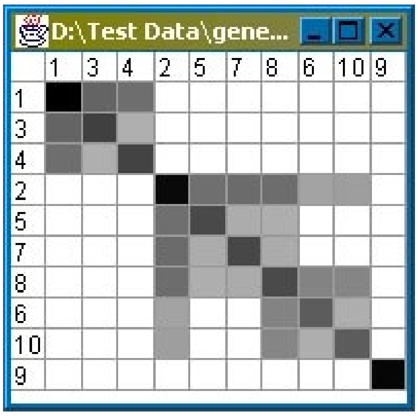

Figure 2: An example of the Correlation Grid

As explained in section 3, this grid is based on the cross correlation functions of neuron pairs. Note that the cluster analysis based on the Brillinger method, inherent in this representation, reorders the spike trains in order to highlight similarity between train pairs. This significantly increases the usefulness of this representation. The Correlation Grid shows two clusters of synchronously working neurons (#1, 3 and 4; #2, 5, 7, 8, 6, 10) and one independent neuron (#9). Also, the second cluster is consists of two overlapping sub-clusters: (#2, 5, 7, 8 and 8, 6, 10). All these findings correspond to connection scheme for spike train generator (see figure 1).

4.3 The Tunnel visualization

The "Tunnel" visualization is a method of analyzing the firing patterns of multiple neurons. This environment presents different views of the same dataset and an additional overlay that encodes spike coincidence.

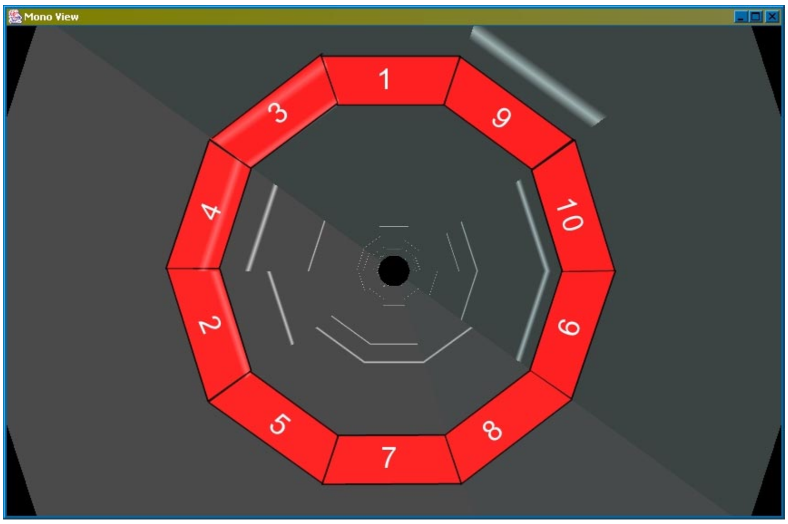

Figure 3: A snapshot of the Tunnel representation of the generated dataset over 500ms.

The Tunnel is a cylindrical virtual environment that has been designed to provide useful user interaction. Figure 3 shows the Tunnel visualization of the generated dataset from 1000ms to 1500ms. Each of the numbered horizontal bands, that comprise this Tunnel visualization, encodes the spike train of the corresponding neuron. The two 'end' bands, band 1 and band 9 in Figure 3, are adjacent to each other, thus forming the tunnel environment.

Note that in figure 3 the order of the spike trains within the Tunnel is based on the cluster analysis shown in Figure 2. Thus, it is possible for the user to reorder spike trains in order to highlight synchrony between trains. Additionally, inside the tunnel, the user is able to navigate or "fly" through the tunnel at different speeds, in order to identify "interesting" features in the dataset at different positions in the tunnel.

5. Conclusion

Since the VISA tool is now equipped with the fundamental functionality required to investigate neural assemblies, this paper will describe a series of analyses that are currently underway. The paper shall report on the usefulness of the visualization techniques currently available, and the results obtained by using a combination of all the techniques available using VISA.

Note that this research and the development of the VISA software is an ongoing project. It is anticipated that further use of the tool will also lead to further requirements definition.

Keywords: Multidimensional spike train data, Information visualization, Data analysis.

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