Quantifying continuous behavior to account for neural variability

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A central question in investigating neural function is to understand the nature of the computations being implemented in different neural circuits. To address this question we need to understand what exactly populations of neurons encode. In experimental neuroscience, neural activity is usually recorded in highly controlled contexts where different aspects of the environment are systematically varied. Neural responses are then studied in response to these systematic experimental manipulation. However, some aspect of neural responses are likely to vary with additional uncontrolled parameters such as the animal's continuous behavior or movement states. Here, our goal is to develop an approach to quantify the dynamics of an animals' behavior. This will allow us to investigate if there is any structure in neural dynamics that could be explained by the structure of behavior during the task.

There are two key aspects to consider in quantifying behavior for this purpose— first, what is an appropriate, unbiased measure of behavior? And second, what is the most succinct yet minimally lossy representation of the measured behavior? The problem of representation is usually not an issue when only a few variables are recorded since the original measures can be directly used for analysis. But, measuring only a few variables may fail to capture important features of animal behavior. On the other hand, when the number of variables is increased, it becomes harder to characterize the trends in the data. Hence, an appropriate low-dimensional representation of the high-dimensional data is required.

With regard to the first issue—conventional techniques of obtaining continuous measures of behavior involve identifying and tracking some set of features of an animal's body, such as the position of the animal's centre of mass, head position, paw position, orientation, etc. These features can be combined to define different behavioral states of the animal. This allows a clear interpretation of relationships between well defined behavioral states and relevant environmental or task related variables. However, it suffers from several image processing problems in extracting relevant features and, more profoundly, from the bias introduced by the experimenter in the choice of features that are tracked. To overcome these, we directly use high speed videos of animals performing a stimulus categorization task as an unbiased measure of the animal's ongoing behavior.

This brings us to the second issue. In working directly with high speed videos, we are treating each pixel in the video frames as a continuous time-varying variable. Clearly, this is an extremely high-dimensional representation. Especially when high resolution images are collected. Hence, the task of determining an appropriate low-dimensional representation is paramount. Since we are using a top view of an animal performing a task in a box, we may be justified in assuming that the intrinsic geometry of the data is likely to be rather low-dimensional. The different dimensions of this underlying structure would correspond to translation, rotation, and changes in the contours of the animal's body as it performs the experimental task. There are several analysis methods with which high-dimensional data can be compactly represented. Among the most commonly used are linear unsupervised techniques such as principle component analysis (PCA). However, the structure in images of animals is likely to be highly non-linear in pixel space and linear techniques, such as PCA, may be inadequate in pulling out any underlying low-dimensional structure. Hence, we are investigating the efficacy of a non-linear dimensionality reduction technique called Isomap [1] to represent videos of behaving animals.

Dimensionality reduction procedures such as PCA can be understood in terms of two steps—1. Determine a measure of similarity between all data point. In the case of PCA, this would be covariance. 2. Find an arrangement of data points in a low dimensional space such that it preserves the measured similarity between the data points. Isomap is implemented using a similar procedure. The key distinguishing point, however, is the choice of the similarity metric. Isomap uses an approximation of Geodesic distances between data points. The second embedding step finds an arrangement of points in a low dimensional space in which the Euclidian distance between the points approximates the Geodesic distances computed in the original high dimensional space. This procedure unfolds curved manifolds to reveal their true underlying dimensionality.

Isomap has been previously used for analysis of image sequence [2]. The presented work is an attempt to investigate its relevance as a technique to represent videos of behaving animals. We describe the nature of high-dimensional representations, in pixel space, generated by different transformations of objects in images. Subsequently we show how well the representations extracted by linear and non-linear dimensionality reduction techniques capture the structure of the original data. Some of the considerations in implementing Isomap, that affect the result of the analysis, are discussed, as well as some of its limitations. Furthermore, using toy data as control reference, we discuss the appropriateness of this method to work with videos of behaving animals and what criteria do the data need to satisfy for Isomap to be a suitable technique to obtain a low dimensional representation.

Ethical statement

All experiments were approved by the Champalimaud Foundation Bioethics Committee and the Portuguese Direção Geral Veterinária. The animals were allowed ad libitum food and access to bedding and sheltering material. They were maintained in a 12 hr-12 hr light-dark cycle. And to create motivational drive for the experimental task, they were water deprived to a maximum of 80% ad libitum body weight.

The data discussed in the presented work involves rats that were trained on a classification task. They were required to classify the duration of the delay between two tones as being either longer or shorter than a reference duration determined by the experimenter. This duration was not explicitly available to the animal but was learned by reward contingency based on choices in response to the different durations presented. Detailed descriptions of the experimental setup and paradigm are available in [3].

References

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