Neuron Activity Analysis Using NMF and PCA

Zongqi Han

Imperial College London

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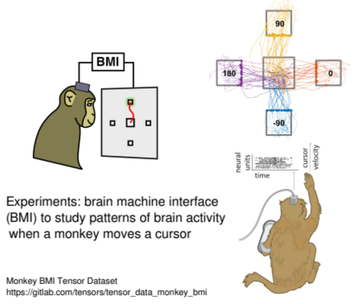


Experiments: brain machine interface (BMI) to study patterns of brain activity when a monkey moves a cursor

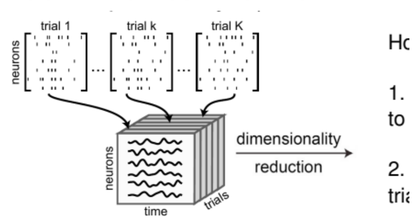
Monkey BMI Tensor Dataset
https://gitlab.com/tensors/tensor_data_monkey_bmi

Introduction

In an experiment, the activities of 43 neuron cells of a monkey when it moves the computer cursor in 4 different directions, are recorded.

The data set we obtain have 3 different dimensions—-**neurons, time steps and trials**, which will from a **3D** matrix in python of **43x200x88**.

In this project **PCA** and **NMF** are used to analyse the data obtained. We will also use **Mean Square Error (MSE)** to help analyse the data. After performing the analysis, we will try to draw conclusions on the critical time steps as well as differences between the results from NMF and PCA.



43 neurons whose activity is recorded over time
200 time steps
88 trials (same neurons are recorded in different sessions, corresponding to different angles of movement)

Brief Intro to PCA and NMF

PCA: Principal Component Analysis

PCA is used to produce an approximation of a data set. The main idea is to project the data onto smaller number of orthogonal directions on which the variance of the data is maximize, in other words, that capture the most information.

These orthogonal directions(vectors) are called ***Principal Components*** ϕ_j. They are actually eigenvectors of the data matrix. And $\{\phi_j\}_{j=1}^{k}$ is the collection of such vectors. k ***is the dimension we reduce the original data*** $\mathbf{x^{(n)}}$ ***to.***

And the $a_j^{(n)}$ are ***the result of dot product of*** ϕ_j ***and*** $\mathbf{x^{(n)}}$

NMF:Non-negative Matrix Factorization

NMF is similar to PCA except we use ***an iterative algorithm*** to obtain the non-negative version of the results in PCA.

We use W to refer to the none-negative version of matrix formed by vectors $a_j^{(n)}$. H to refer to the none-negative matrix of principle components ϕ_j.

Organize the data

Two different methods to organize the data are used in the project

1. Fix a time step (t = 50) to get a matrix of size 88x43
2. Average over the same angel trials, to get four different matrices of size 200x43 representing the data of 4 different angles.

We will then perform PCA. as well as NMF. to both method 1 and method 2 to obtain the result.

References

[1] M.P Deisenroth. Mathematics for Machine Learning, Cambridge University Press, 2020. - chapter 10

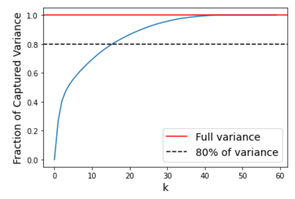
[2] D.D. Lee Learning the parts of objects by non-negative matrix factorization, Nature, 401 (1999)

[3] T.G. Kolda, Monkey BMI Tensor Dataset https://gitlab.com/tensors/tensor_data_monkey_bmi 2021.

Apply PCA to method 1

Choose K, the dimension we reduce to – graph 1 and 2

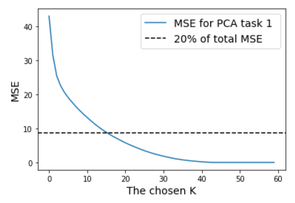
Firstly, we want to obtain the ideal k for PCA on method 1. If we chose to set the threshold to 80% of captured variance and 20% of total MSE, we will get the same k for PCA, which is 15.



1

Obtain the scatter plot – graph 3

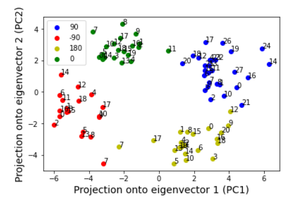
After we obtain the k, PCA could be applied to the 88x43 data matrix. We then look at the projections of the data onto the 1st and 2nd principle components of the data, with angles of movements being labeled in different colors.



2

Result from scatter plot – graph 3

Looking at the scatter plot, it is clear that there is a clustering of data for each angle of movement, which highlights that ***there exist some systematic differences*** between neuron activities when monkey moves the cursor in different directions.



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Apply NMF to Method 1

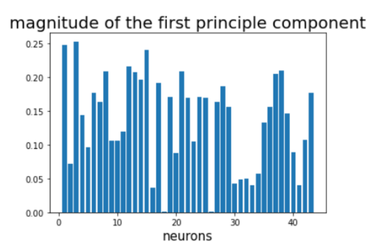


figure 1

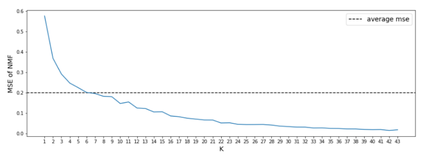


figure 2

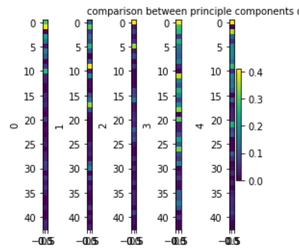


figure 3

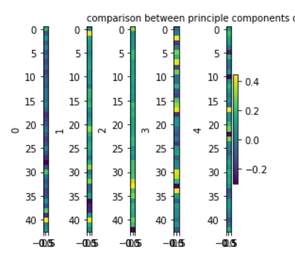


figure 4

Plot of the First Component- figure 1

The plot is of the magnitude of the first component with respect to the neurons. The y-axis of the plot represents the overall active level of the 43 neurons, as the coefficients $a_j^{(n)}$ are produced by applying $\phi_j^T \mathbf{x^{(n)}}$, and $a_j^{(n)}$ can directly influence the value of approximations. This plot will be used to compare with the results obtained in NMF.

Choose K in NMF- figure 2

Different from the process of choosing k in PCA, only MSE can be used to obtain the k for NMF, so we plot the value of MSE of each k and set the threshold of MSE as 0.2, choosing k as 6 for NMF.

Compare the result- figure 3 and 4

We basically visualize the previous barplot of principle components in a different way. The 3rd graph represents the first 5 columns of matrix H in NMF. The 4th one represents the first 5 principle components in PCA.

The differences are:

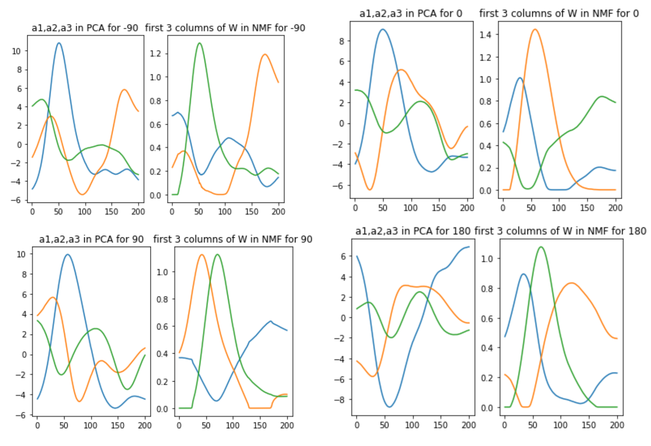
1.While the eigenvectors have many positive values across neurons, the results from NMF seem to be ***'sparser'***, with much fewer values being significantly positive.

2.Results from NMF seem to ***highlight some patterns*** in activities of neurons, as only few positive values are highlighted. While on the other hand eigenvalues from PCA seem to be a mixture of information.

Explain the differences

The reason why the results of NMF and PCA have such differences is that after we apply *the iterative algorithm*, the data sort of being 'blended together'. The negative and positive values in the original data compensate and converge to a stable positive value that is smaller than the original positive values. After this kind of process, only large values in original data will still be significant, which is the reason why results of NMF seem to highlight some critical features of the original data.

Apply NMF and PCA to Method 2



After applying PCA and NMF to four different matrices obtained in method 2, we compare first 3 principle components of each matrix with the first 3 columns of W in NMF.

Conclusions we could get

1.Consistent with the conclusions obtained in method 1, the values of y-axes of the plots of PCA are significantly larger than those of NMF.

2.By looking for critical points in plots we could find the important time steps in the experiment. For example ***time steps around 50, 100 and 175*** may be important, as these times steps are stationary points in NMF and PCA plots of all 4 different angles.

Conclusions and Highlights

1. By the scatter plot in PCA of method 1, systematic differences between the neuron activities are spotted. **2.** By comparing the principle components with the columns of W in NMF for method1, two main differences are found. **3.** From the properties of NMF, the reasons why the results from NMF and PCA have such differences are given. **4.** By comparing the NMF and PCA of method 2, important time steps are found, respectively those around $50, 100$ and 175.