Decoding the representation of space in the auditory cortex

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Introduction

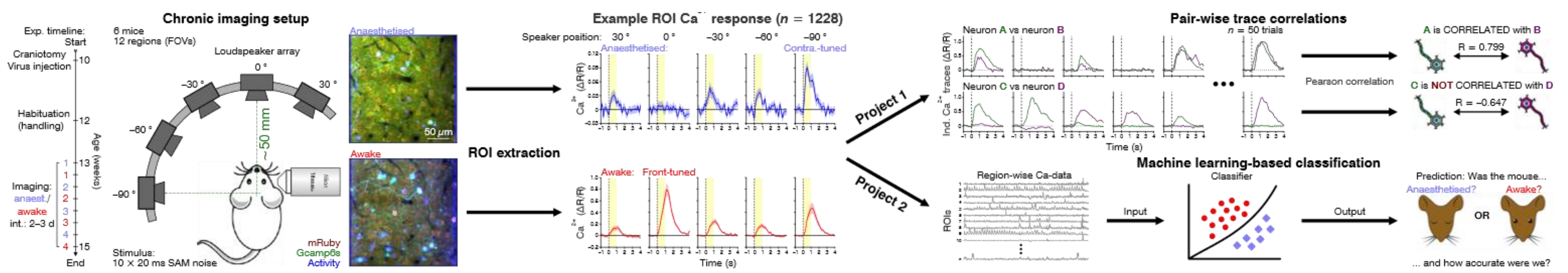

Fig1: Graphic abstract

The manner in which our brain encodes and represents auditory space remains an enigma, despite decades of intense research on the topic. Human psychophysical experiments have long suggested the importance of neuronal tuning toward the front of an individual, but existing data have been insufficient to support or contradict this claim because most animal experiments are performed under anesthesia.

Using functional in vivo imaging in the auditory cortex (AC) of mice, we previously demonstrated a preponderance of frontal spatial tuning that was indeed suppressed by anesthesia. However, these data remain exceedingly difficult to interpret because there is no topographical representation of auditory space in the AC, whereby the specific location of an object can be simply read out from a corresponding location on the cortical surface.

- Various mathematical analyses can be used in this field, to obtain any patterns of the joint behavior of different sets of neurons in the auditory cortex of the brain. Therefore, the main aim of this project is to observe correlations between the single neuronal pairs and finding a difference in their existence between anesthetized and awake states (Fig1).

Correlation

(Fig2) shows the representation of same region in auditory cortex in an anesthetized and awake state. Amongst many conclusions of these plot that highlight the significant difference between the two conditions, the main ones are:

- A big group of neurons that are tuned to different speakers in anesthetized, shift their tuning to the front speaker in the awake state.
- A large number of high correlations (>0.6) are concentrated in the anesthetic state.
- There are fewer correlations in the awake state, but they are stronger.

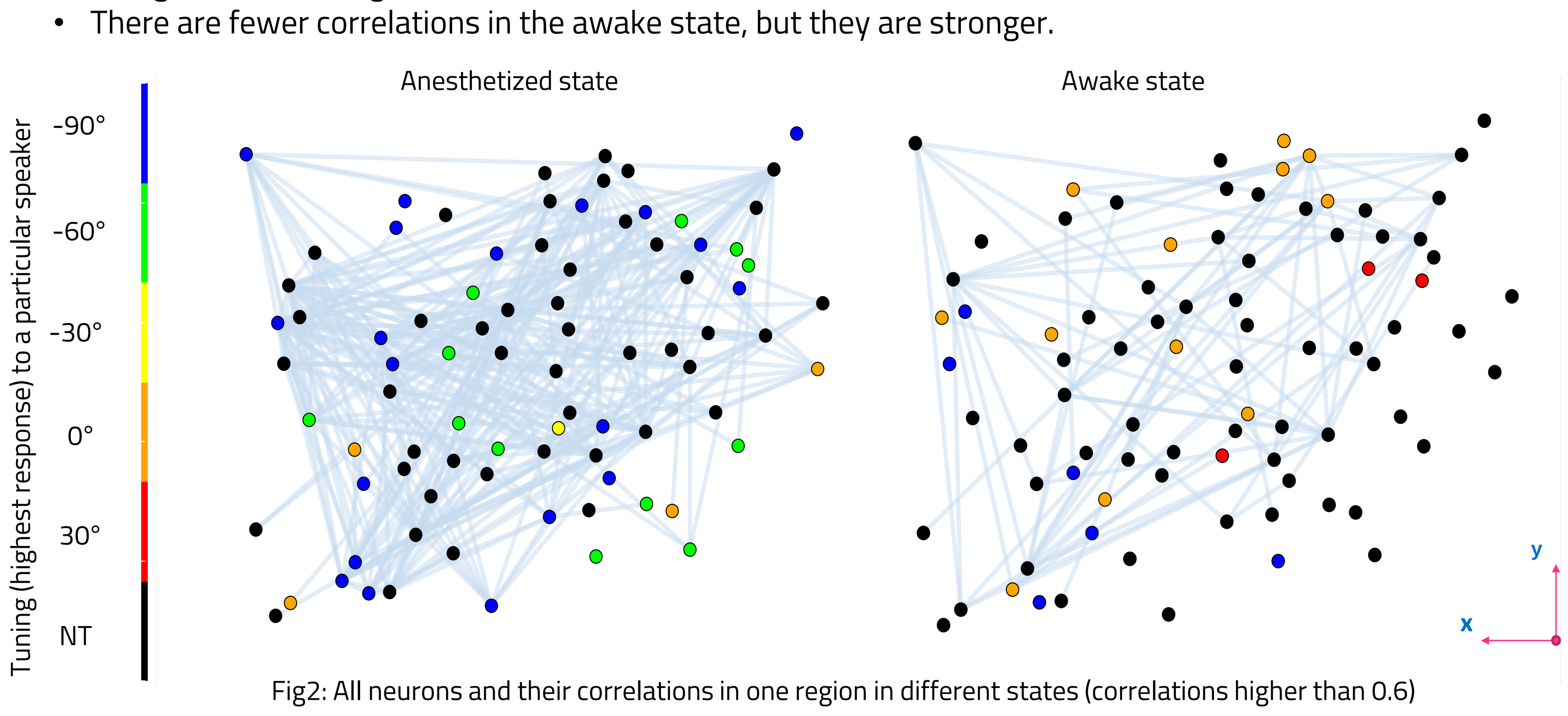

Fig2: All neurons and their correlations in one region in different states (correlations higher than 0.6)

Seeing that the correlations change their strength between states, the individual behavior of the strongest in different states was analyzed.

- Neurons that were highly correlated in the anesthetized state, change their property to anti-correlated (Fig3).

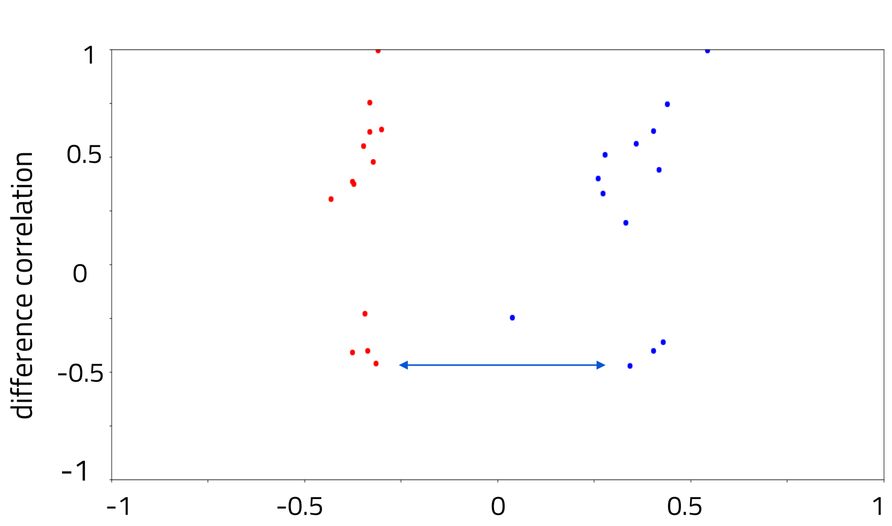

Fig3: Change of correlation strength of single neurons between states

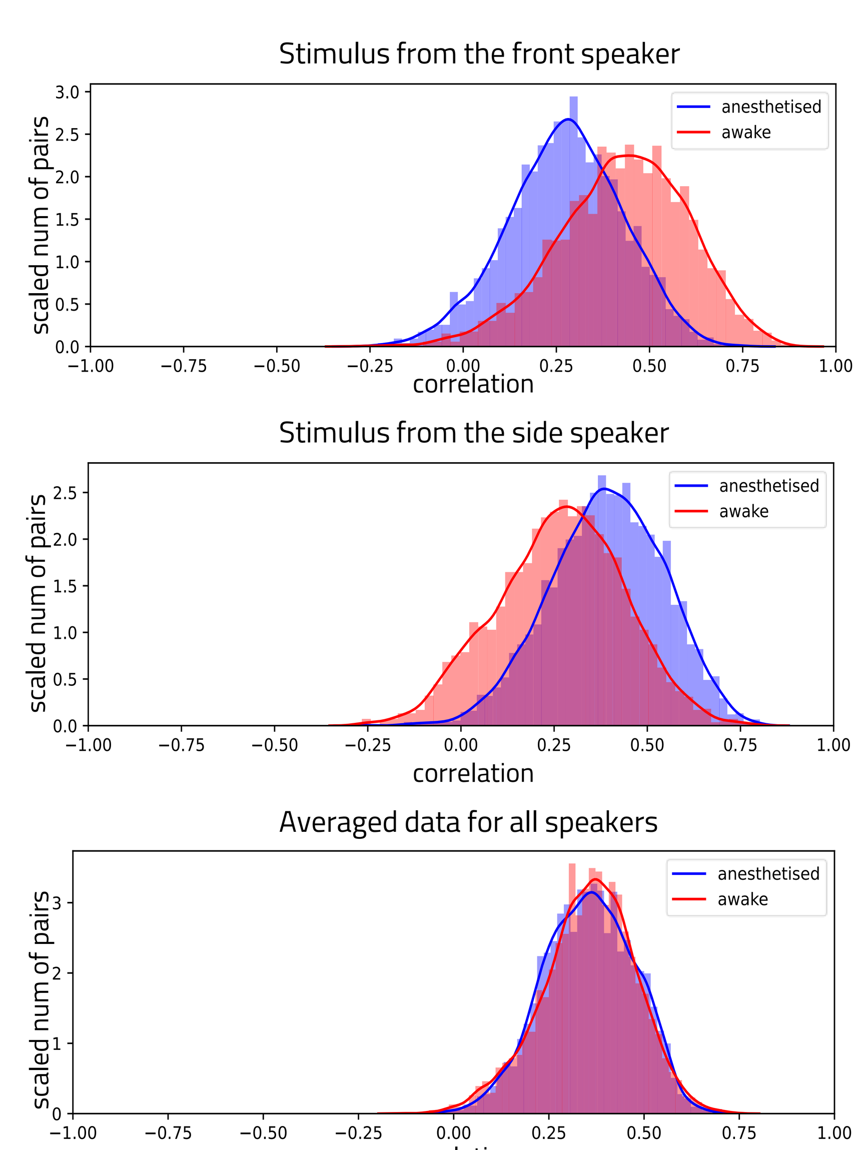

Fig4: Comparison of neuronal correlation between states during different speakers and on averaged data

When dealing with averaged data, the strength in neuronal correlation between the two states changes only slightly. On the contrary, during an activity of individual speakers, some shifts can be seen (Fig4).

- When speaker placed in front of the mouse is active, right shift in correlation strength between anesthetized and awake state is clearly visible. That implies stronger correlations in the awake state.
- When the speaker on the side is active, neuronal correlations, by same principles, shift to the left, implying weaker correlations.

Classification

With a simple analysis of data by looking at individual correlations between neurons, it is practically impossible to observe any significant patterns. The differences are evident, but their aggregate analysis is very complicated. In order to determine whether the data contains enough information to find a meaningful difference between the two examined states (or e.g. five different speakers), it is necessary to analyze the data in a much more complex way. On that occasion, various machine learning models were applied and their performance is discussed below.

Data preparation for the classification

- Before classification, all data was normalized for better algorithm performance, and divided into a train (70%), validation (15%), and test (15%) set.
- K-Nearest Neighbors, Random Forest, and Extreme Gradient Boosting are used as models for different classification purposes.

Classification of data on different states

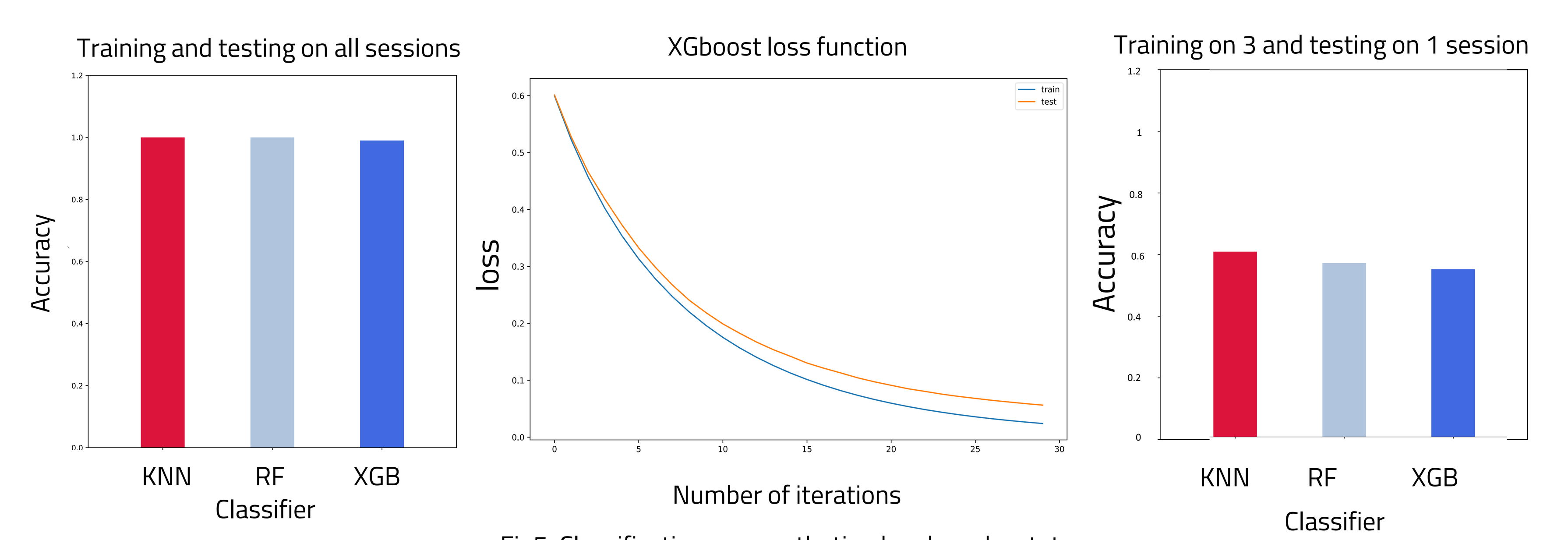

Fig5: Classification on anesthetized and awake state

- Training and evaluation of data on all sessions were performed with the accuracy of slightly more than 99% for all of the classifiers. Taking that into account, it can be said that differences between anesthetized and awake states are clearly enough encoded in the data that can be extracted as model features.
- On the contrary, training models on 3 different sessions and evaluating them on 4th shows much worse results. The RF can not extract any useful features, XGboost performance is around 56%, and KNN gives the best accuracy of 60% on average. Keeping in mind how noisy brain can be, different sessions are very hard to be separated (Fig5).

Classification of data on different speakers

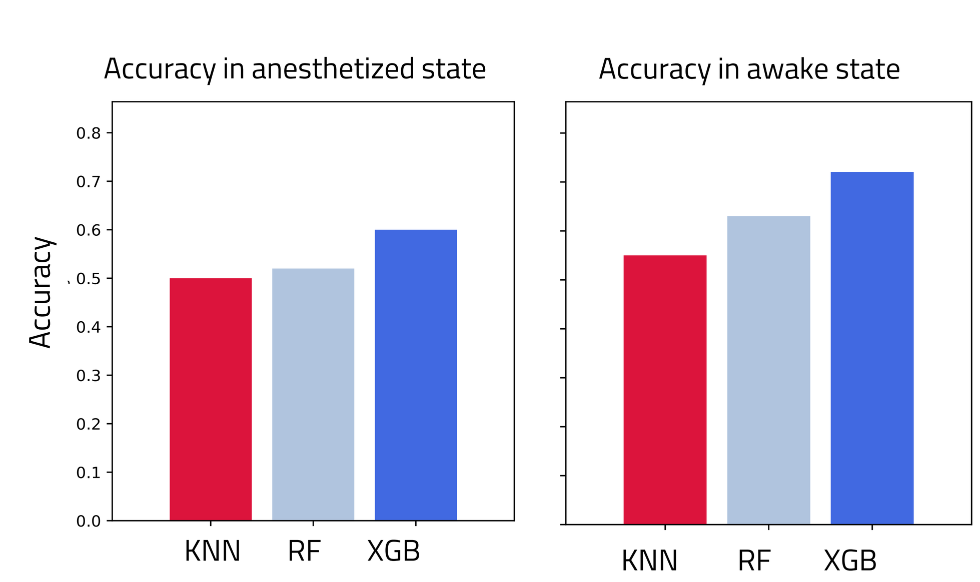

Fig6: Classification on two different speakers

Due to the very sensitive data, classification of neuronal activity on different speakers is also proved to be challenging. Accuracy of all classifiers can be considered as random. Having that in mind, it was decided for each pair of two speakers to observe the possibility of their classification, and also which pairs are easily mixed.

- All the models gave similar accuracy from 60-65% where XGboost always performs the best. The highest division accuracy have classes of data obtained when the speaker at 30° and speaker on the totally opposite side (-90°) were active (Fig6).

Conclusion

Understanding the brain's auditory cortex has been a great mystery to the scientific community for years. Basic methods of data analysis, as well as advanced methods of machine learning, indicate evident differences in the encoding of information in the brain. The different response of neurons to different spatial stimuli, as well as the dependence of the reactions on the state (anesthetized/awake), are only some of the confirmed hypotheses in this project. Besides, the final impression remains that the brain is very noisy, and the analysis of this area stays an open topic for all interested readers.