Predicting Axon Collaterals using Branch Angles

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Summary

- **Motivation:** Our goal is to better understand characteristics of neuron trajectories for main versus collateral branches of axons.
- **Method:** Predict neuron trace trajectories using branch angle.
- **Result:** On a dataset of neurons traced in a mouse brain, we were able to achieve 95.75% accuracy in predicting trajectories of main branches and 82.42% accuracy in predicting trajectories of collateral branches

Introduction

Performing morphological analysis on neurons can reveal important information about neuron subpopulations. Further, understanding and characterizing branch patterns and geometrical features of neuronal axons can allow scientists to study changes in neuron structure related to neurological disease[1]. Individual neuron traces can be represented as points in 3D space organized as a tree structure. In order to study the morphology of axons represented as traces, we are interested in characterizing main and collateral branches of axons. Previously, our lab has developed software to classify axon branches within these categories using the longest root-to-leaf paths within the axon. However, further study on accurate ways to characterize neuron branches is needed. In this work, we analyze how well manually traced axon trajectories can be predicted based on branch angles.

Materials

Our work uses data from the Kolodkin Lab in the Johns Hopkins University Department of Neuroscience. The dataset includes neuron traces containing 1 or more neurons from pyramidal cells in layer 2 and 3 of the mouse cortex. Each neuron trace has been further divided into individual paths, including the main axon and collateral branches through manual tracing. A total of 33 neuron traces were used.

Methods

For each neuron trace, we found all branching points on the neuron's main axon. Then for each branching point, we calculated the angle between the 2 continuing pathways and the main axon. Collateral branches were predicted to be the continuing pathway with the smaller angle.

Branch angle was found using the following equation, where P is the vector representing the main axon and Q represents the vectors for either path.

We repeated this experiment using branching points located on collateral branches within the same data.

$$\theta = \arccos\left(\frac{P \cdot Q}{|P||Q|}\right)$$

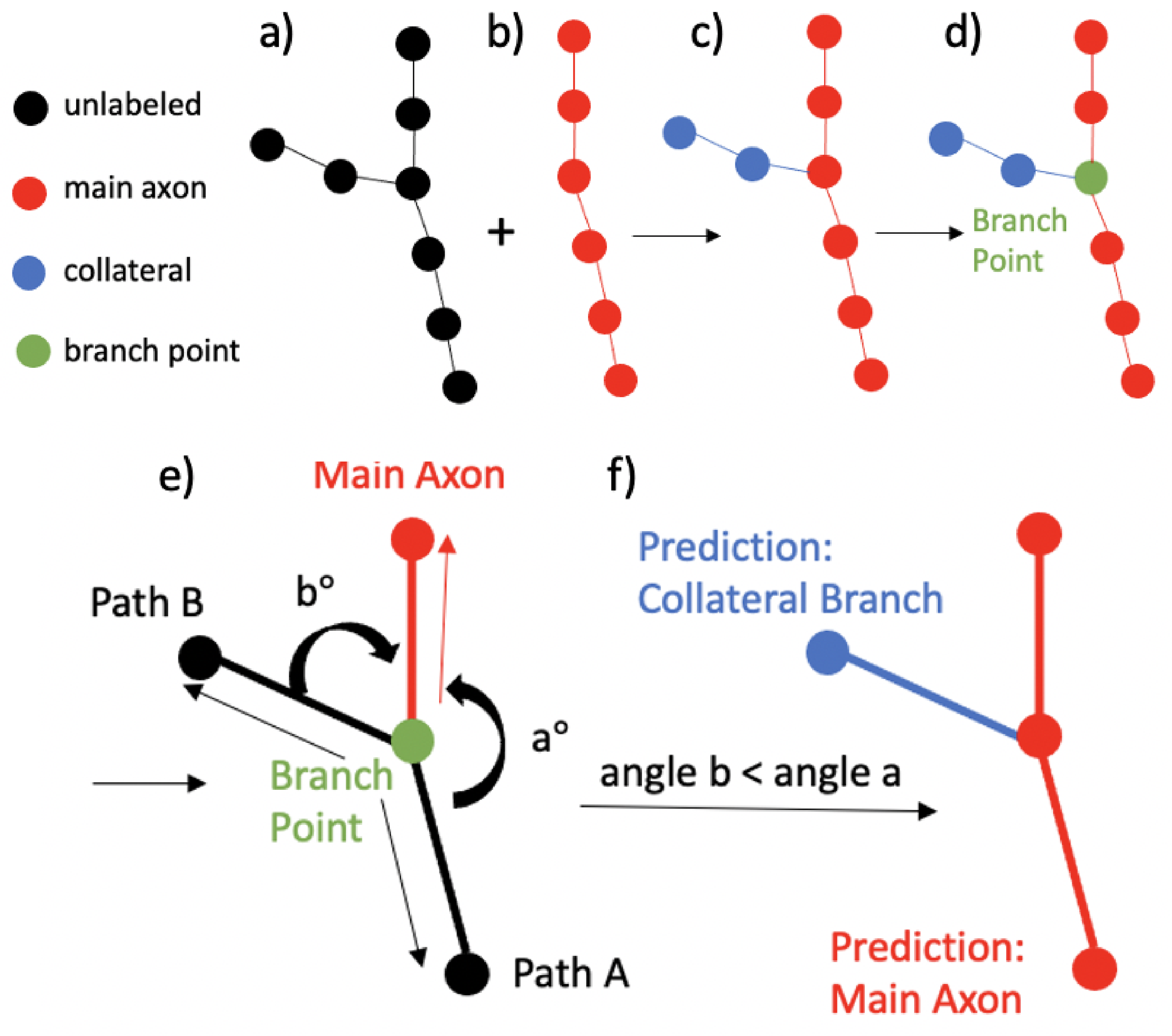

Figure 1: Given (a) the trace of an entire neuron, and (b) the trace of that neuron's main axon, (c) a neuron trace's branches were classified as either main or collateral. (d) Then, all branching points within the trace were identified (green). Branching points were defined as points on the main axon that are parents to 2 nodes. (e) Vectors representing the path from a branch point towards each node and the main axon were identified (Path A, Path B, and Main Axon). Angles a and b were then calculated using the equation shown above, representing the definition of the angle between 2 vectors. f) The smaller angle was then predicted to be the collateral branch. This method was applied to 33 neurons, and we calculated accuracy of branch classification prediction.

Results

We were able to achieve an accuracy of 95.75% for predicting branch trajectory between main and collateral axons. This means for all branch points, 95.75% of them had correct trajectory predictions using our method. Additionally, we were able to achieve an accuracy of 82.42% for predicting branch trajectory of collateral branch pathways. Fig. 2 below reveals angle difference distributions for each experiment. We calculate the angle difference by subtracting the 2 branch angles calculated at each branching point. The average angle difference for main vs collateral is 83.58 ± 37.28 degrees and for collateral pathways is 50.88 ± 30.54 degrees.

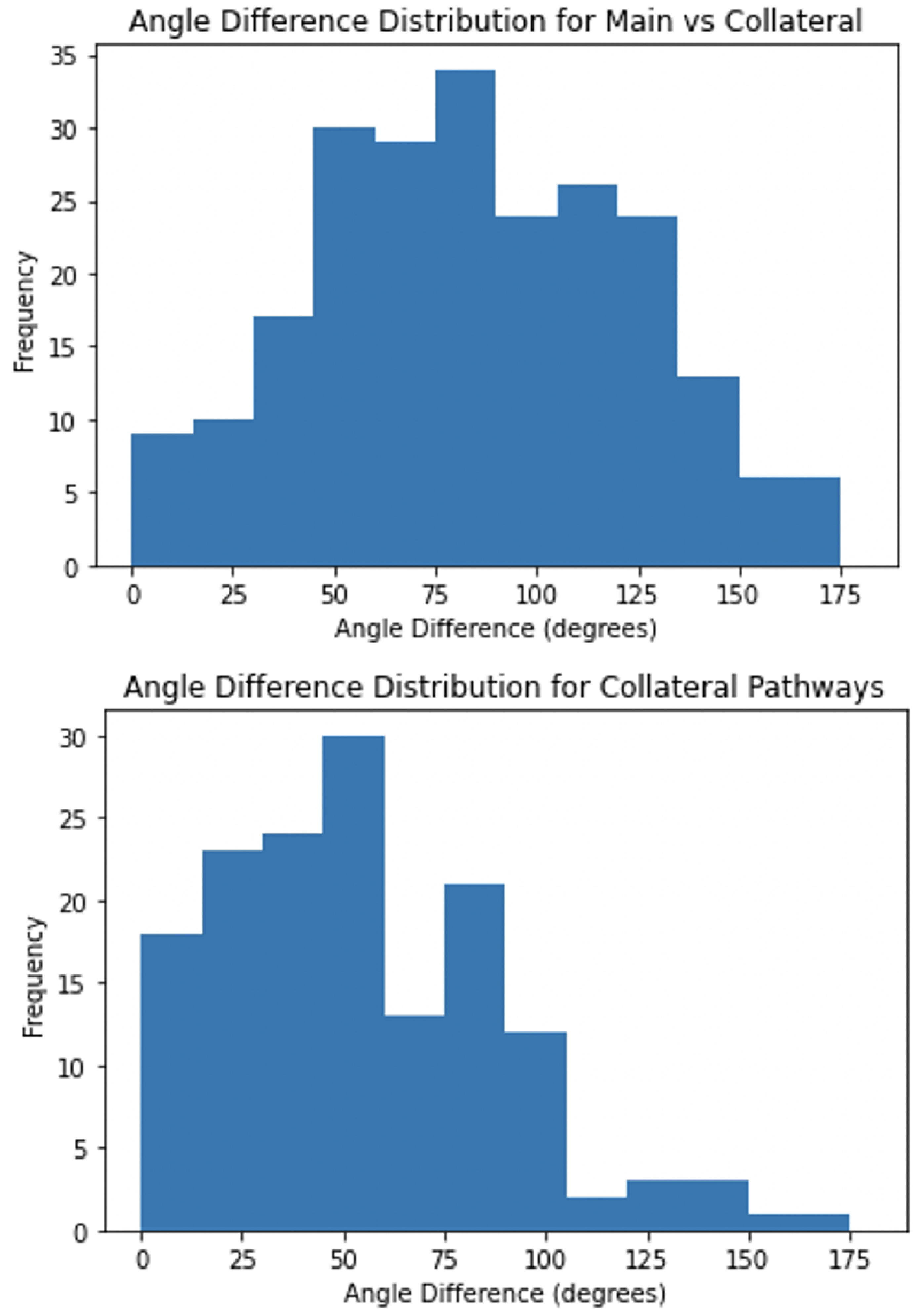

Figure 2: The difference between Path A and B angles for (above) main vs collateral and (below) collateral trajectory prediction. Overall, angle differences are much lower for branch points located on collateral axons when compared to branch points located on main axons.

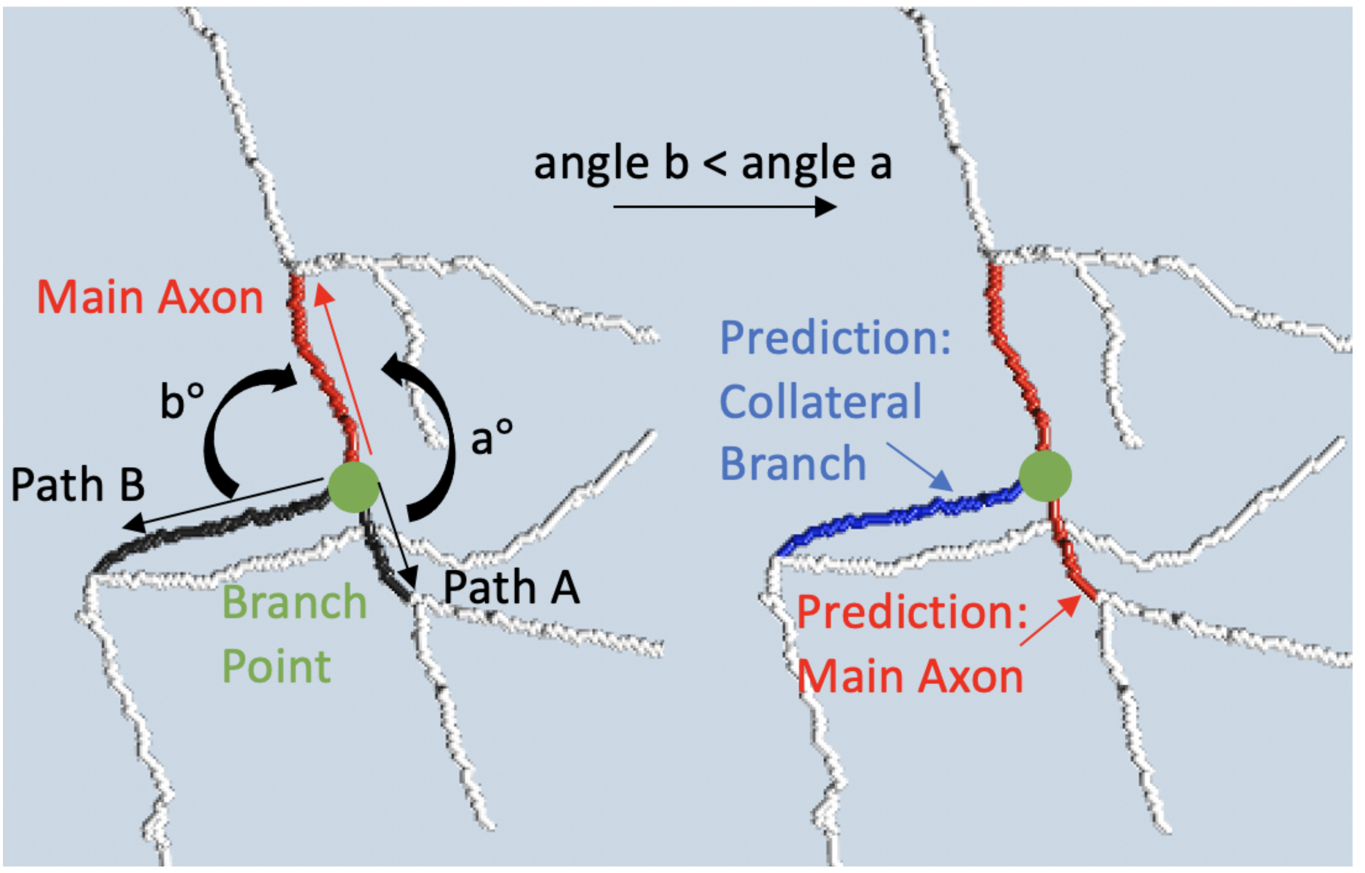

Figure 3: An example of our methodology for prediction on a real neuron trace.

Conclusion

Through our work, we find that for our dataset, manual tracers have largely classified main versus collateral axon trajectories based on branch angle In the future, we will need to perform experiments applying our technique to data with different methods of defining collateral branches, as well as to data within different brain regions. Additionally, differences in branch angle for collateral branches coming off of a main axon versus collateral branches coming off of a collateral branch are apparent, as the average angle difference between paths is lower for our collateral trajectory experiment. Our study has helped improve our understanding on the morphology of neurons, and helped us better define main and collateral branches. Studying branch angles could help reveal differences between neuronal subtypes.

References

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