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Topological Representation of Neuronal Morphologies

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The shape of neuronal arborizations defines amongst other aspects their physical connectivity and functionality. Yet an efficient method for quantitatively analyzing the spatial structure of such trees has been difficult to establish. The wide diversity of neuronal morphologies in the brain, even for cells identified by experts as of the same type, renders an objective classification scheme a challenging task.

We propose a novel Topological Morphology Descriptor (TMD), inspired by Topological Data Analysis, to quantitatively analyze the branching shapes of neurons, which overcomes the limitations of existing techniques. The TMD of a tree is a filtration of the sub-level sets defined by a set of spheres of decreasing diameter, centered at the neuronal soma. The distance between the persistence barcodes of neuronal morphologies can be used as a metric of distance between the trees and hence it is useful for their objective separation into morphological groups.

This method is applicable to any tree-like structure, and we demonstrate this property by applying it to groups of mathematical random trees as well as neuronal trees. Our results show that the TMD of tree shapes is highly effective for reliably and efficiently distinguishing different groups of trees and neurons. Therefore, the TMD provides an objective benchmark test to asses the quality of any classification of branching cells into discrete morphological classes.

Finally, we propose a generalization of the TMD to study time series of tree. This method is used to track the morphological evolution of trees in time, in order to enhance our understanding of neuronal development.