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Elastic Shape Analysis of Neuronal Tree Structures

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Neuron morphology plays a central role in characterizing cognitive health and functionality of brain structures. The problem of quantifying neuron shapes, and capturing statistical variability of shapes, is difficult because neurons differ both in geometry and in topology. We restrict our attention to trees that consist of: (1) a main branch viewed as a parameterized curve in $\mathbb{R}^3$, and (2) some number of secondary branches also parameterized curves in $\mathbb{R}^3$ – which emanate from the main branch at arbitrary points. In this space of geometric tree structures, we define a distance metric in terms of the elastic shape distances between individual branches that are optimally matched to one another. Topological variation is naturally accounted for by allowing branches to remain unmatched. The combinatorial problem of matching side branches across trees is reduced to a linear assignment problem which has well-known algorithmic solutions. This framework can be used to compare, summarize, and classify neurons using fully automated algorithms. We illustrate these methods on a set of axonal tree structures of Drosophila Melanogaster neurons, showing example geodesics paths, Fréchet means, modes of variability, samples generated from simple distributions, and cross-validated classification between genetically different groups.