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Estimation of one-dimensional structures from noisy empirical observation

Given a data distribution which is concentrated around a one-dimensional structure, can we infer that structure? We consider versions of this problem where the distribution resides in a metric space and the 1d structure is assumed to either be the range of an absolutely continuous curve, a connected set of finite 1d Hausdorff measure, or a general 1-rectifiable set. In each of these cases, we relate the inference task to solving a variational problem where there is a tradeoff between data fidelity and simplicity of the inferred structure; the variational problems we consider are closely related to the so-called "principal curve" problem of Hastie and Steutzle as well as the "average-distance problem" of Buttazzo, Oudet, and Stepanov. For each of the variational problems under consideration, we establish existence of minimizers, stability with respect to the data distribution, and consistency of a discretization scheme which is amenable to Lloyd-type numerical methods. Lastly, we consider applications to estimation of stochastic processes from partial observation, as well as the lineage tracing problem from mathematical biology.