Topological Data Analysis and Machine Learning Theory

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October 15–19, 2012

1   Persistent homology

Perhaps the most important idea in applied algebraic topology is persistence. It is a response to the first difficulty that one encounters in attempting to assign topological invariants to statistical data sets: that the topology is not robust and has a sensitive dependence on the length scale at which the data set is being considered. The solution is to calculate the topology (specifically the homology) at all scales simultaneously, and to encode the relationship between the different scales in an algebraic invariant called the persistence diagram. The effective algorithm for doing so was published in 2000 by Edelsbrunner, Letscher and Zomorodian [2]. Topological data analysis would not be possible without this tool.

Since then, persistence has been developed and understood quite extensively. Cohen-Steiner, Edelsbrunner and Harer [3] proved the important (and nontrivial) theorem that the persistence diagram is stable under perturbations of the initial data. Zomorodian and Carlsson [7] studied persistence algebraically, identifying the points of the persistence diagram with indecomposable summands of a module over the polynomial ring $k[t]$, the monomial t representing a change of scale by a fixed increment. Generalising this approach using polynomial rings with two or more variables, they showed that the corresponding situation with two or more independent length scales is in some sense algebraically intractable, with no complete descriptive invariants available. Carlsson and de Silva [1] showed that persistence can be made to work over "non-monotone" parameters, in contrast to "monotone" parameters such as length scale; this is known as zigzag persistence. Bubenik and Scott [4] have described and studied persistence in terms of category theory.

Measured view.   In becoming familiar with the literature on persistence, one quickly realises that the existing mathematical foundations are dependent on certain strong finiteness assumptions. For instance, one can do persistence on the sublevelsets of a function on a compact manifold, but it is usually assumed that the function be a Morse function. This ensures that the resulting persistent data is finite: each sublevelset has finite-dimensional homology, and there are only finitely many essentially distinct levels, separated by the critical points. In computational terms, this is a perfectly natural assumption (a computer can only handle finite data), but for some of the theoretical work this assumption is

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