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Topological Detection of Singularities in Nonlinear Time Series via Persistent Homology

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The detection of abrupt transitions and structural breakpoints in nonlinear systems remains a fundamental challenge in scientific computing and applied analysis. In complex systems, these transitions often represent a loss of regularity or a shift in the underlying manifold, manifesting as topological singularities in the system's evolution. This work proposes a robust computational framework for the identification of such phenomena using Topological Data Analysis (TDA). By employing delay embeddings to reconstruct the phase space of an implicit nonlinear dynamical system, we utilize persistent homology to track deviations in the persistence landscape of topological invariants, specifically H_0 (clusters) and H_1 (loops) persistence. These changes serve as indicators of structural breakpoints, signaling regime shifts that traditional statistical methods often fail to capture. We demonstrate the efficacy of this nonparametric approach by analyzing Philippine stock price data during the COVID-19 pandemic, where the method successfully identifies singular events corresponding to major market disruptions. Our findings suggest that TDA provides a powerful lens for the modeling and analysis of nonlinear phenomena, offering a stable, noise-robust algorithm.

Keywords: Nonlinear Dynamics, Topological Data Analysis, Persistent Homology, Singularities, Scientific Computing

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