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Koopman operators and a programme on the foundations of infinite-dimensional spectral computations

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Koopman operators are infinite-dimensional operators that globally linearise nonlinear dynamical systems, making their spectral information valuable for understanding dynamics. Their increasing popularity, dubbed "Koopmania", includes 10,000s of articles over the last decade. However, Koopman operators can have continuous spectra and lack finite-dimensional invariant subspaces, making computing their spectral properties a considerable challenge. This talk describes data-driven algorithms with rigorous convergence guarantees for computing spectral properties of Koopman operators from trajectory data. We introduce residual dynamic mode decomposition (ResDMD), the first scheme for computing the spectra and pseudospectra of general Koopman operators from trajectory data without spectral pollution. By combining ResDMD and the resolvent, we compute smoothed approximations of spectral measures associated with measure-preserving dynamical systems. When computing the continuous and discrete spectrum, explicit convergence theorems provide high-order convergence, even for chaotic systems. Kernelized variants of our algorithms allow for dynamical systems with a high-dimensional state-space. We compute the spectral measures of a protein molecule (20,046-dimensional state-space) and computing nonlinear Koopman modes with error bounds for chaotic turbulent flow past aerofoils with Reynolds number greater than 100,000 (295,122-dimensional state-space). Finally, these algorithms are placed within a broader programme on the foundations of infinite-dimensional spectral computations, which extends beyond spectra to numerical solutions of PDEs, optimisation, computer-assisted proofs, and the foundations of AI.

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