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Linear algebraic aspects of ultraspherical spectral methods

Spectral methods solve elliptic partial differential equations (PDEs) numerically and offer spectral convergence, meaning the error decays exponentially when the solution is analytic. We present numerical schemes for solving linear time-dependent PDEs using the ultraspherical spectral method in both space and time, achieving spectral convergence in the full discretization. The resulting systems are sparse and well-conditioned due to the underlying recurrence relations and operator representations. We discuss the linear algebraic features of these systems, including condition number behavior and their implications for numerical stability and solver efficiency. We also compare their performance with classical spectral schemes and briefly explore the potential for parallelization in time through linear algebraic techniques.