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Stable Mesh-Free Variational Radial Basis Function Approximation for Elliptic PDEs and Obstacle Problems

We present a comprehensive study of radial basis function (RBF) network approximations for elliptic and obstacle-typed boundary value problems under a variational formulation. Our focus is on practical accuracy, robustness and efficiency across a range of partial differential equations. To address ill-conditioning in dense systems, we apply truncated singular value decomposition (TSVD) in the linear regime and quantify its effect on stability and accuracy trade-offs. Numerical experiments on benchmark problems demonstrate fast error decay and high accuracy. We map the trade-off between approximation and truncation errors for practical settings for number of basis functions N , oversampling ratio ζ and truncation threshold τ . Compared with other numerical methods, RBF variational approach would deliver competitive accuracy for boundary value problems.