ML-Enhanced SUPG Stabilization for General Meshes

Manoj Prakash[1] Petr Knobloch[2]

Numerical simulation of fluid flows often requires solving convection–diffusion–reaction (CDR) equations, which model the transport of quantities such as temperature, concentration, or vorticity. In convection-dominated regimes, standard finite element methods suffer from spurious oscillations and instability. The Streamline Upwind/Petrov–Galerkin (SUPG) method addresses these issues by introducing a residual-based stabilization term controlled by an element-wise parameter δ_K. Since the choice of δ_K strongly influences solution accuracy, selecting an appropriate value remains a key challenge because classical parameter selection strategies often lead to either insufficient stabilization or excessive numerical diffusion.

In this work, we extend our machine learning–based framework for computing optimal SUPG stabilization parameters to unstructured and anisotropic meshes, which are far more common in practical CFD applications than structured meshes. A neural network is trained within the SUPG framework to learn local flow and mesh features and predict element-wise optimal stabilization parameters δ_K. The model is trained on a diverse range of mesh configurations, enabling robust generalization across structured, unstructured, and strongly anisotropic meshes. Comparative numerical experiments show that the proposed ML-enhanced SUPG method consistently produces more accurate solutions than the standard SUPG method on all tested mesh types, effectively suppressing spurious oscillations while maintaining the solution quality achieved on structured grids. These results demonstrate the potential of data-driven stabilization strategies for delivering reliable and accurate finite element solutions to convection-dominated problems on general computational meshes.

[1] Charles University, Department of Numerical Mathematics
manoj@karlin.mff.cuni.cz

[2] Charles University, Department of Numerical Mathematics
knobloch@karlin.mff.cuni.cz