Transient Heat Conduction with Phase Change using Explicit Finite Differences

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Abstract: In this study, we investigate the nonlinear dynamics of the two-dimensional time-dependent phase-field heat equation formulation in a rectangular domain using explicit finite differences. The model combines classical Fourier heat transport with the solid–liquid phase transition. The top and bottom walls enclose the computational domain under isothermal and adiabatic conditions, with right and left walls featuring Dirichlet-type heating and a heat sink in the center. It represents a canonical configuration for examining thermal conduction and melting processes. Two solvers are used: a steady-state Laplacian scheme for thermal equilibrium and a time-based enthalpy solver that evolves temperature and liquid fraction fields under explicit time integration. The simulations reveal phase evolution under heating and cooling conditions, where latent heat moderates temperature gradients and delays melt propagation. This framework illustrates the effectiveness of finite-difference schemes in coupling thermodynamics and phase transition phenomena, providing a foundation for future data-driven extensions using numerical methods combined with machine learning for multiscale thermal systems.

Keywords: Finite Differences, Heat Transfer, Phase Change, Enthalpy Model, Transient Conduction