Abstract

This paper presents a comprehensive analysis of gradient descent optimization algorithms applied to quadratic minimization problems. We implement and evaluate the classical gradient descent method with fixed step size, examining convergence behavior across a range of learning rates from $\alpha = 0.01$ to $\alpha = 0.20$. Our experimental framework includes theoretical convergence bounds, numerical stability analysis, and performance benchmarking using infrastructure-backed scientific utilities.

The key contributions of this work are: (1) a rigorously tested implementation of gradient descent with 100% test coverage and deterministic reproducibility via fixed random seeds; (2) empirical validation of theoretical convergence rates on quadratic objective functions; (3) automated analysis pipelines generating publication-quality visualizations; and (4) integration patterns demonstrating how optimization algorithms connect with infrastructure modules for logging, validation, and performance monitoring.