Kartikey Singh

Undergraduate Researcher | Scientific Machine Learning & PDEs

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Portfolio | Published Paper

Summary

Undergraduate researcher who **discovered and formalized Solution Manifold Incompatibility**—a fundamental structural flaw in linear multi-fidelity physics-informed neural networks. The work followed an **implementation-first research approach**: building and stress-testing multi-fidelity PINN systems, isolating systematic failure under linear fusion, and subsequently formalizing the observed behavior via operator non-closure and tangency arguments. Validated findings using PyTorch PINNs and a custom high-performance CFD solver benchmarked to Re=1000. Published independent paper with permanent DOI and open-sourced 5000+ lines of reproducible research code. Demonstrated ability to identify core failure modes, design diagnostics, and translate computational observations into rigorous theory.

Context: Conducted independently prior to the formal research year of the undergraduate program.

Research approach: Implementation-driven discovery — building computational experiments to reveal fundamental principles, then formalizing insights mathematically.

Research Experience

Sep 2025–Present **Independent Research: Solution Manifold Incompatibility**

- **Implementation-Driven Exploration** (Sep–Oct 2025):
  - Built and trained baseline multi-fidelity PINN implementations for nonlinear PDEs
  - Observed systematic degradation under linear solution fusion despite accurate, independently validated single-fidelity models
  - Isolated failure to the fusion mechanism via freeze-and-blend experiments
- **Formalization, Diagnostics & Validation** (Oct–Nov 2025):
  - Formalized Solution Manifold Incompatibility as operator non-closure under linear blending
  - Derived nonlinear cross-interaction expansions and tangency failure results
  - Designed structural diagnostics (C_{NL}, blending activity index)
  - Validated findings via PyTorch PINNs and custom CFD solver (Re=1000)
- **Dissemination** (Late 2025–Present):
  - Published paper with permanent DOI (Zenodo)
  - Open-sourced 5000+ LOC codebase
  - Defended research before academic panel

Publications

2025 **Solution Manifold Incompatibility in Multi-Fidelity PINNs**, *K. Singh*

- Zenodo (preprint), 35 pages
- Introduces the SMI framework with operator-level analytical proofs
- Presents numerical experiments across three PDE classes
- Open-source code: `https://github.com/KartikeyGangwar/MF-PINN-SMI-Failure-Modes`

Technical Skills

Machine Learning & AI: Physics-Informed Neural Networks, Multi-fidelity learning, PyTorch (automatic differentiation, custom training loops), Neural operator architectures (theoretical exposure), Research code development

Scientific Computing & High Performance Computation: High-performance CFD (Finite Difference Methods: ADI, SOR), Streamfunction–Vorticity formulation, Vectorized NumPy, Convergence analysis, Benchmark validation (to Re=1000), GPU-accelerated PINN training with PyTorch (CUDA)

Mathematical Foundations	Nonlinear PDE theory, Numerical analysis, Solution manifold geometry, Functional analysis, Differential geometry, Operator theory
Software Development & Tools	Python (PyTorch, NumPy, SciPy, Matplotlib), LaTeX, Git/GitHub, Linux, VS Code, Research pipeline automation, Documentation
Research Communication	Publication-quality visualization, Technical writing, Research presentations, Academic defense, Open-source documentation, Reproducible workflows
Research Methodology	Implementation-first research, Empirical analysis of numerical methods, Debugging complex computational systems, Translating observations to theory

Software & Research Tools

2025–2026 **Open-Source Research Suite: SMI Study**

- **Purpose:** Demonstrate Solution Manifold Incompatibility in multi-fidelity PINNs
- **Implementation:** Complete PyTorch pipeline for three PDE families (Allen–Cahn, Burgers, Navier–Stokes)
- **Features:** Automated diagnostics (C_{NL}), multi-level documentation, reproducibility protocols
- **Repository:** GitHub | **DOI:** 10.5281/zenodo.17794638

2025–2026 **Physics-Informed Neural Networks for Fluid Dynamics**

- Implemented PINN solvers for Burgers' equation and 2D incompressible Navier–Stokes
- Studied formulation sensitivity at moderate-to-high Reynolds numbers (Re $\approx 10^3$)
- Compared streamfunction–vorticity (ψ–ω) and streamfunction–pressure (ψ–p) formulations
- Demonstrated failure modes of data-free and physics-dominated PINNs in cavity flow
- Showed superior robustness of ψ–p formulation without explicit wall-vorticity closure
- Emphasized transparent documentation of failure modes over aggressive tuning
- **Repository:** GitHub

2025 **High-Performance CFD Solver**

- **Purpose:** Generate high-fidelity ground truth for ML validation
- **Methods:** Streamfunction–Vorticity formulation with ADI scheme (vorticity) and Red-Black SOR (Poisson)
- **Performance:** Validated solutions up to **Re=1000** on 251×251 grids, matching classical benchmarks
- **Repository:** GitHub | **DOI:** 10.5281/zenodo.18312938

Education

2023–2027 (Expected) **B.Sc. (Honors) Mathematics**, *University of Delhi*, Delhi, India

- **Program Structure:** 4-year undergraduate program with a formal research year (2026–2027)
- **Relevant Coursework:** Real Analysis, Differential Equations, Numerical Methods, Complex Analysis, Linear Algebra
- **Independent Research:**
  - Self-directed study in Physics-Informed Machine Learning (2024–2025)
  - Advanced PDE theory and scientific computing (2024–present)
  - Developed complete research pipeline outside formal curriculum
- **Achievements:**
  - Published independent research paper as undergraduate
  - Developed and open-sourced research software with DOIs
  - Successfully defended research before professor panel

Additional Information

Languages: English (Professional proficiency), Hindi (Native)

Technical Interests: Scientific machine learning, Nonlinear PDEs, High-performance computing, Open-source scientific software

Research Philosophy: Belief in reproducible research, open science, and bridging theory with practical implementation