

Kartikey Singh

Undergraduate Researcher in Scientific Machine Learning, Geometric DL & Computational Mathematics

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Education

University of Delhi

Delhi, India

B.Sc. (Honours) Mathematics (4-Year Undergraduate Research Degree)

2023 – 2027

- **Undergraduate Dissertation Supervisor: Prof. Vinay Kumar** (Department of Mathematics).
- **Core Specialization:** Real & Complex Analysis, Differential Equations, Symplectic Geometry, Numerical Methods, and Autodiff Systems developed through self-directed mathematical research alongside formal undergraduate coursework.

Technical Expertise

Scientific Machine Learning: PINNs, Hamiltonian Neural Networks (HNNs), Symplectic Neural ODEs, Deep Surrogate Inversion, Fourier Positional Encodings, Multi-Task Mixture-of-Experts (MoE), Boundary-Encoded Neural Ansätze.

Mathematical Foundations: Symplectic Geometry, Canonical Differential 2-Forms, Extended Contact Phase Space, Nonlinear Parabolic/Elliptic PDEs (Navier–Stokes, Black–Scholes), Free-Boundary Obstacle Problems, Optimal Transport (Wasserstein Distance).

Autograd & Deep Learning Systems: PyTorch (torch.func.vmap, forward-mode autodiff, JVP/VJP, Hessian trace contractions), CUDA acceleration, GPU memory chunking, JAX, NumPy, SciPy, Matplotlib.

Numerical Methods & HPC Infrastructure: Finite Difference Schemes (ADI, Red-Black SOR), Symplectic RK4, L-BFGS (Strong-Wolfe), MCMC, C++, Lua, Linux/Bash, Git, LaTeX, Kaggle/Colab GPU Environments.

Flagship Research Manuscripts & Preprints

Shape Inversion in Electrical Impedance Tomography

Under Review

IEEE Transactions on Computational Imaging (TCI)

[GitHub Code](#) | [Preprint DOI: 10.5281/zenodo.22096368](#)

- **Authors: Kartikey Singh** (Sole Author / Lead Investigator).
- Parameterized closed interfaces via 64D periodic cubic B-splines; verified sensitivities $\mathbf{J}_{\text{FEM}}$ against finite differences ($< 3.2 \times 10^{-4}$).
- Introduced **Stochastic Directional JVP Supervision** on $\mathbb{S}^{63}$, reducing backprop tangent branches from 64 to 1 (342.8 MB peak VRAM).
- Delivered zero-online-FEM deterministic inversion with **56.8×** wall-clock speedup (35.6 ms vs 2.02 s/step) and 99.57% noise robustness.

CPA-SHNN: Symplectic Neural Networks for Celestial Mechanics

Working Paper

Target: Astronomy & Computing / New Astronomy

[GitHub Code](#)

- **Authors: Kartikey Singh** (Lead Author), **Prof. Vinay Kumar** (Supervisor & Senior Author).
- Proved *Theorem 1* (Separable Symplectic Kinetic-Coriolis Decomposition, $\nabla_{\mathbf{z}} \cdot \mathbf{f}_{\theta} \equiv 0$) and *Theorem 2* (Arnold Extended Contact Phase Space $\mathbf{Z}_{\text{ext}} = (\mathbf{q}, t, \mathbf{p}, p_t)$, $\mathcal{K}_{\theta} \equiv 0$), preserving energy to machine precision ($\Delta \mathcal{H} \leq 10^{-4}\%$) across 6 chaotic systems.
- Multi-scale Fourier features achieved up to a **126.40×** error collapse on multi-body gravitational saddle singularities.

Formulation-Induced Failure Modes in High-Re Incompressible Flows

Working Paper

Target: Computer Methods in Applied Mechanics and Engineering (CMAME) / Physics of Fluids

[GitHub Code](#)

- **Authors: Kartikey Singh** (Sole Author / Lead Investigator).
- Controlled study on 2D cavity flow at $\text{Re} = 1000$; showed that $\psi - \omega$ suffers from **False Convergence** due to missing discrete Thom wall vorticity, attenuating secondary corner eddies by $> 50\%$.
- Proved retaining pressure p in $\psi - p$ serves as an elliptic Lagrange multiplier (Helmholtz-Hodge projection), successfully capturing primary/secondary vortices. Benchmarked against Ghia et al. (1982) and Botella & Peyret (1998).

The Adaptive Subspace (AS) Optimization Trilogy

Act I: Null-Space Gradient Conflict Decoupling in PINNs

Preprint

Target: Journal of Computational Physics (JCP)

[GitHub Code](#) | [Preprint DOI: 10.5281/zenodo.22132799](#)

- **Authors: Kartikey Singh** (Lead Author), **Samarjeet Malik** (Co-Author).
- Partitioned parameter manifold into orthogonal direct-sum subspaces ($\Theta_0 \oplus \Theta_1, \mathcal{W}_0 \mathcal{W}_1^T = \mathbf{0}$) blended via C^2 Quintic Hermite operator.
- Proved structural gradient orthogonality ($\langle \nabla \mathcal{L}_{\text{if}}, \nabla \mathcal{L}_{\text{des}} \rangle \equiv 0$) on saturated domains; evaluated on 3D Linear Paul Ion Traps.

Act II: Adaptive N-Subspace PINN (AS-PINN)

Working Paper

Target: SIAM Journal on Scientific Computing (SISC) / JCP

[GitHub Code](#)

- **Authors: Kartikey Singh** (Lead Author / Principal Investigator).

- Autonomous parameter-space AMR via vectorized Gram clash profiling (`torch.func.vmap`) with zero-disruption cleavage invariance.
- Validated across 9 canonical PDEs; achieved **725.6×** lower loss on high-frequency Helmholtz ($k = 4\pi$) over PCGrad and CAGrad.

Act III: AS-ViT: Adaptive Subspace Vision Transformers

Working Paper

Target: *IEEE Transactions on Pattern Analysis and Machine Intelligence (TPAMI)* / *CVPR*

[GitHub Code](#)

- **Authors:** Kartikey Singh (Lead Author / Principal Investigator).
- Resolved multi-task negative transfer in dense vision (segmentation, depth, normals) via feature-conditioned Partition of Unity (PoU) gating.
- Outperformed monolithic ViTs and fixed MoEs by +5.84% multi-task gain (ΔM) across NYUv2, Cityscapes, and Taskonomy benchmarks.

High-Dimensional Stochastics & Uncertainty Quantification

High-Dimensional American Basket Options (Deep-EEP-PINN)

Working Paper

Target: *Quantitative Finance*

[GitHub Code](#)

- **Authors:** Kartikey Singh (Lead Author / Principal Investigator).
- Priced correlated American basket options up to **d = 50 assets (1,225 correlations)** via Directional Autograd Hessian Trace Contraction in $\mathcal{O}(d)$ linear complexity (< 3 GB VRAM on Tesla P100). Validated against 100k-path Longstaff-Schwartz Monte Carlo (0.37% error).

Bayesian PINN Fidelity & Parameter-Resolved Error Localization

Working Paper

Target: *Reliability Engineering & System Safety* / *Inverse Problems*

[GitHub Code](#)

- **Authors:** Kartikey Singh (Lead Author / Principal Investigator).
- Formulated **Bayesian Fidelity Ratio (BFR)** based on 1-Wasserstein optimal transport distance normalized by paired MCMC stochastic noise floors.

Scientific Software & Computational Infrastructure

High-Performance 2D Navier–Stokes FDM Solver

Open-Source

C++ / *Vectorized NumPy*

[GitHub Code](#) | [DOI: 10.5281/zenodo.18312938](#)

- **Lead Developer:** Kartikey Singh. Coupled ψ - ω solver with ADI vorticity transport and Red-Black SOR Chebyshev Poisson acceleration. Validated to $Re = 1000$ on 251×251 grids against benchmark spectral data from Ghia et al. (1982) and Botella & Peyret (1998).

BeamNG Research SDK (BRSDK)

Open-Source

Lua / Python / *Systems Programming*

[GitHub Code](#) | [DOI: 10.5281/zenodo.21729606](#)

- **Architect & Lead Developer:** Kartikey Singh. High-frequency deterministic telemetry extraction operating inside the **2000 Hz Vehicle Lua physics thread** of BeamNG.drive/tech with near-zero GC allocations and RFC 8259 JSON metadata sidecars.