VisTrust: Uncertainty Visualization for Trusted Scientific Analysis and Discovery

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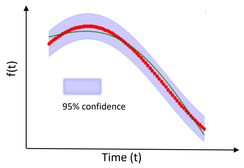
Introduction

Why Visualize Data Uncertainty?

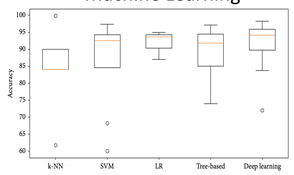
- Uncertainty exists in all simulation, observational, and experimental data
- Leads to inaccurate analysis, if neglected
- Knowing uncertainty is essential to gain trust in the data

1D Error Bars – A Solved Problem

Physics

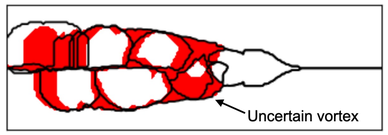


Machine Learning



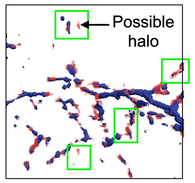
Have You Seen Error Bars in 2D/3D Visualization?

Fluid Dynamics: Kármán Vortex Simulation



Error bounds visualized in red

Astrophysics: Nyx Cosmology Simulation



Barriers to 2D/3D Uncertainty Visualization

Lack of theoretical foundation

High cost of empirical solutions

Poor scalability to multivariate data

Obstacles to 2D/3D Uncertainty Visualization

Storage and compute overheads for visualizing uncertainty

No standardized ways to portray uncertainty

Lack of support in production tools, e.g., ParaView, VisIt

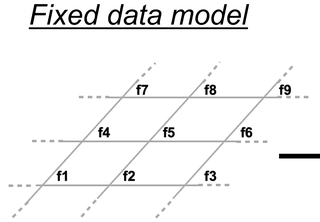
Research Objectives

- Create probabilistic algorithms to address the lack of theory and poor efficiency of empirical techniques.
- Create memory-efficient representations, leverage leadership computing resources, and investigate cost-accuracy trade-offs to address cost overheads of visualizing uncertainty.
- Derive novel visual mappings for effective depiction of uncertainty and integration with production tools.

Methods

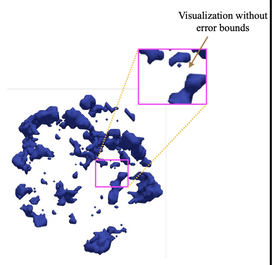
New Probabilistic Visualization Algorithms

Fixed data model

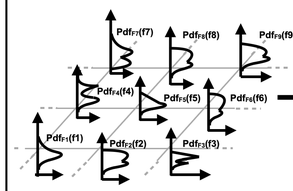


No uncertainty propagation

Classical Visualization Algorithms



Probabilistic data model

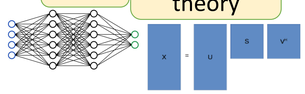


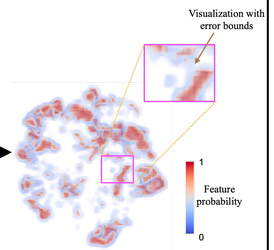
Closed-form derivations

Probabilistic Visualization Algorithms [1,2]

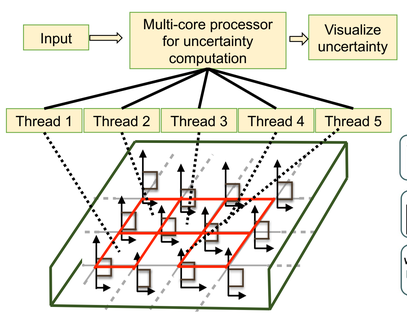
ML/AI

Information theory

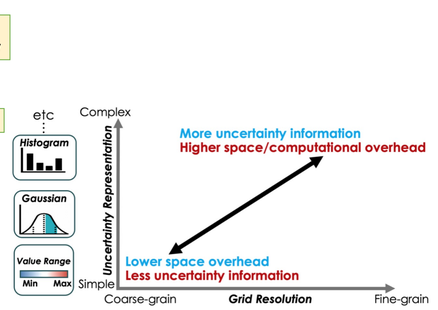




Parallelization and Cost-Accuracy Trade-off Analysis

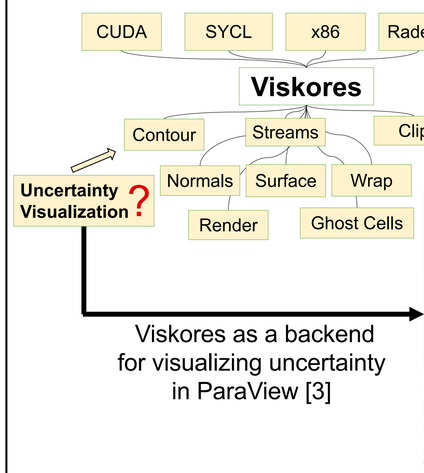


Shared-memory parallelism for fast uncertainty computation [3]

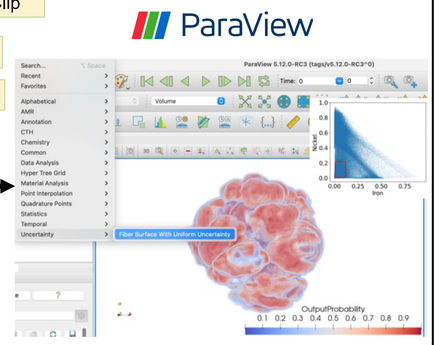


Cost-accuracy trade-off analysis [1]

Integration with Production Visualization Tools

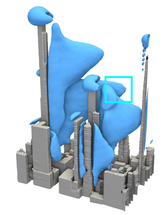


Viskores as a backend for visualizing uncertainty in ParaView [3]

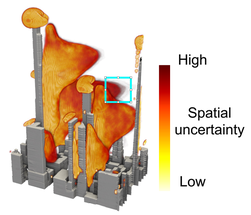


Results

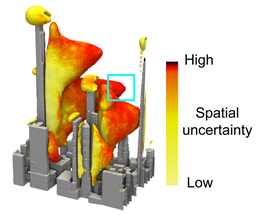
Wind Velocity Uncertainty over NYC



Mean
(No depiction of uncertainty)

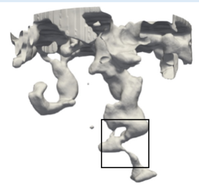


State of the art [4]
T_{serial}=813.14 s

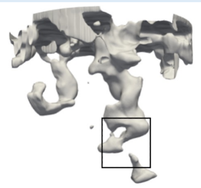


MAGIC (Ours) [1]
T_{serial}= 1.57 s **(~517x speedup)**

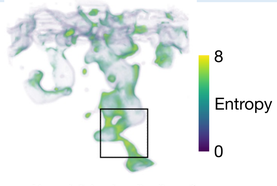
AI Inference Uncertainty (Critical to the Genesis Mission)



Ground truth



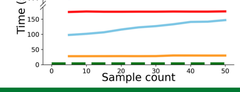
AI-predicted data



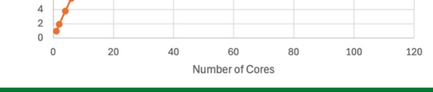
Uncertainty visualization of AI-predicted data [2]

Performance Gains on the Frontier – NYC Wind Dataset

Monte Carlo Vs. Closed Form [1]

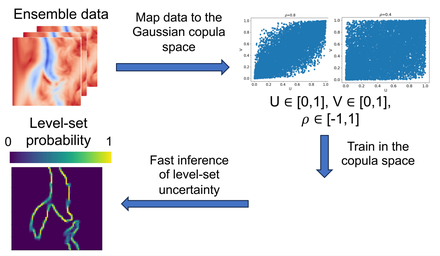


Viskores Acceleration [1]

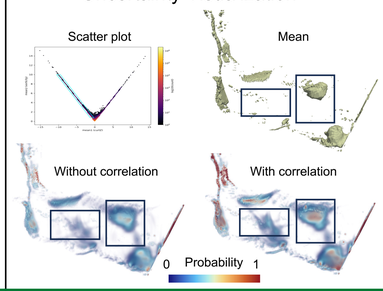


Future Research

Generalized Copula-Based AI Models for Uncertainty Visualization (Critical to the Genesis Mission)



Correlation-Aware Multivariate Uncertainty Visualization



Impact

Our efficient and scalable uncertainty visualization algorithms significantly reduce time to assess complex uncertain 2D/3D data and radically increase reliability of scientific analysis.

Acknowledgements

This work was supported in part by the U.S. Department of Energy (DOE), Office of Science (SC), Advanced Scientific Computing Research (ASCR), Early Career Research Program and RAPIDS-2 SciDAC project and used resources of the Oak Ridge Leadership Computing Facility (OLCF) under contract number DE-AC0500OR22725.

References

[1] Athawale, T. M., *et al.*, "MAGIC: Marching Cubes Isosurface Uncertainty for Gaussian Uncertain Data With Spatial Correlation", *IEEE TVCG*, vol. 32, no. 7, pp. 4987-5002, 2026.
[2] Saklani, S., *et al.*, "REV-INR: Regularized Evidential Implicit Neural Representation for Uncertainty-Aware Volume Visualization", 2026 *IEEE PacificVis,* Sydney, Australia, pp. 204-214, 2026.
[3] Moreland, K., *et al.*, "Viskores: Integrating Parallel Scientific Visualization Research into Applications", To appear in VisGap'26, Nottingham, UK, 2026.
[4] Pöthkow, K., *et al.*, "Probabilistic Marching Cubes", EuroVis'11, Bergen, Norway, pp. 931-940, 2011.