Uncertainty Visualization 2D/3D Scientific Data for Trusted Analysis and Decision-Making

Tushar M. Athawale

DOE CGF 2024

My Educational and Job Journey

University of Florida (2010 – 2015)
Thesis: Uncertainty quantification for isosurface visualization

→

MathWorks (2015 – 2016)

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SCI Institute, University of Utah
(2016 – 2021)

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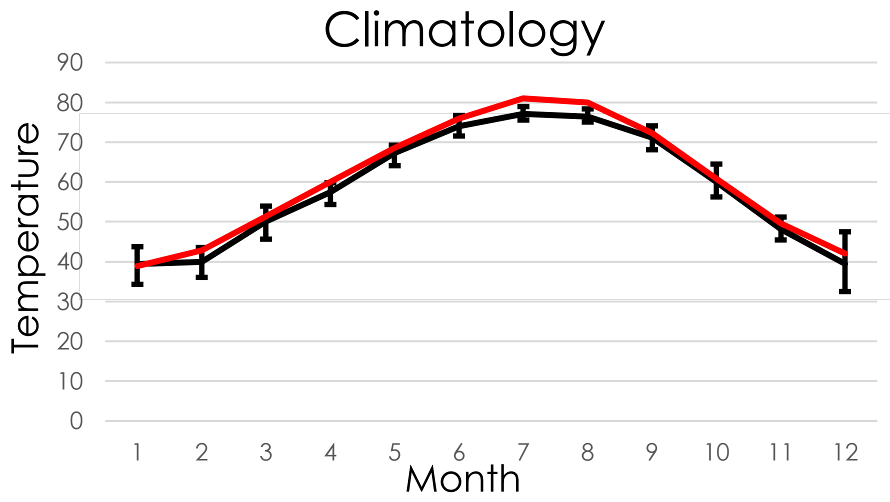
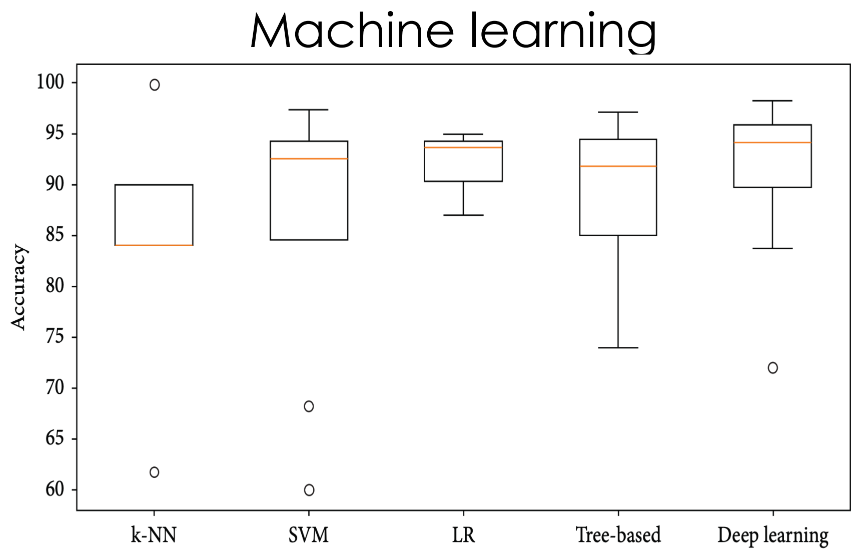
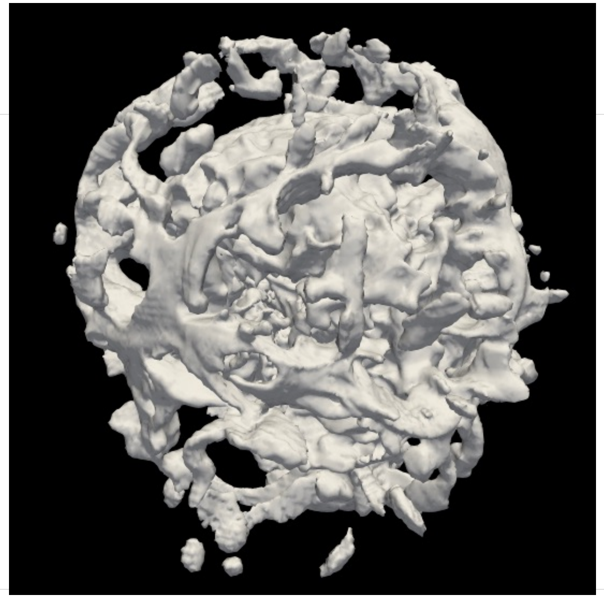
Oak Ridge National Laboratory
(2021-Present)

How Often Do We See Error Bars in 2D/3D Visualizations?

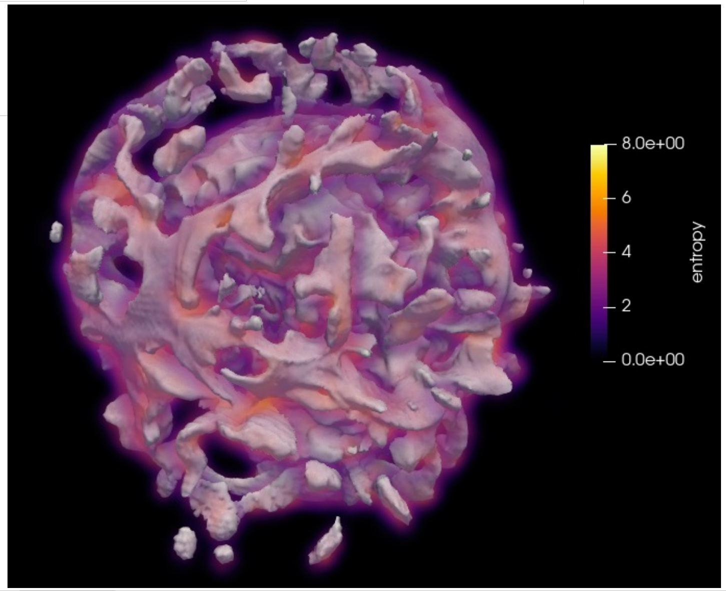




Supernova dataset



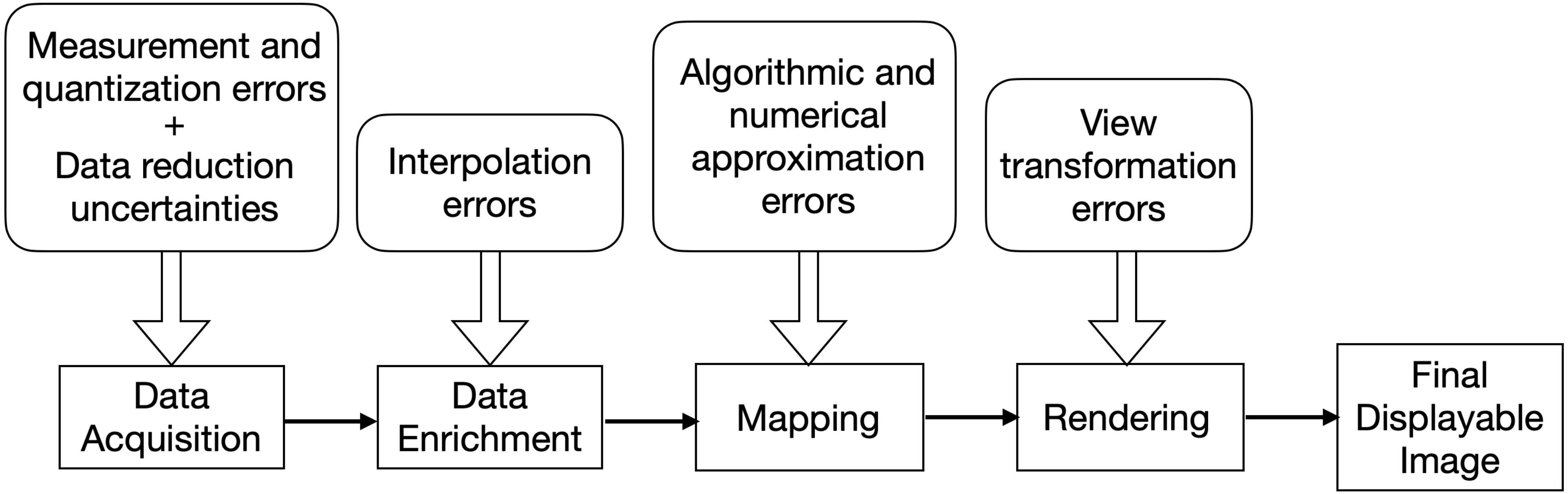
Isosurface without uncertainty



Isosurface with uncertainty

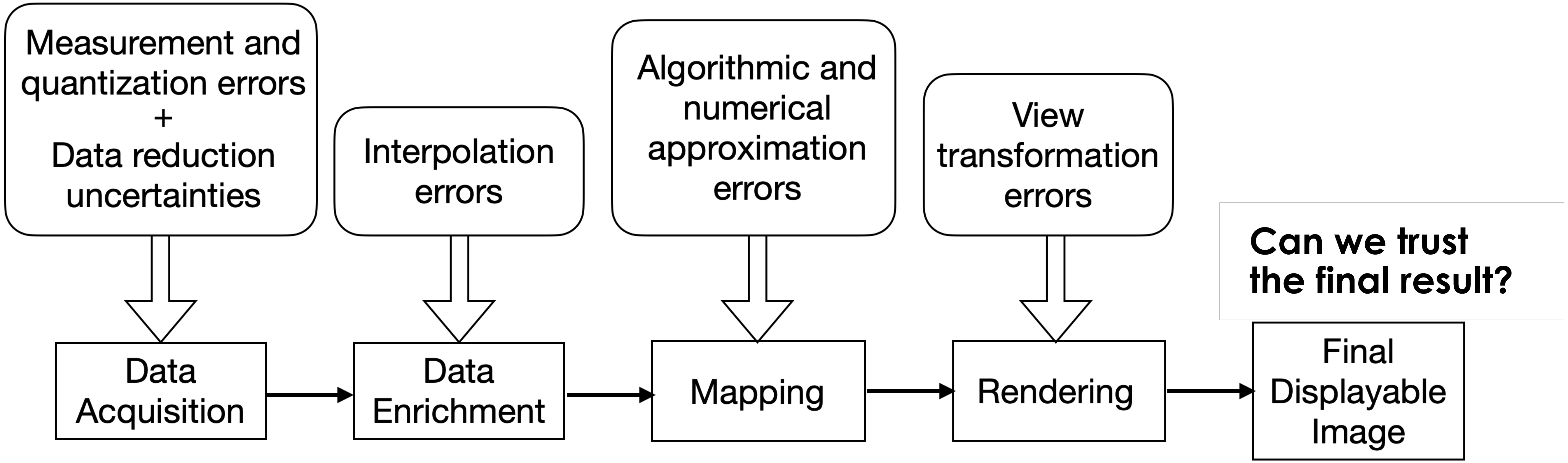
OAK RIDGE National Laboratory

Why Should We Visualize Uncertainty?



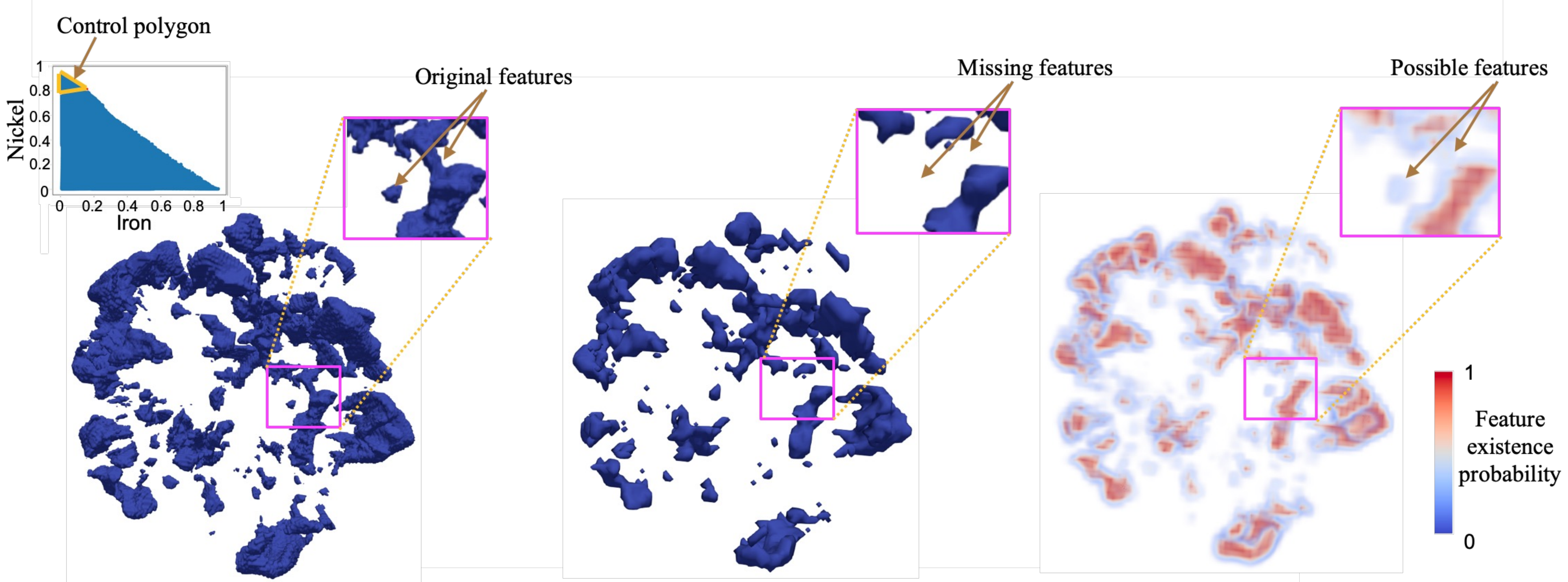
The Visualization Pipeline

Why Should We Visualize Uncertainty?



The Visualization Pipeline

Uncertainty Visualization for Trustworthy Analysis



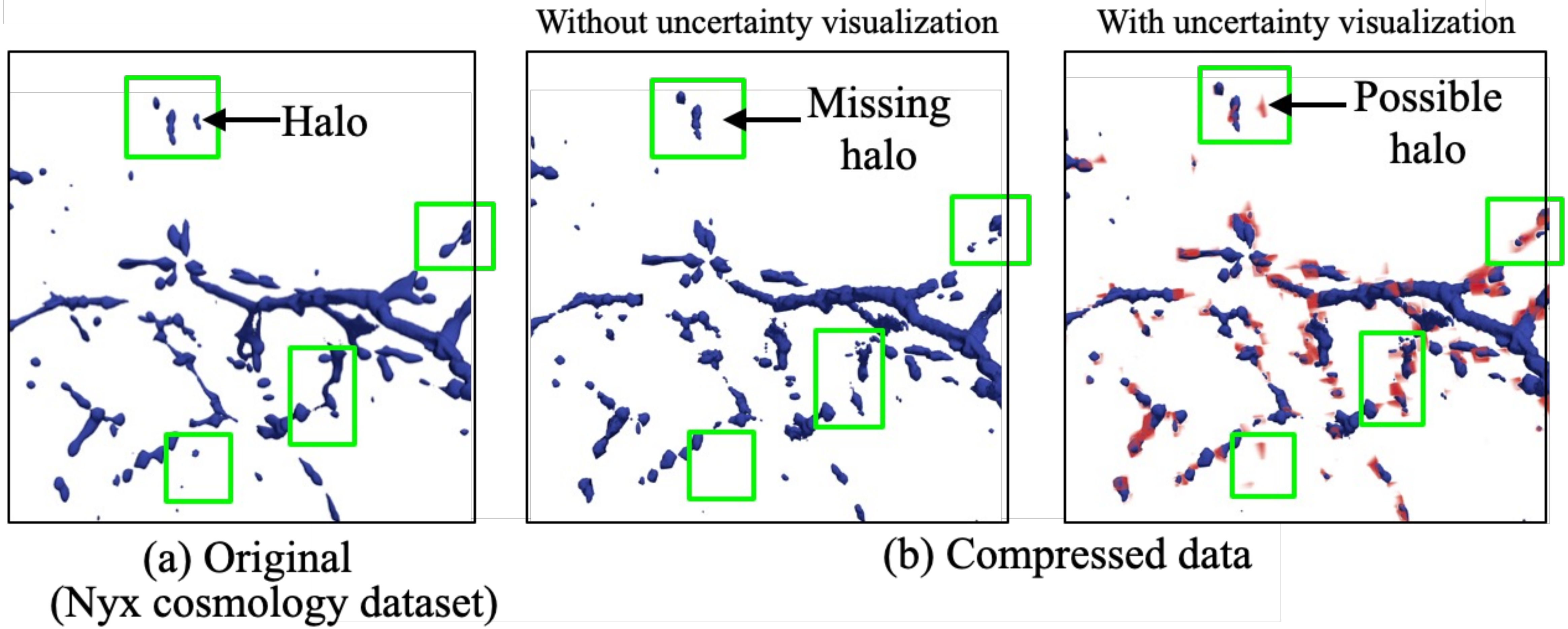
300×300×300×2 (~432MB)
(a) High-resolution features

75×75×75×2(~6.75MB)
(b) Visualization without uncertainty (Mean)

75×75×75×2×4 (~27MB)
(c) Visualization with uncertainty (Histogram with 4 bins)

[Athawale et al., Fiber Uncertainty Visualization of Bivariate Data for Parametric and Nonparametric Noise Models, IEEE VIS 2022]

Uncertainty Visualization for Trustworthy Analysis

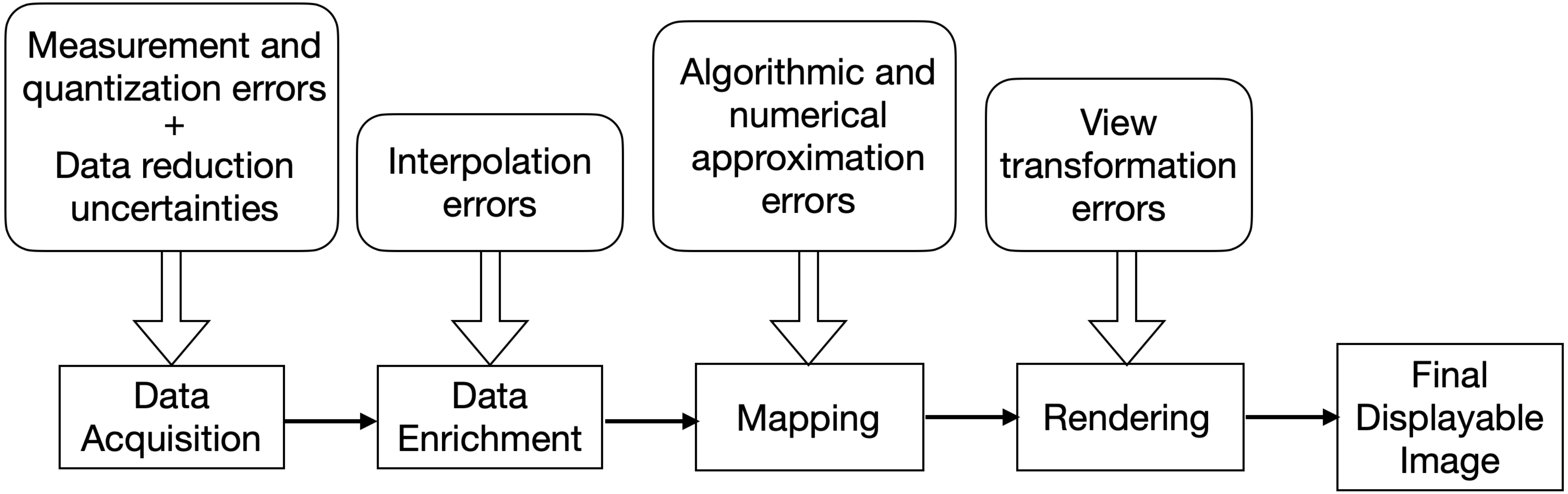


[Athawale et al., Uncertainty Visualization of Marching Squares and Marching Cubes Topology Cases, IEEE VIS 2021]

Uncertainty Visualization: Top Research Challenge

[A. T. Pang, C. M. Wittenbrink, and S. K. Lodha, “Approaches to Uncertainty Visualization”, 1997]
[C. R. Johnson and A. R. Sanderson, “A Next Step: Visualizing Errors and Uncertainty”, 2004]

Challenge: Lack of theory in uncertainty visualization because of the complexities related to uncertainty propagation, cost overhead, rendering, perception, cognition, decision-making



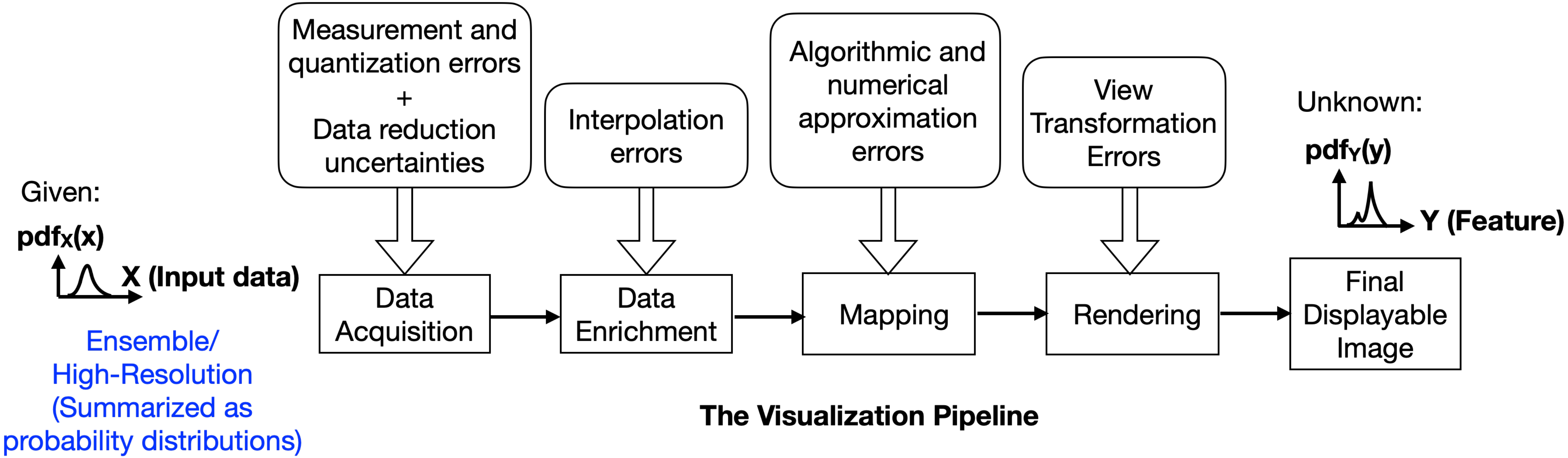
The Visualization Pipeline

[K. Brodlie, R. A. Osorio, and A. Lopes, “A Review of Uncertainty in Data Visualization”, 2012]
[A. Kamal et al., “Recent Advances and Challenges in Uncertainty Visualization”, 2021]

Our Approach to Uncertainty Visualization

Monte Carlo (easy but expensive) vs. Analytical (difficult but fast)

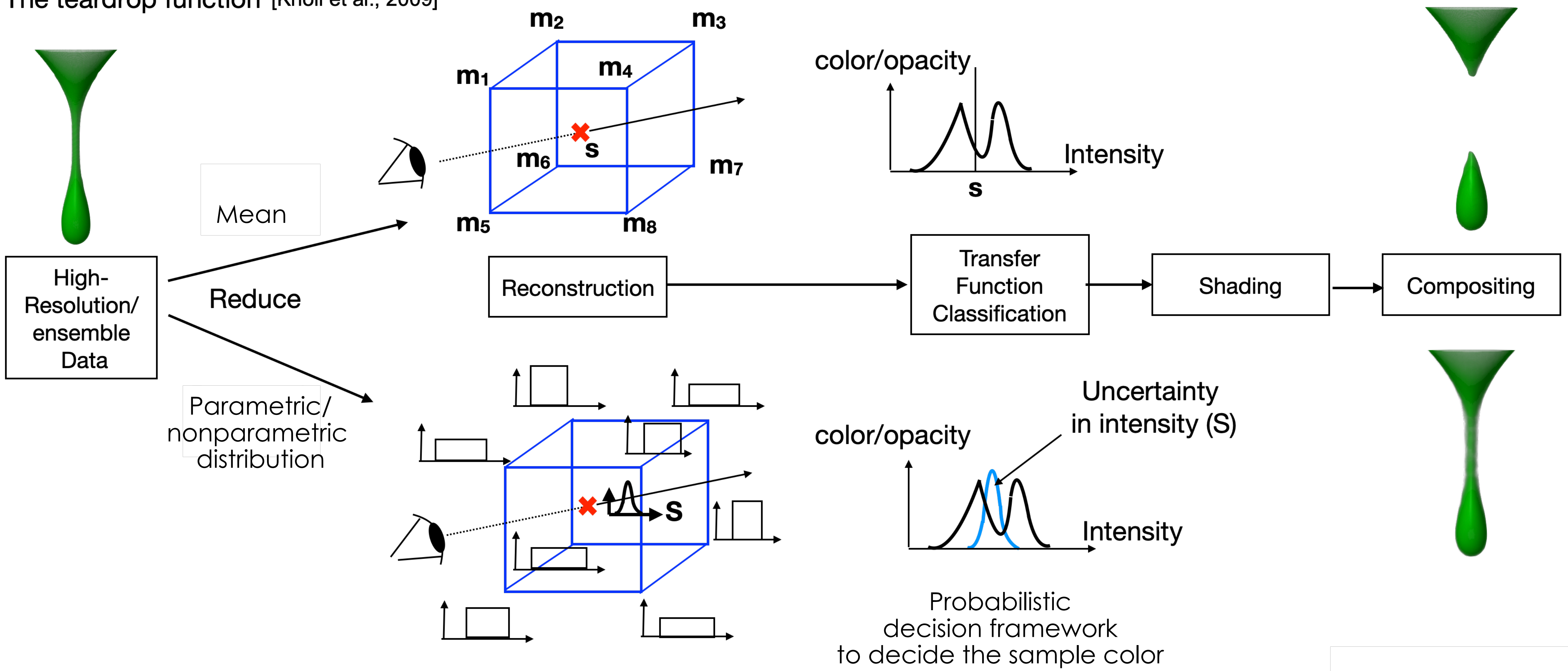
(State of the art) (Our approach)



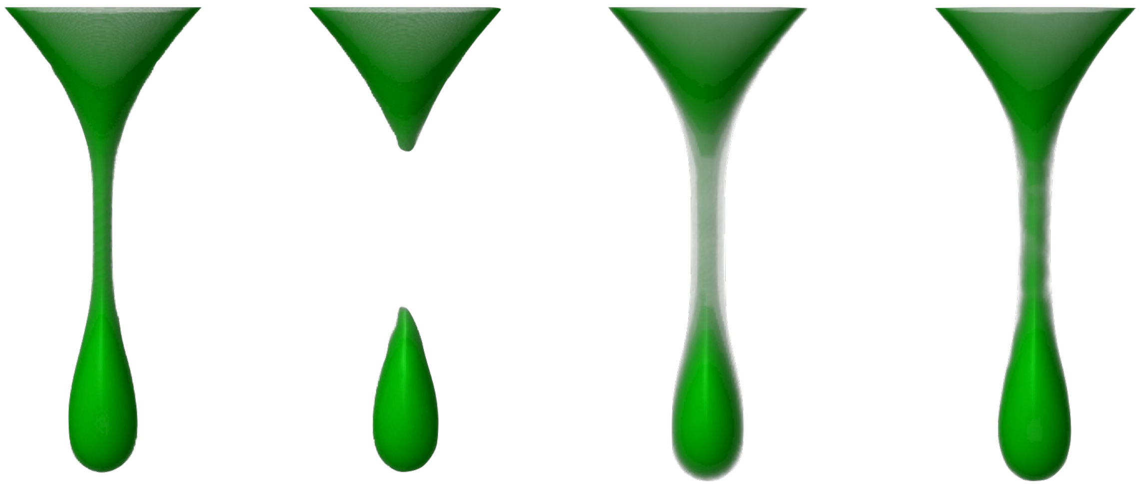
The Visualization Pipeline

Uncertainty-Aware Direct Volume Rendering (theoretical approach)

The teardrop function [Knoll et al., 2009]



Uncertainty-Aware Direct Volume Rendering



(a) Ground truth

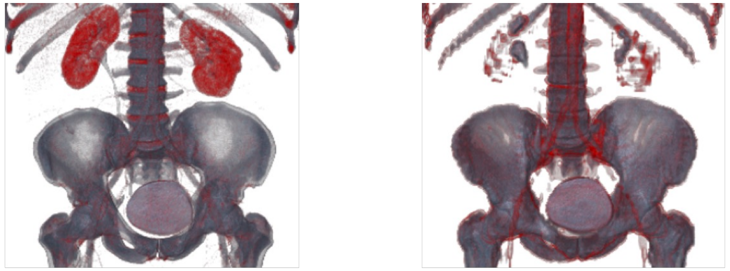
(b) Mean

(c) Parametric [Sakhaee and Entezari, 2017]

(d) Nonparametric (Our contribution) [Athawale et al., 2020]

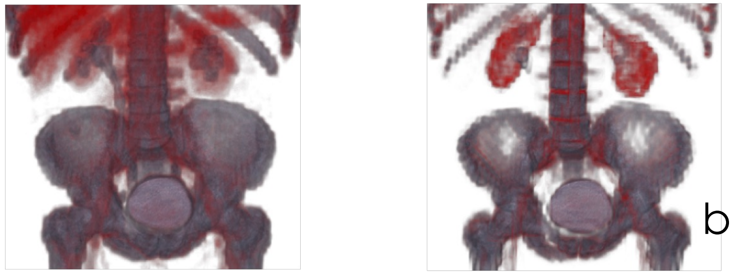
The teardrop function (ensemble dataset)

Visualization software: Voreen (http://voreen.uni-muenster.de)



(a) Ground truth (512x512x1559)

(b) Mean (64x64x195)



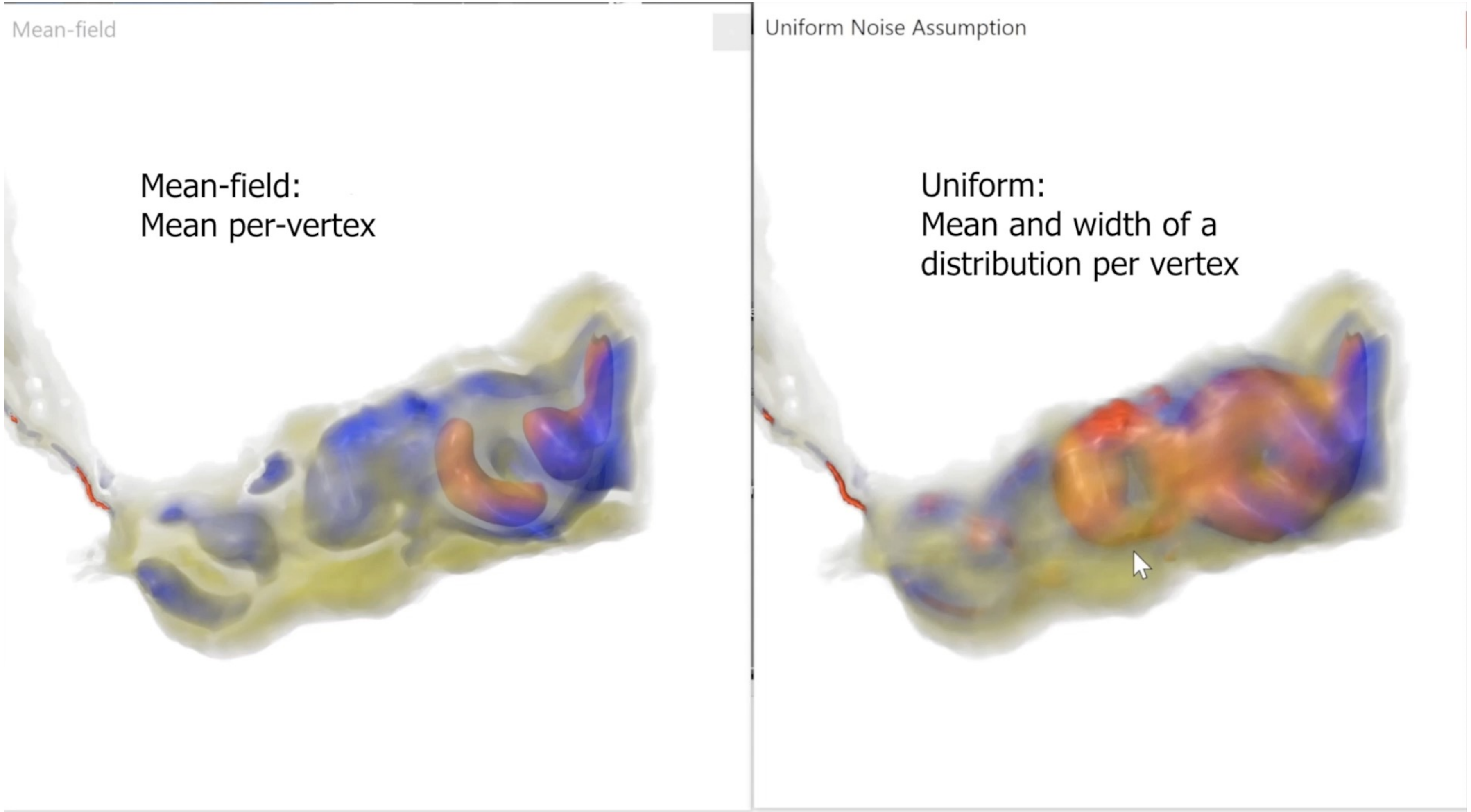
b = # histogram bins

(c) Parametric (64x64x195) x 2 [Sakhaee and Entezari, 2017]

(d) Nonparametric (64x64x195) x b (our contribution) [Athawale et al., 2020]

Osirix OBELIX dataset (http://medvis.org/datasets/)

Uncertainty-Aware Volume Rendering: Interactive Exploration



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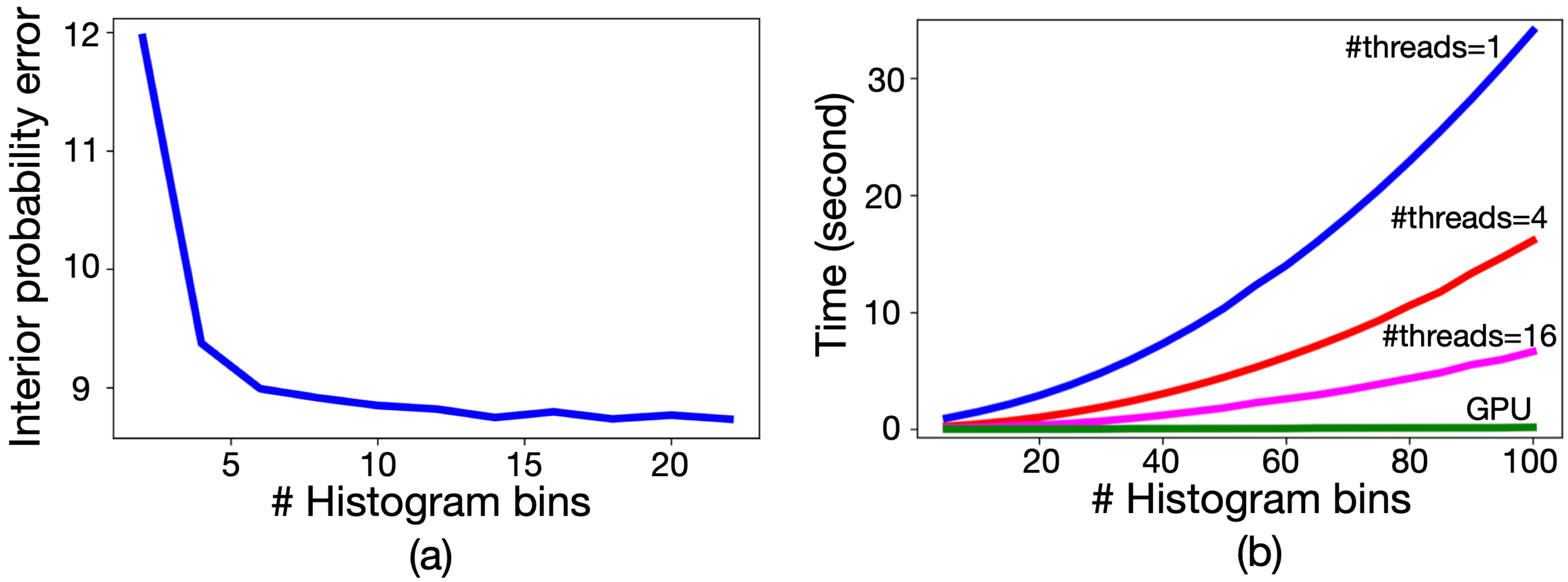
Addressing Cost Overhead of Visualizing Uncertainty

Create scalable algorithms

The GPU CUDA (NVIDIA V100 graphics card) and C++ openMP (Power9 CPU) implementations

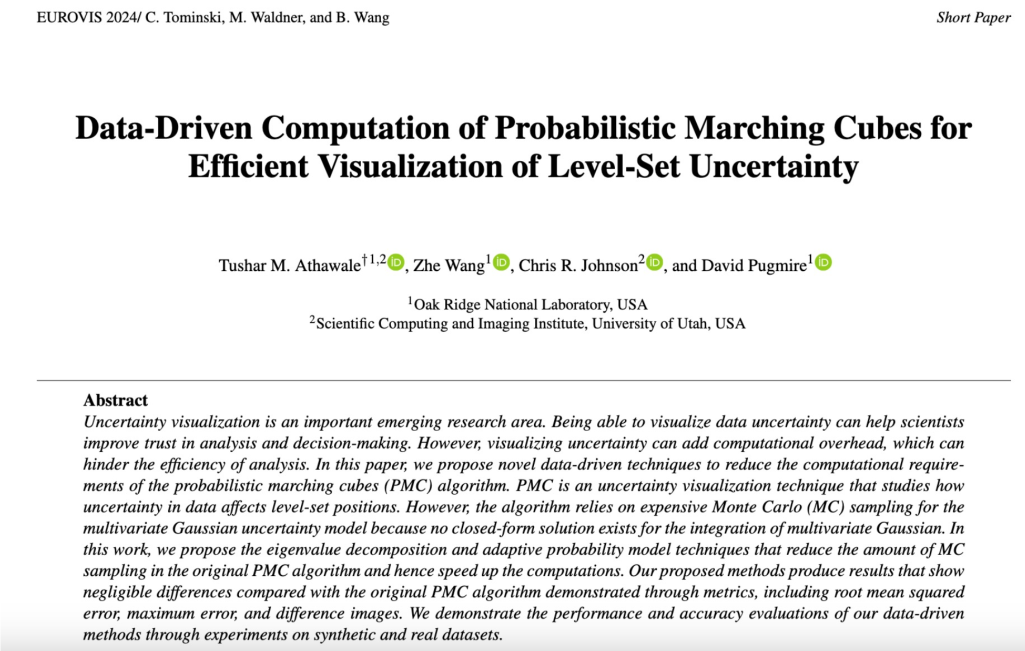


Accuracy (a) Vs. Timing (b) Curves

The computing resources are courtesy of the Summit Supercomputer at the Oak Ridge National Laboratory.

[Athawale et al., Fiber Uncertainty Visualization of Bivariate Data for Parametric and Nonparametric Noise Models, IEEE VIS 2022]

Addressing Cost Overhead of Visualizing Uncertainty


EUROVIS 2024/ C. Tominski, M. Waldner, and B. Wang *Short Paper*

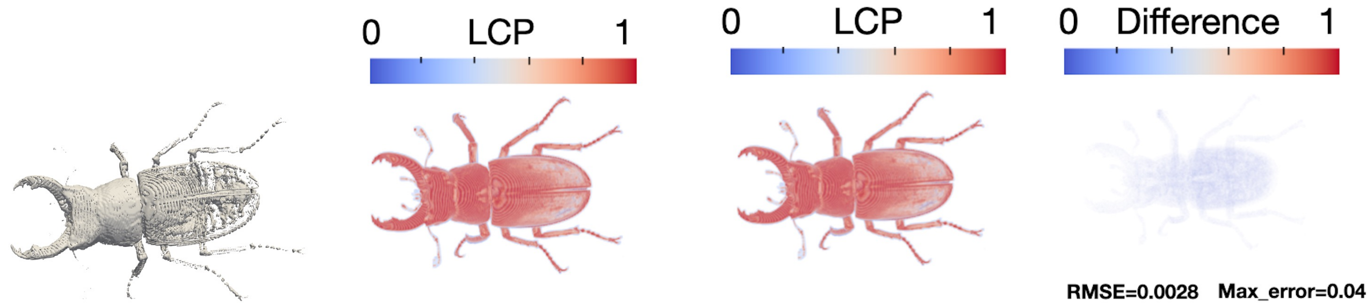
Data-Driven Computation of Probabilistic Marching Cubes for Efficient Visualization of Level-Set Uncertainty

Tushar M. Athawale[†1,2], Zhe Wang[1], Chris R. Johnson[2], and David Pugmire[1]

[1]Oak Ridge National Laboratory, USA
[2]Scientific Computing and Imaging Institute, University of Utah, USA

Abstract
Uncertainty visualization is an important emerging research area. Being able to visualize data uncertainty can help scientists improve trust in analysis and decision-making. However, visualizing uncertainty can add computational overhead, which can hinder the efficiency of analysis. In this paper, we propose novel data-driven techniques to reduce the computational requirements of the probabilistic marching cubes (PMC) algorithm. PMC is an uncertainty visualization technique that studies how uncertainty in data affects level-set positions. However, the algorithm relies on expensive Monte Carlo (MC) sampling for the multivariate Gaussian uncertainty model because no closed-form solution exists for the integration of multivariate Gaussian. In this work, we propose the eigenvalue decomposition and adaptive probability model techniques that reduce the amount of MC sampling in the original PMC algorithm and hence speed up the computations. Our proposed methods produce results that show negligible differences compared with the original PMC algorithm demonstrated through metrics, including root mean squared error, maximum error, and difference images. We demonstrate the performance and accuracy evaluations of our data-driven methods through experiments on synthetic and real datasets.

Data size = 680 MB



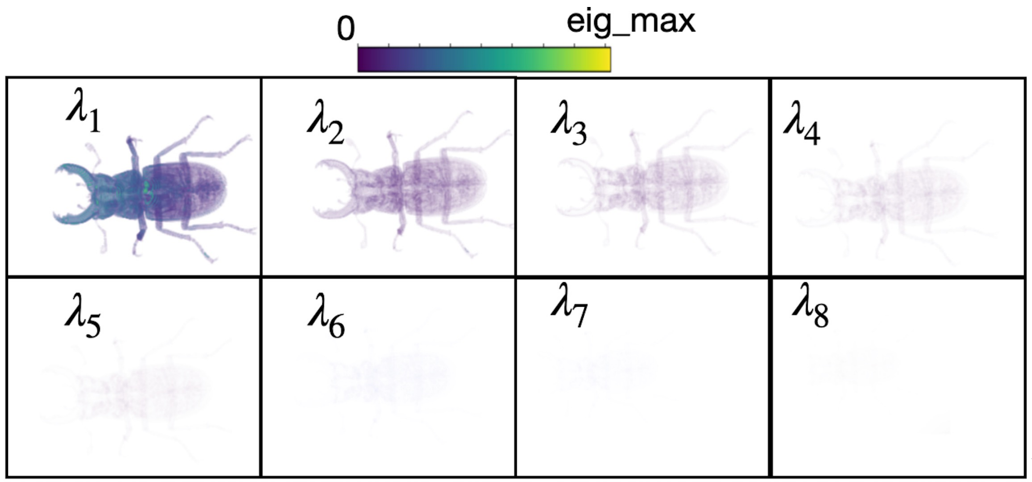
(a) Without uncertainty

(b) PMC (Reference)

27.18 seconds

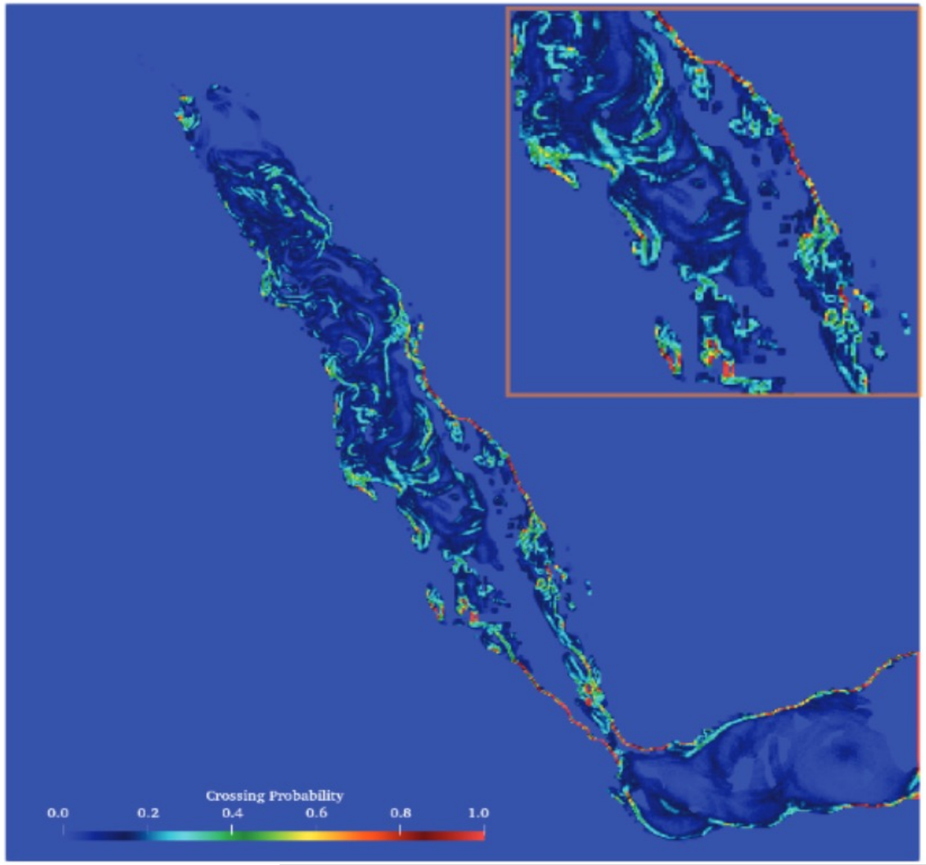
(c) PMC (Eigenvalue-based) 1.63X faster than the reference

16.72 seconds

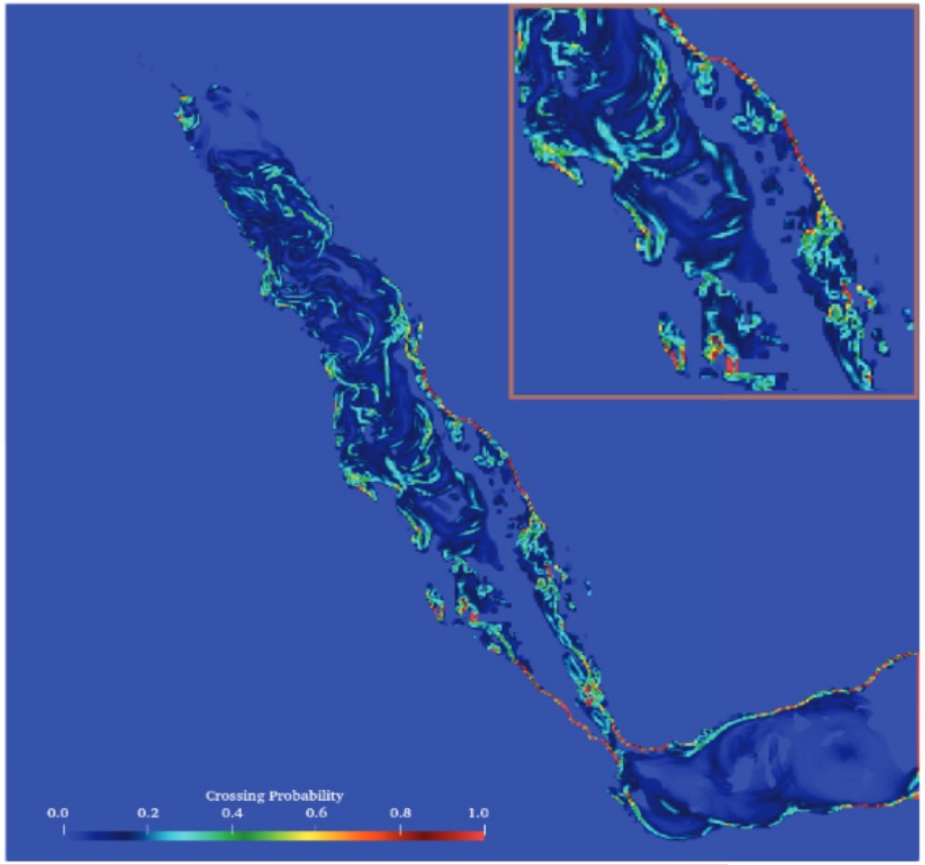


Machine Learning for Uncertainty Visualization

Learn uncertainties pertinent to isosurfaces from a bunch of time steps and predict uncertainty for future time steps



Monte Carlo
[K. Pöthkow, B. Weber, and H.-C. Hege, "Probabilistic Marching Cubes", 2011]



Our Machine-predicted result (170X faster)

[M. Han, T. M. Athawale, D. Pugmire, and C. R. Johnson, accepted at IEEE VIS 2022 short papers]

Open Research Challenges

- Theoretical research in uncertainty visualization for 2D/3D/high-dimensional data
- Devising uncertainty-aware decision frameworks to perform optimal algorithmic decisions, reduce uncertainty, and enhance quality of visualizations
- Handling cost overhead of visualizing uncertainty
- Effective rendering of uncertainty
- Assessing perception, cognition, and decision-making quality under uncertainty

Uncertainty Visualization Workshop at IEEE VIS 2024!

You all are invited to submit full/short papers and posters, which will be archived on IEEE Xplore

Uncertainty Visualization 2024

IEEE Workshop on
Uncertainty Visualization: Applications, Techniques, Software, and Decision Frameworks
in conjunction with IEEE VIS 2024, Florida, USA

IEEE

Menu

- Home
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- Accepted Papers
- Awards
- Organization
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Important Dates

Paper/Poster Submissions
June 26, 2024

Author Notifications
July 31, 2024

Camera-ready Paper Due
August 18, 2024

Uncertainty Visualization: Applications, Techniques, Software, and Decision Frameworks

Uncertainty visualization has become an increasingly important topic given the ubiquity of noise in data and computational processes. Although the research in uncertainty visualization has steadily progressed over the past few years, this critical branch of visualization is still in its infancy given many difficult challenges (e.g., computation, rendering, perception and decision-making) relevant to communication and understanding of uncertainty. One important step to address these challenges is to provide a venue that attracts a wide range of experts across many disciplines. A venue that allows experts in visualization, applications, applied math, perception, and cognition to publish and discuss effective ways to convey and understand uncertainty is an important step in advancing this critical area of research.The goal of the workshop is to bring together this multi-disciplinary group to enlighten the visualization community in the following four areas: (1) use cases in diverse application domains that can benefit from visualization of uncertainty (2) theory, techniques, and state-of-the-art software for uncertainty visualization (3) Methods/workflows that enable robust decisions under uncertainty (4) development of a future roadmap of uncertainty visualization research goals.

Venue: St. Pete Beach, FL, USA

Submission deadline: June 26, 2024

Topics: Applications, Techniques, Software, and Decision Frameworks

Chairs: Tushar M. Athawale, Chris R. Johnson, Kristi Potter, Paul Rosen, and David Pugmire

Oak Ridge National Laboratory

Thank you!

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Personal website: http://tusharathawale.info

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