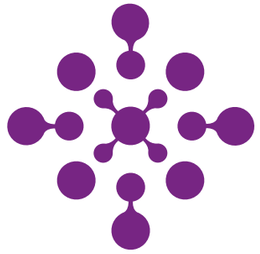


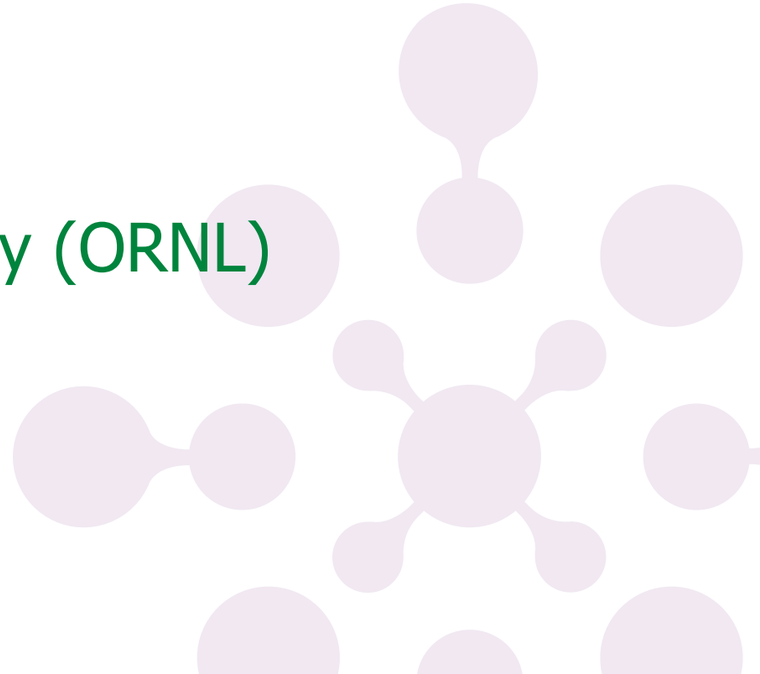
VIS 2021

Application Spotlights

Statistical Analysis for Uncertainty Quantification and Visualization of Scientific Data

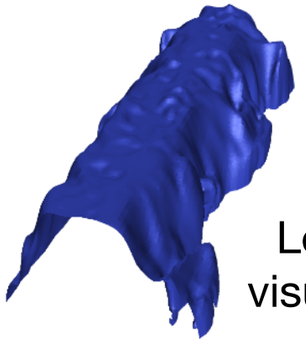
Tushar M. Athawale,

Visualization Group @ Oak Ridge National Laboratory (ORNL)

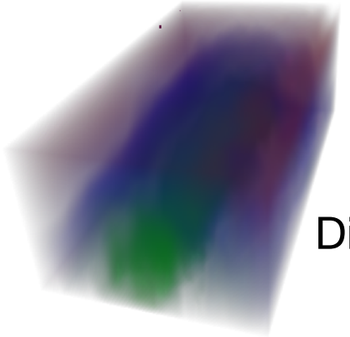


Outline

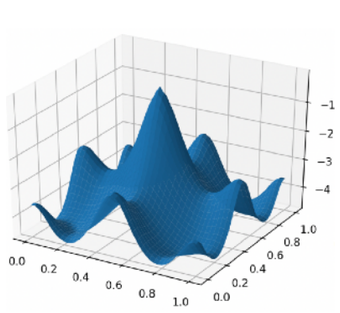
- Uncertainty visualization
  - Why it is important?
  - Abstract statistical techniques for uncertainty quantification
- Uncertainty analysis applications
  - Scientific visualization techniques
  - Domain-specific data
- Open challenges in uncertainty quantification/visualization

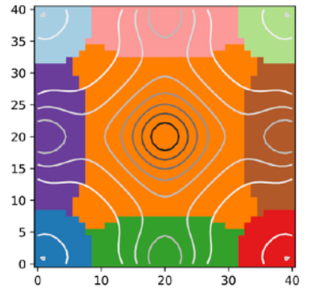


Level-set visualization

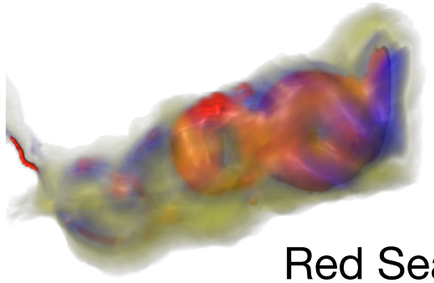


Direct volume rendering

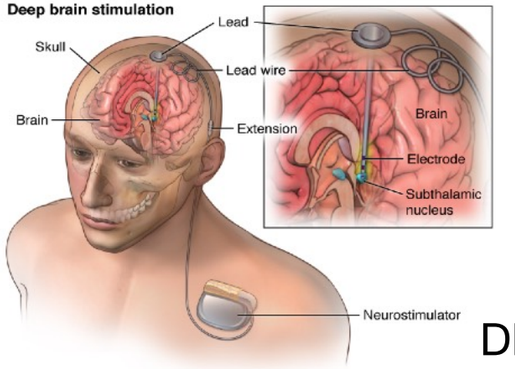




Morse complex visualization



Red Sea simulations



DBS

Uncertainty Quantification: Example

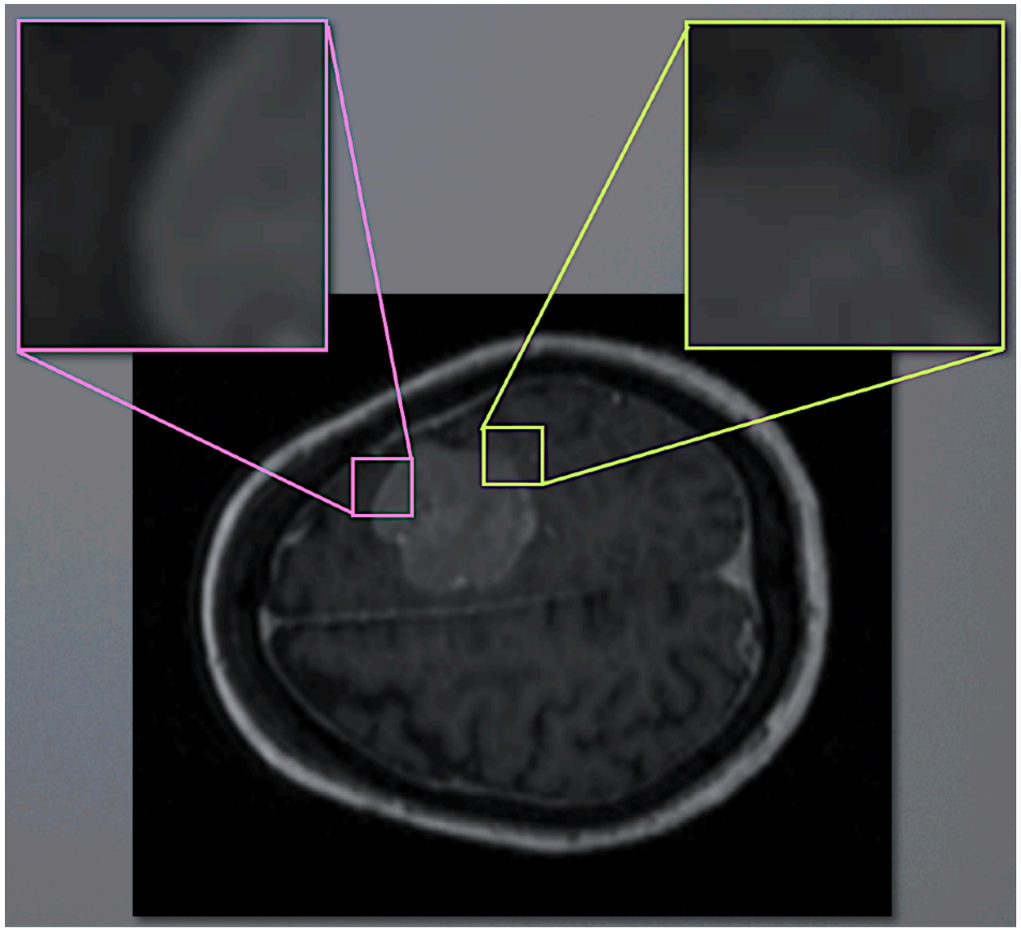
Attach confidence information or add error bounds denoting uncertainty to your answer

Today Oct 4	Isolated T-Storms	87°F 78°F	CHANCE OF RAIN: 30%	WIND: ESE at 11 mph Details
Fri Oct 5	Partly Cloudy	87° 76°	CHANCE OF RAIN: 20%	WIND: ENE at 11 mph Details
Sat Oct 6	Scattered T-Storms	85° 76°	CHANCE OF RAIN: 60%	WIND: ENE at 9 mph Details

Decision: Whether to carry umbrella or not?

Uncertainty Visualization: Example

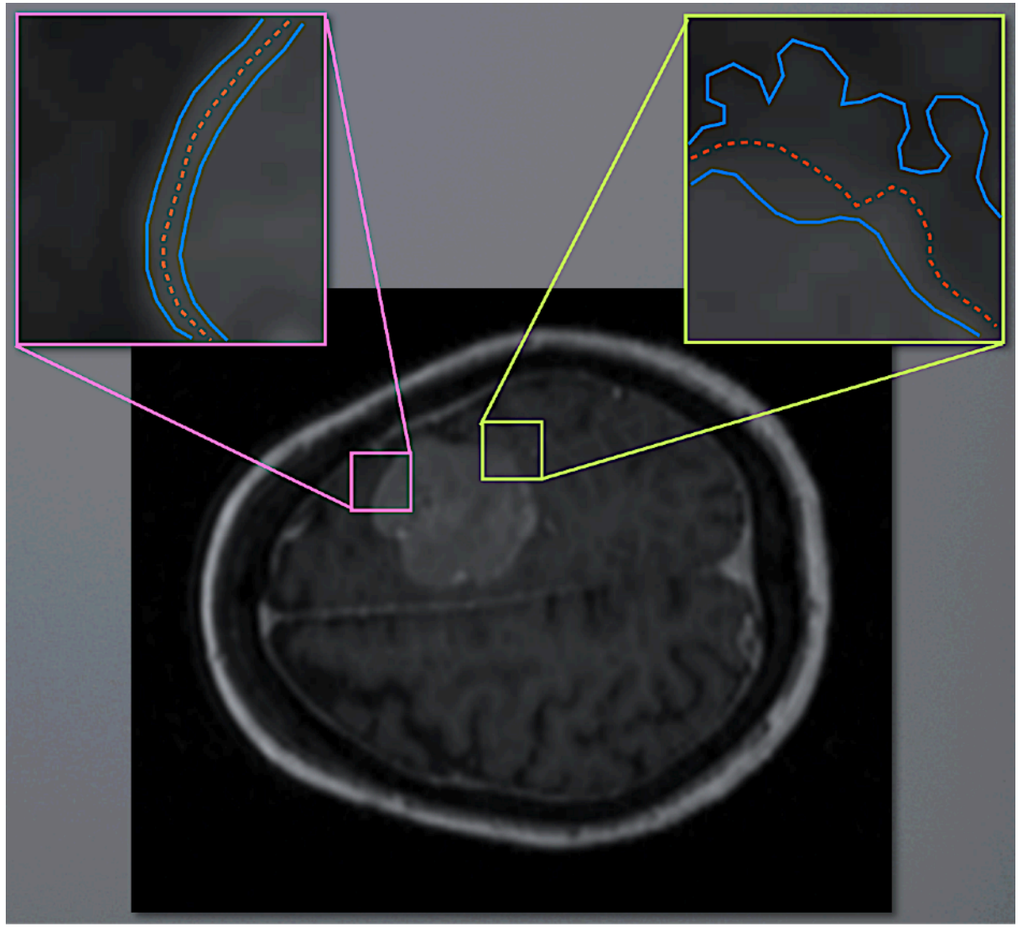
Can you identify a tumor boundary?



Whole brain atlas: http://www.med.harvard.edu/AANLIB/home.html

Uncertainty Visualization: Example

Red dotted lines: Likely tumor boundaries
Blue lines: Error bounds

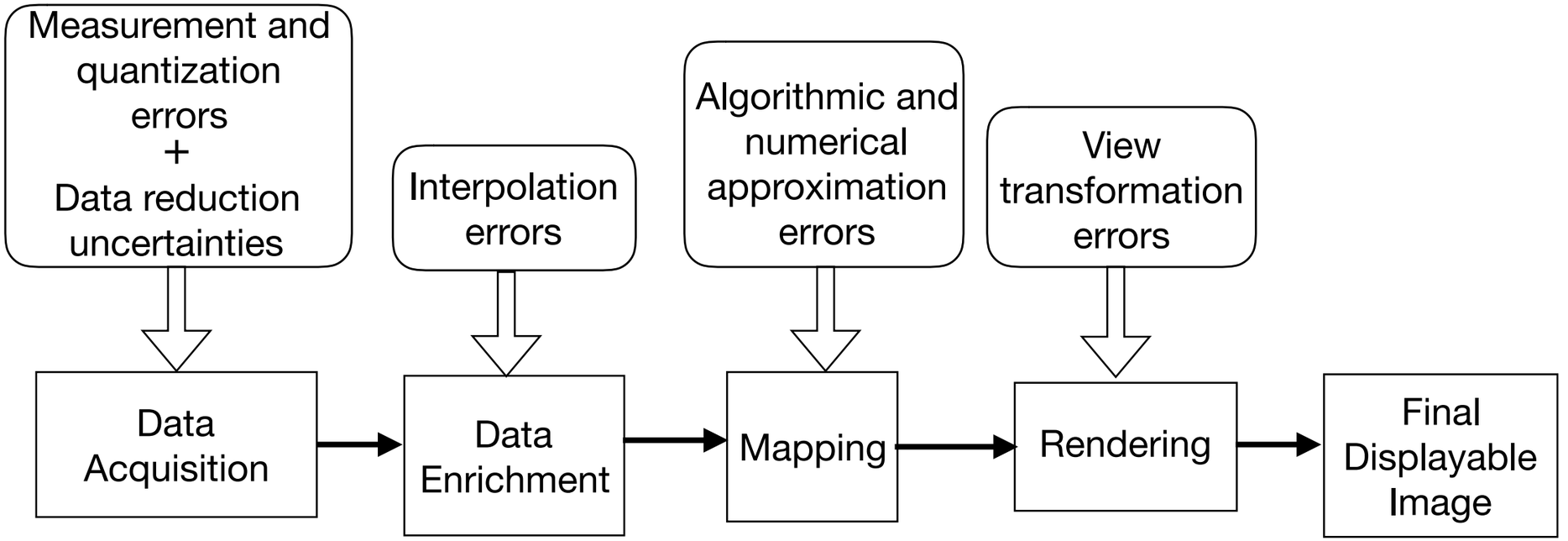


Whole brain atlas: http://www.med.harvard.edu/AANLIB/home.html

Uncertainty Visualization

[Johnson and Sanderson, A next step: Visualizing errors or uncertainty, 2004]
[Potter, Rosen, and Johnson, From quantification to visualization: A taxonomy of uncertainty visualization approaches, 2011]

Additional tool for domain scientists to reason regarding scientific decisions



The Visualization Pipeline

[Brodlie, Osorio, and Lopes, A review of uncertainty in data visualization, 2012]

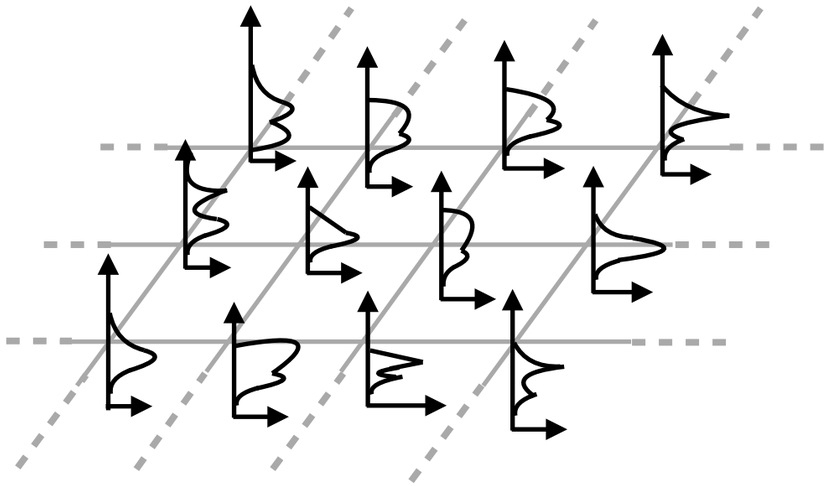
Probability Distributions for Modeling Data Uncertainty

High-Resolution Data: Hixel representation/ in-situ statistical summaries for large-scale data

[Thompson et al., Analysis of large-scale scalar data using hixels, 2011]

Ensemble Data: Multiple simulations for PDE solutions (approximate distributions from samples)

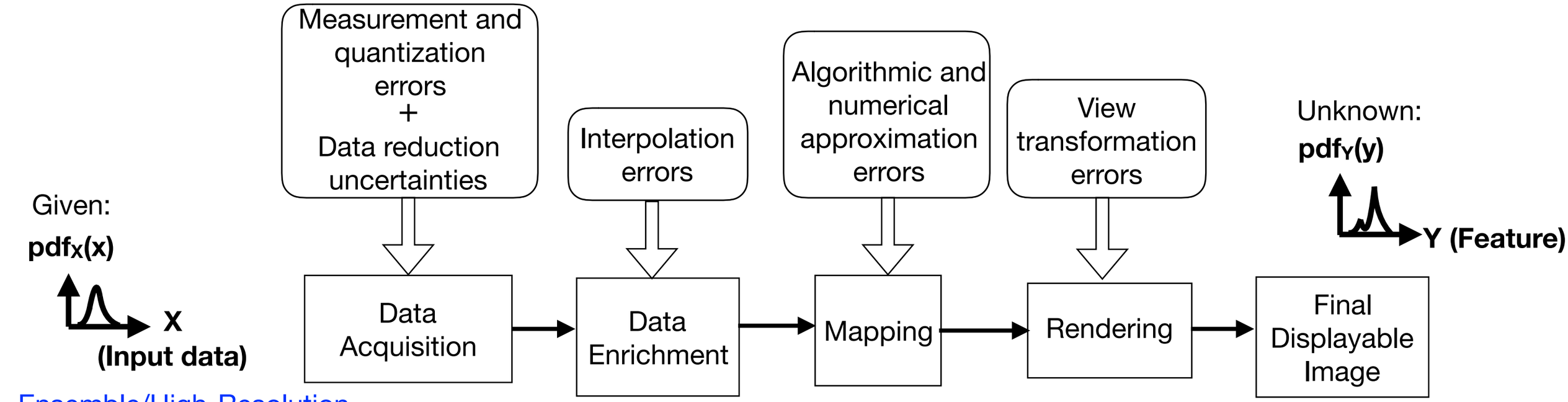
[Wang et al., Visualization and visual analysis of ensemble data: A survey, 2018]



Distribution field

Uncertainty-Aware Visualization (Abstract Statistical Methods)

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

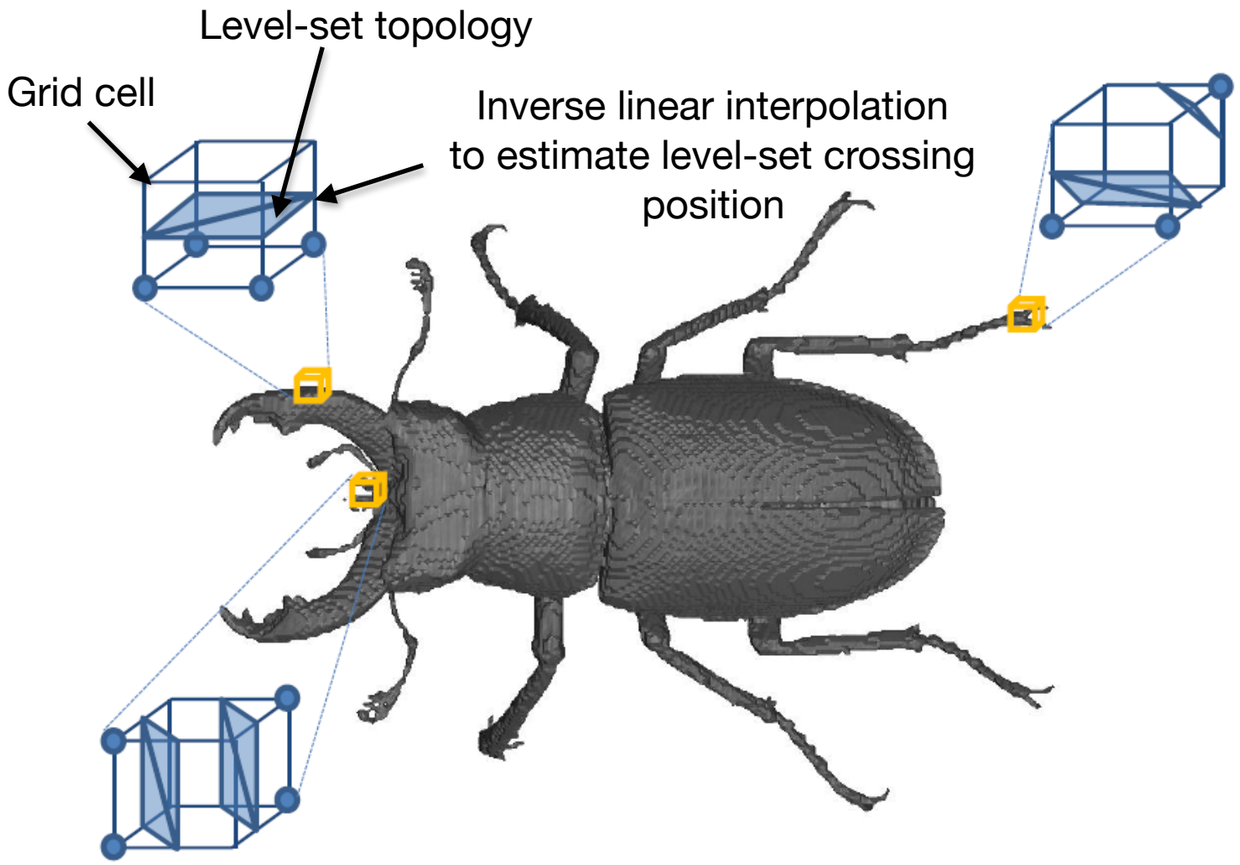


The Visualization Pipeline

[Brodlie, Osorio, and Lopes, A review of uncertainty in data visualization, 2012]

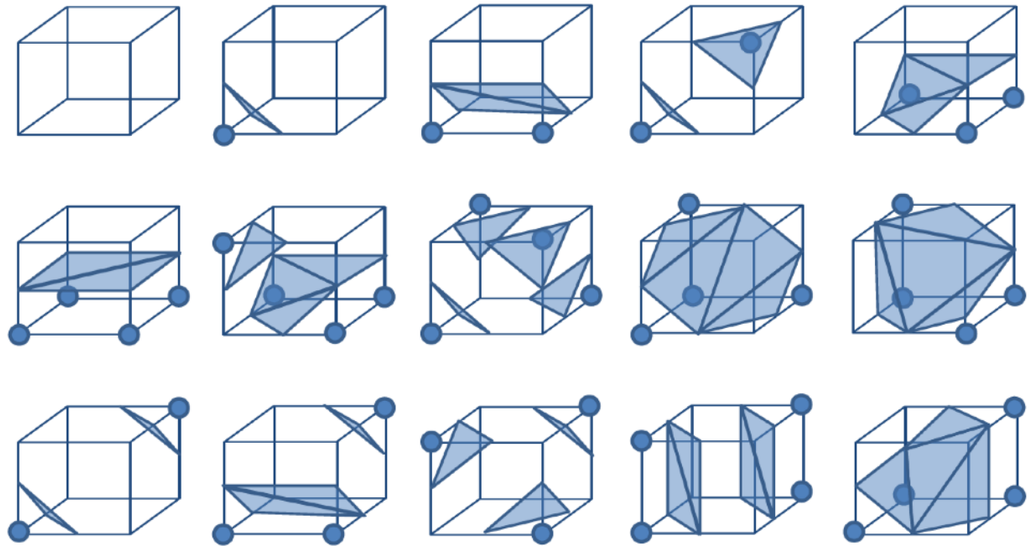
Uncertainty Visualization of Level-Sets

Marching Cubes Algorithm [Lorensen and Cline, 1987]



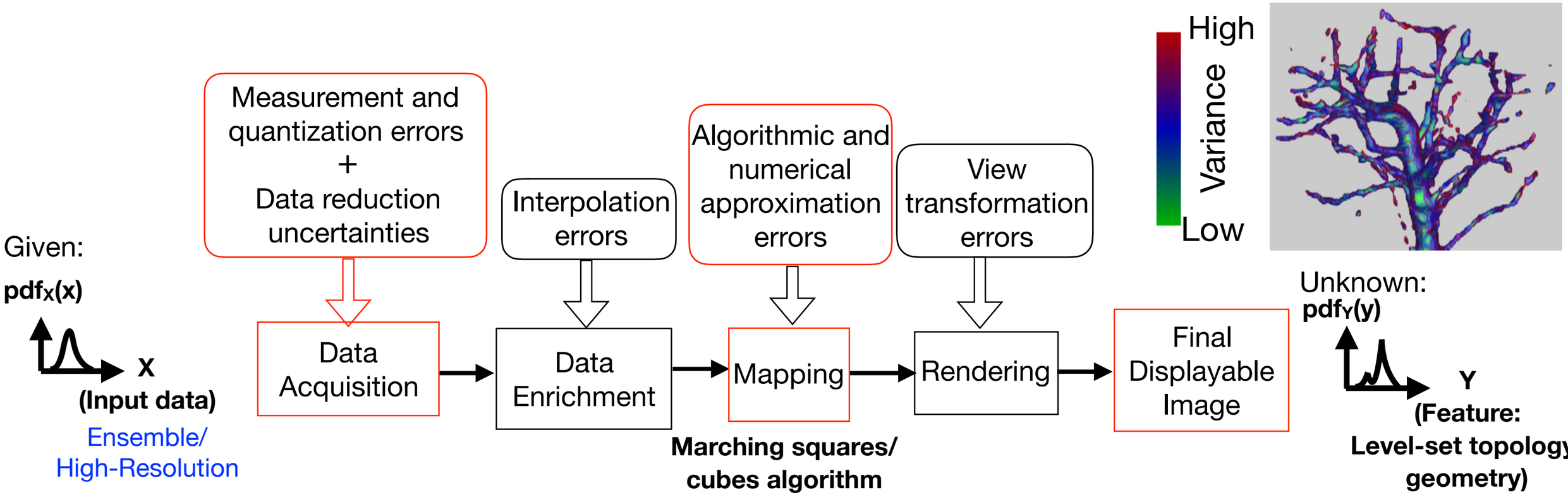
The Stag Beetle dataset is courtesy of Vienna University of Technology
https://www.cg.tuwien.ac.at/research/vis/datasets/

Topology cases



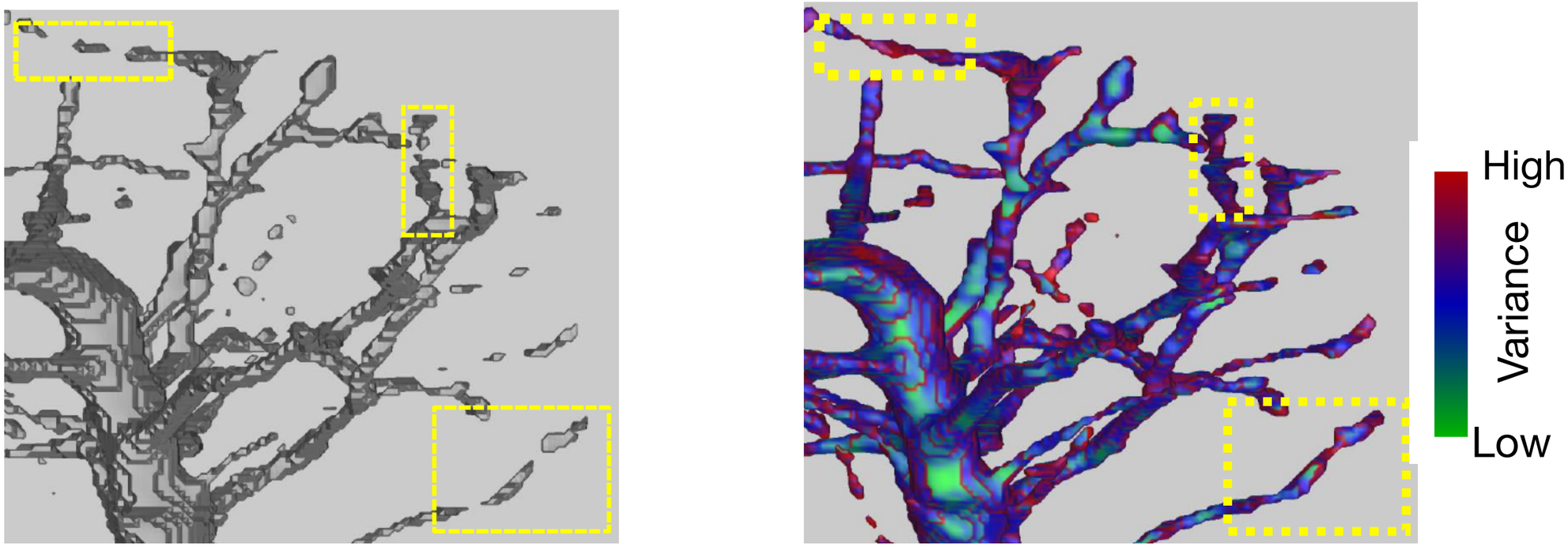
Uncertainty Visualization of Level-Sets

Marching cubes algorithm for certain [Lorensen and Cline, 1987] vs. uncertain data (our contribution!)



Uncertainty Visualization of Level-Sets (Inverse Linear Interpolation)

Bonsai tree (real data)



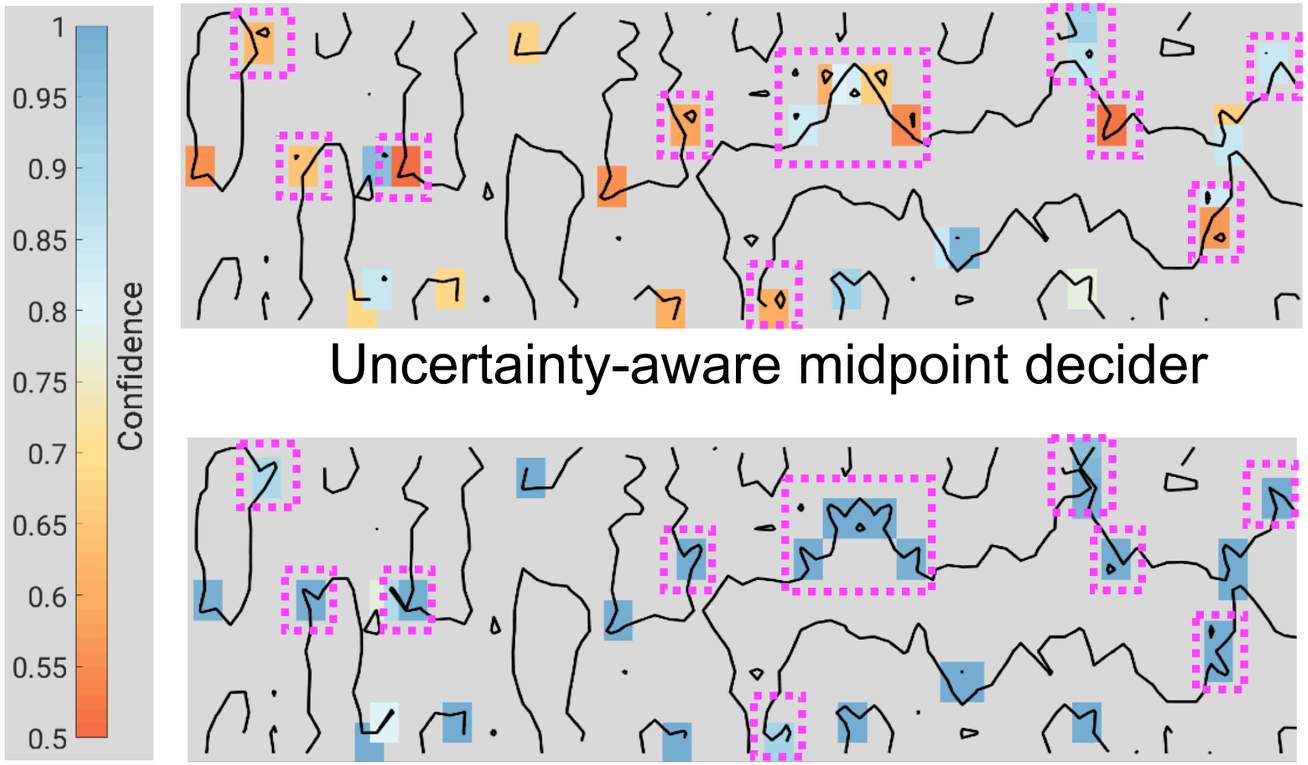
Mean

Uncertainty-aware inverse linear interpolation

[Athawale and Entezari, 2013; Athawale et al., 2016]

Uncertainty Visualization of Level-Sets (Topology)

Karman Vortex Street Dataset [Popinet, 2003]

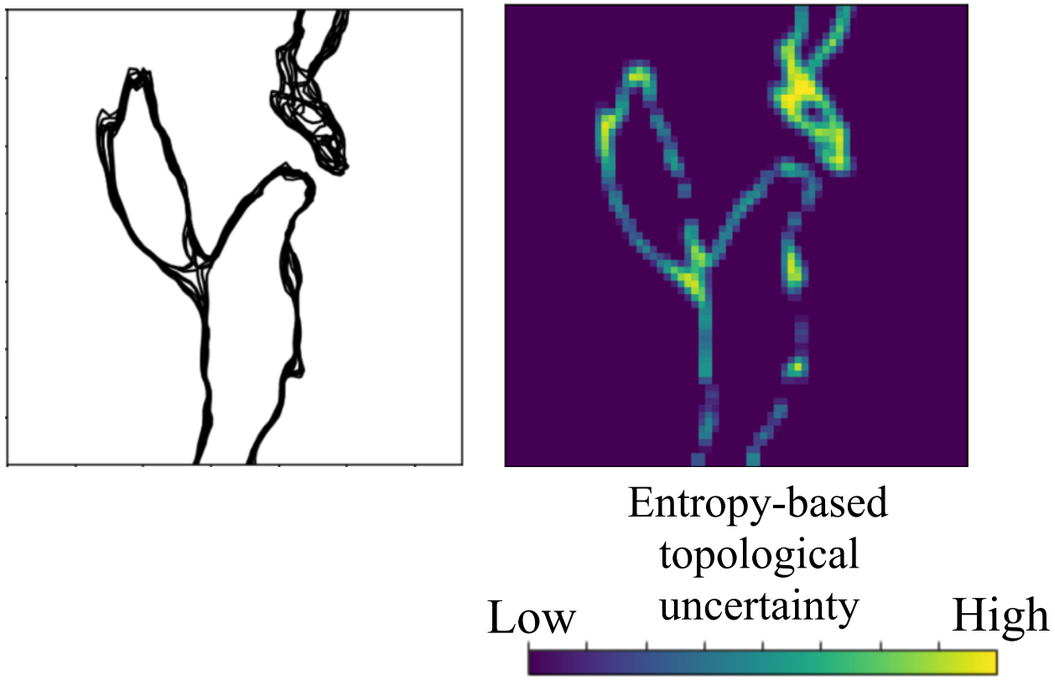


Uncertainty-aware midpoint decider

Uncertainty-aware asymptotic decider

[Athawale and Johnson, 2018]

Wind Dataset [Vitart et al., 2017]



[Athawale, Sane, and Johnson, 2021]

Uncertainty-Aware Direct Volume Rendering

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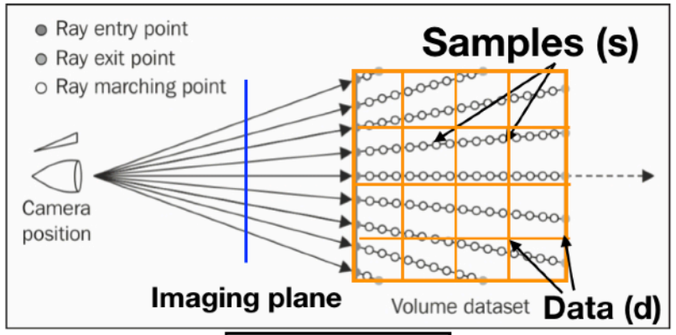
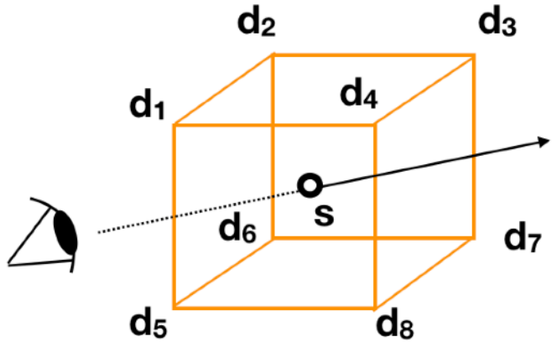
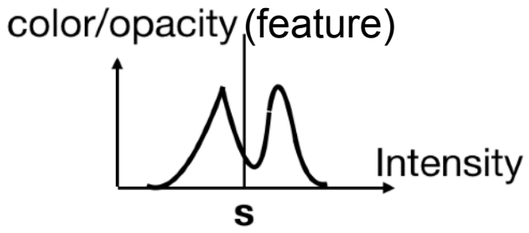
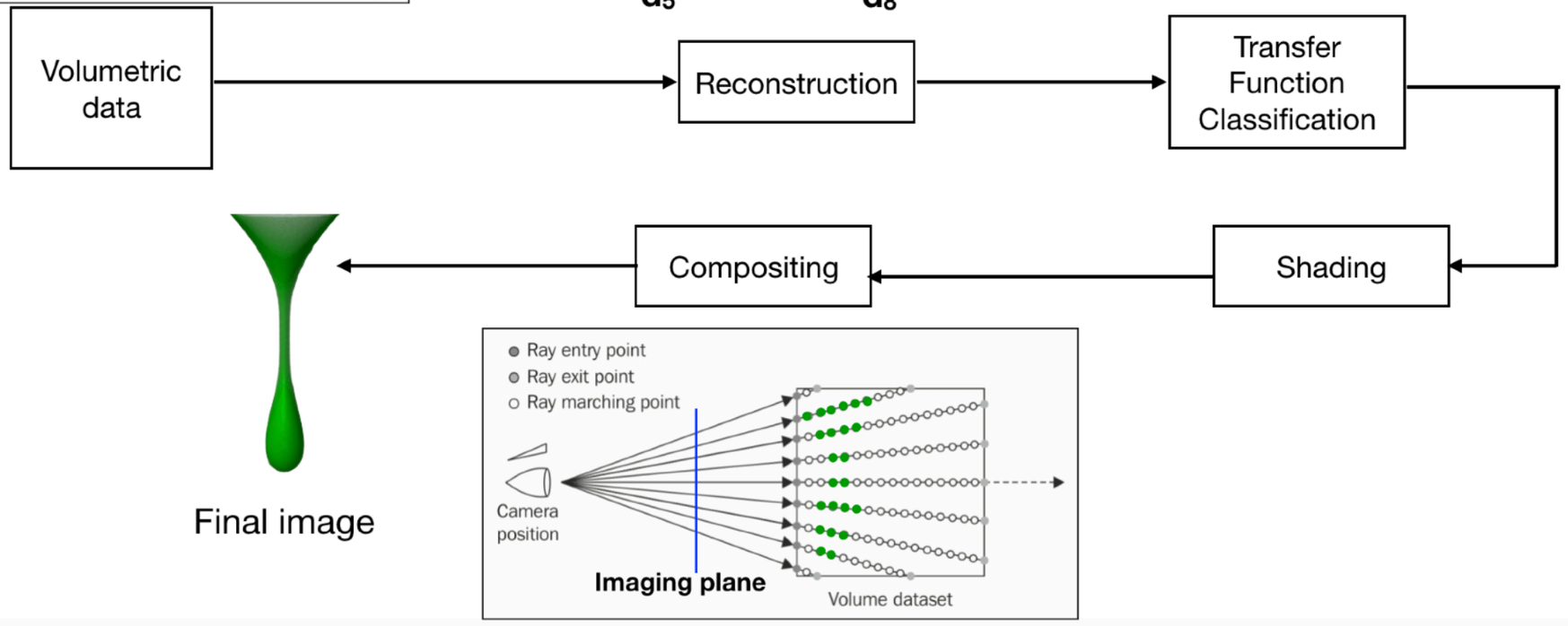
Direct Volume Rendering [Hadwiger et al., 2006]



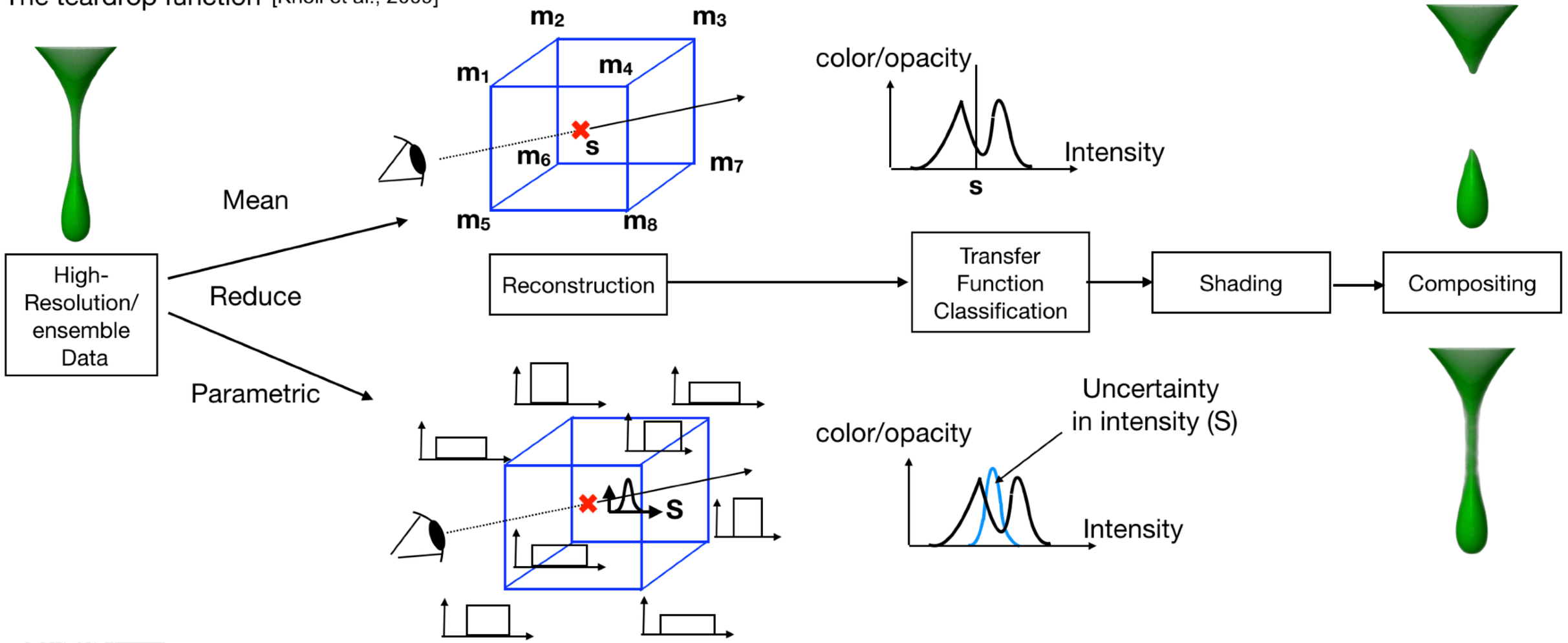






Uncertainty-Aware Direct Volume Rendering

The teardrop function [Knoll et al., 2009]

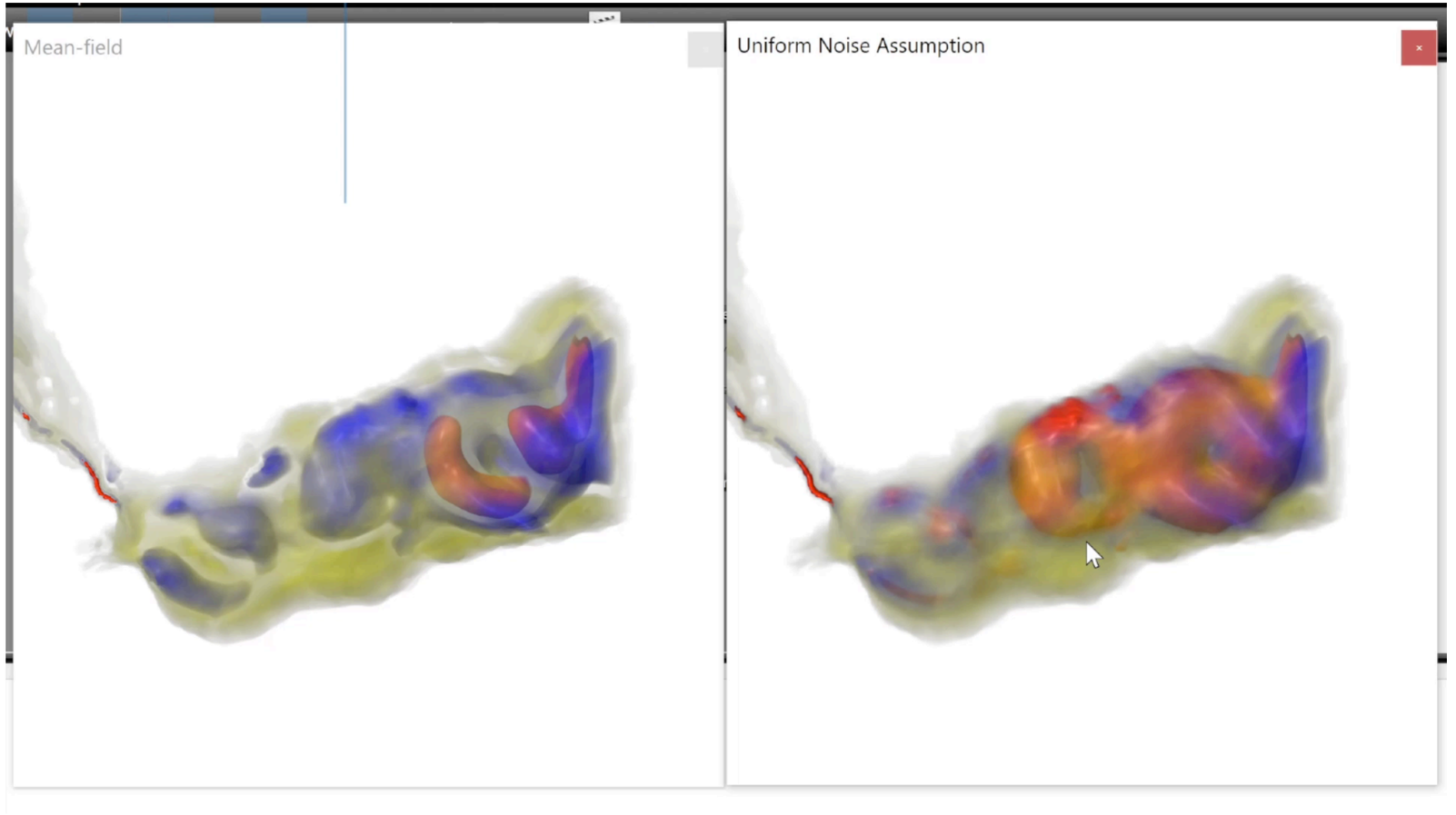


Uncertainty-Aware Direct Volume Rendering

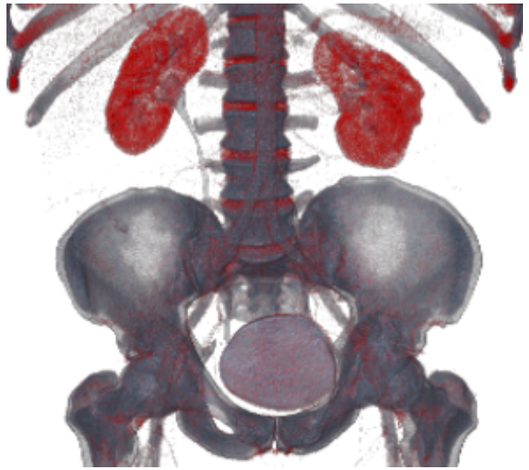
Scivis contest 2020 dataset:

- Simulation of flow eddies for the Red Sea

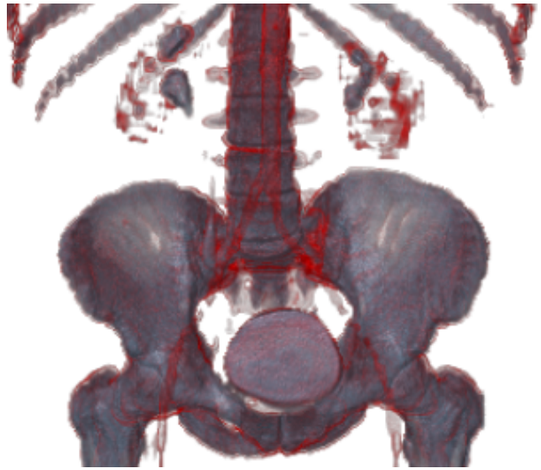
- Dataset size (~1.5TB)



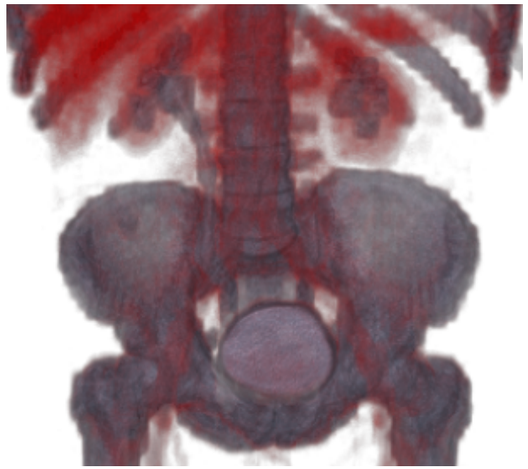
Uncertainty-Aware Direct Volume Rendering



(a) Ground truth (512x512x1559)



(b) Mean (64x64x195)



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

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

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

Uncertainty Visualization for Multivariate and Topology-Based Visualization algorithms

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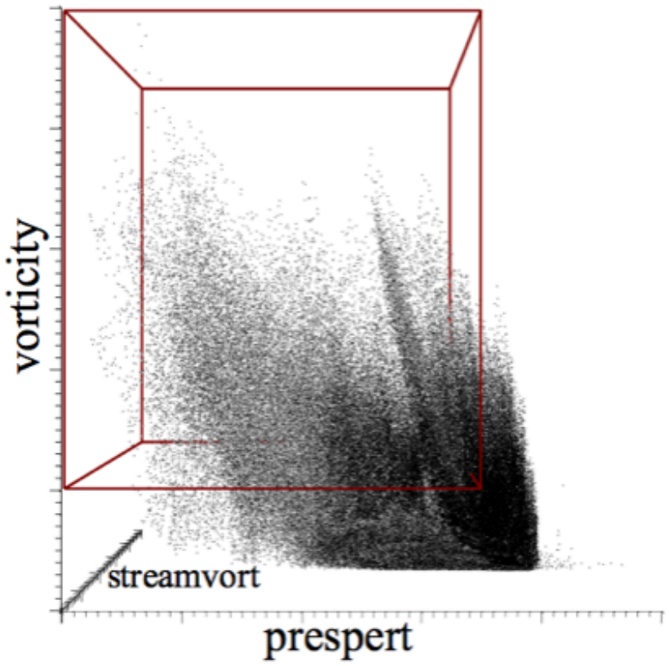
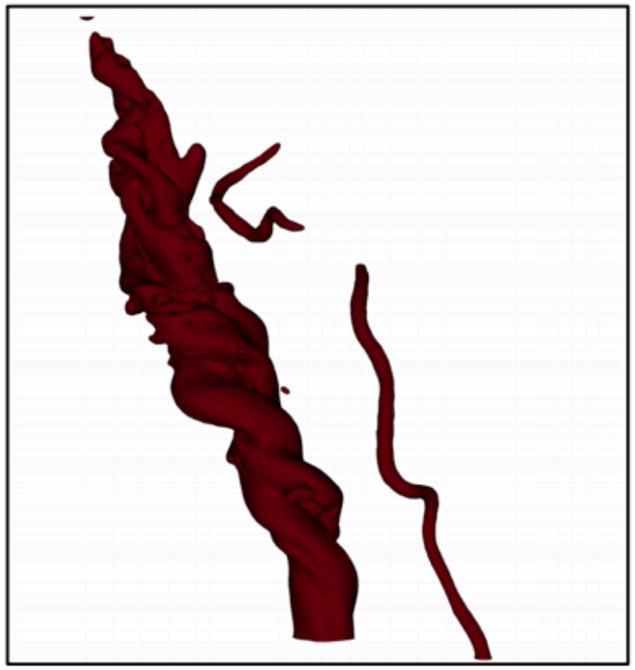
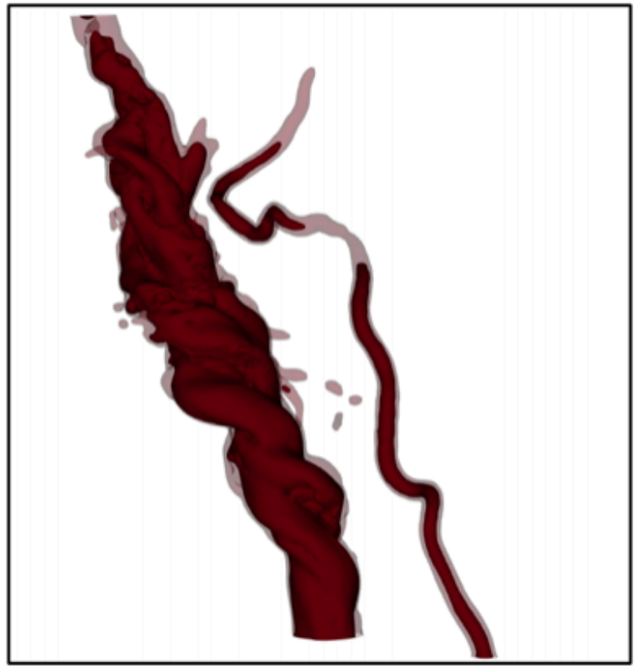
Multivariate Data Visualization





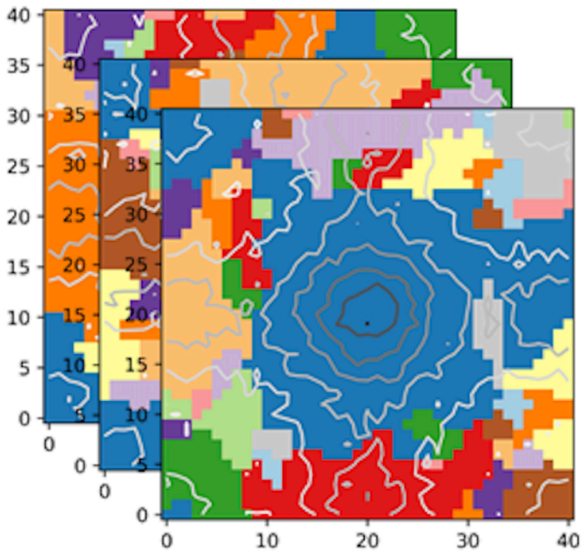
Feature level-sets
[Jankowai, 2018]



Feature confidence
level-sets
[Sane, Athawale, and
Johnson, 2021]

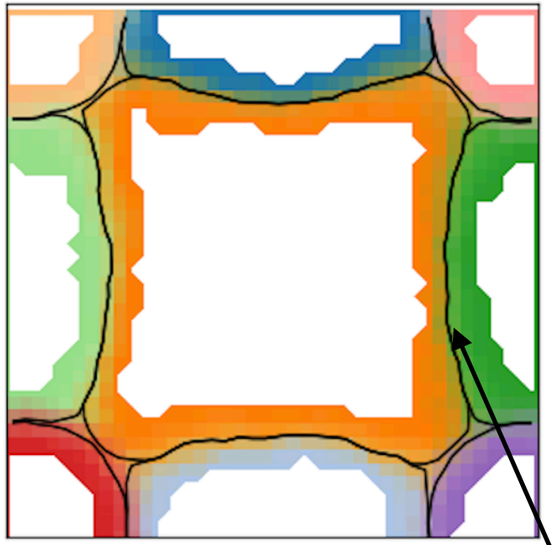
Morse-Complex Segmentation Uncertainty

Visualize uncertainty of gradient or vector fields across ensembles



Ensemble of Morse Complexes

Agreement Regions



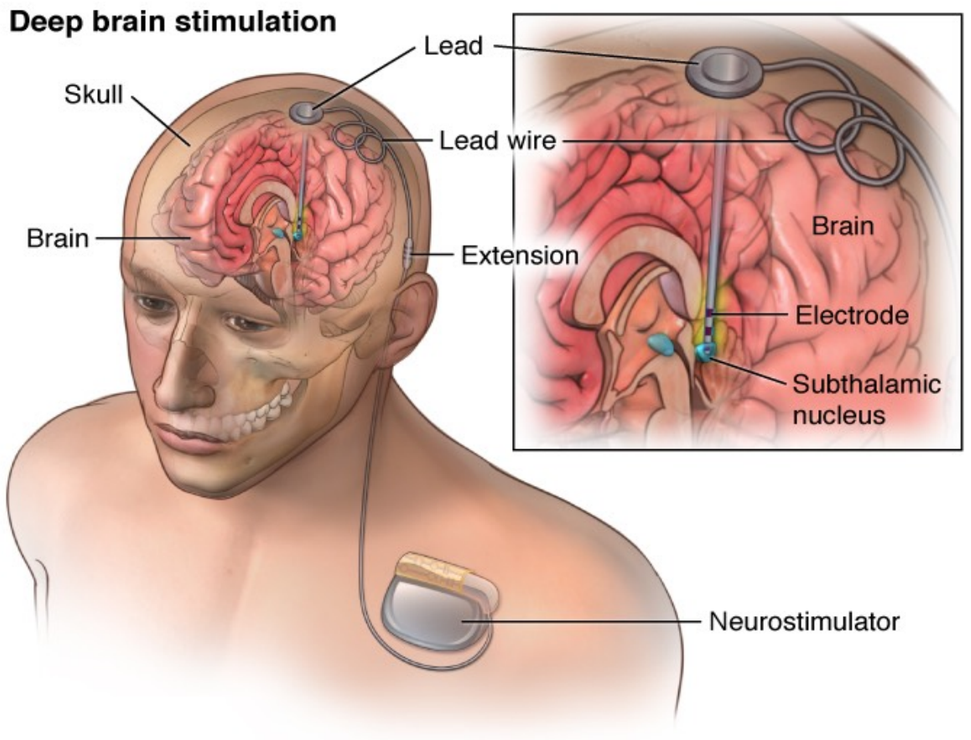
Uncertainty Regions

Expected boundaries

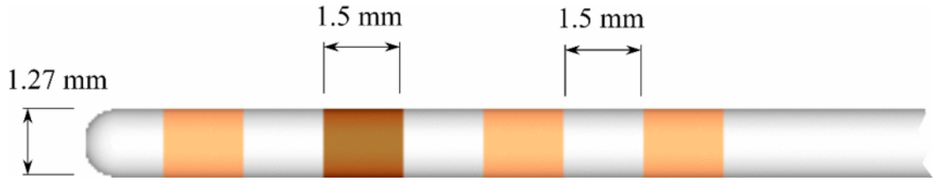
[Athawale et al., 2020]

Visualization of Uncertainty for Domain-Specific Data

Deep Brain Stimulation (DBS)



Medtronic DBS electrode Mo. 3387

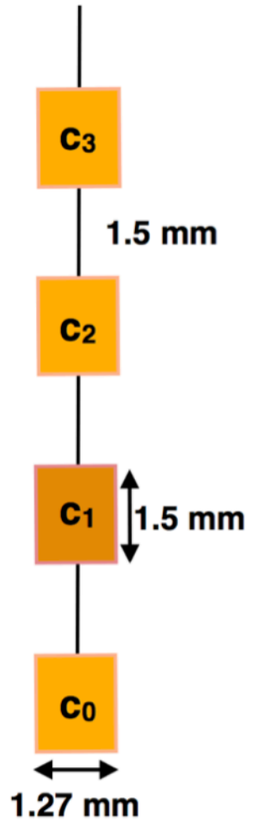


Voltage: 1-5 V
Frequency: 120-185 Hz
Pulse width: 60-200 μs
Contacts: Cathode(-)/Anode(+)/.Off

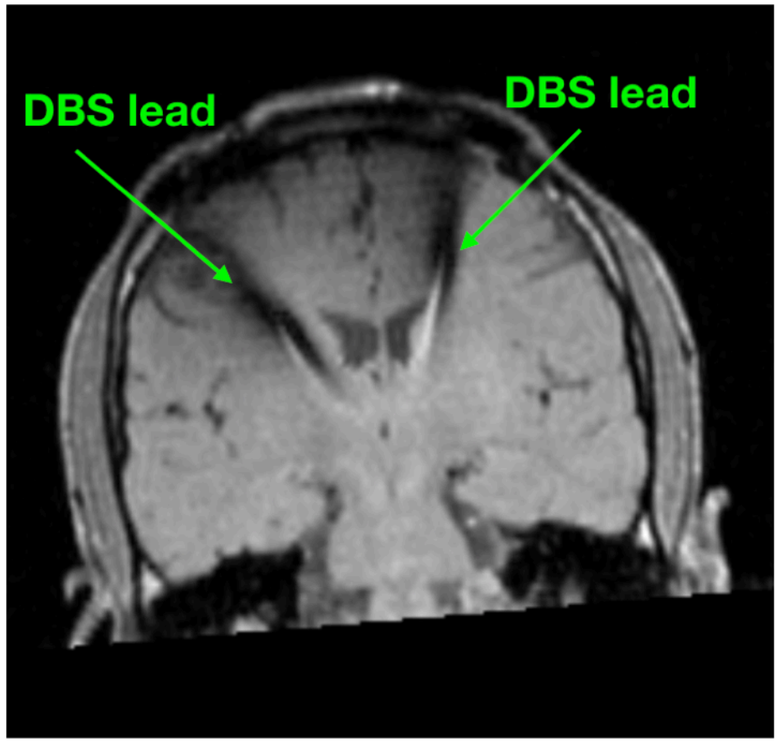
Knowledge of precise electrode positions in the patient head is essential for clinicians in order to set optimal patient-specific electric stimulation pattern.

Patient-Head Image to Understand Electrode Positions

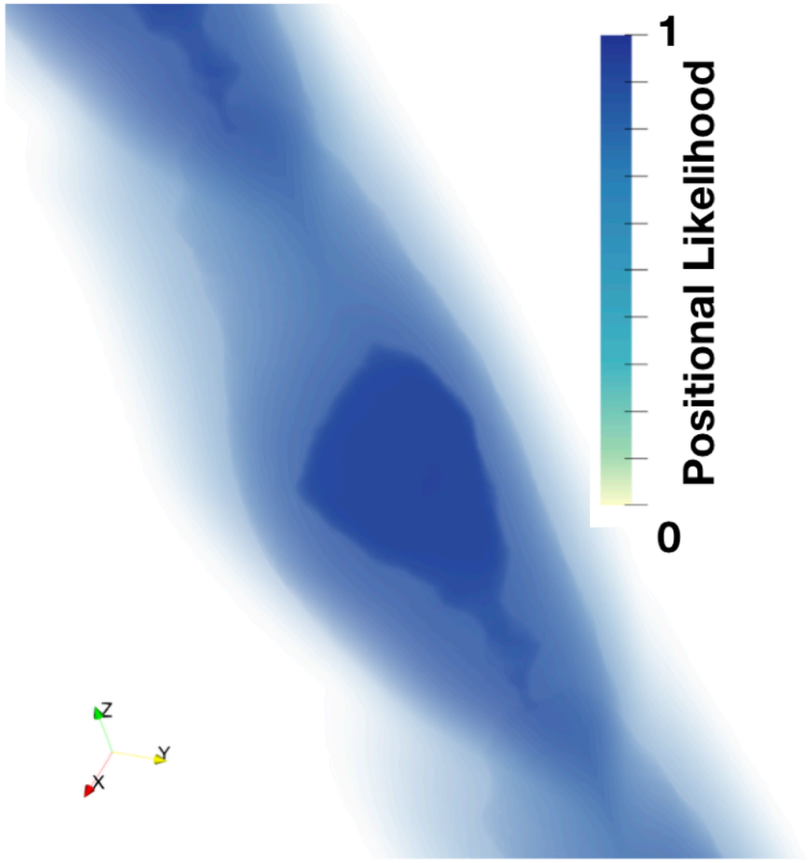
DBS lead schematic



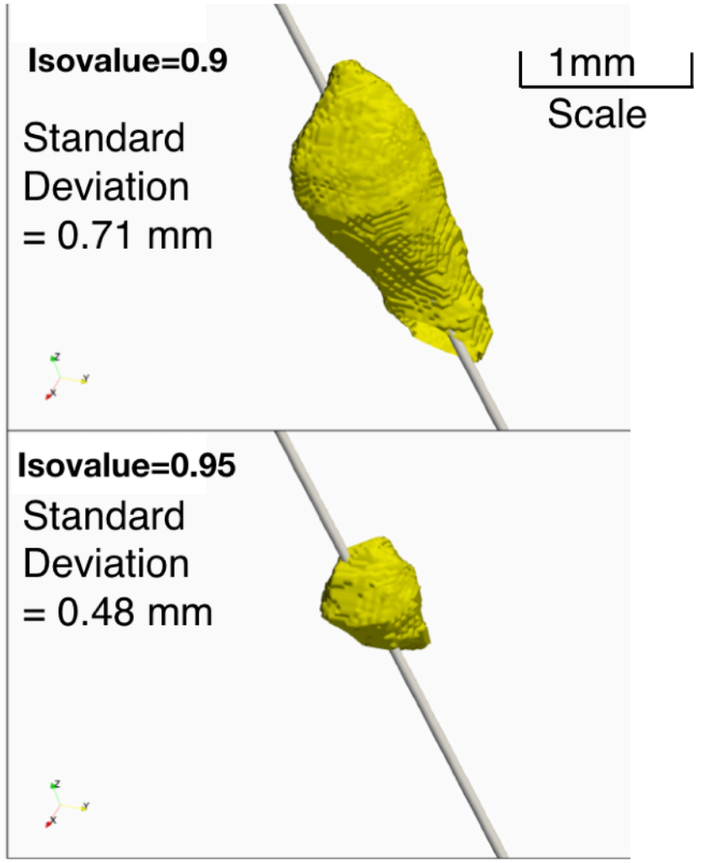
Post-surgery MRI to capture electrode positions



Uncertainty Visualization of Electrode Positions



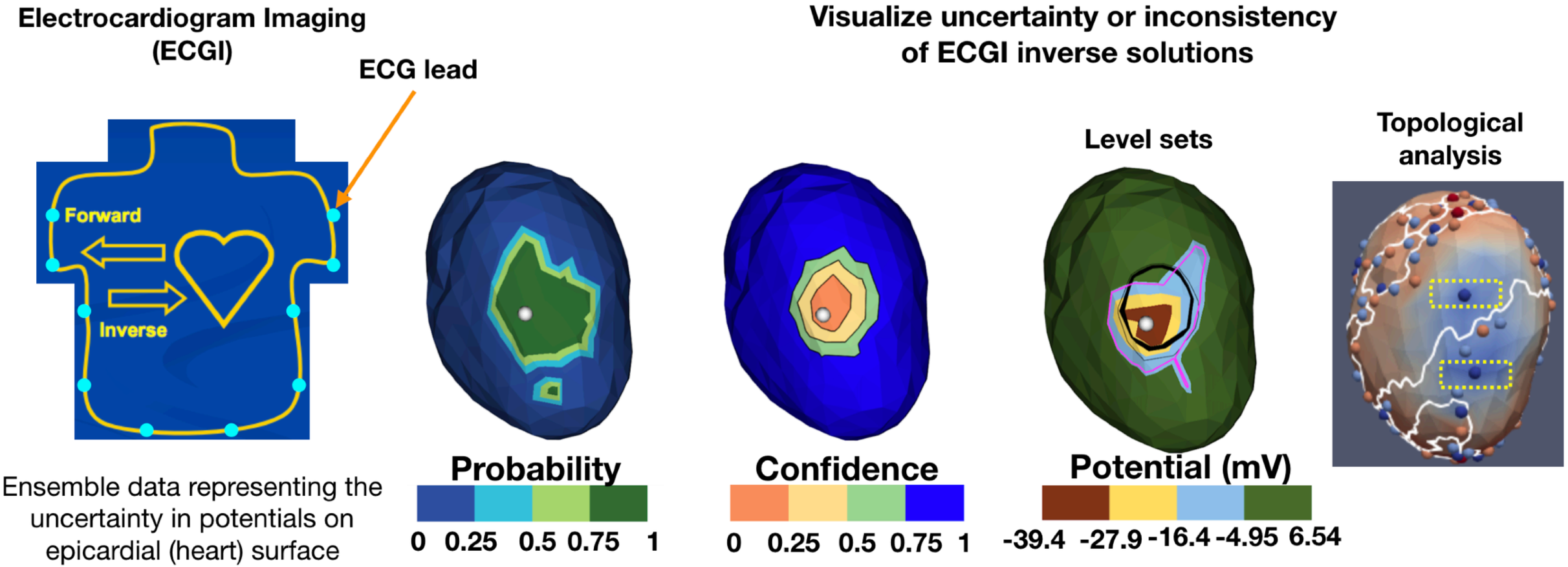
The volume visualization



The confidence visualization

[Athawale et al., 2019]

Electrocardiogram Imaging

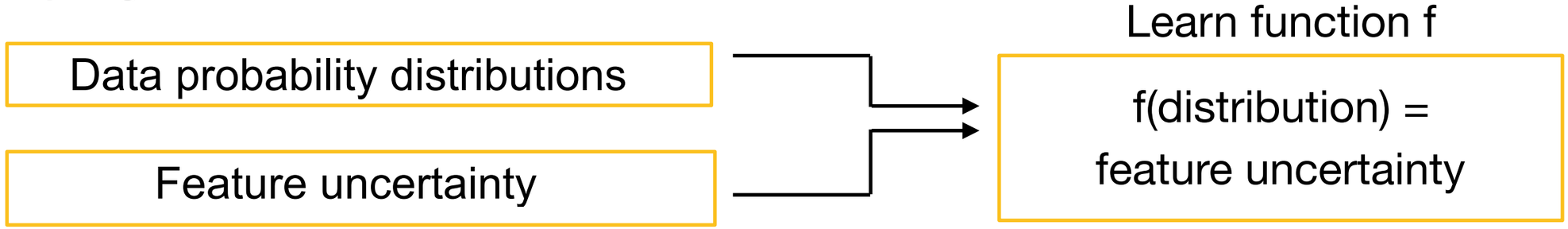


Ensemble data representing the uncertainty in potentials on epicardial (heart) surface

(Ongoing work!)

Future Work

- Uncertainty quantification for more scientific visualization algorithms, e.g., contour trees, fibre surfaces, image segmentation and registration algorithms
- Uncertainty visualization for vector field, tensor field, and high-dimensional data (visualizing uncertainties in even 3D is quite challenging!)
- Uncertainty visualization for more domain-specific data and computational pipelines
- Machine learning for uncertainty quantification to avoid expensive Monte Carlo Sampling?



Journal Publications

- **T. M. Athawale**, B. Ma, E. Sakhaee, C. R. Johnson, and A. Entezari; **Direct Volume Rendering with Nonparametric Models of Uncertainty**, *IEEE Transactions on Visualization and Computer Graphics, Special Issue on IEEE VIS Conf*, *2020*.

- **T. M. Athawale**, D. Maljovec, L. Yan, C. R. Johnson, V. Pascucci, and B. Wang; **Uncertainty Visualization of 2D Morse Complex Ensembles using Statistical Summary Maps**, *IEEE Transactions on Visualization and Computer Graphics (to appear), 2020*.

- **T. M. Athawale** and C. R. Johnson; **Probabilistic Asymptotic Decider for Topological Ambiguity Resolution in Level-Set Extraction for Uncertain 2D Data**, *IEEE Transactions on Visualization and Computer Graphics, Special Issue on IEEE VIS Conf*, vol.25, no. 1, pp. 1163-1172, Jan. 2019.

- **T. M. Athawale**, K. A. Johnson, C. R. Butson, and C. R. Johnson; **A Statistical Framework for Visualization of Positional Uncertainty in Deep Brain Stimulation Electrodes.**, *Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization*, pp. 1-12, Oct. 2018.

- **T. M. Athawale**, E. Sakhaee, and, A. Entezari; **Isosurface Visualization of Data with Nonparametric Models for Uncertainty**, *IEEE Transactions on Visualization and Computer Graphics, Special Issue on IEEE VIS Conf*, vol.22, no.1, pp.777-786, Jan. 2016.

- **T. M. Athawale** and A. Entezari.; **Uncertainty Quantification in Linear Interpolation for Isosurface Extraction**, *IEEE Transactions on Visualization and Computer Graphics, Special Issue on IEEE VIS Conf*, vol.19, no.12, pp.2723-2732, Dec. 2013.

Conference Proceedings/ Workshops

- **T. M. Athawale**, S. Sane, C. R. Johnson; **Uncertainty Visualization of the Marching Squares and Marching Cubes Topology Cases**, *to appear in VIS 2021 short paper track, 2021 (virtual)*.

- S. Sane, **T. M. Athawale**, and C. R. Johnson; **Investigating Multivariate, Vector, and Topological Data Analysis Techniques for Mantle Flow Pattern Visualization,** *IEEE VIS 2021 SciVis Contest Finalist, USA (virtual).*

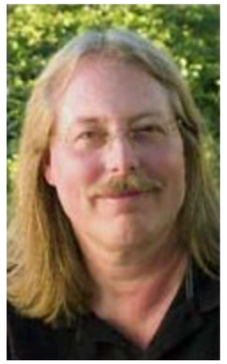
- **T. M. Athawale**, B. Stanislawski, S. Sane and C. R. Johnson; **Visualizing Interactions Between Solar Photovoltaic Farms and the Atmospheric Boundary Layer,** *e-Energy'21: Proceedings of the Twelfth ACM International Conference on Future Energy, pp. 377-38, June 2021, Torino, Italy (virtual).*

- S. Sane, **T. M. Athawale**, and C. R. Johnson; **Visualization of Uncertain Multivariate Data via Feature Confidence Level-Sets**, *to appear in EuroVis 21, 2021, Zurich, Switzerland (virtual).*

- **T. M. Athawale**, A. Entezari, B. Wang, and C. R. Johnson; **Statistical Rendering for Visualization of Red Sea Eddy Simulation Data**, *IEEE VIS 2020 SciVis Contest Finalist, Salt Lake City, USA (virtual).*

- **T. M. Athawale**, K. A. Johnson, C. R. Butson, and C. R. Johnson; **A Statistical Framework for Visualization of Positional Uncertainty in Deep Brain Stimulation Electrodes**, *2019 IEEE Workshop on Visual Analytics in Healthcare (VAHC), Vancouver, Canada.*

Thanks to all Co-authors!



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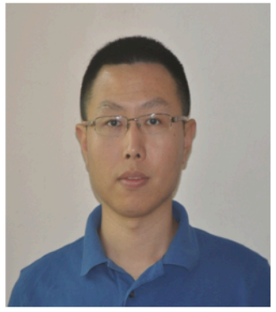
(Postdoctoral advisor)

Dr. Alirea Entezari
(PhD advisor)

Dr. Chris Butson
(DBS project)

Dr. Bei Wang
(Morse complex project)

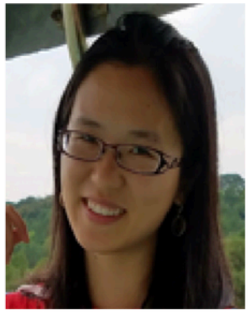
Dr. Valerio Pascucci
(Morse complex project)



Dr. Bo Ma
(Direct volume rendering project)

Dr. Elham Sakhaee
(Direct volume rendering project)

Dr. Kara Johnson
(DBS project)



Lin Yan
(Morse complex project)

Dr. Dan Maljovec
(Morse complex project)

Dr. Sudhanshu Sane
(Multivariate uncertainty analysis project)

Dennis Njeru
(ECGI project)

Thank you!

For any questions, please contact me at:

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