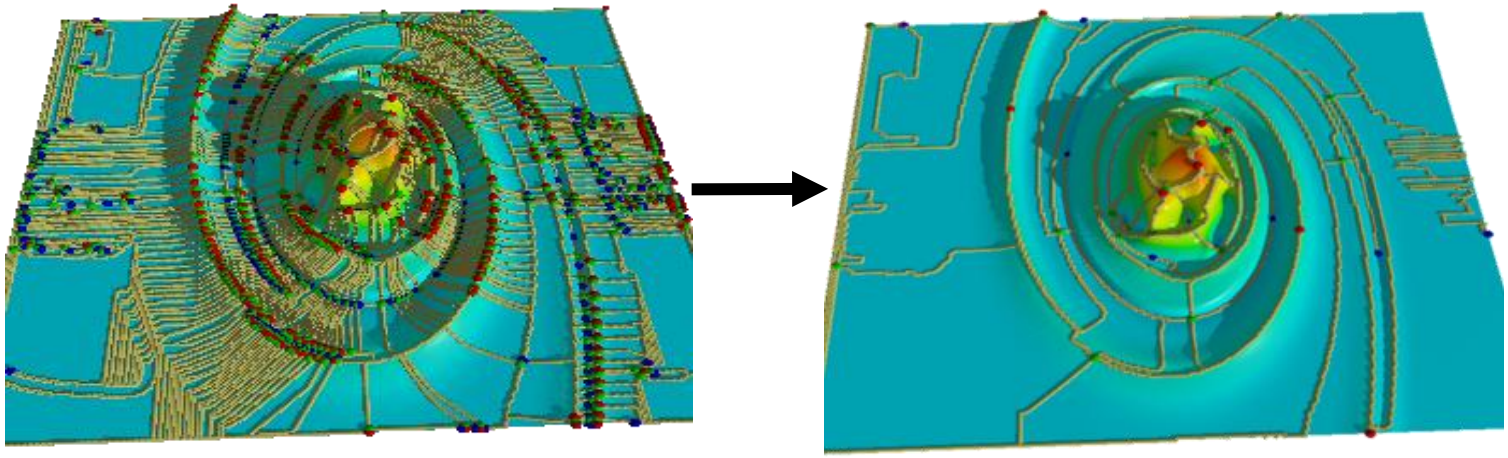
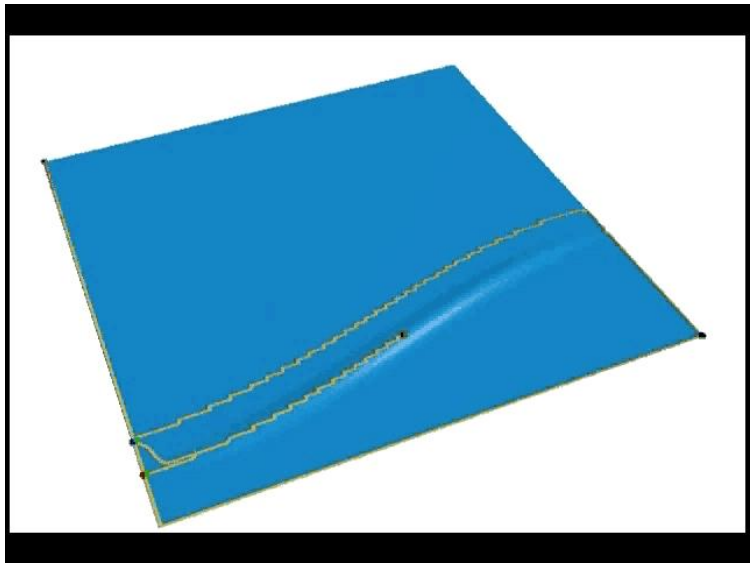
Topology is and Effective Language to Describe Abstractions of Features from Raw Data

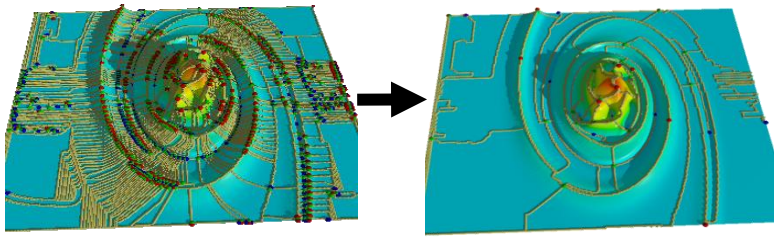


Hierarchical topology of a 2D Miranda vorticity field

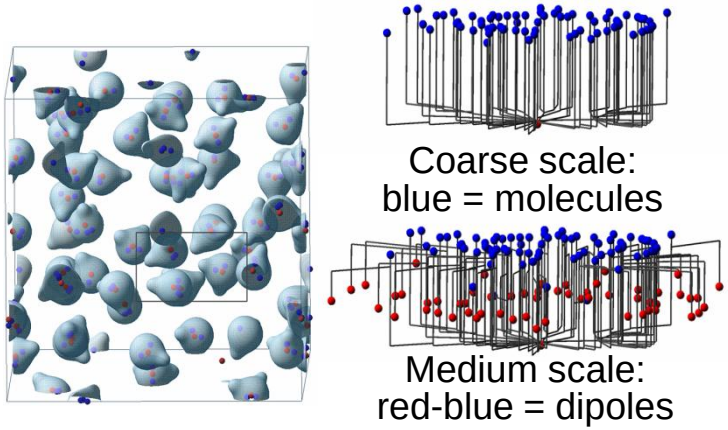


Our Framework is Based on Robust Topological Computations for Quantitative Data Analysis

- **Provably robust computation**
- **Provably complete feature extraction and quantification**
- **Hierarchical topological structures used to capture multiple scales**
- **Error-bounded approximations associated with each scale**
- **Formal mathematical definition associated with each analysis**
- **Scalable performance in association with streaming techniques**



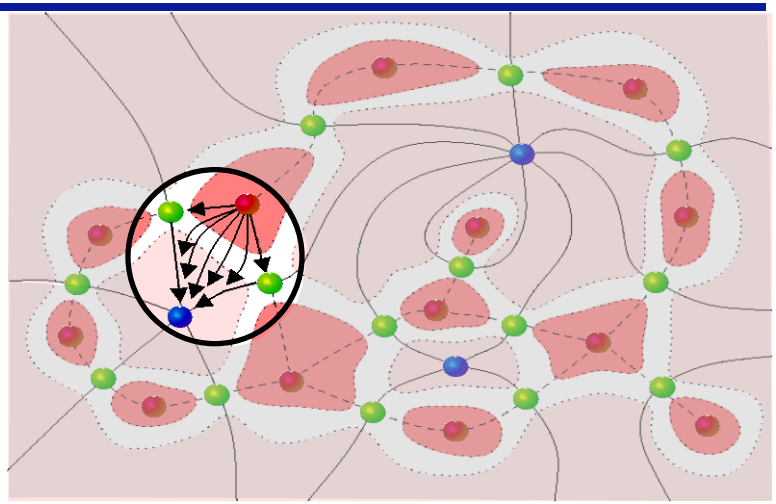
Hierarchical topology of a 2D Miranda vorticity field

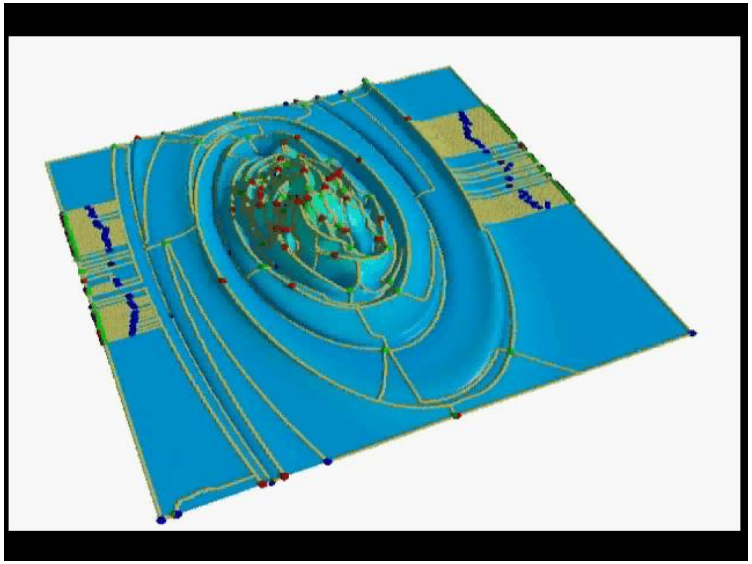


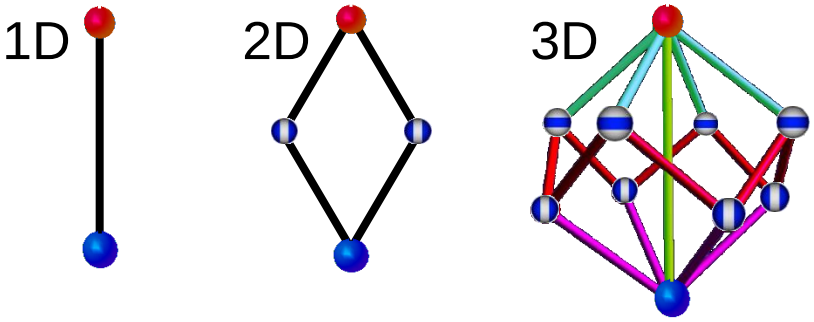
Molecular dynamics simulation (left) with abstract graph representation of its features at two scales (right)

We Introduced the Morse–Smale Complex for Complete Data Analysis

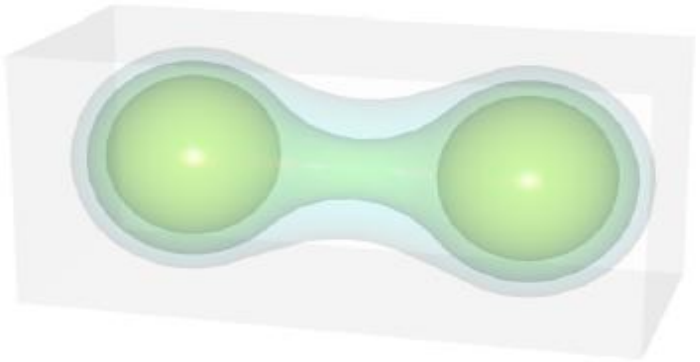
- **The Morse–Smale complex partitions the domain of *f* in regions of uniform gradient**
- **Generalizes the notion of monotonic interval**
- **Dimension of a region equal index difference of source and destination**
- **Remove inconsistency of local gradient evaluations**



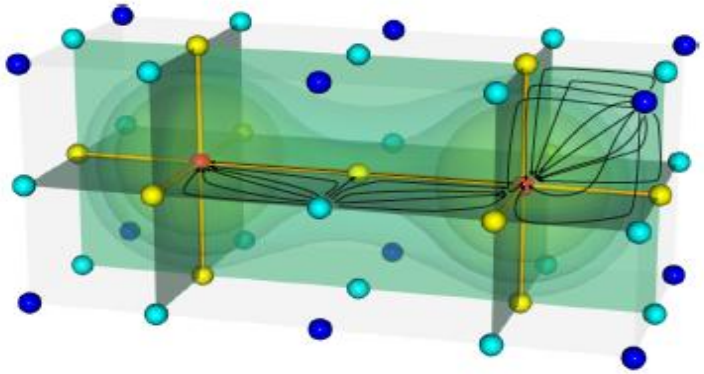




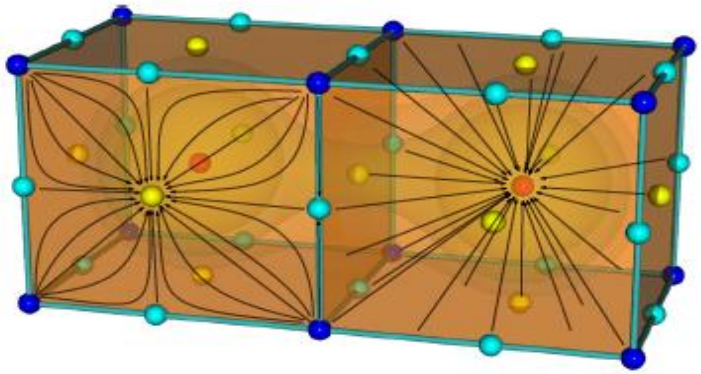
Topology Provides a Well Defined Formalism for Communicating Shape



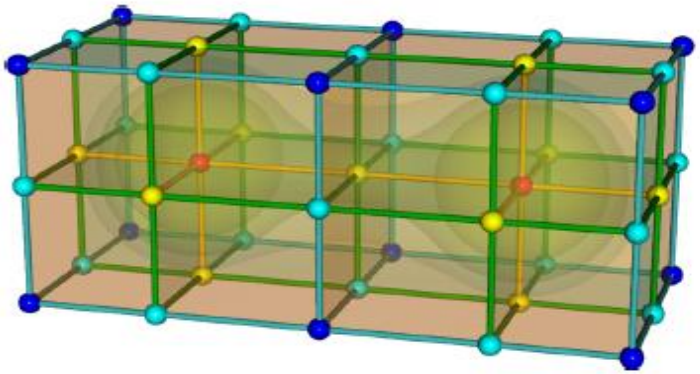
Morse Function:



Ascending Manifold:

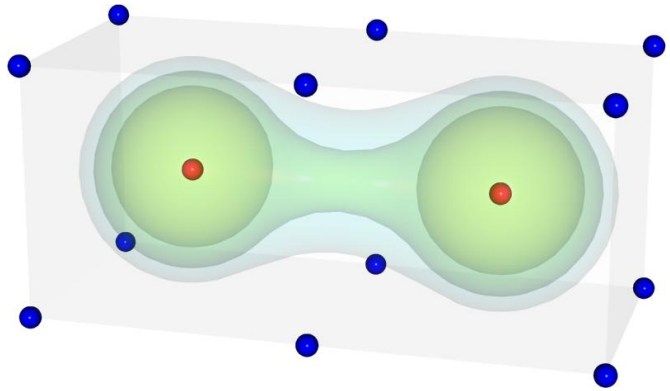


Descending Manifold:

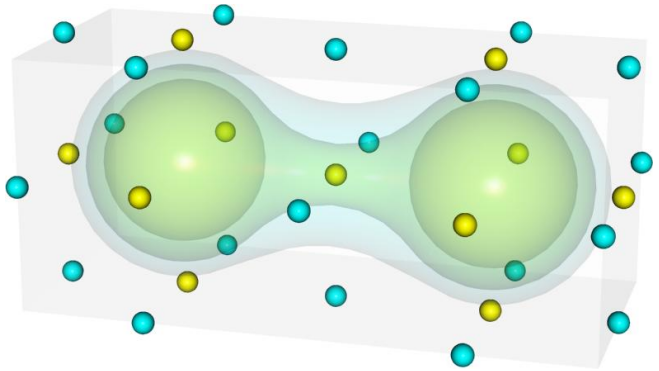


MS Complex:

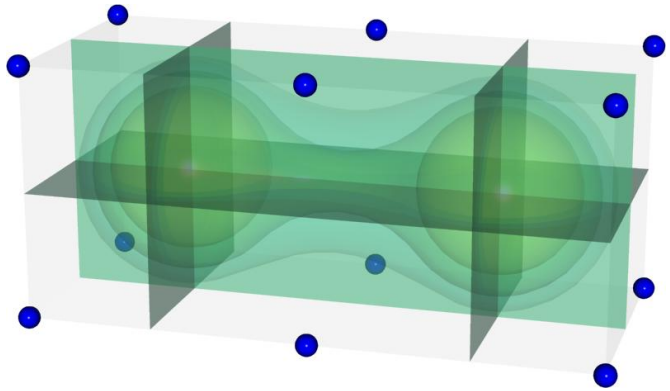
Topology Provides a Well Defined Formalism for Communicating Shape



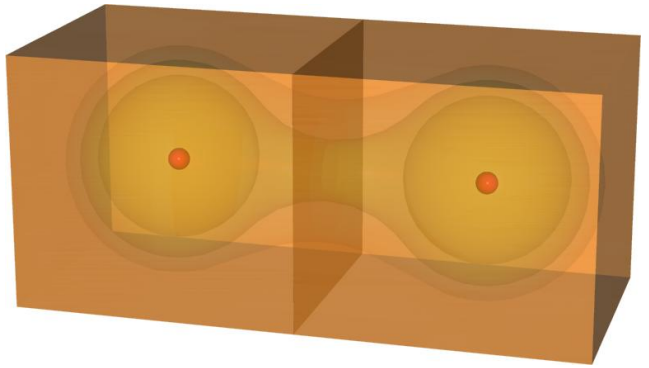
Picks/Pits



Saddles

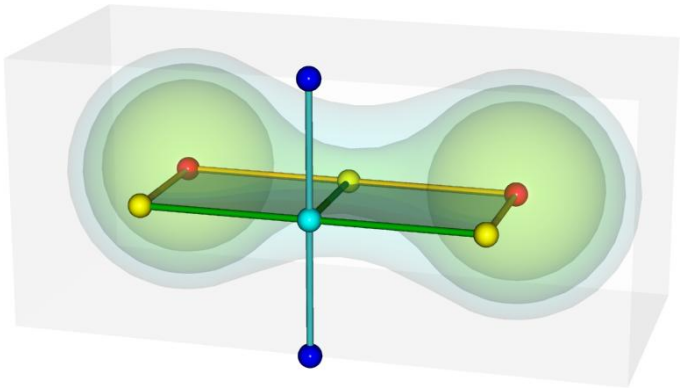


Basins

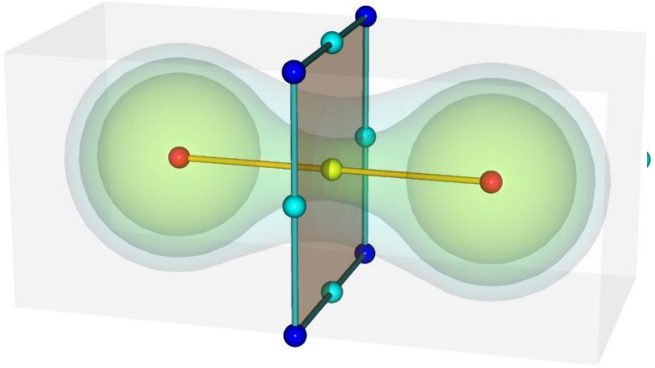


Mountains

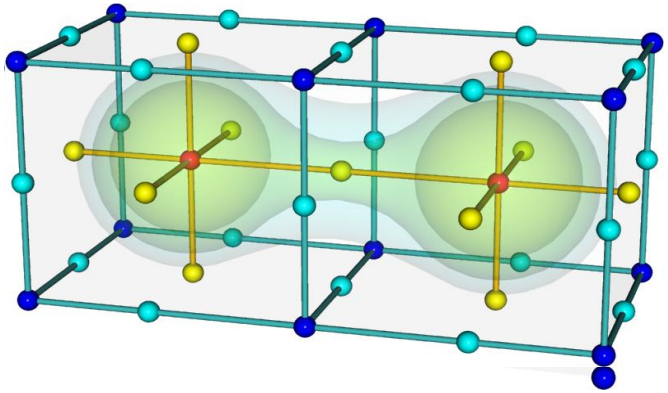
Topology Provides a Well Defined Formalism for Communicating Shape



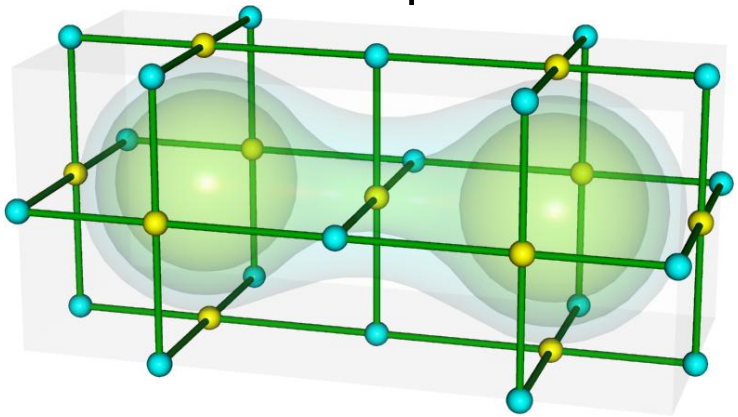
B-separatrices



M-separatrices

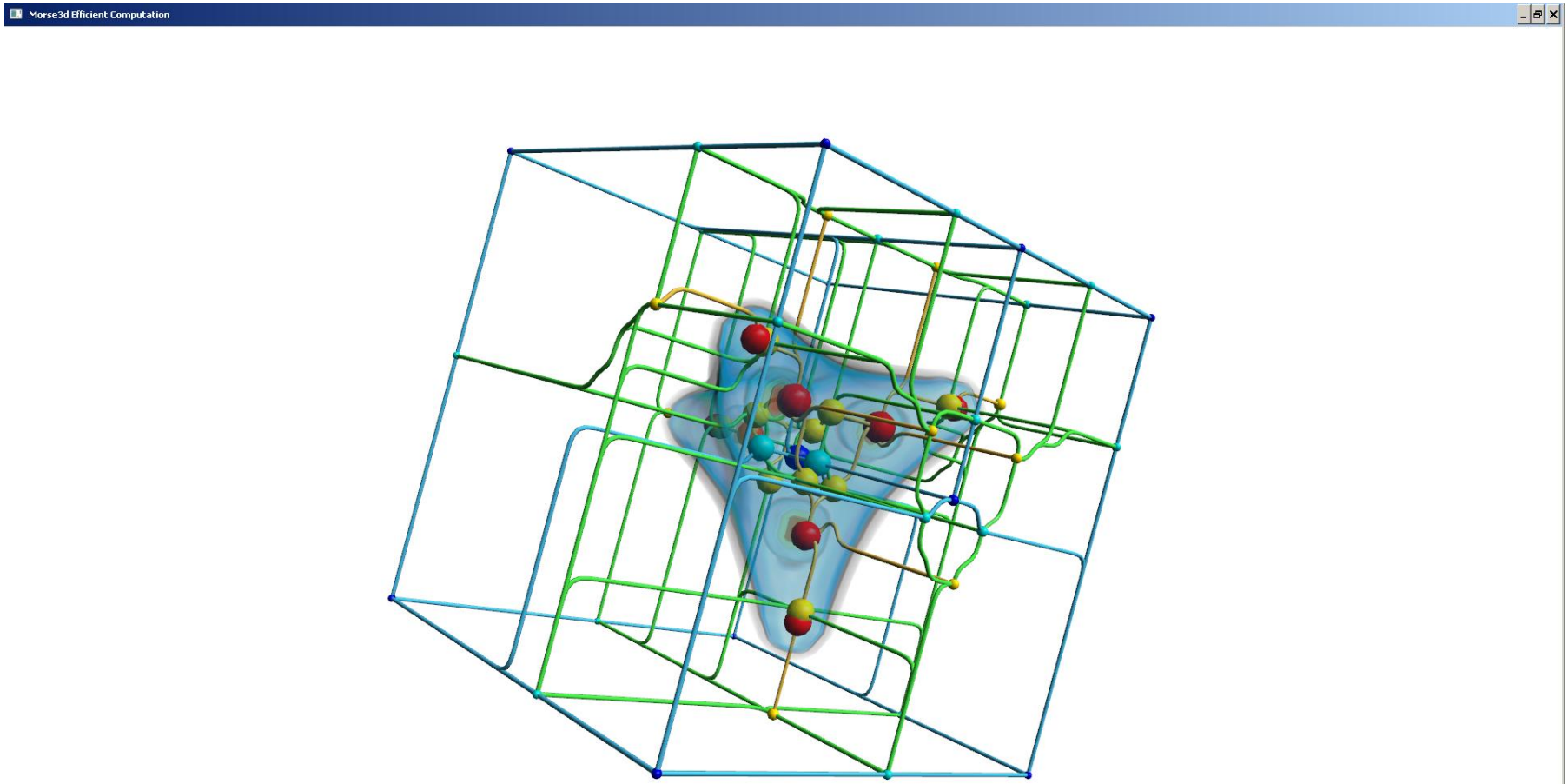


Ridge/Valley lines



Saddle Connectors

Demo C_4H_4

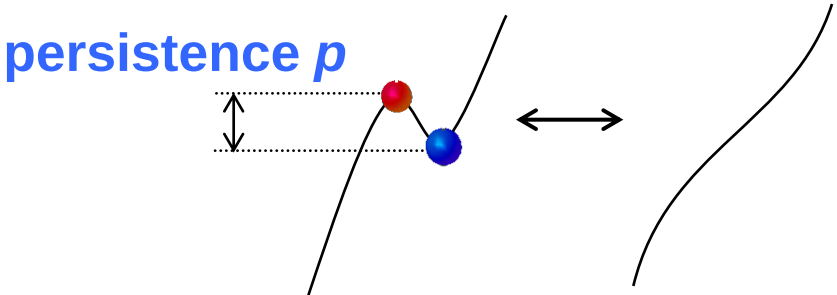


We Use Cancellations to Create a Multi-scale Representation of the Trends in the Data

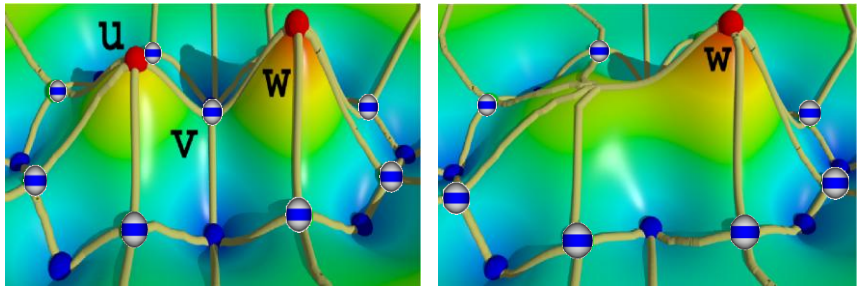
Cancellations: critical points can be created or destroyed in pairs that are connected 1-manifolds

Approximation: error = persistence/2 (proven lower bound)

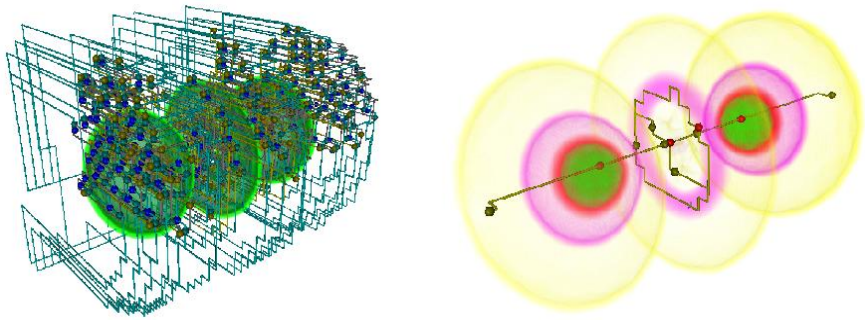
Multi-scale: consistent gradient segmentation at all scales



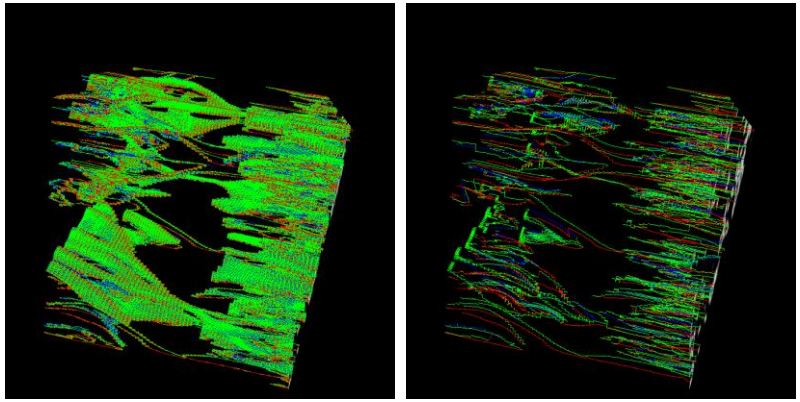
1D: **cancellation=contraction**



2D: **cancellation=contraction + edge removal**

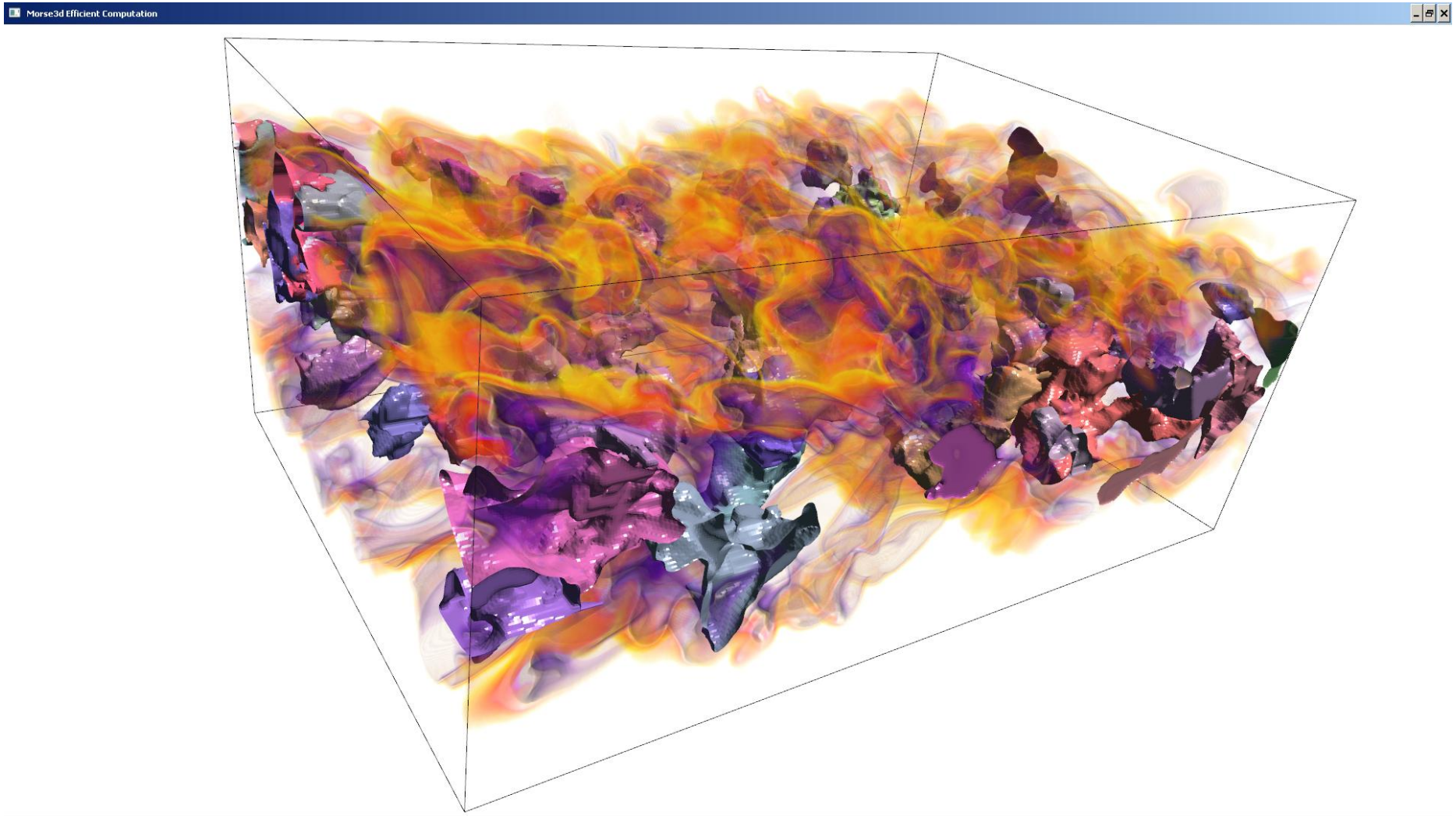


3D

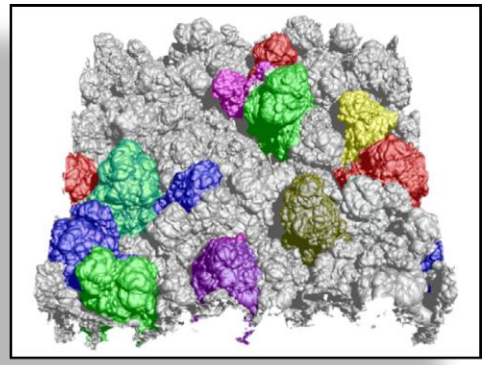


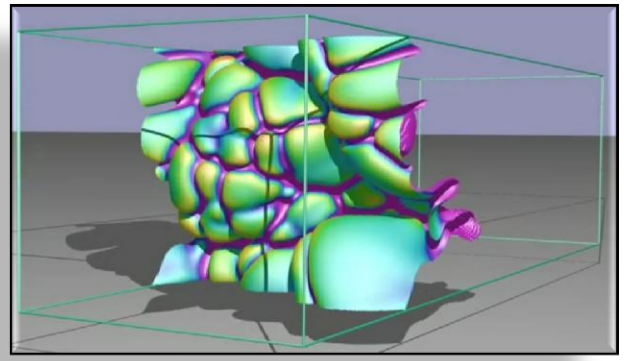
Time

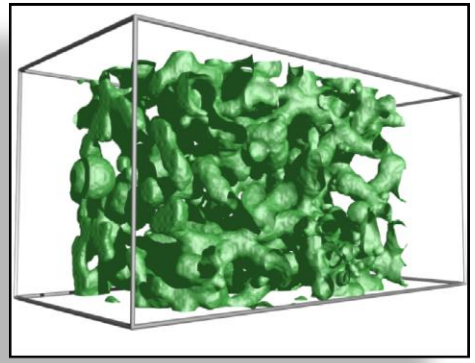
Demo S3D Combustion Simulation

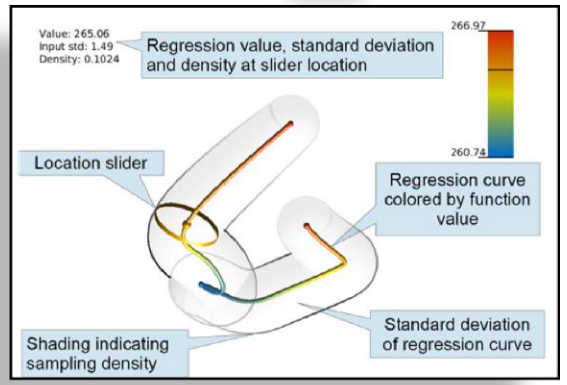


Big Data Analytics Success Stories



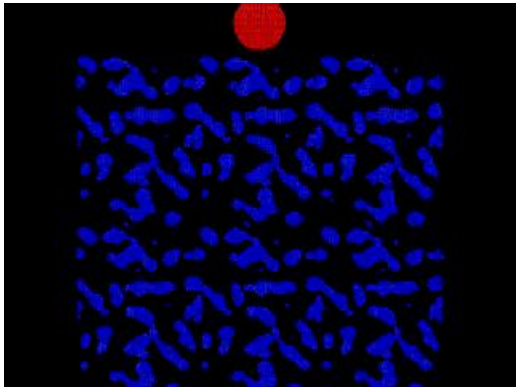


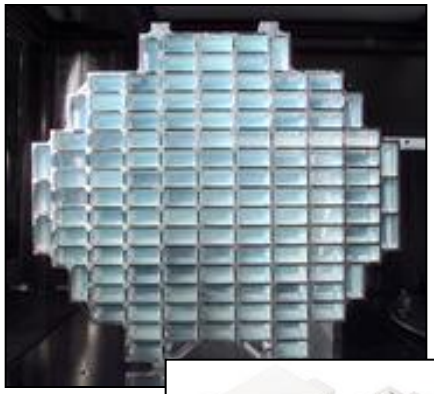


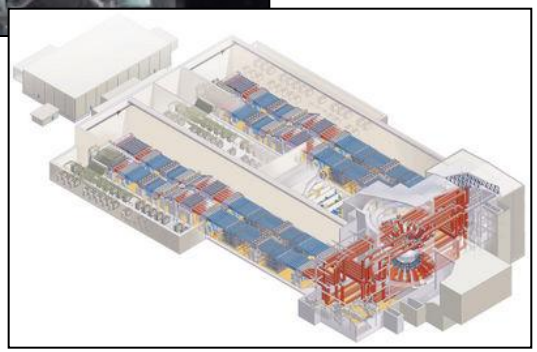


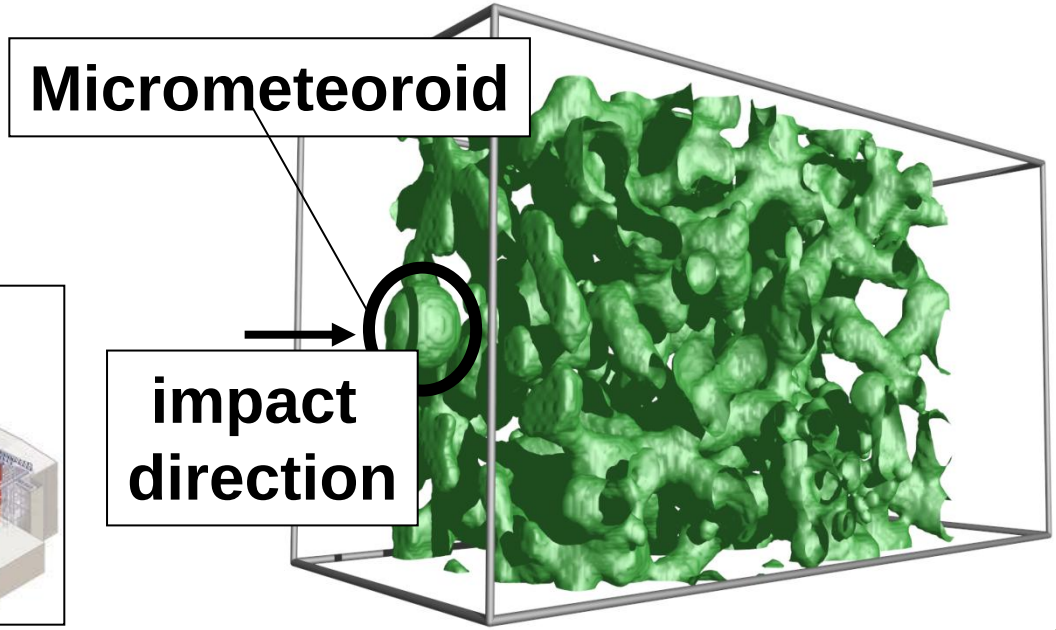
Quantitative Analysis of the Impact of a Micrometeoroid in a Porous Medium

- **Many possible applications:**
  - **NASA's Stardust Spacecraft**
  - **National Ignition Facility Targets**
  - **Light and Robust Materials**
  - **many more...**



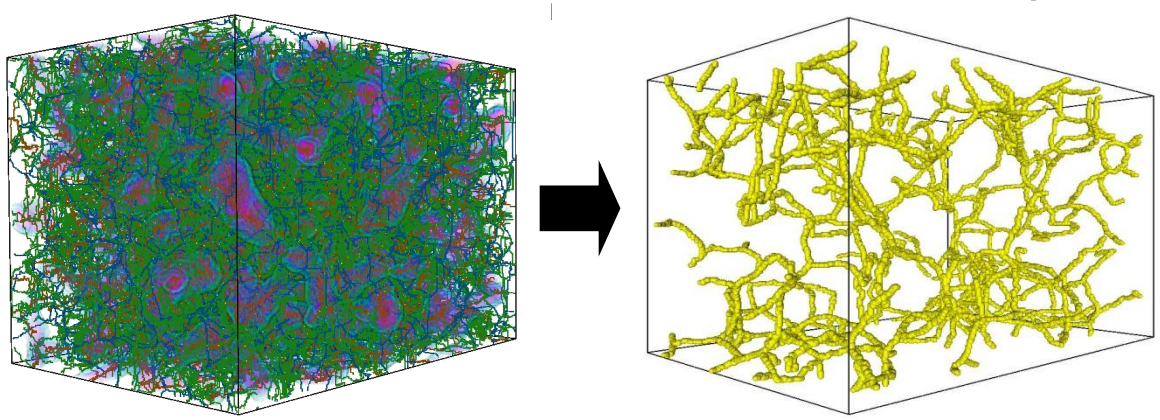




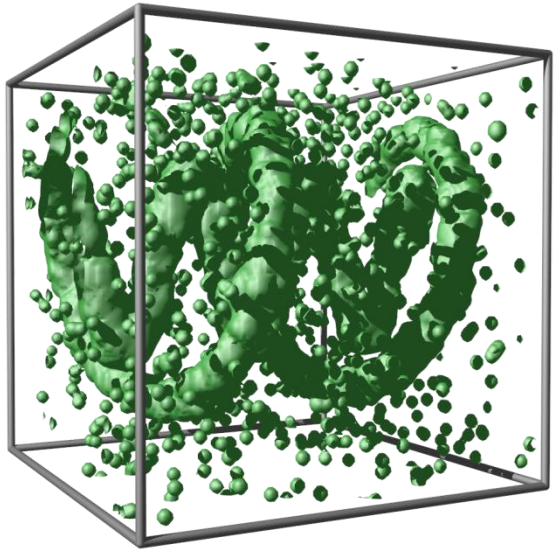


The Topological Reconstruction Method is Validated with a Controlled Test Shape

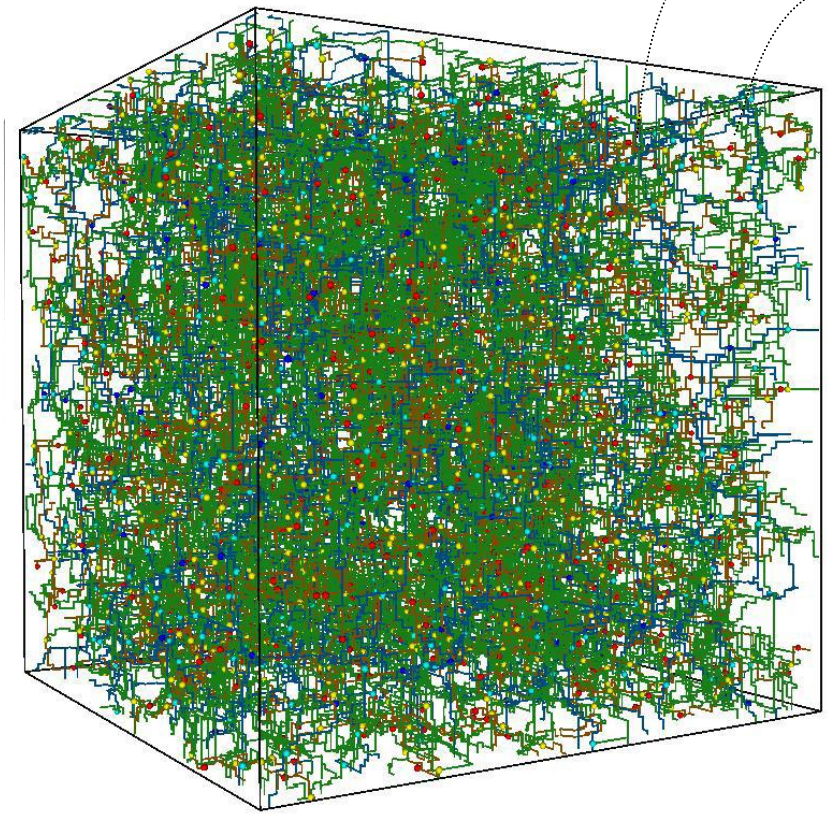
Challenge: robust reconstruction of the structure of a porous medium

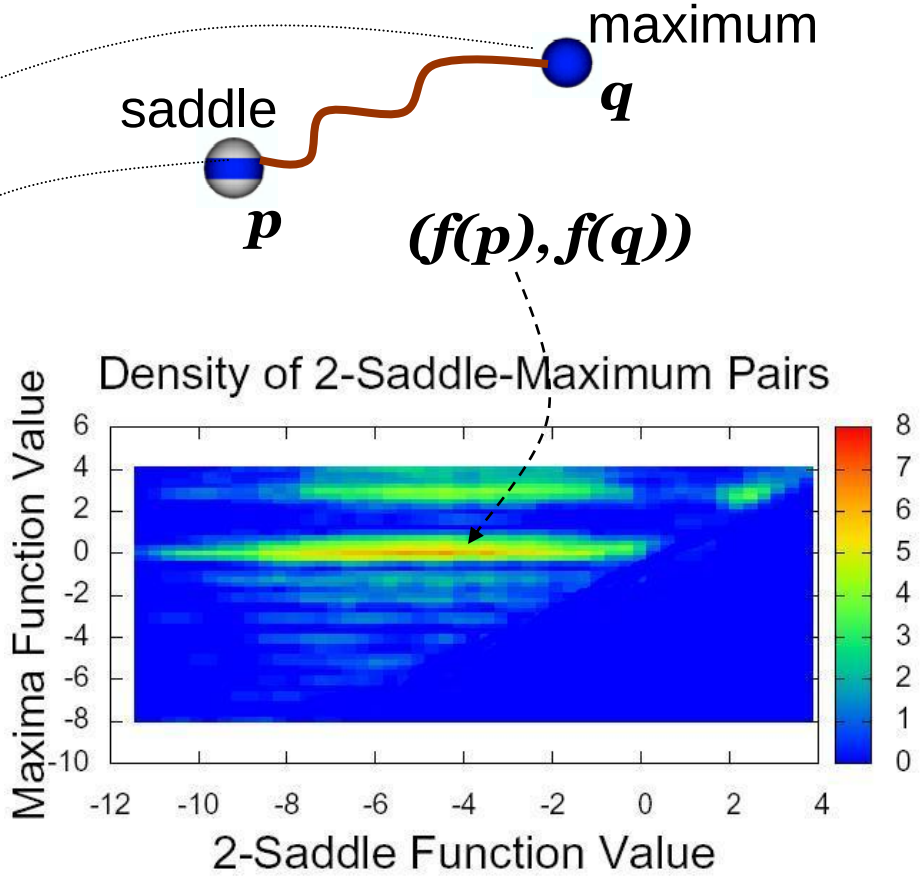


Preparation: we develop control test data to validate the approach

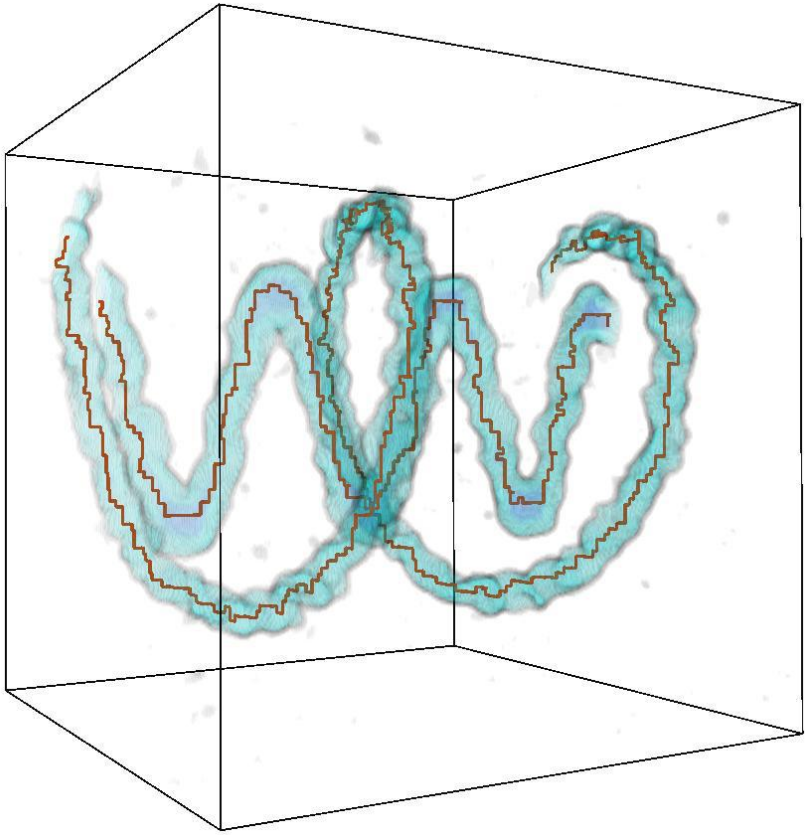


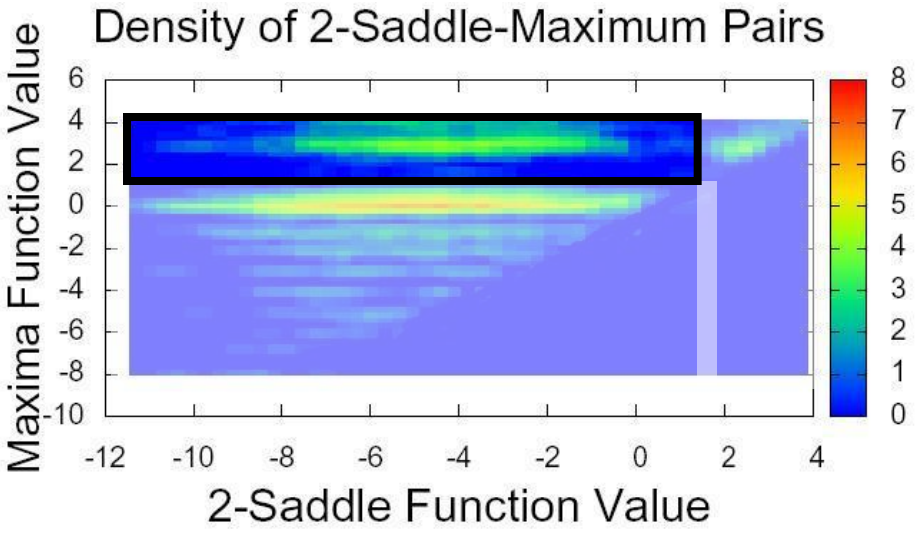
We Report the Distribution of Topological Features in the Full Resolution Data



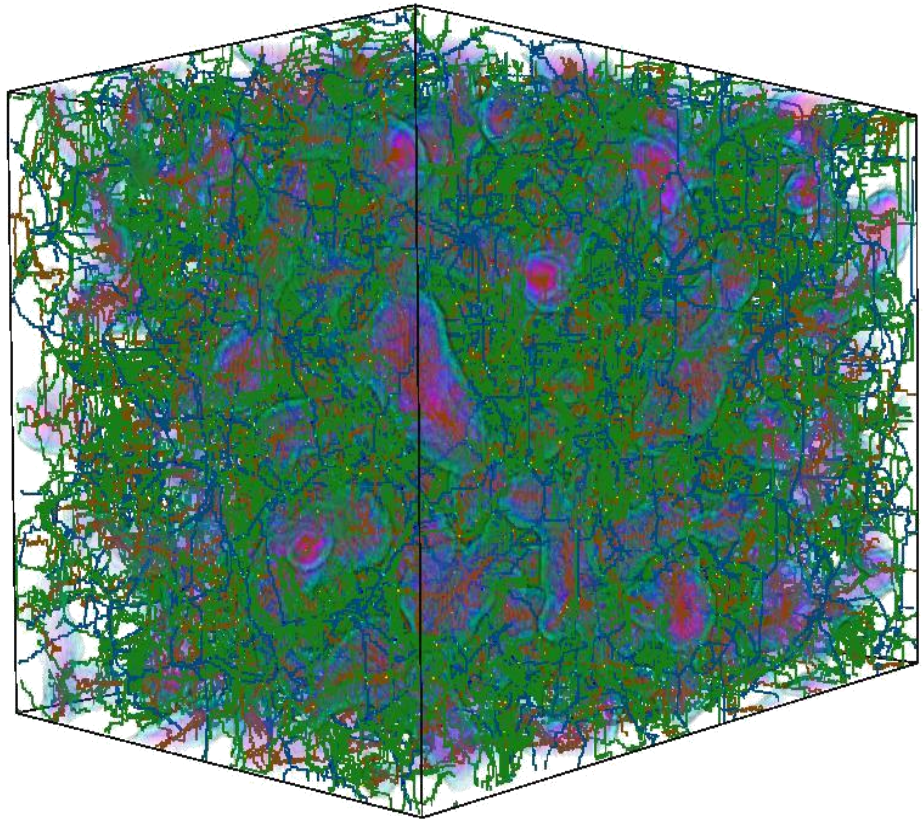


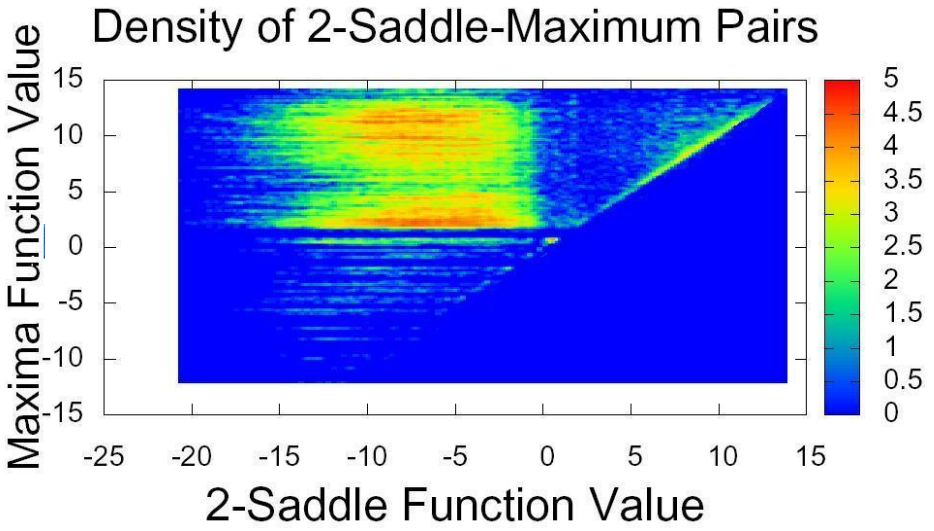
The Hierarchical Morse-Smale Complex Has Very Good Reconstruction Properties



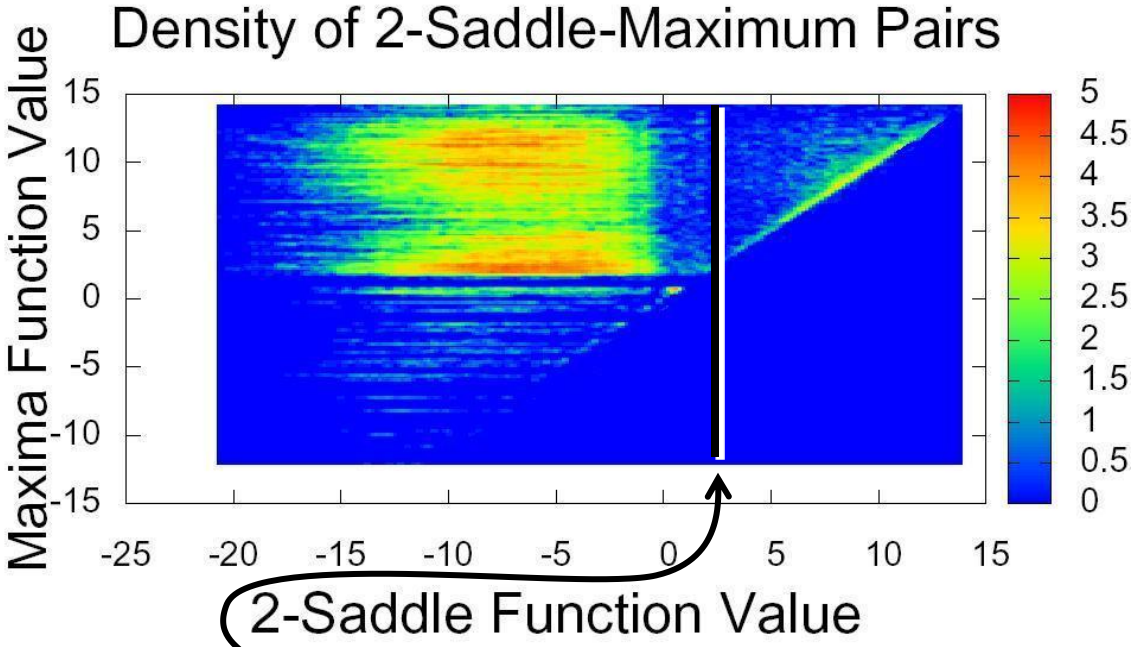


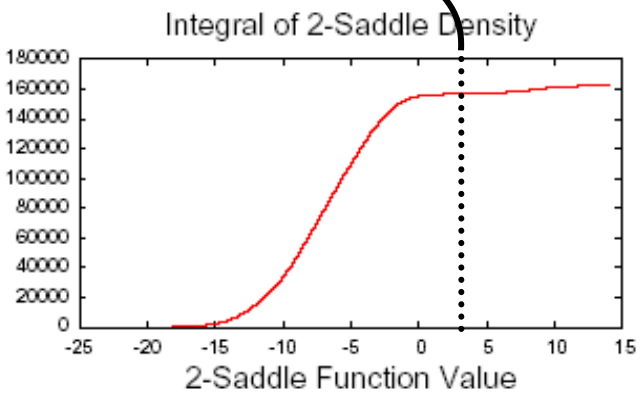
We Compute the Complete Morse-Smale Complex for the Porous Medium

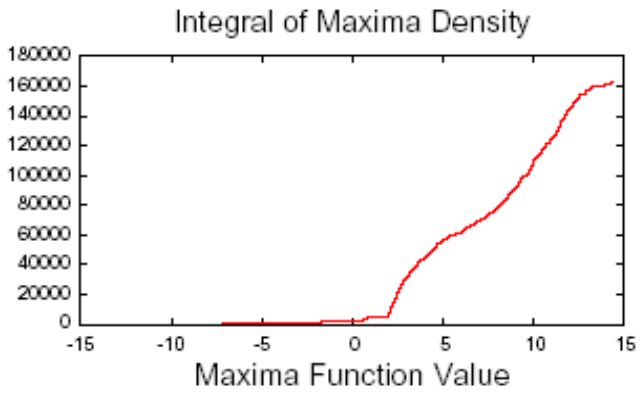




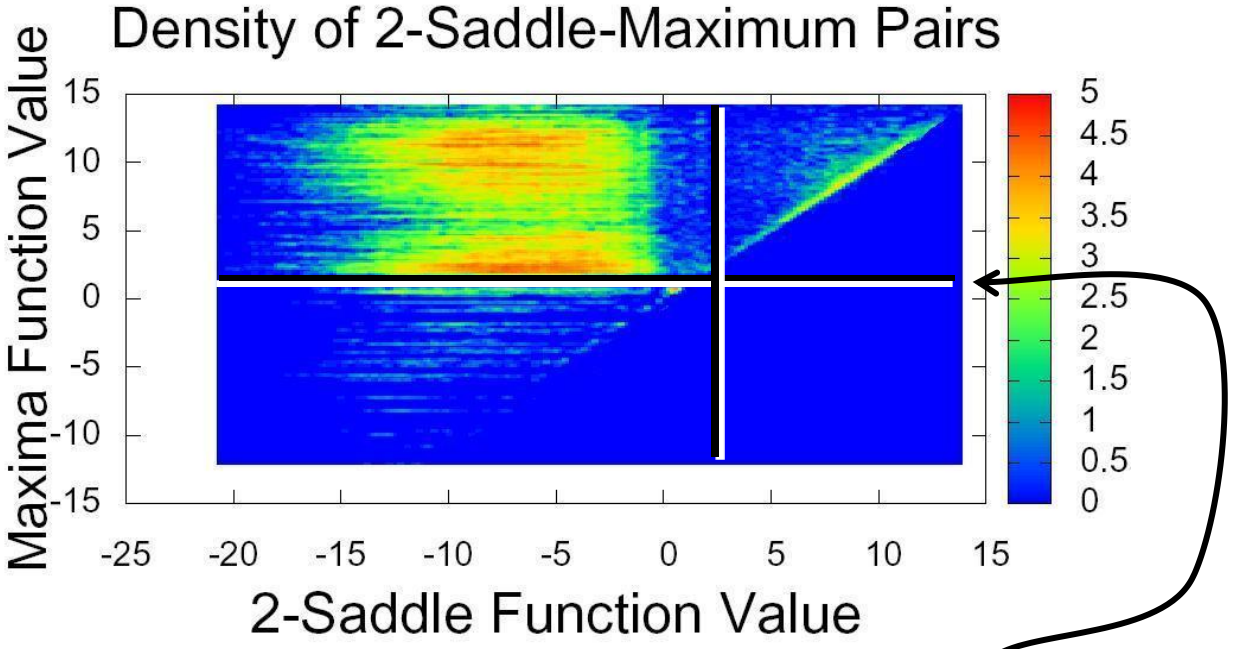
Need to Find Proper Threshold Values and Characterize the Stability of the Solution

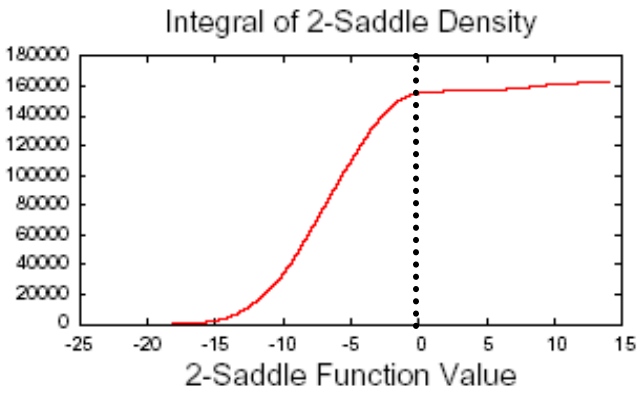


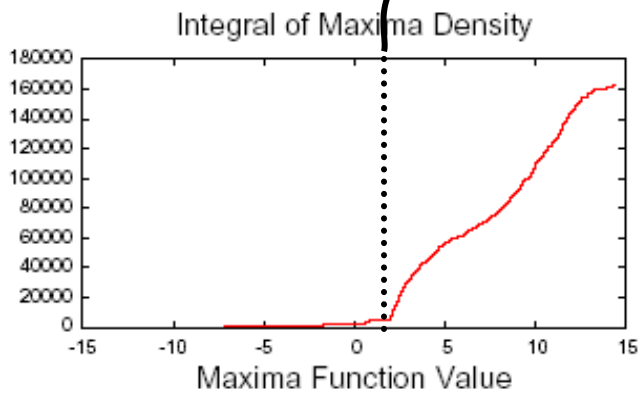




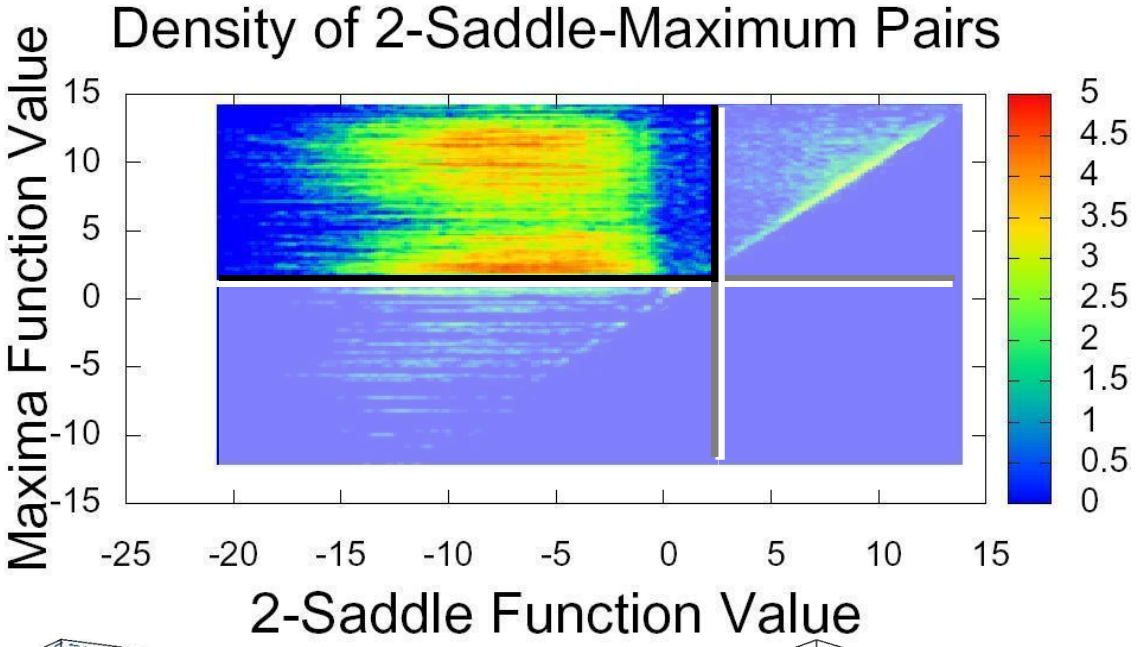
Need to Find Proper Threshold Values and Characterize the Stability of the Solution

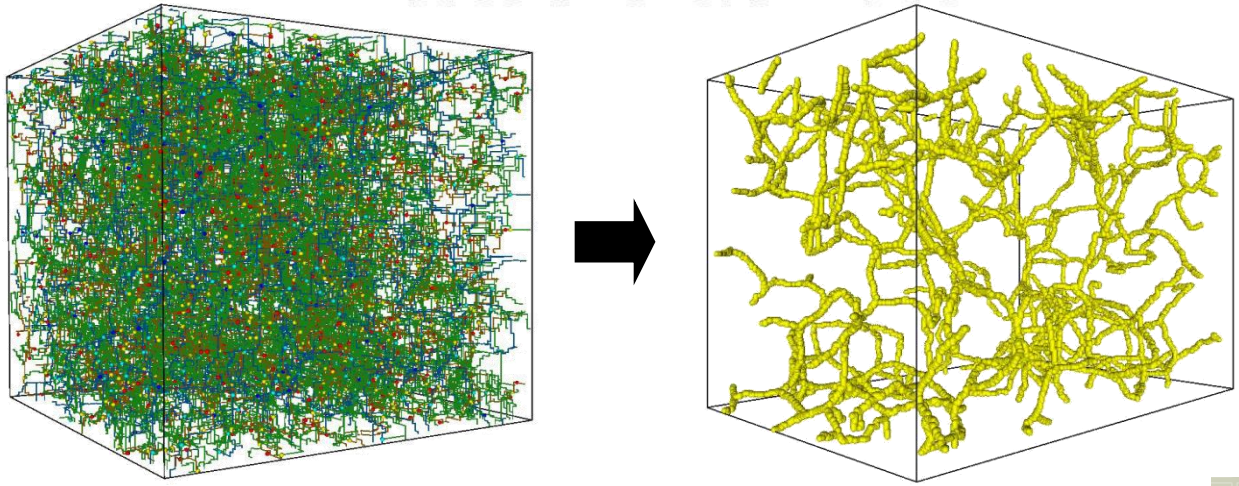




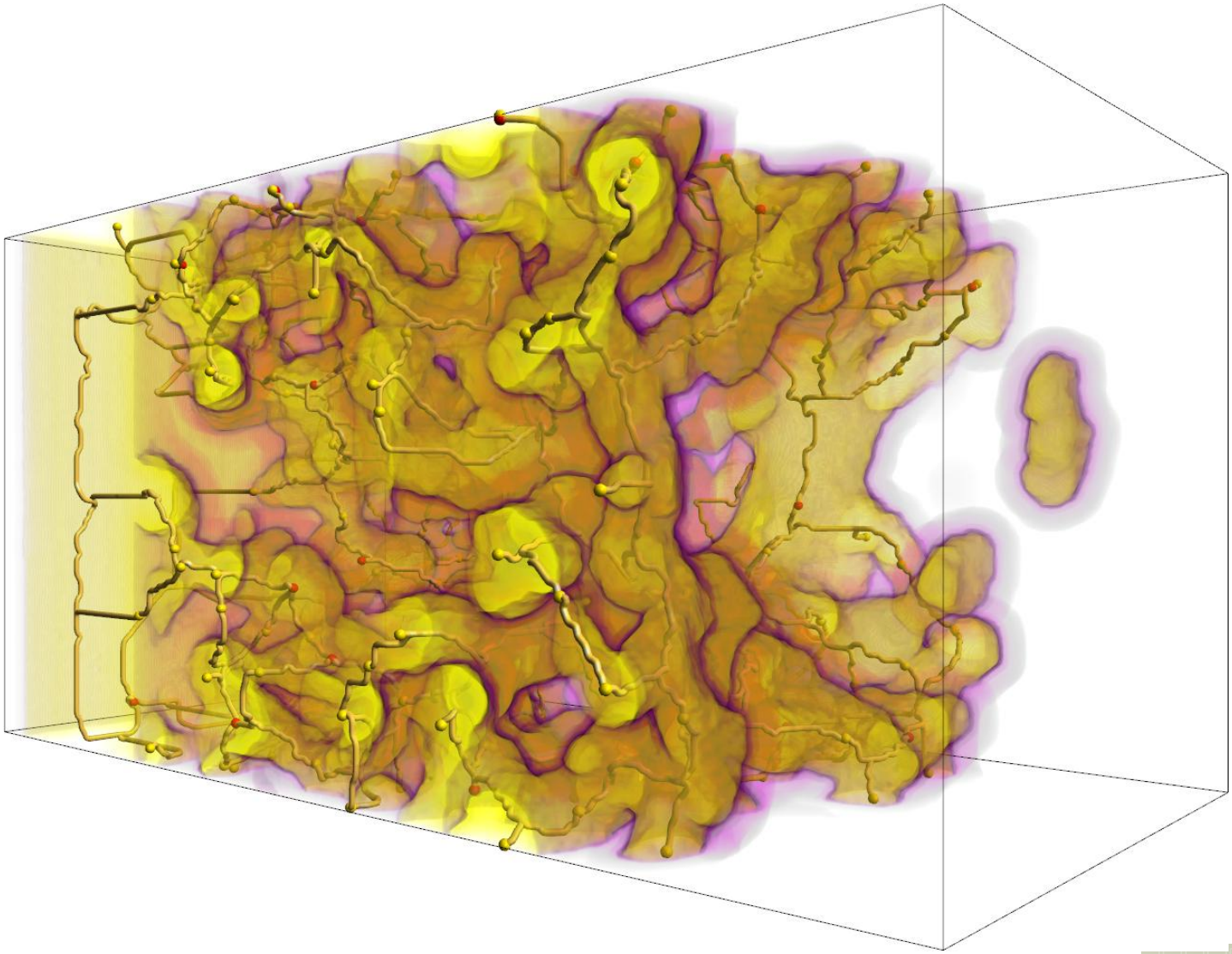


We Obtain a Robust Reconstruction of the Filament Structures in the Material

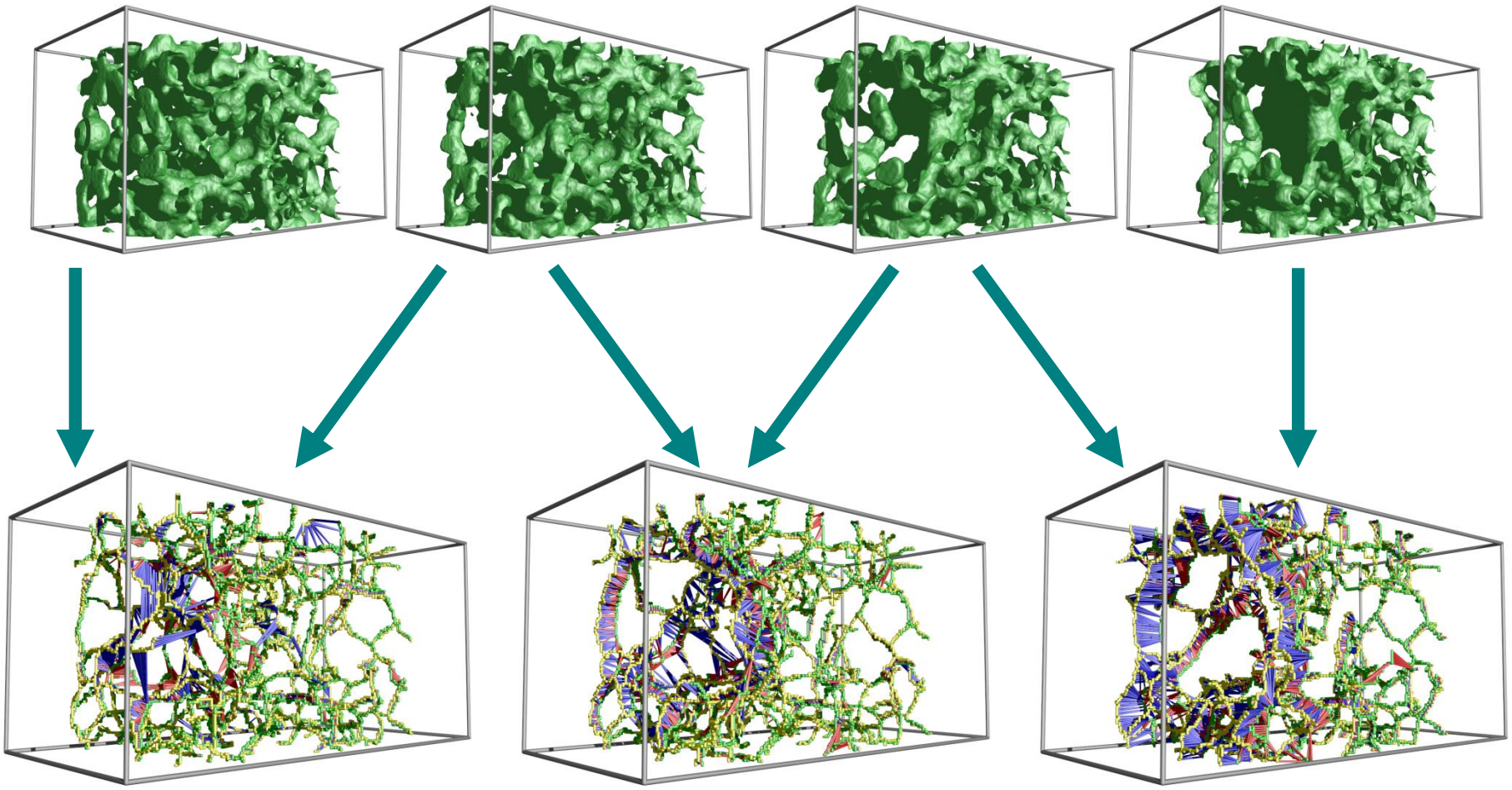




Demo Porous Medium



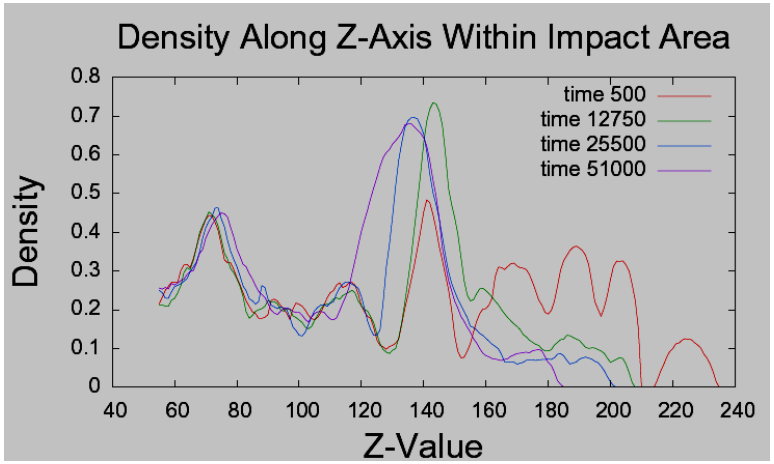
We Track the Evolution of the Filament Structure of the Material Under Impact

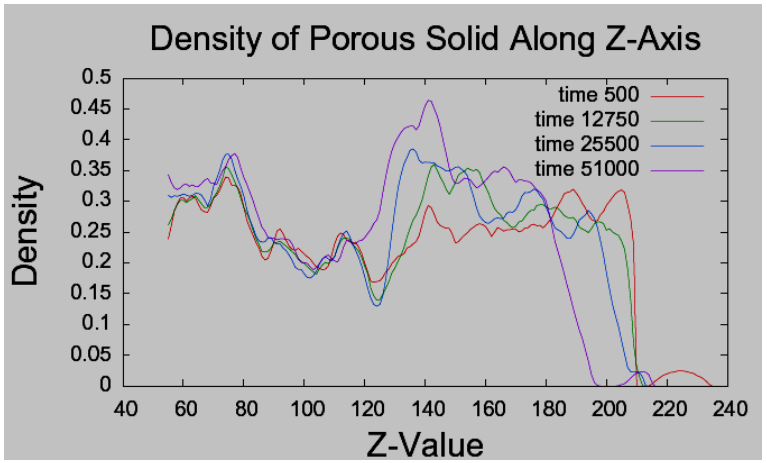


Time comparison of the reconstructions

The Extracted Structures Allow to Quantify the Change in Porosity of the Material

Density profiles





Decay in porosity of the material

Metric	t=500	t=12750	t=25500	t=51000
# Cycles	762	340	372	256
Total Length	34756	24316	23798	18912

Data Analysis and Visualization Center is a Catalyst for a Virtuous Cycle of Collaborative Activities

- Tight cycle of :
  - basic research,
  - software deployment
  - user support
- Coordination among many projects:
  - unified techniques for several applications
- Strong University-Lab-Industry collaboration
- Focused technical approach:
  - performance tools for fast data access
  - general purpose data exploration
  - error bounded quantitative analysis
  - feature extraction and tracking
- Interdisciplinary collaboration with domain scientists (from math to physics):
  - motivating the work
  - formal theoretical approaches
  - feedback to specific disciplines