# Spatio-temporal Feature Exploration in Combined Particle/Volume Reference Frames

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VISUALIZATION & INTERFACE DESIGN INNOVATION

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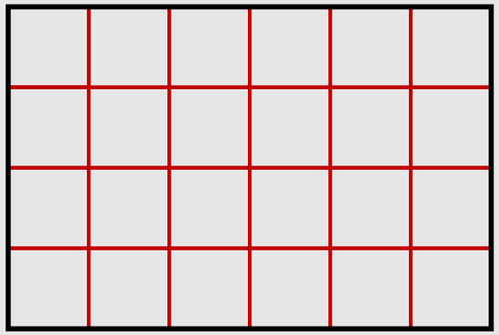
# Introduction: Problem Statement

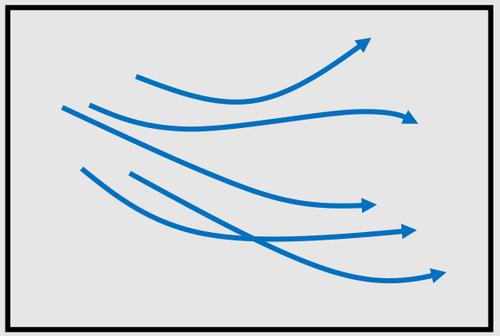
- More scientific simulations are using multiple data representations
  - Volume-based (Eulerian) representation
  - Particle-based (Lagrangian) representation
- Limited work on combining the advantages of each for visualization and analysis purposes
- How can we…
  - …explore the spatial and temporal interplay between each data type?
  - …represent information from each data type simultaneously?

# **Background:** Eulerian/Lagrangian Reference Frames

- Eulerian representation (volume data)
  - Record information on a fixed grid
  - Easy to analyze fluctuations at specific locations
  - Must use interpolation between grid points



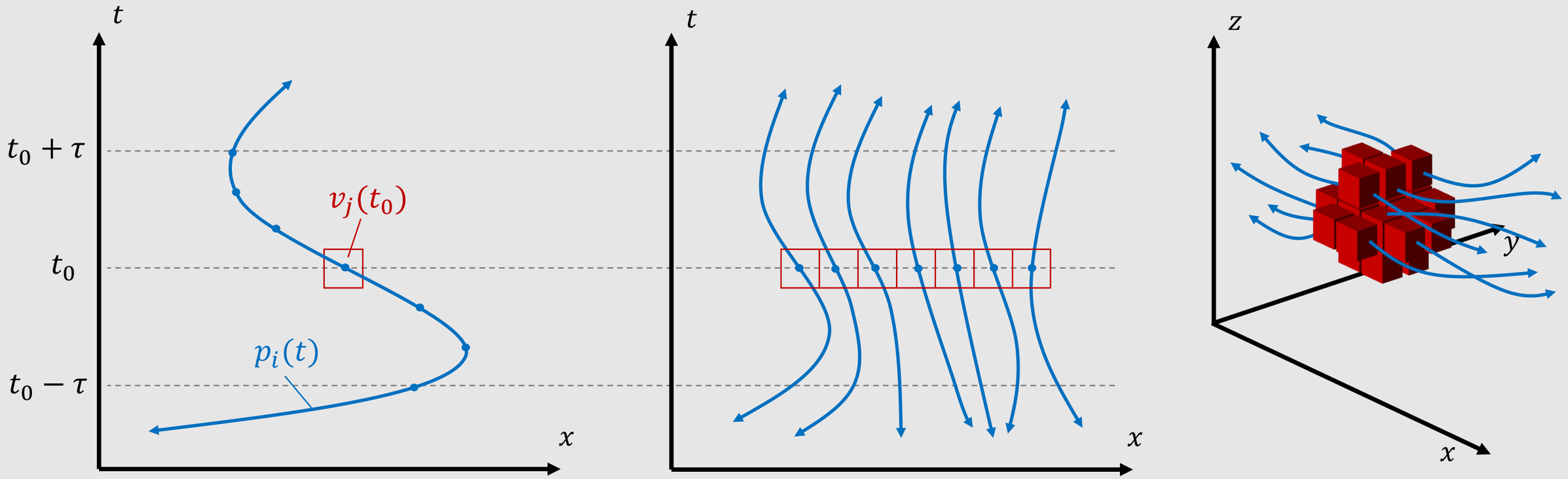
- Lagrangian representation (particle data)
  - Follow the motion of discrete parcels throughout a domain
  - Spatial evolution adds a new perspective (trajectory geometry)
  - Particles may not always be present in certain locations



- Use spatial proximity to connect particles with volume cells
- Use a “spatio-temporal origin” in one data type and explore a temporal window in the other data type

# **Methods:** Spatio-temporal Neighborhood Extraction

Using the Eulerian (volume) reference frame as a spatio-temporal origin:



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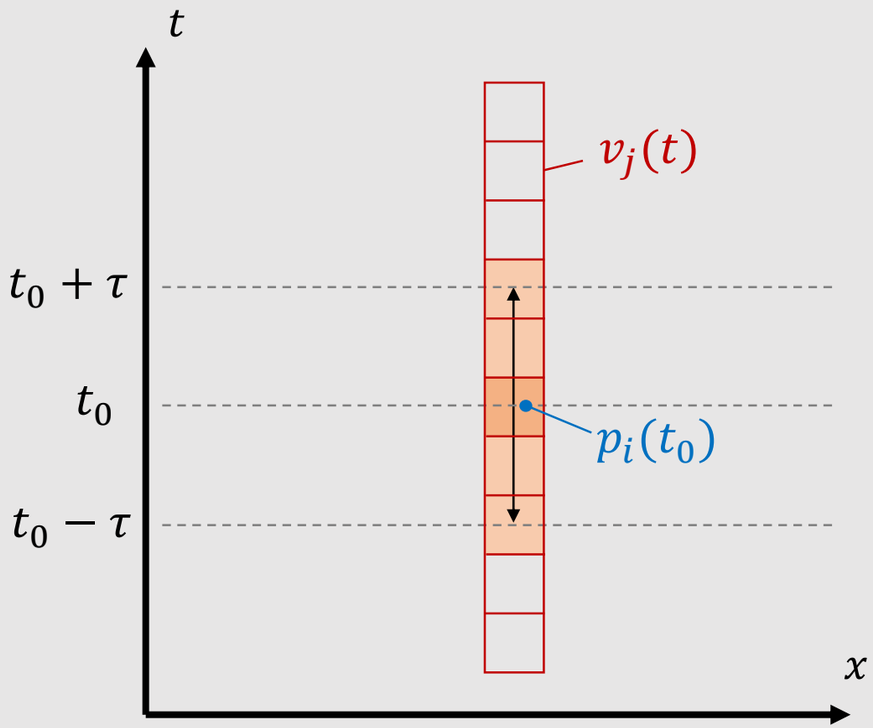
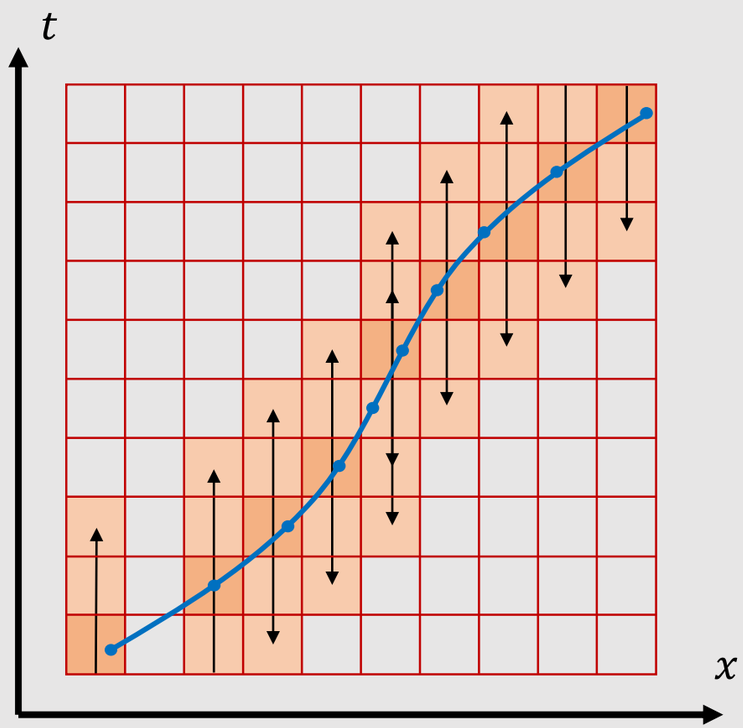
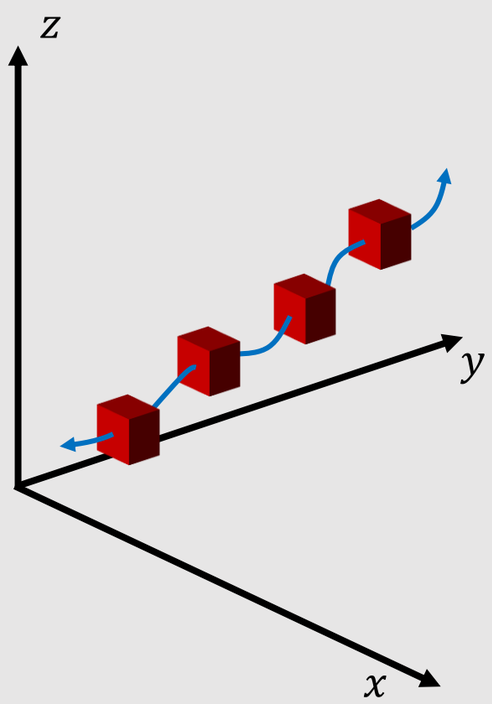


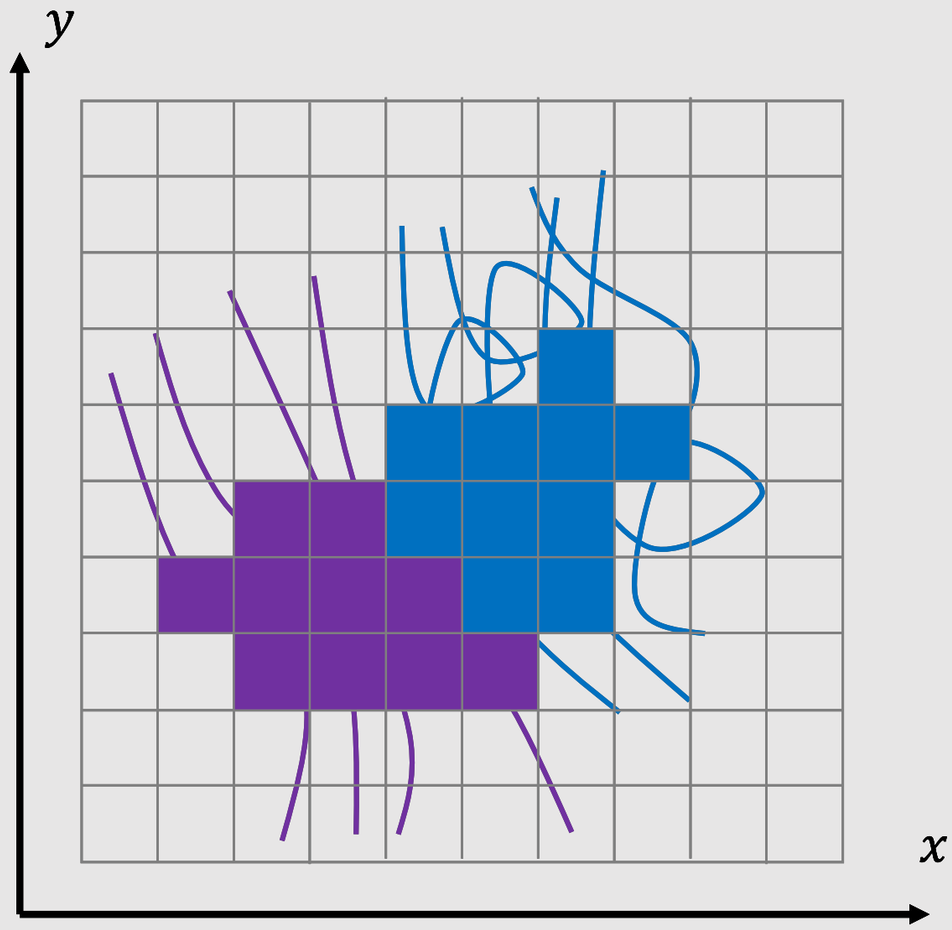



# **Methods:** Spatio-temporal Segmentation

- Propagate segmentation from one frame to another
- Example: segmenting a volume feature using trajectory geometry

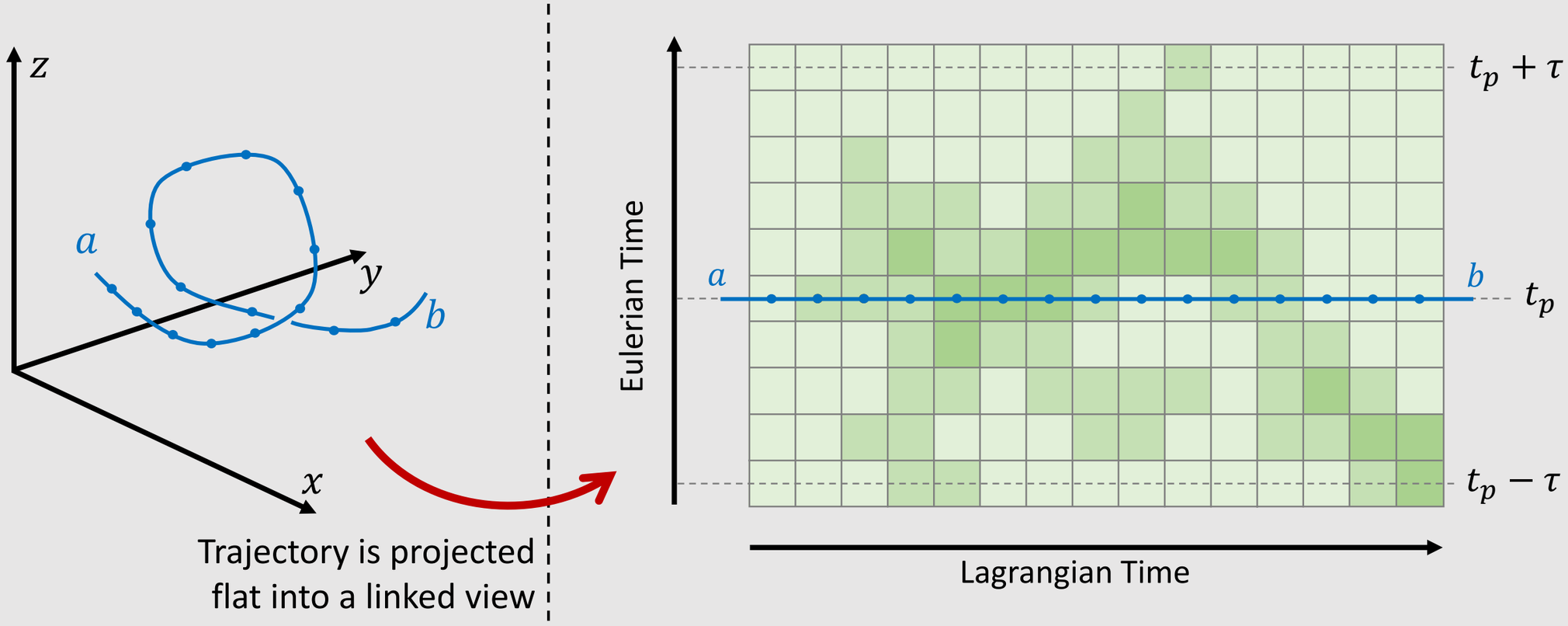
1. Cluster trajectories based on geometry
2. Propagate clusters to spatio-temporal origin
3. Fill in gaps using region growing

Can also be done in reverse
(segment trajectory using volume data)



# **Methods:** Visual Representations

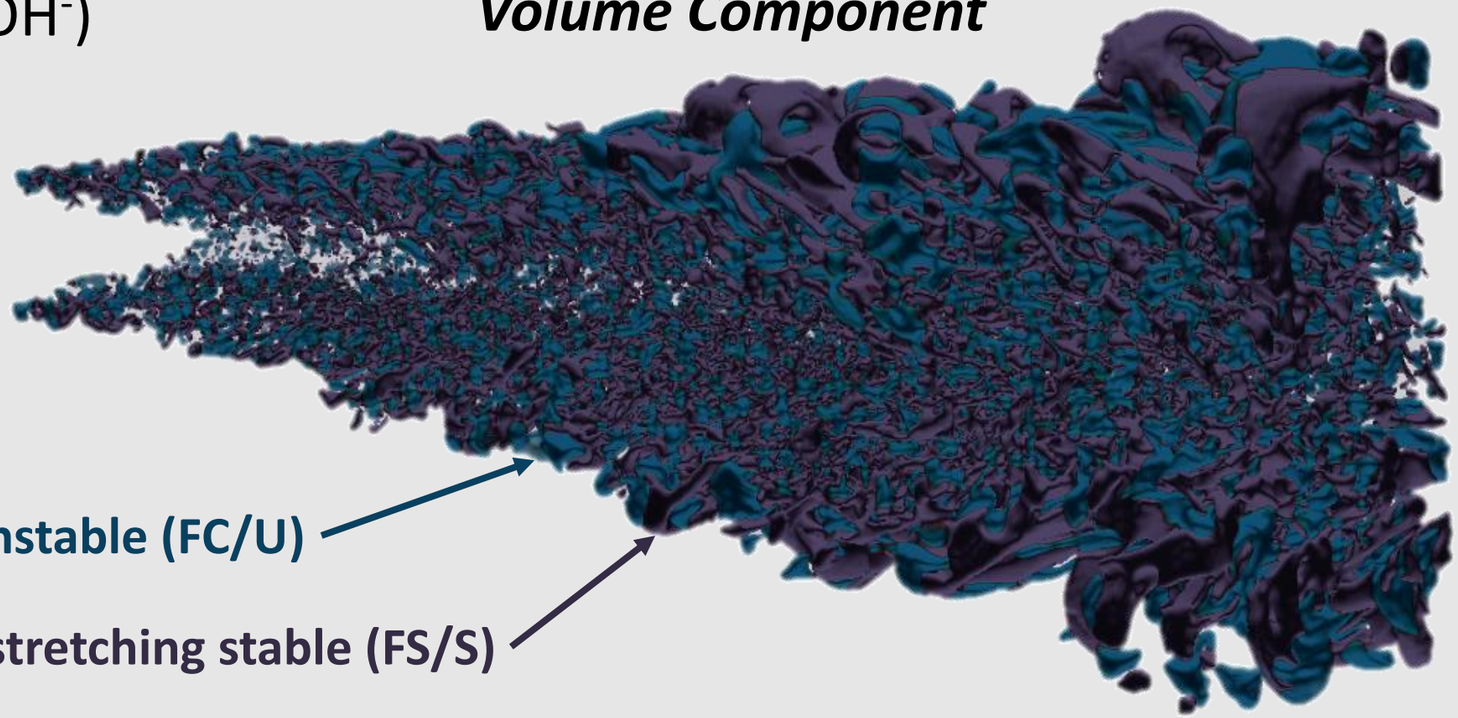
- How to visually depict each type of spatio-temporal feature?
  - **Using a volume feature as an origin:** can draw both components simultaneously
  - **Using a trajectory as an origin:** need something new



# **Results:** Combustion Dataset

- S3D Combustion Simulation by Sandia National Labs
  - Study combustion phenomena like autoignition
  - Design of next generation high efficiency engines
- Particle Data
  - Record chemical mass fractions ($OH^-$)
  - Massless tracers
- Volume Data
  - Scalar/vector fields (structured)
  - Topological flow classifications

***Volume Component***



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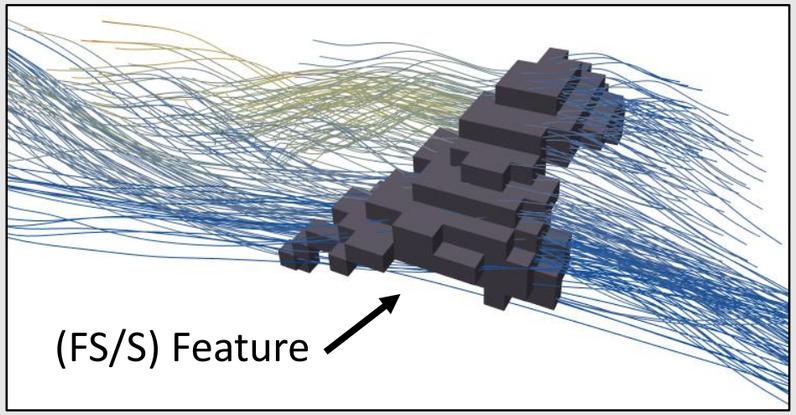
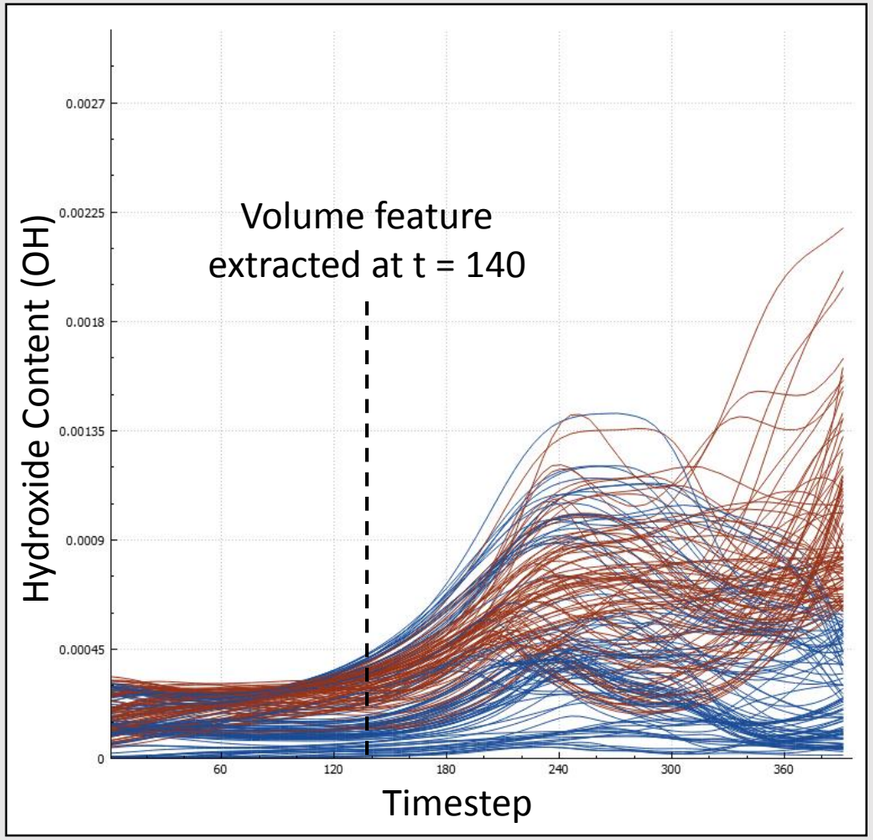
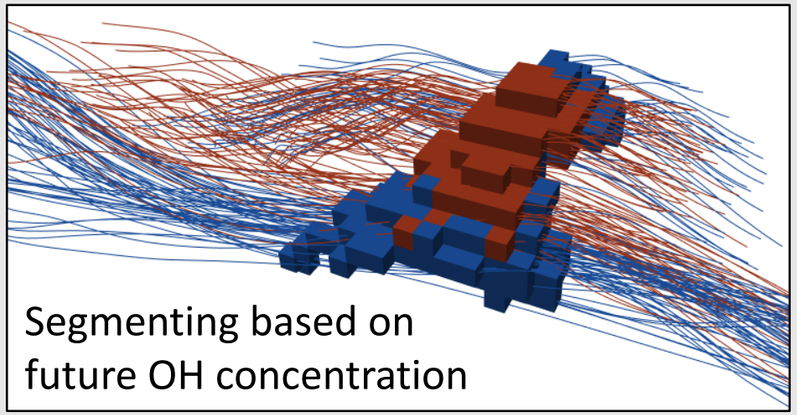


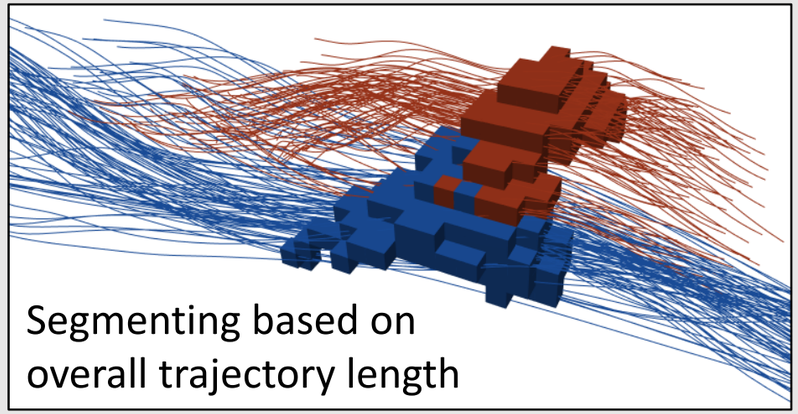

Hydroxide Content (OH)

Low High

Cluster 1 Cluster 2

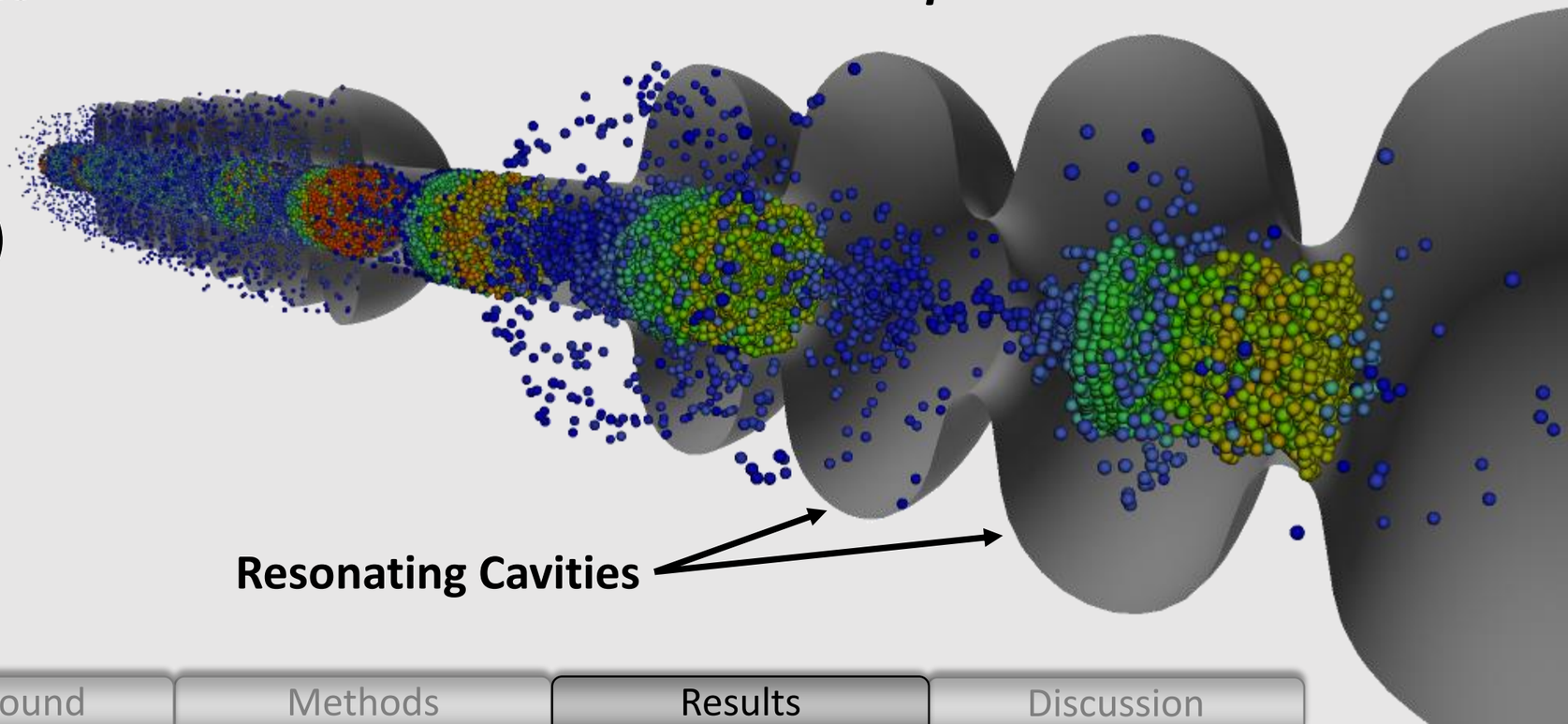


# **Results:** Accelerator Dataset

- ACE3P Simulation by SLAC National Accelerator Laboratory
  - Study electromagnetic dynamics in particle accelerators
  - Dark current in cryomodule devices
- Particle Data
  - Motion of charged particles
  - Emitted from surfaces
- Volume Data
  - Vector field (unstructured)
  - Electromagnetic field



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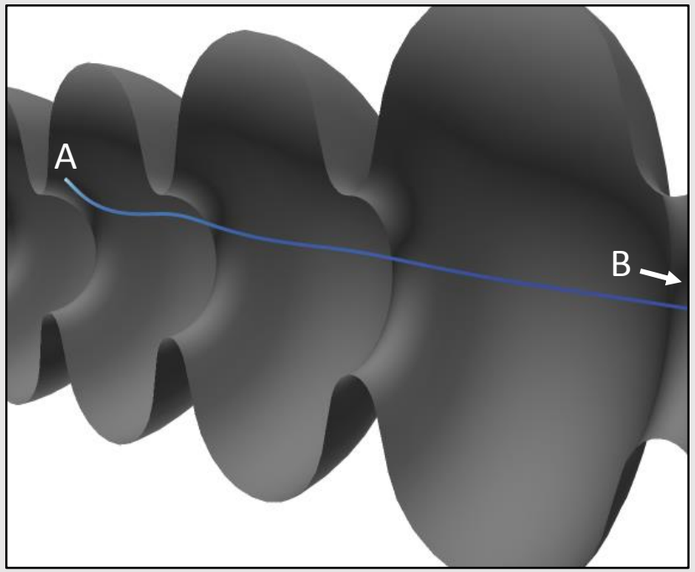
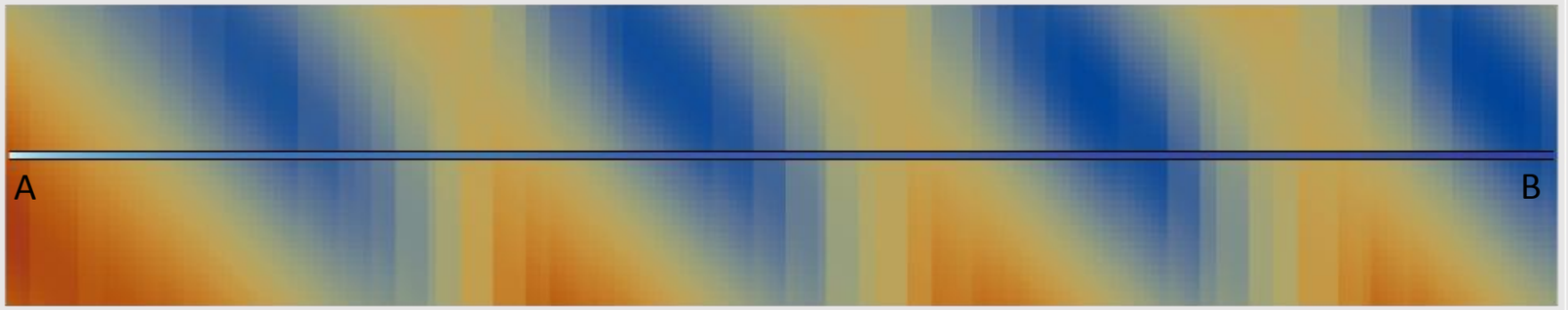
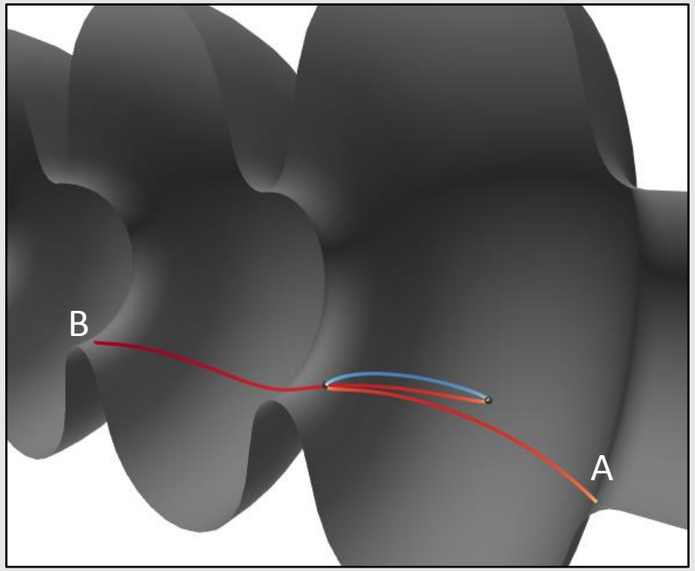
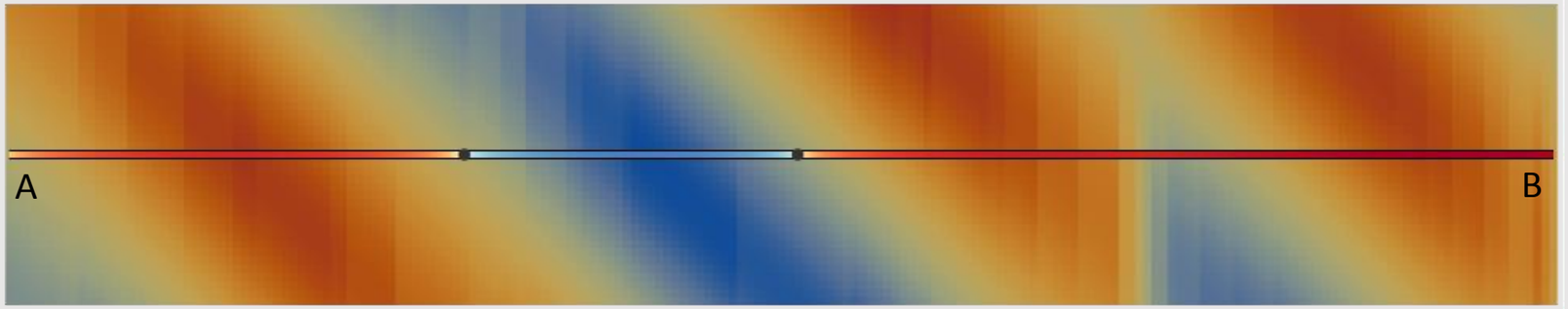


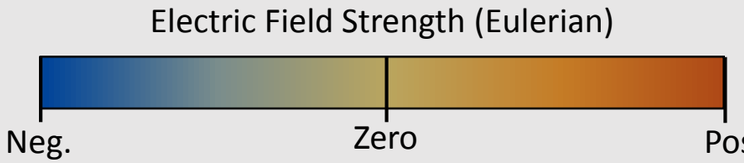



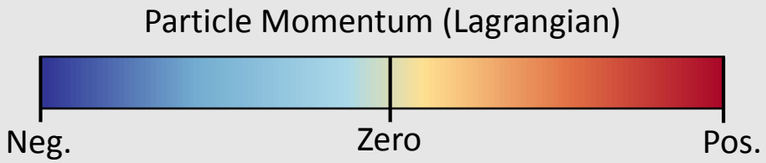

**Vertical Axis:** time in Eulerian frame (each column is a volume cell)

**Horizontal Axis:** time in Lagrangian frame (along a trajectory)



# Discussion: Summary

- Explore spatio-temporal interplay between particle and volume data
  - Extract spatio-temporal neighborhoods
  - Extend this technique to propagate segmentation results
  - Design a new visual representation
- Becoming a necessity as more simulations take advantage of both representations
  - Researchers need to study systems from new perspectives
  - Gain a complete understanding of all aspects of their data

# Thank You
# Questions?

Special thanks to:

- Our collaborators at Sandia National Laboratory
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