# Flow Visualization Research @ IDAV

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CScADS Workshop on
Scientific Data Analysis and Visualization for Petascale Computing

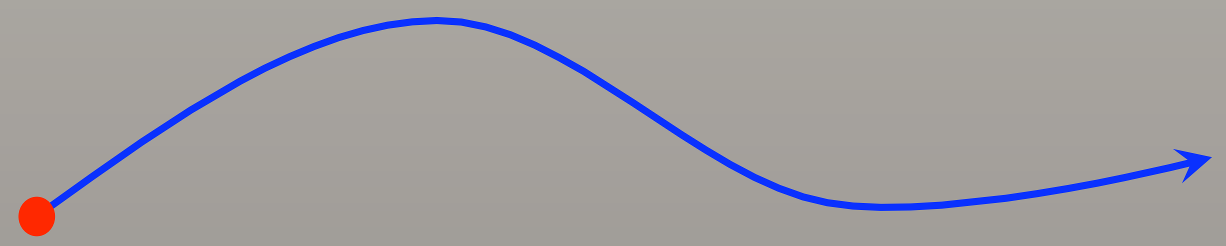
August 6, 2009

# Flow Illustration with Integral Surfaces

(with Hari Krishnan, Ken Joy)

# Integration-Based Flow Vis

## Integral Curve



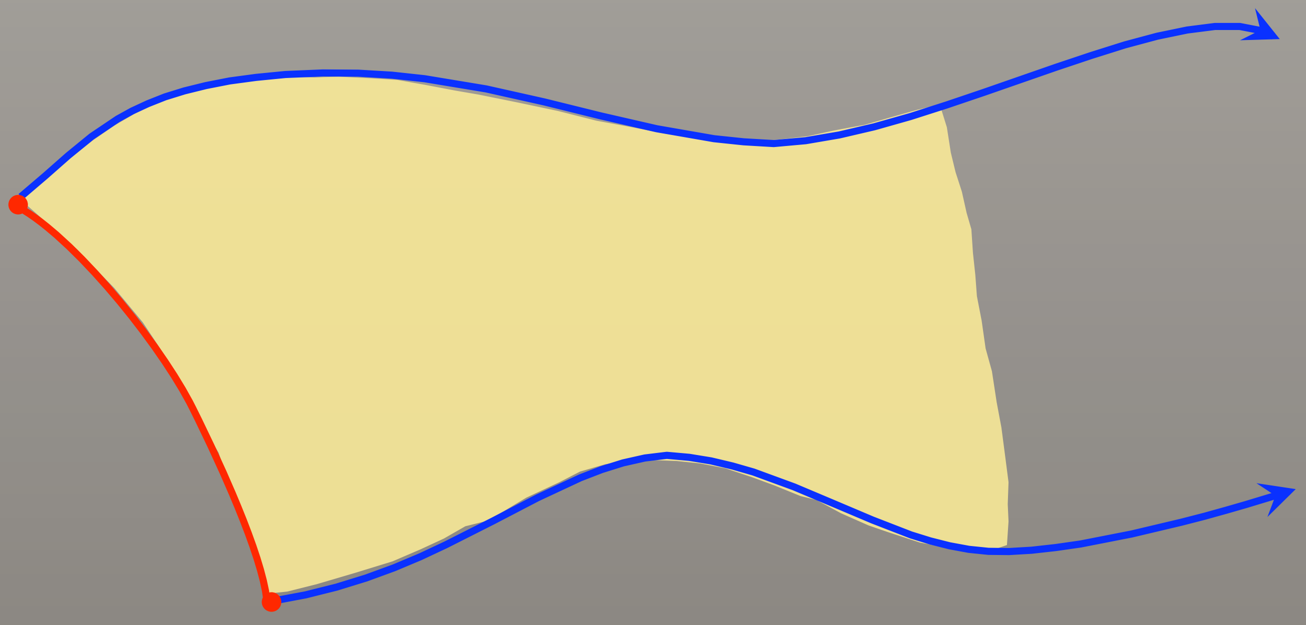
Intuitive interpretation: path of a massless particle

Computation in datasets: numerical integration

# Integral Surfaces

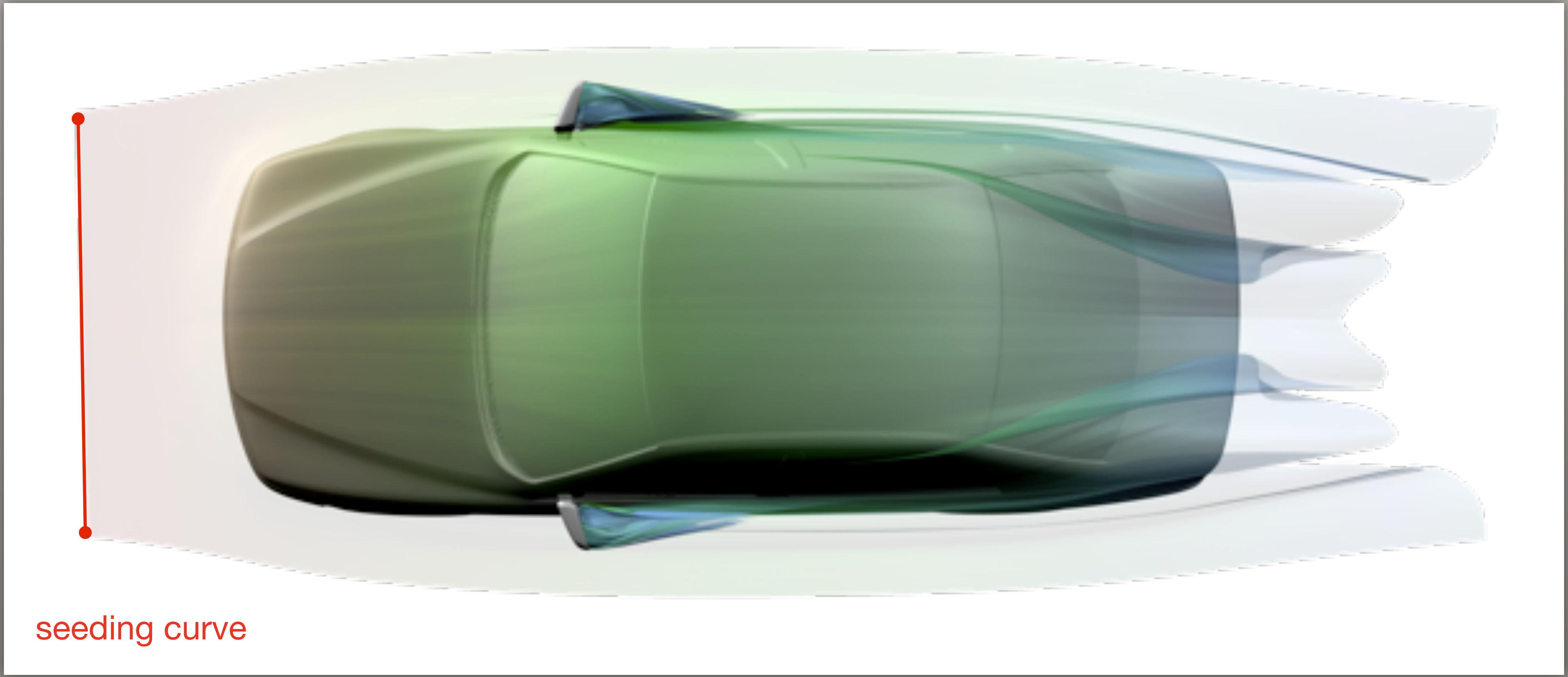
- Generalization: path surfaces

- Interpretation: surface spanned by a family of integral curves, originating from a common curve



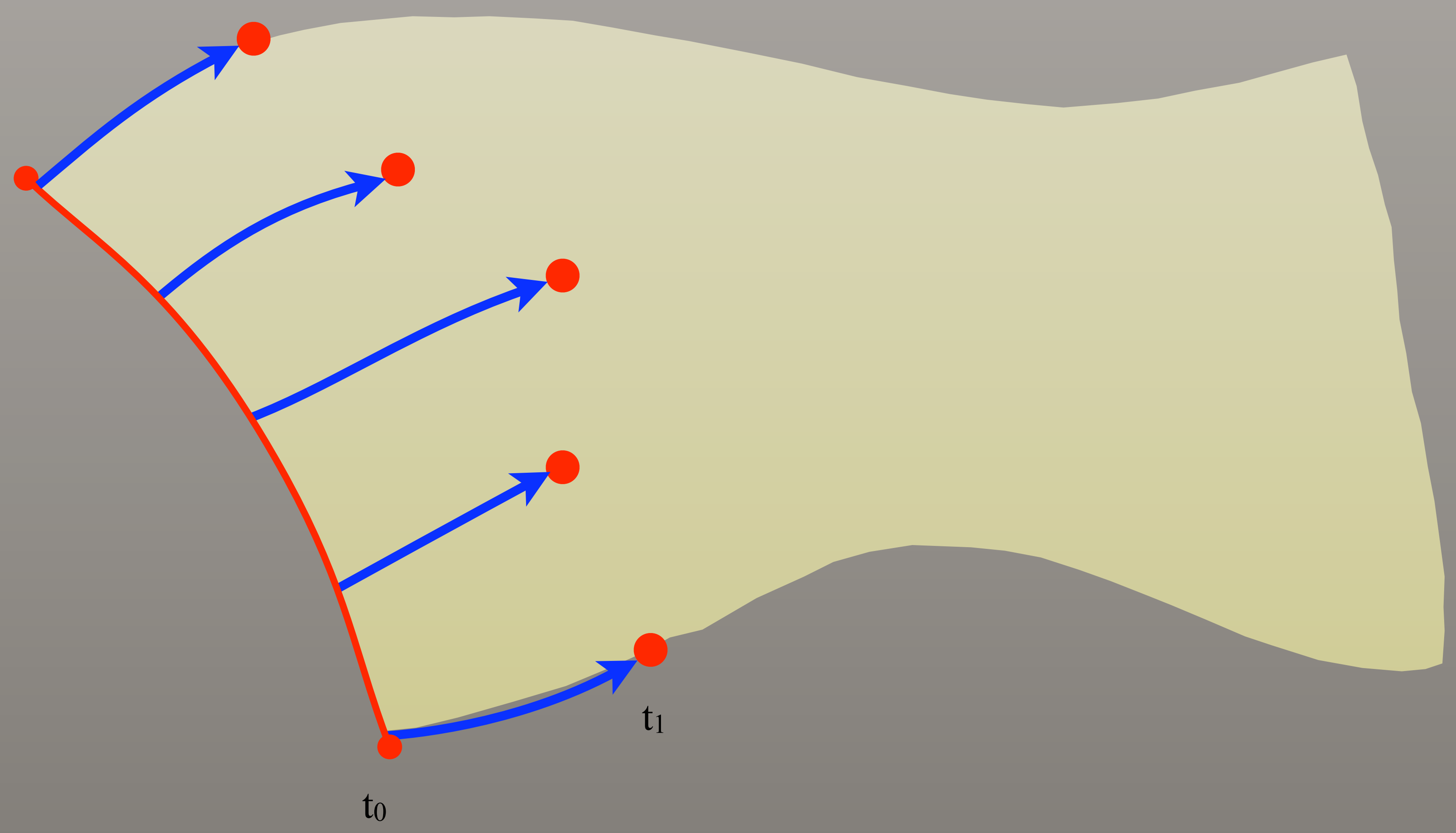
# Integral Surfaces

Flow over a car, 38M unstructured cells



# Integral Surfaces

- Step 1: Compute initial approximation, points on $t_1$ are advected from $t_0$



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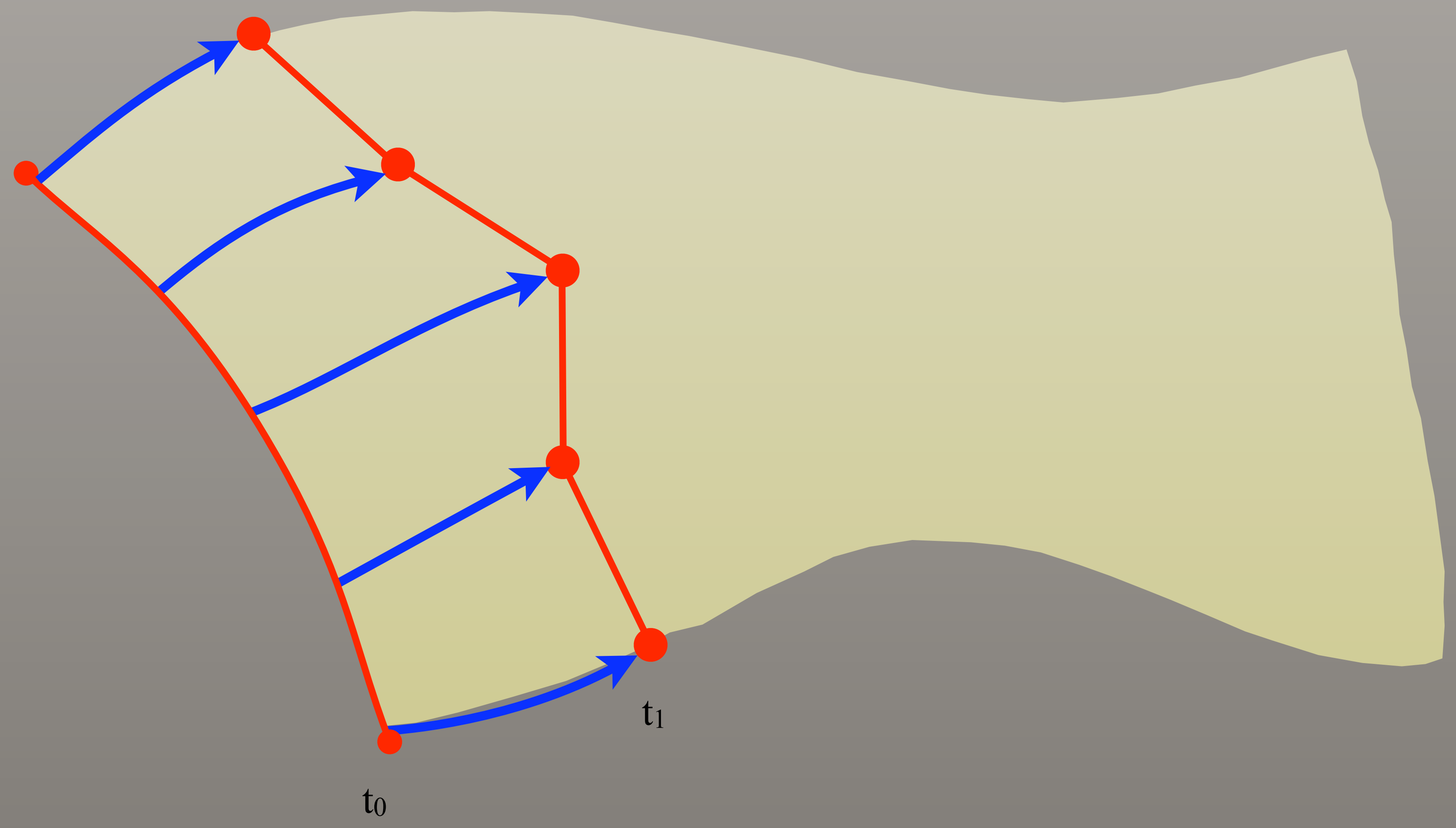
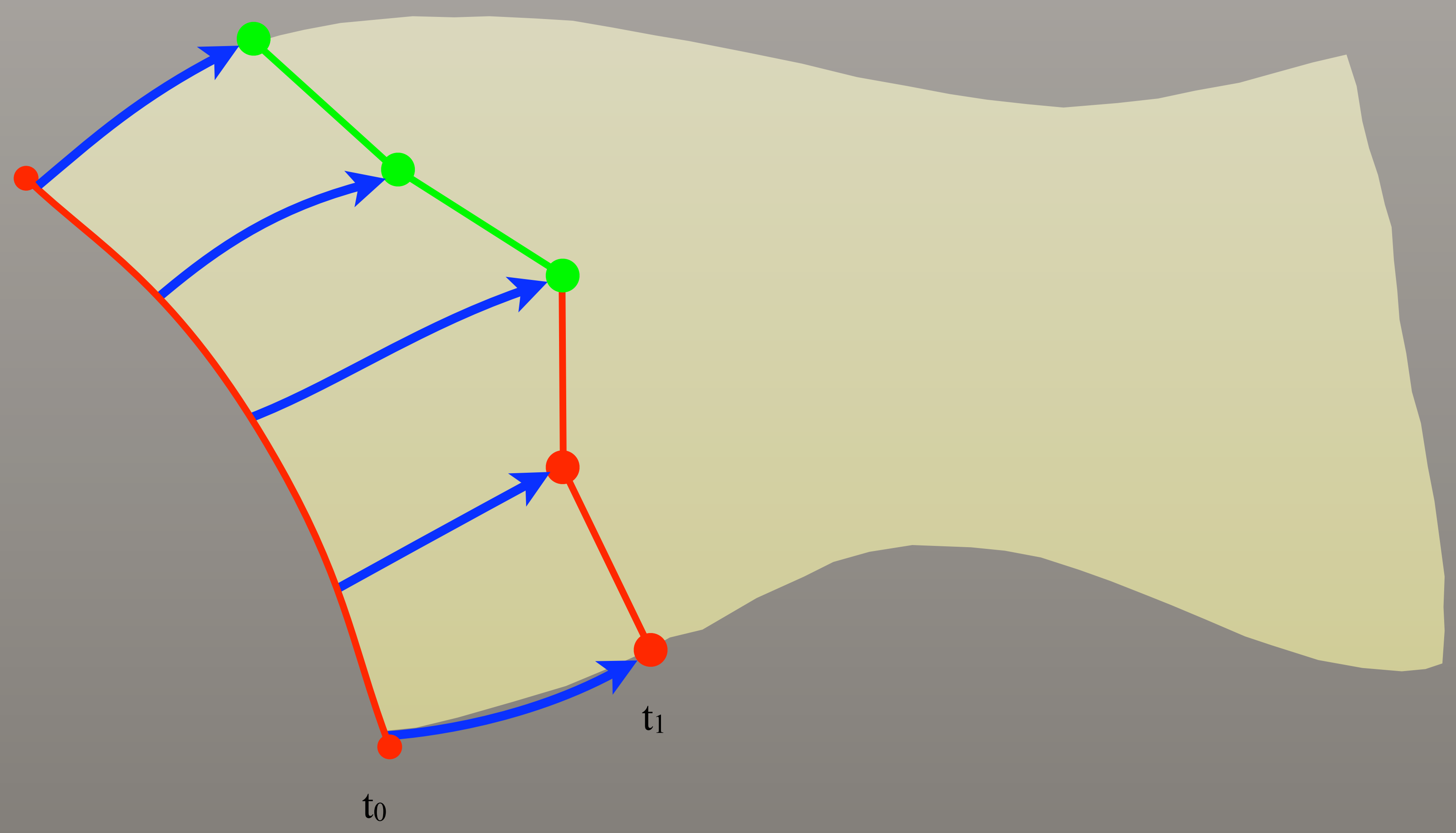


# Integral Surfaces

- Step 2:
  Apply refinement predicate on adjacent point triples to determine where better resolution is needed



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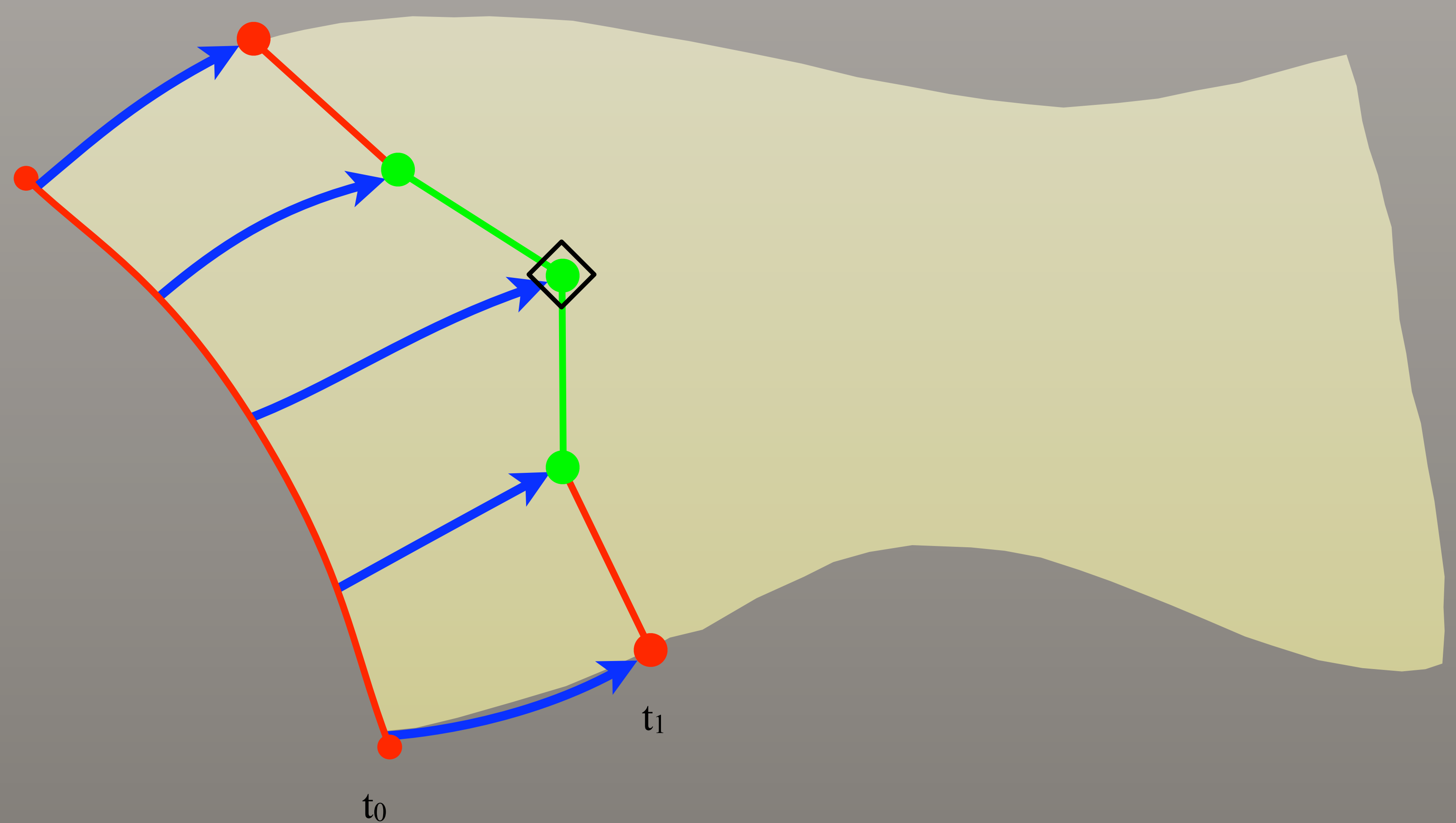

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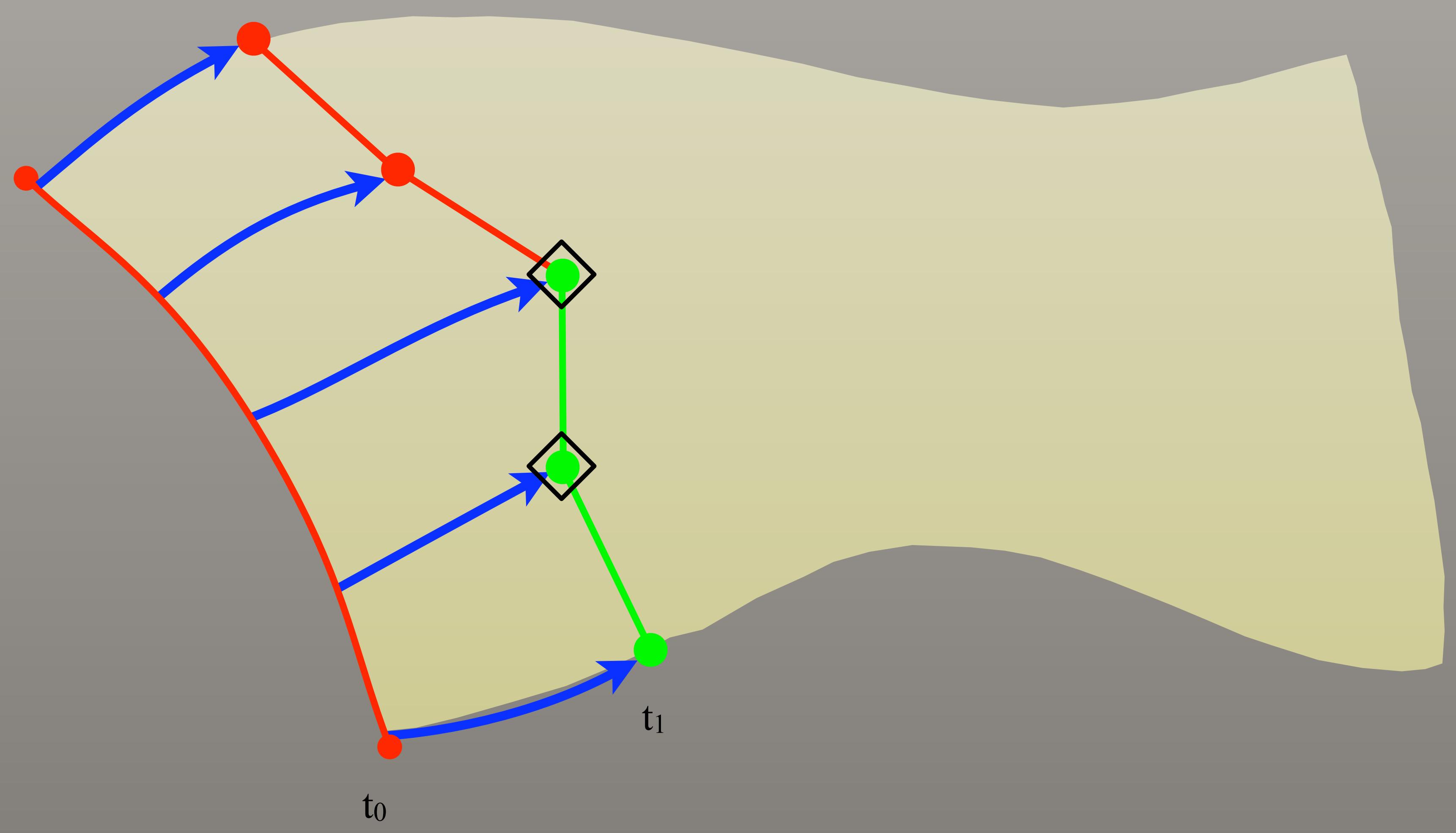

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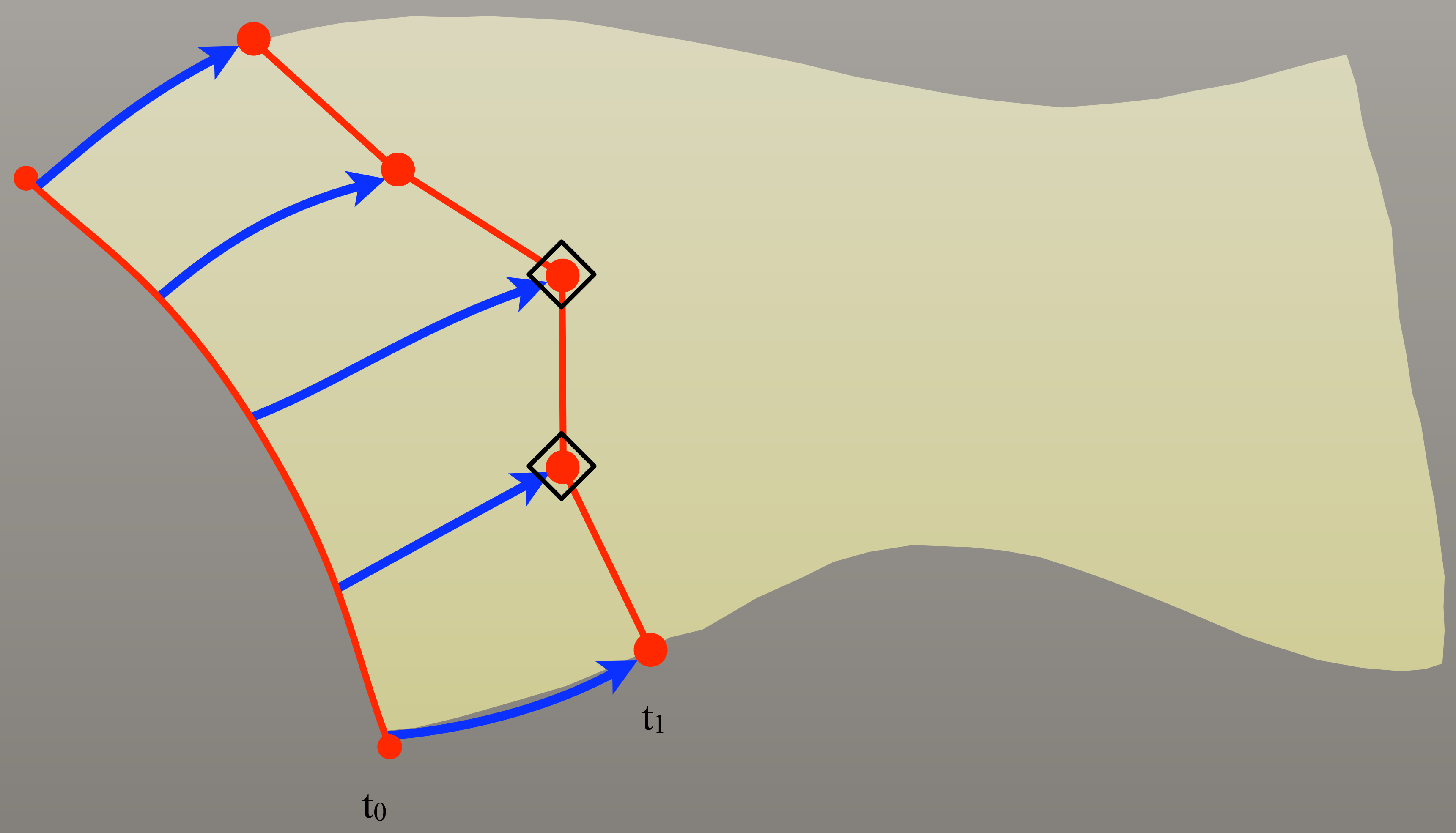
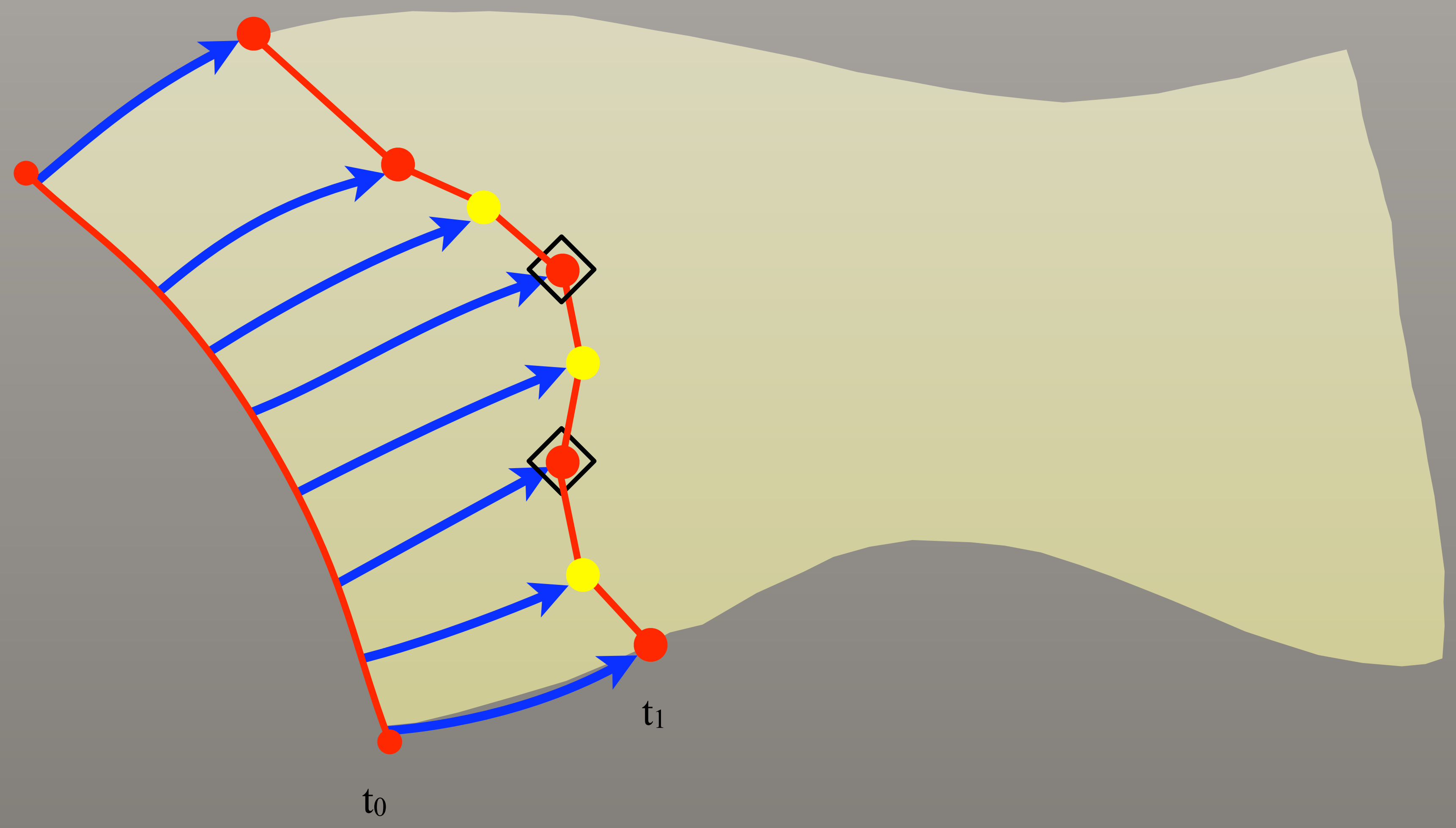


# Integral Surfaces

- Step 3:
  Insert new points



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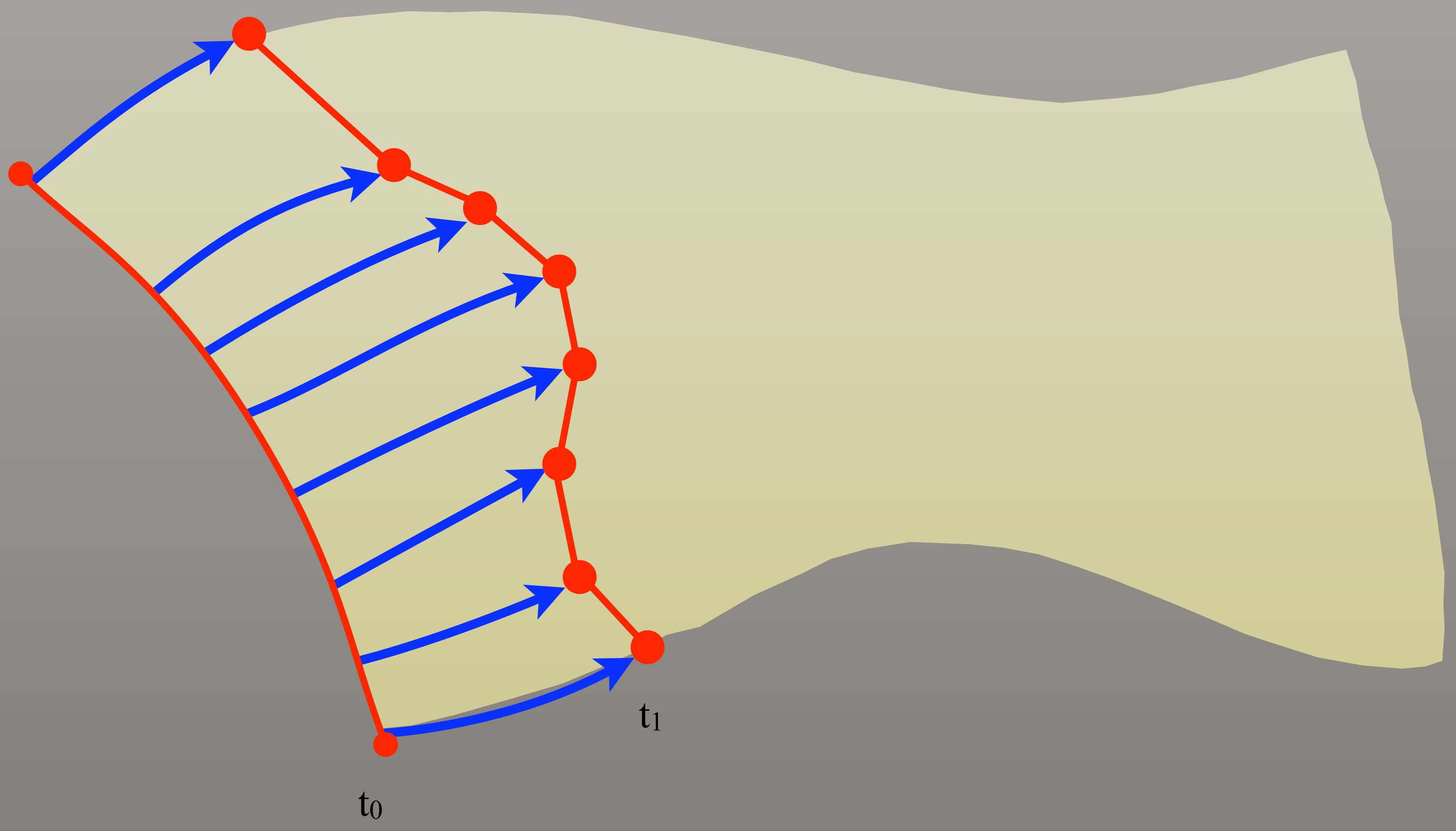
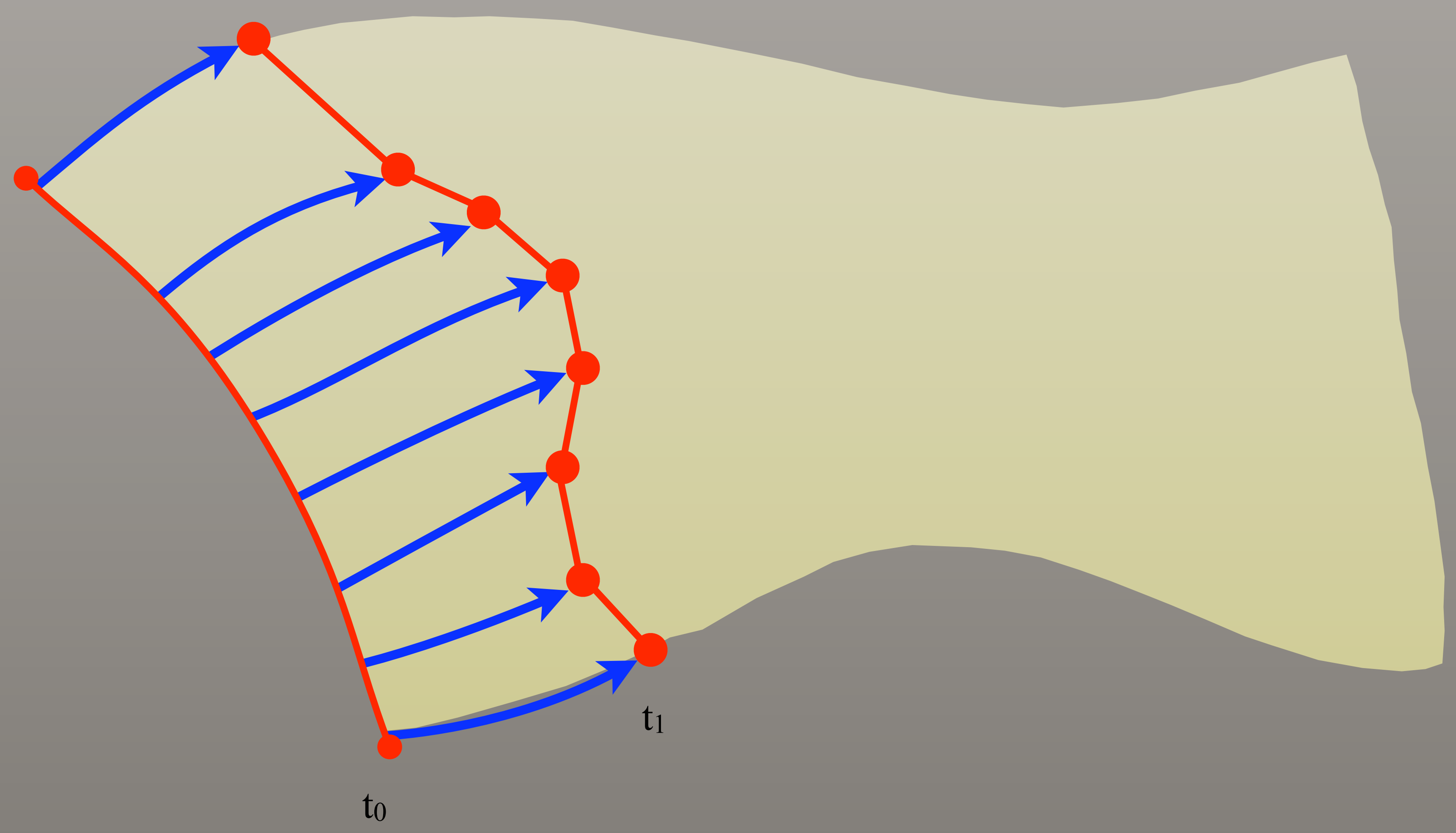


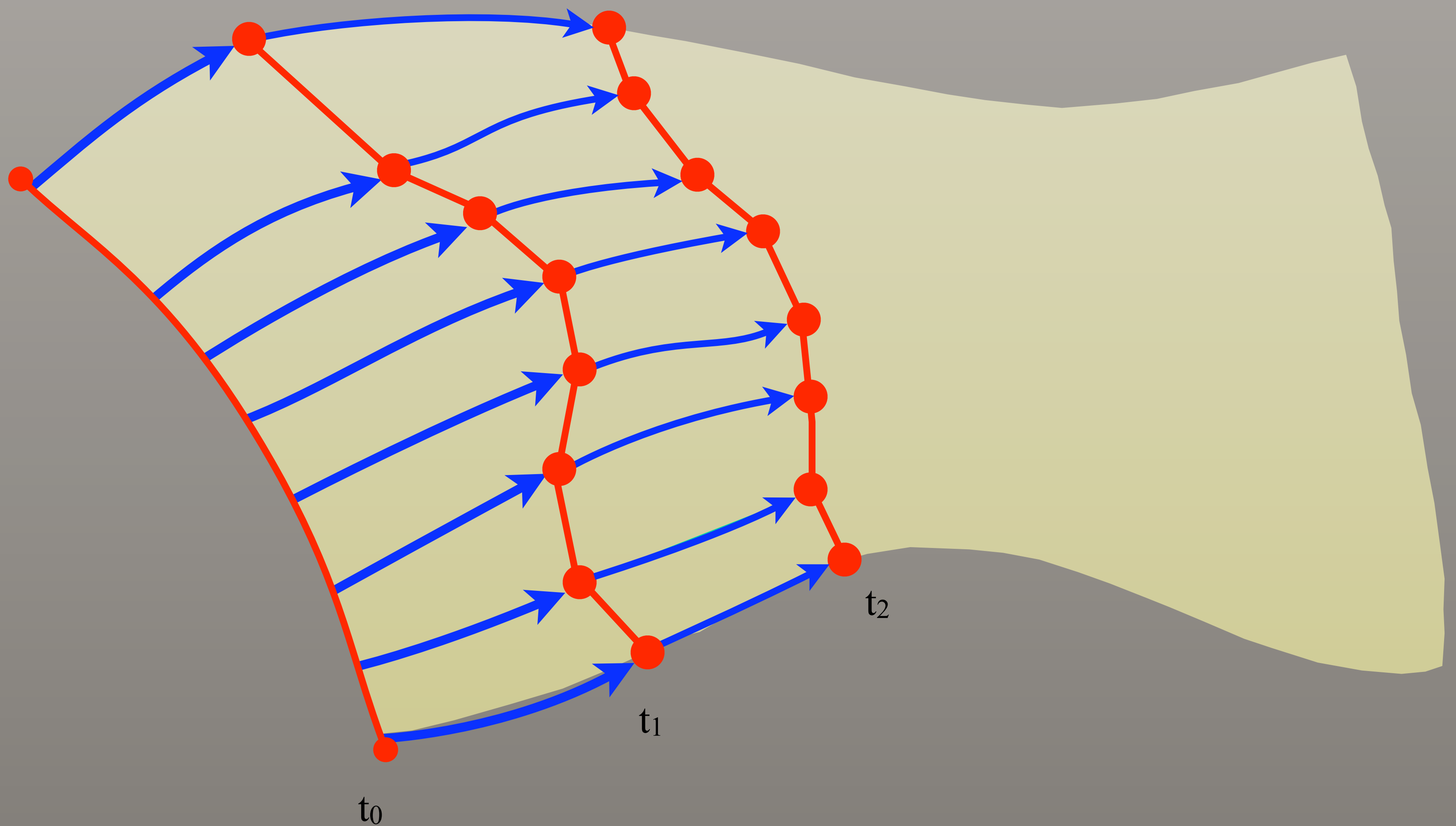
# Integral Surfaces

- Repeat at Steps 2 and 3 until no further refinement is needed



# Integral Surfaces

- Approximate sequence of timelines going from $t_i$ to $t_{i+1}$



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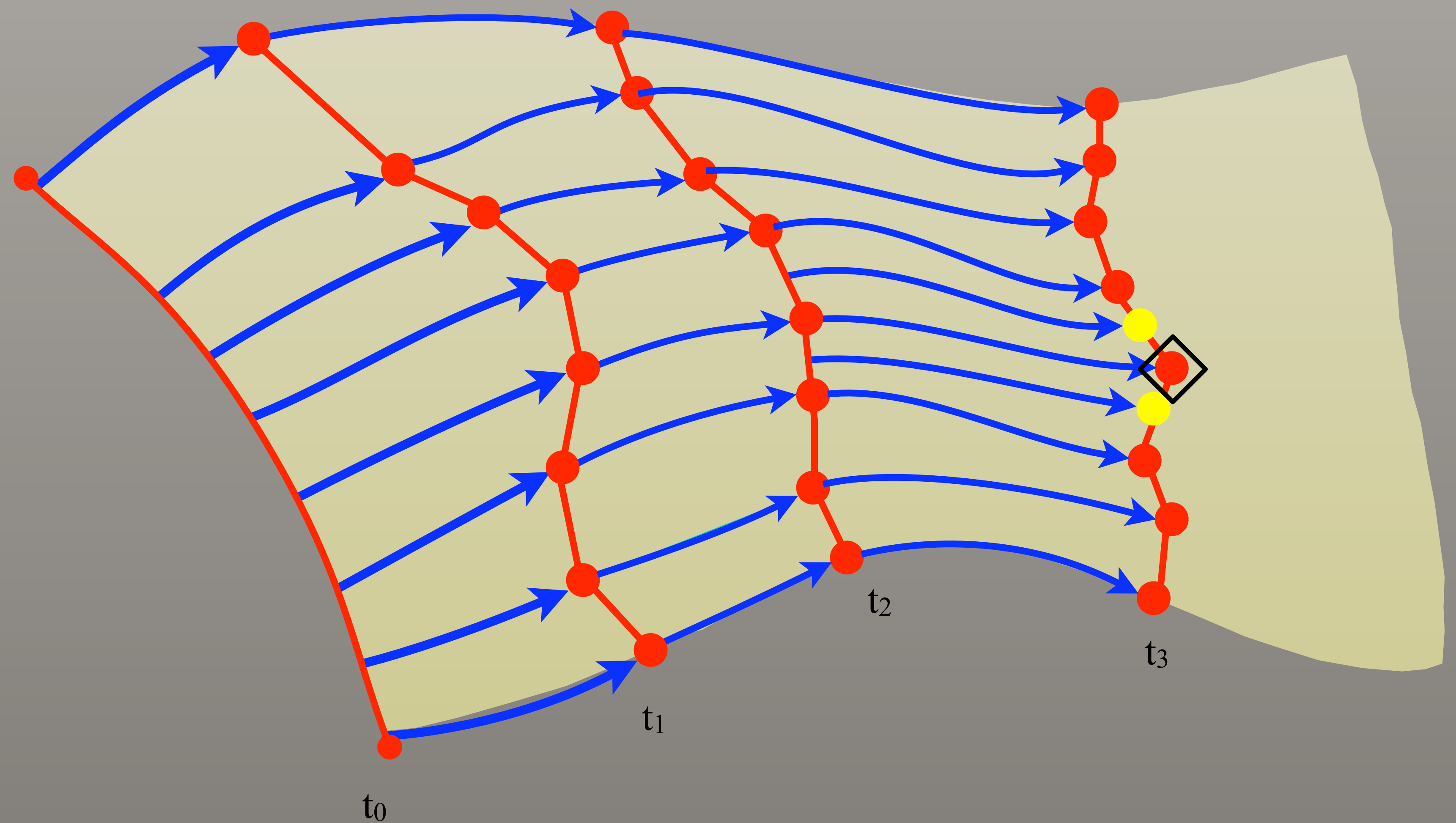

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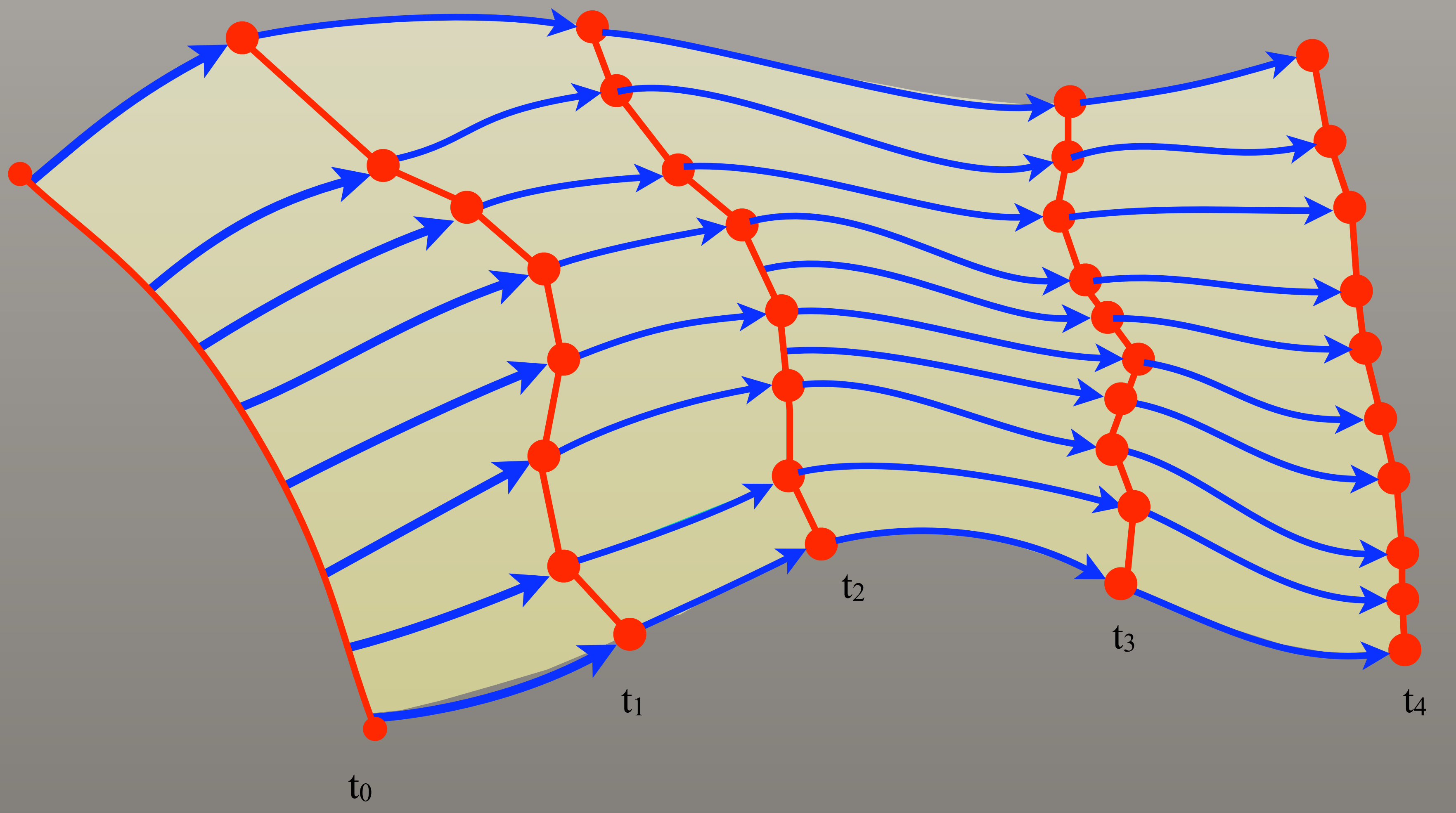
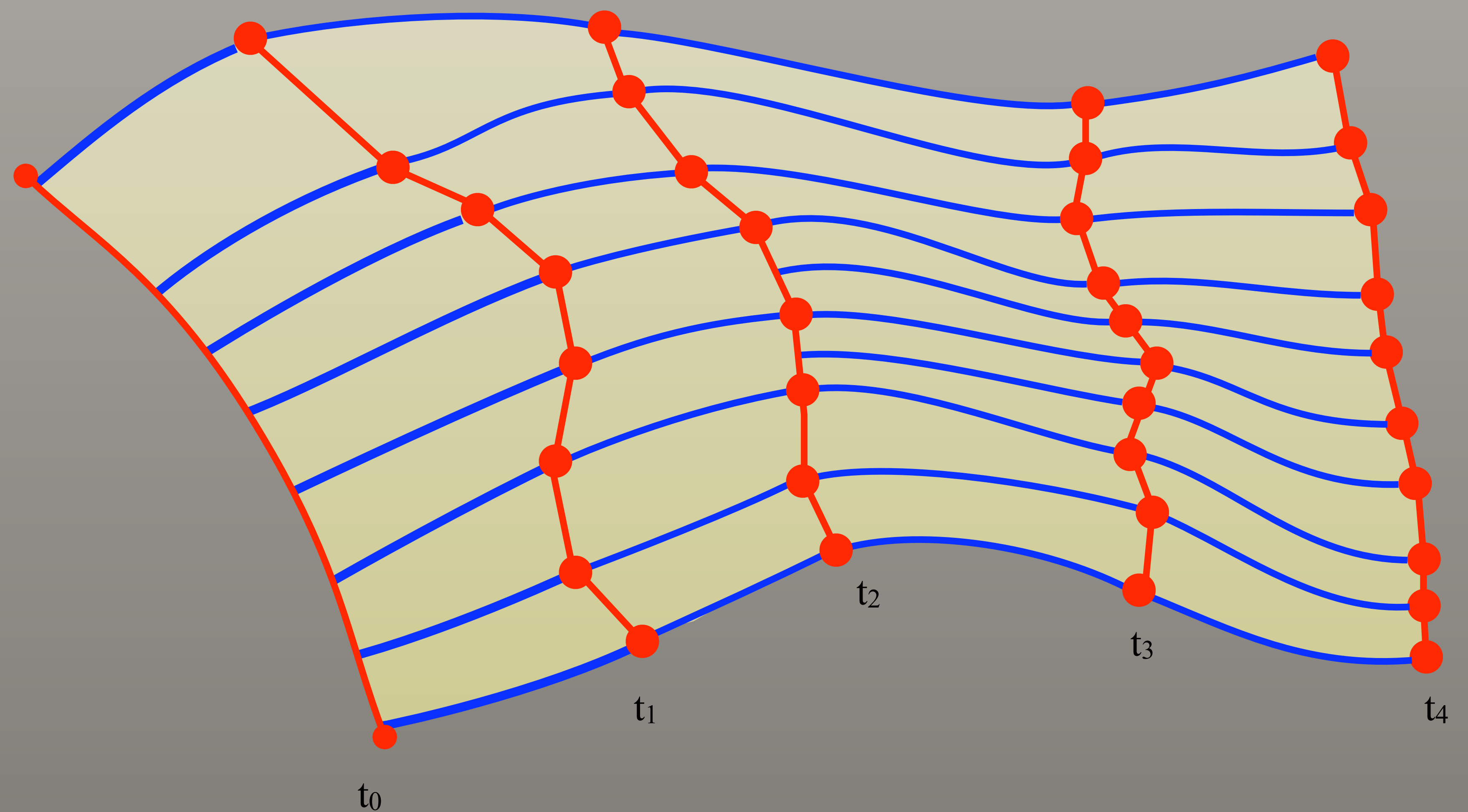


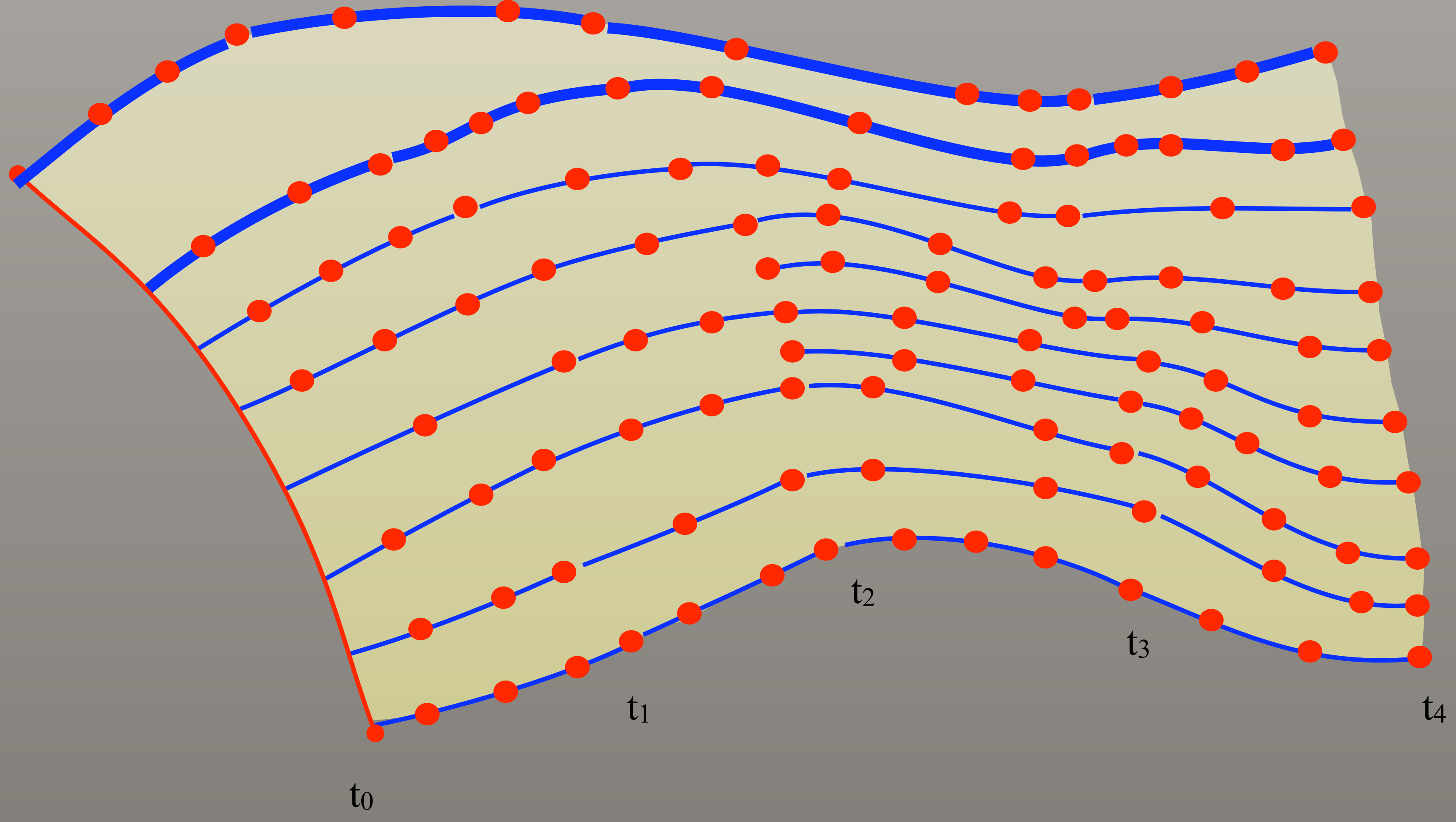
# Integral Surfaces

- Result: Surface skeleton of integral curves + time lines



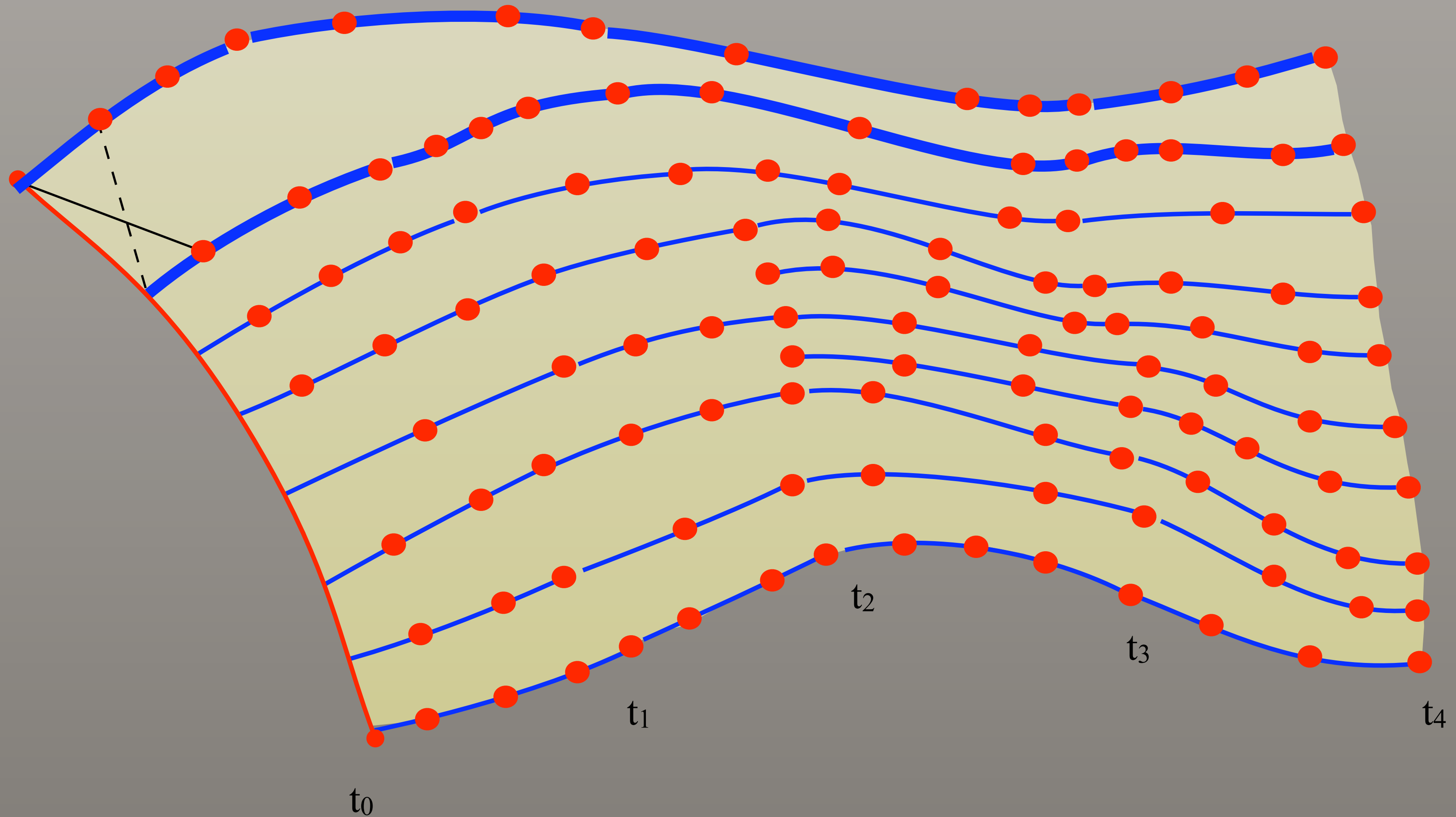
# Integral Surfaces

- Use adjacent integral curves and triangulate heuristically with shortest diagonals.



# Phase 2: Surface Triangulation

- Use adjacent integral curves and triangulate heuristically with shortest diagonals.



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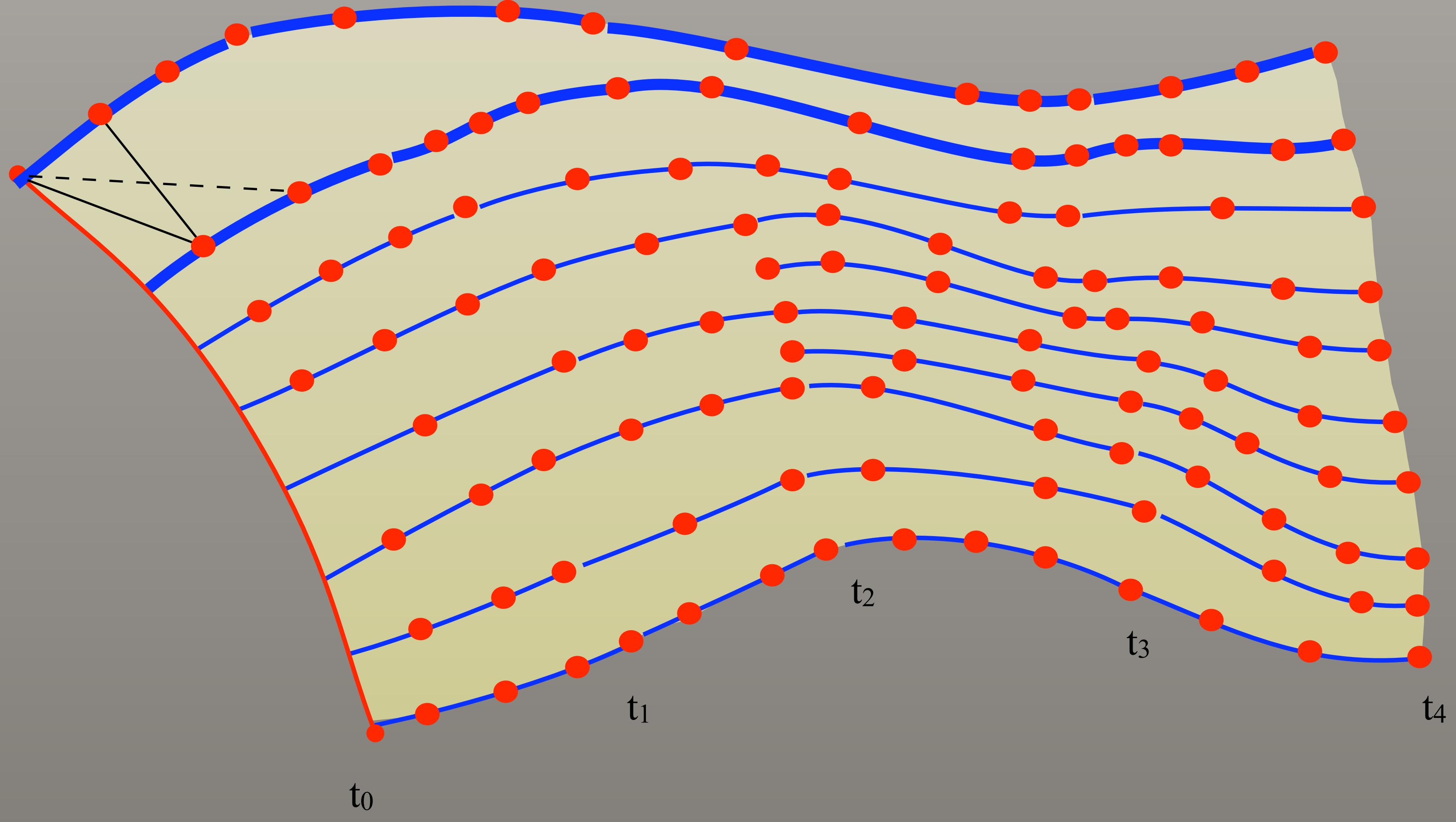

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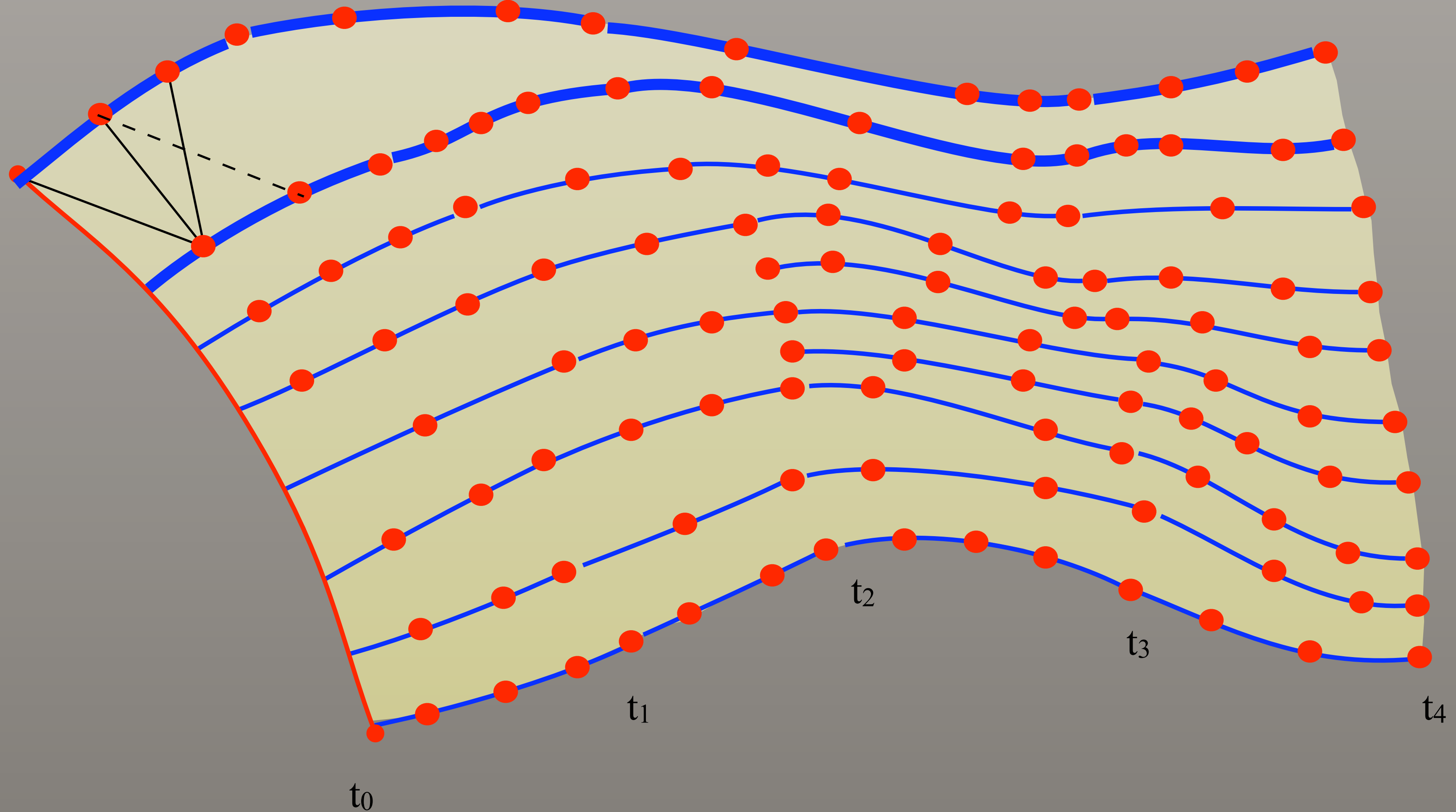

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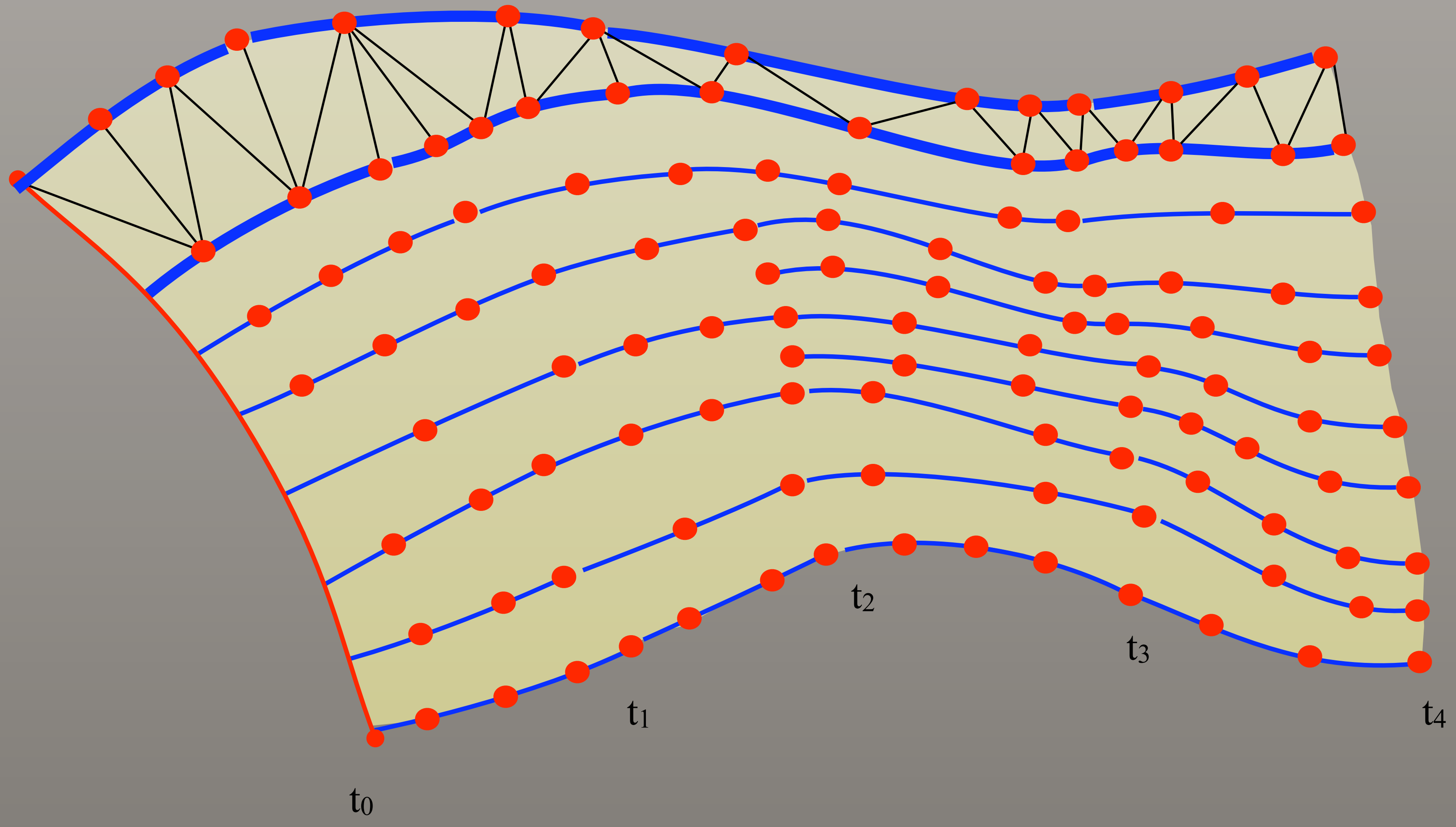
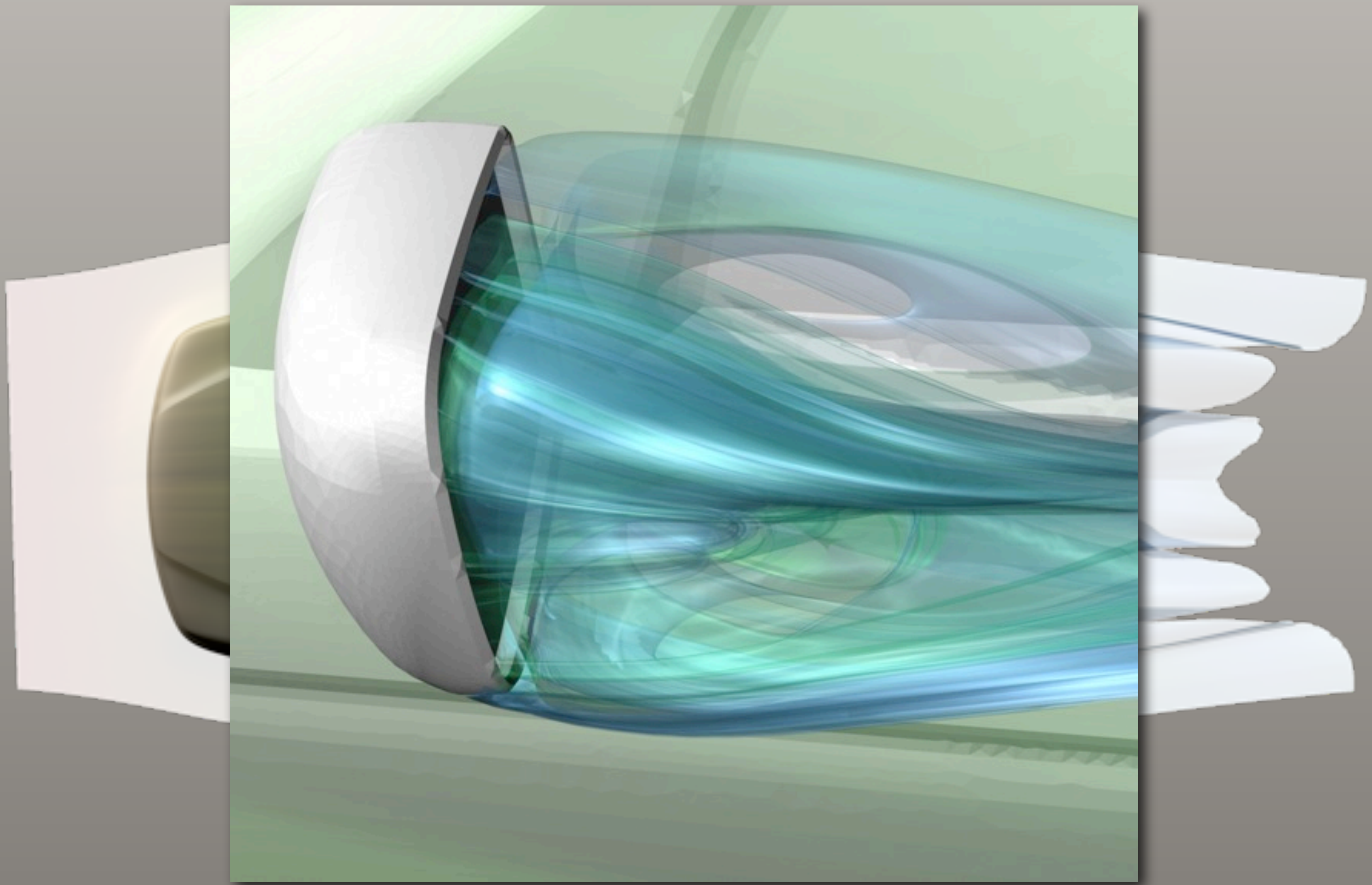


# Integral Surfaces

Proposed method: (Vis 08)

- adaptive approximation
  - integral curve divergence/convergence
  - surface deformation (folding, shearing)
- temporal locality
  - allows streaming of large time-varying vector fields
- spatial locality
  - only considers neighboring curves, allows parallization

# Integral Surfaces



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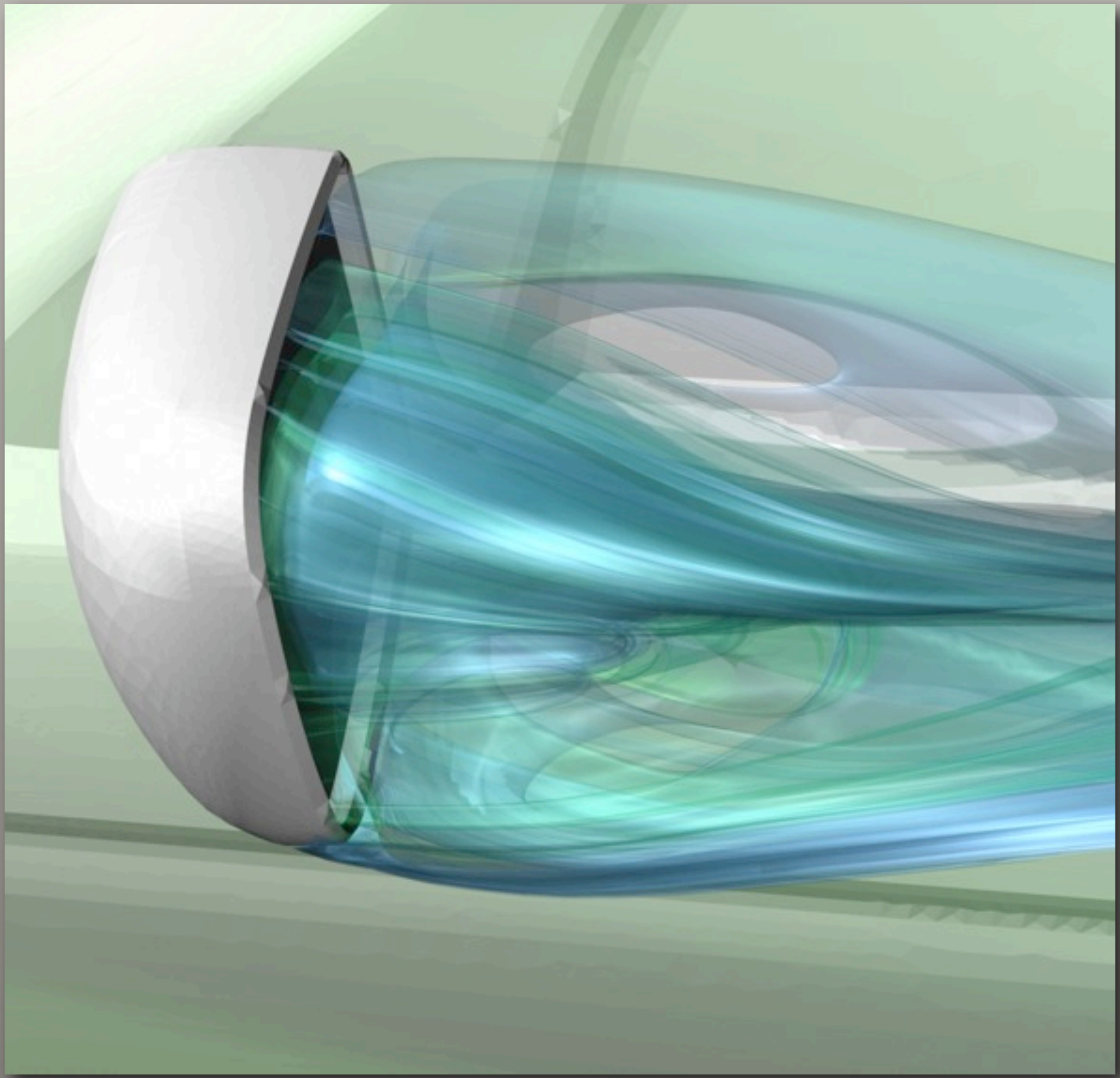
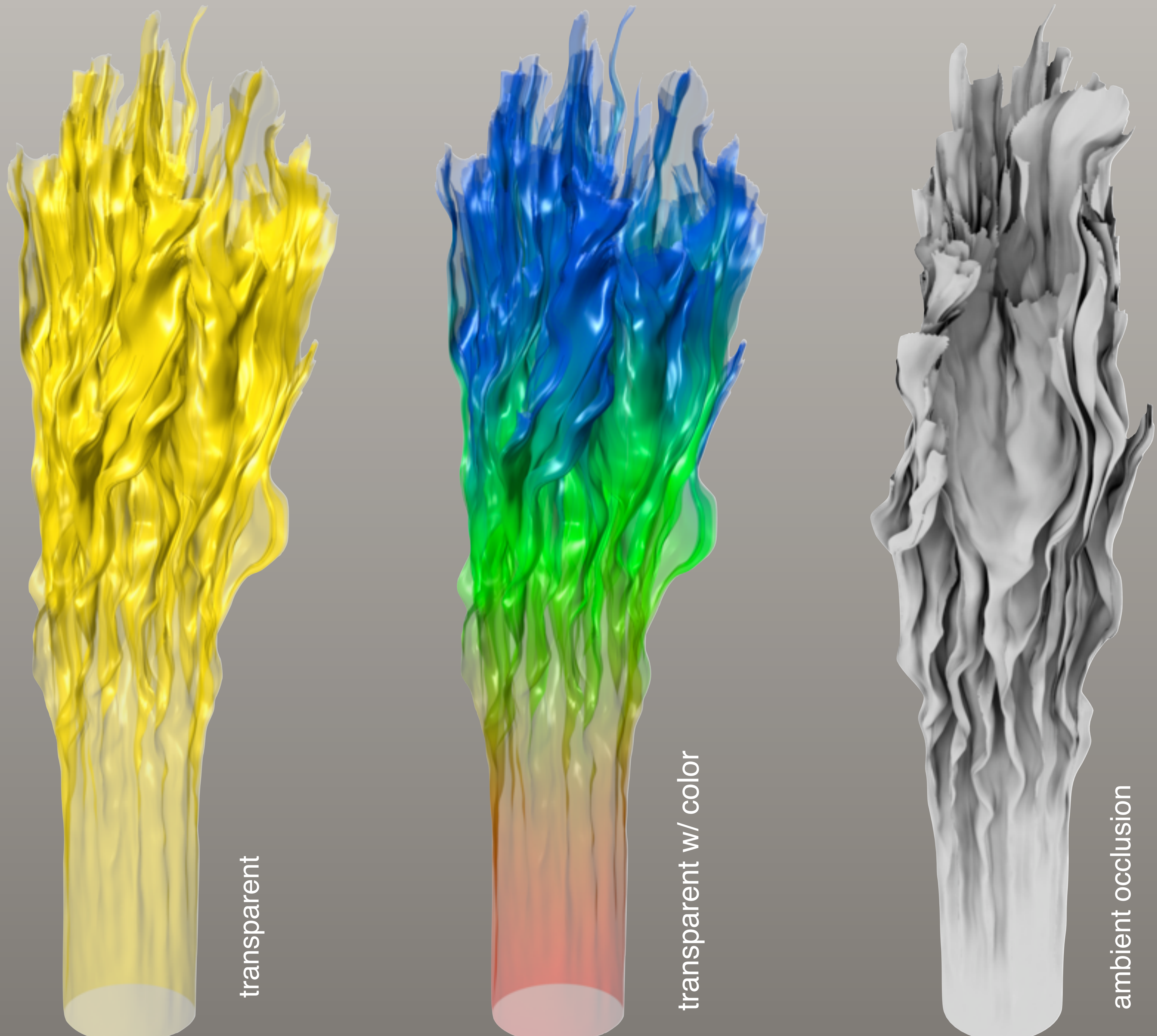


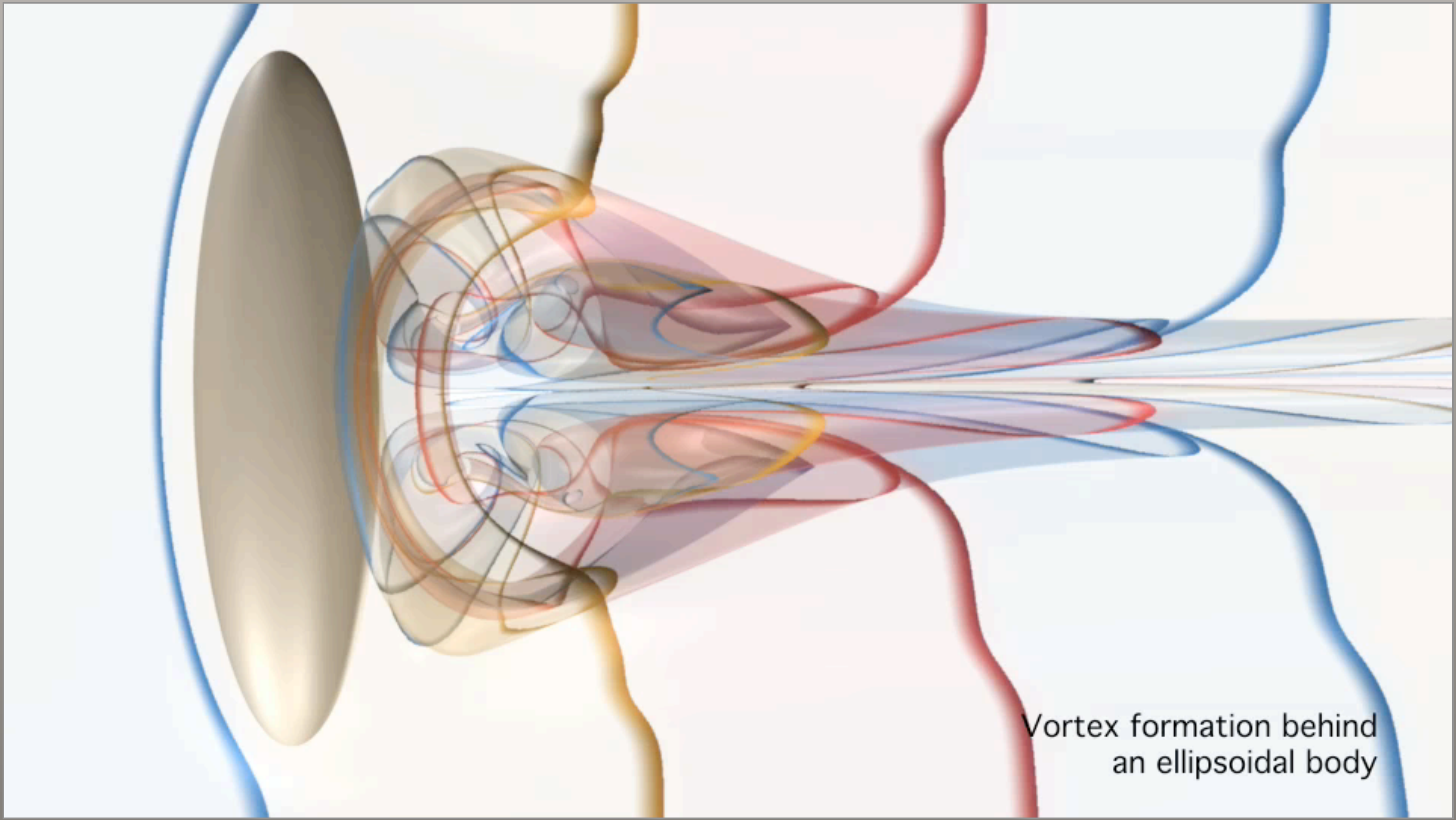
# Turbulent CFD simulation, 200M unstructured cells

Visualization / Rendering options



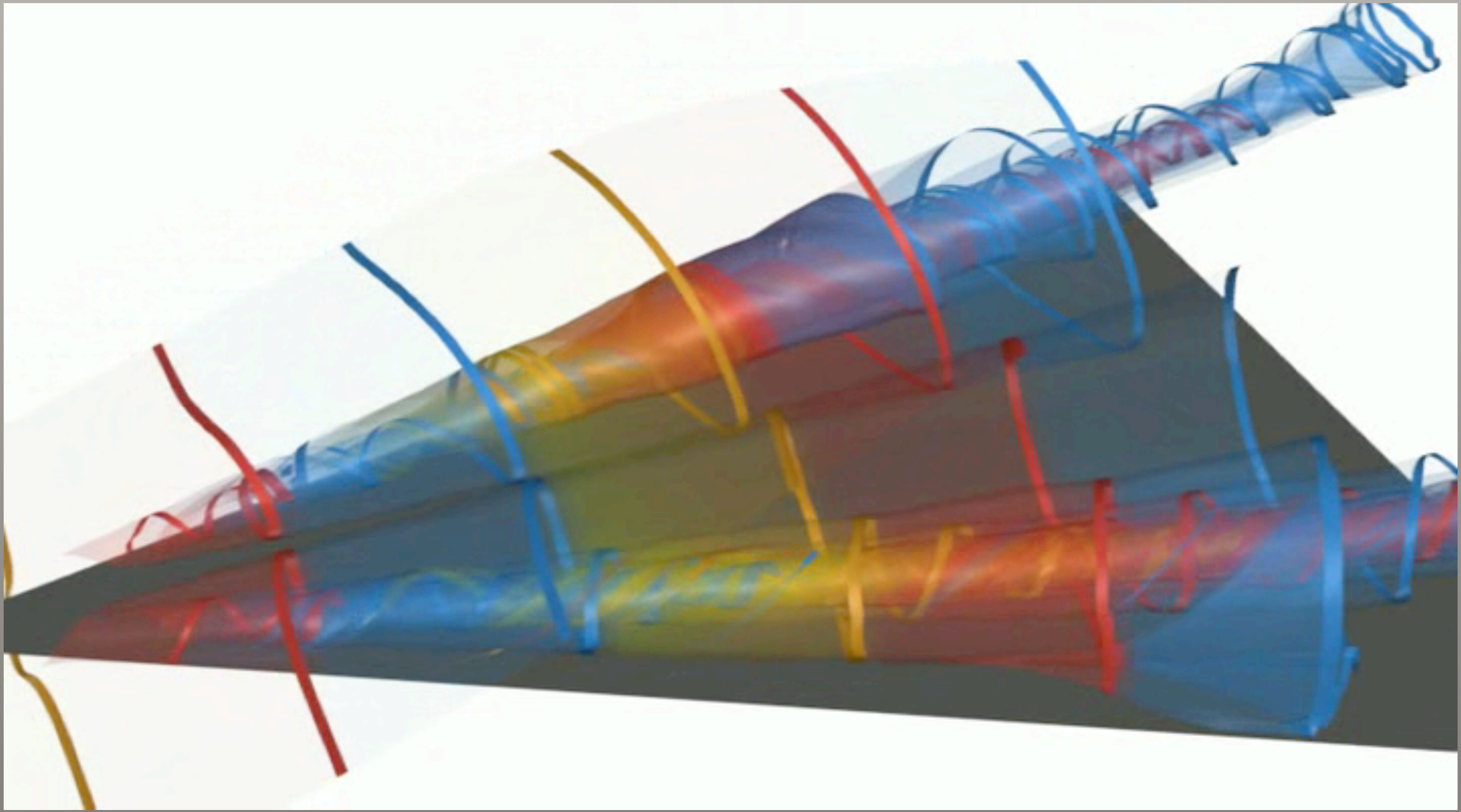
# Integral Surfaces

Flow past an ellipsoid, 2.6M unstructured cells x 1000 timesteps



# Integral Surfaces

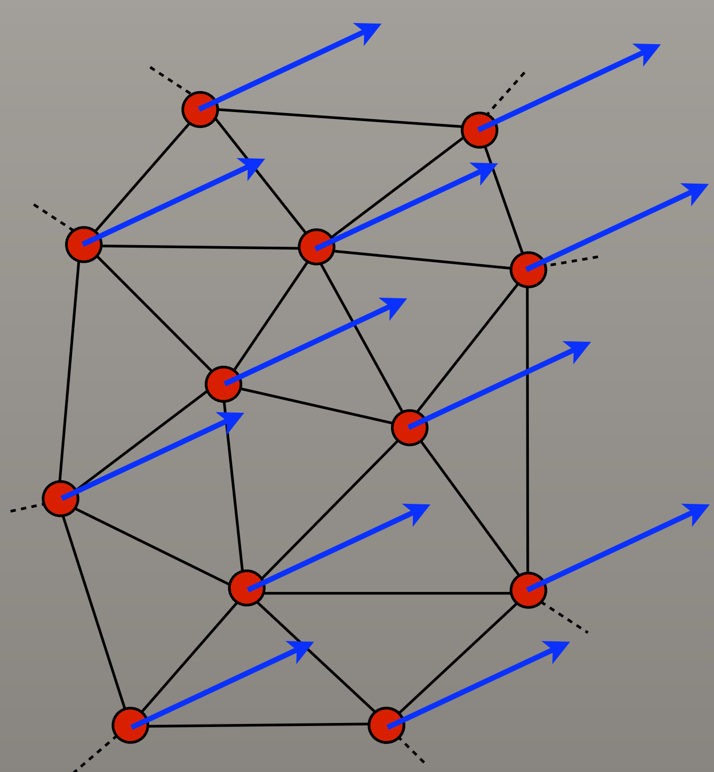
Flow over a delta wing, 18M unstructured cells x 500 timesteps

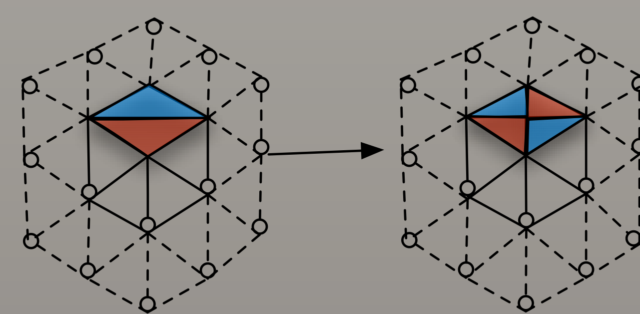


# Integral Surfaces

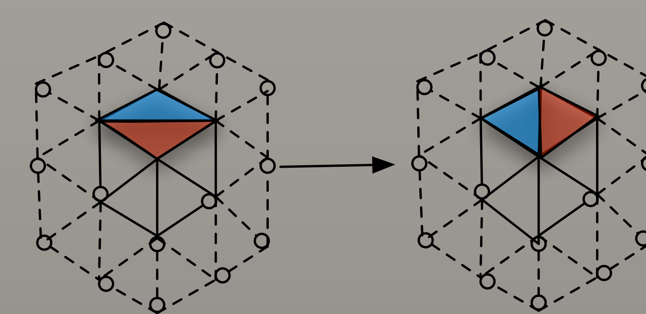
Ongoing work (Vis 09):

- Time Surfaces (seed surface)
- Streak Surfaces (continuous seeding from a curve)

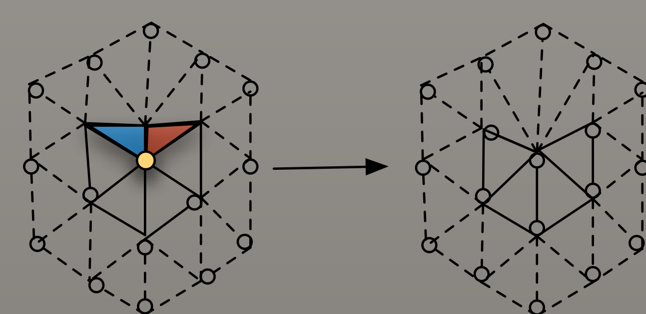




(a) Edge split

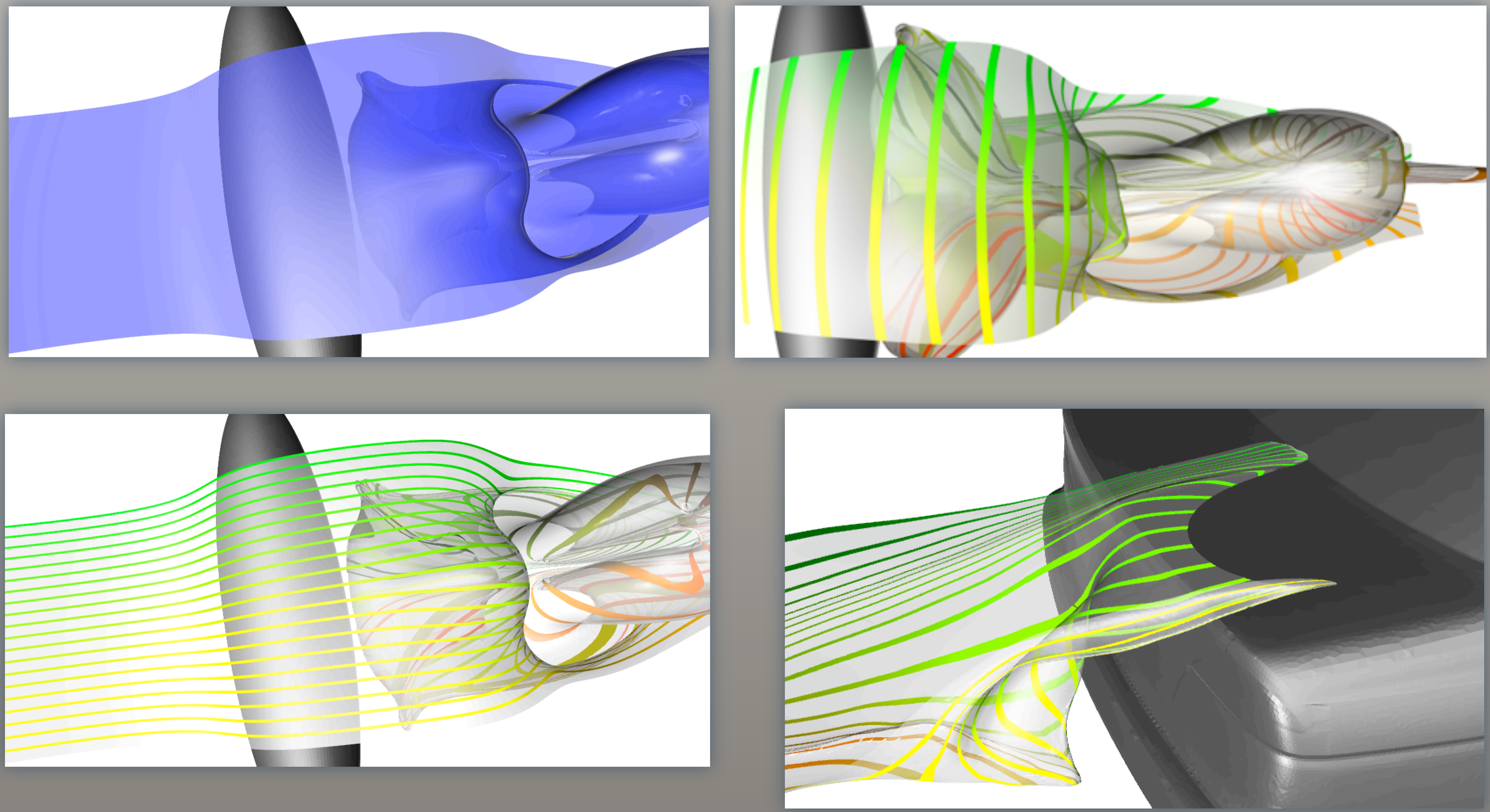


(b) Edge flip



(c) Edge collapse

# Integral Surfaces



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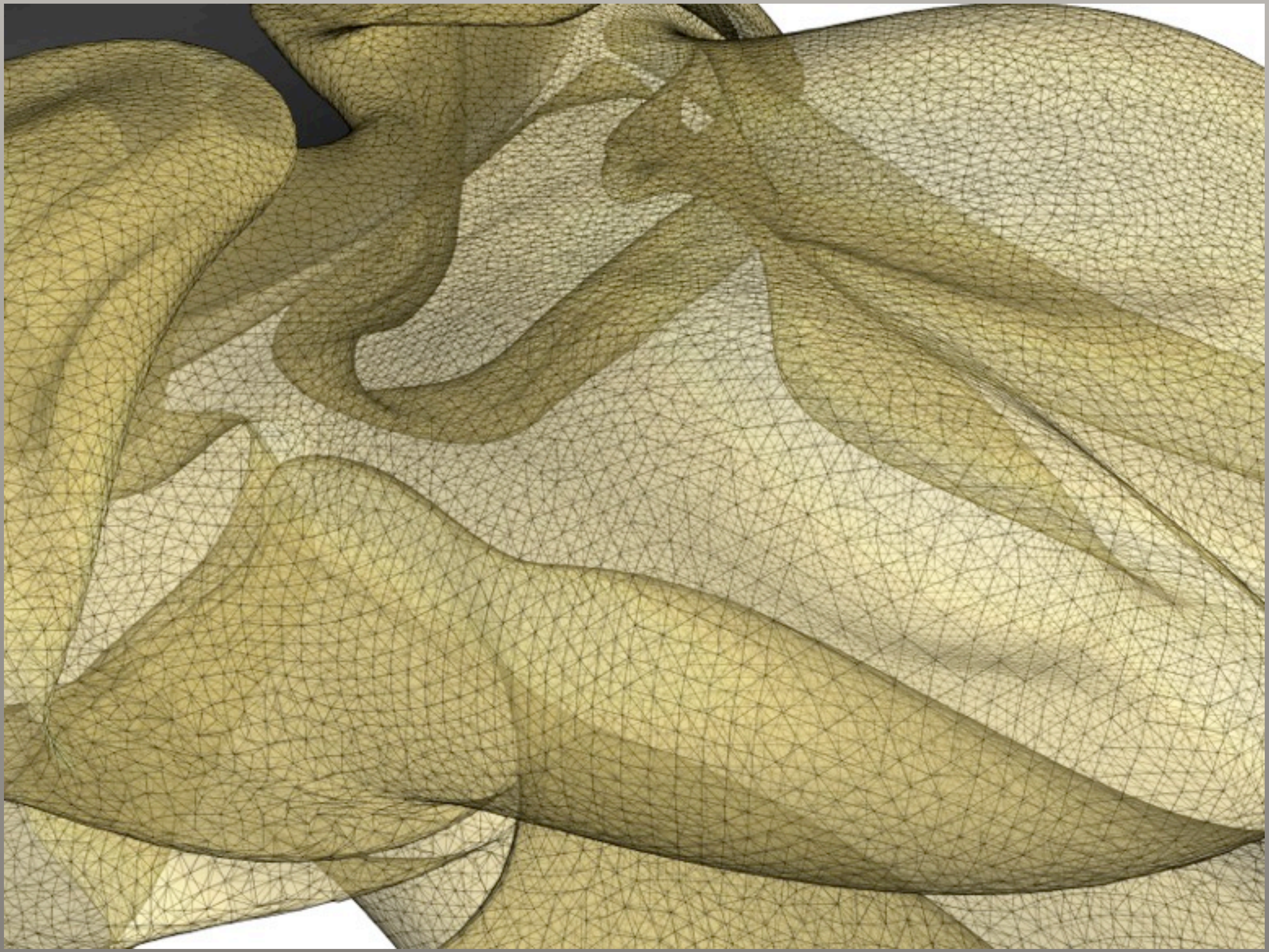


# Integral Surfaces

Performance:

- require 100 - 100,000 pathlines,
  depending on complexity of data and surface

- computation times (1 CPU) can range up to hours for very complex surfaces

- time spent integrating pathlines > 90%

- parallelization is in the works

We provide tools for interactive viewing,
spatial + temporal navigation

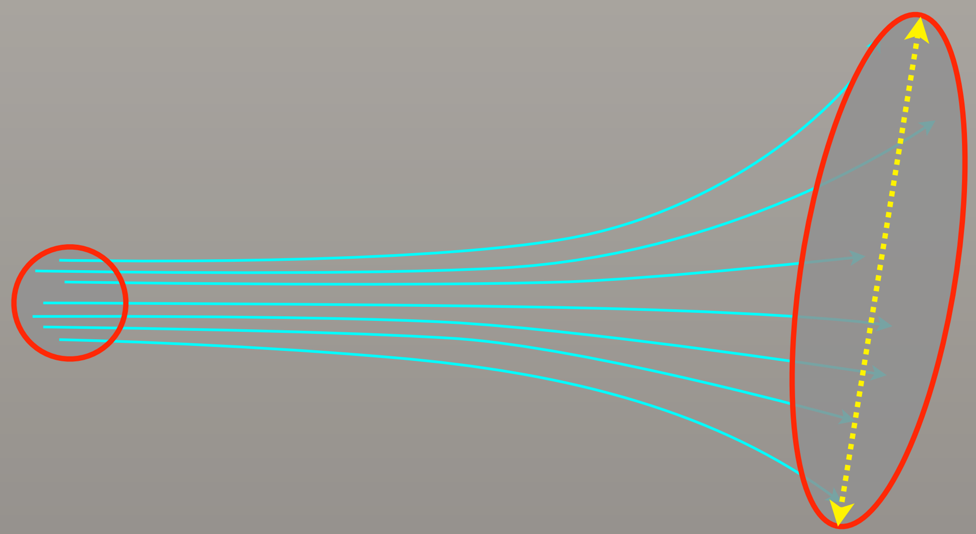
# Lagrangian Flow Visualization

(with Xavier Tricoche, Mario Hlawitschka, Ken Joy)

# Lagrangian Flow Visualization

- Lagrangian Flow Vis - look at what particles do

- Finite-Time Lyapunov Exponent



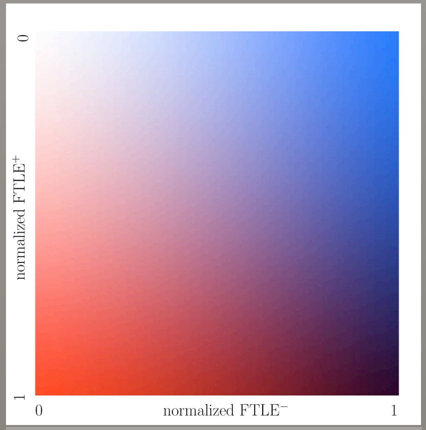
- Measures exponential separation rate between neighboring particles

- Identifies Lagrangian Coherent Structures

# Lagrangian Flow Visualization

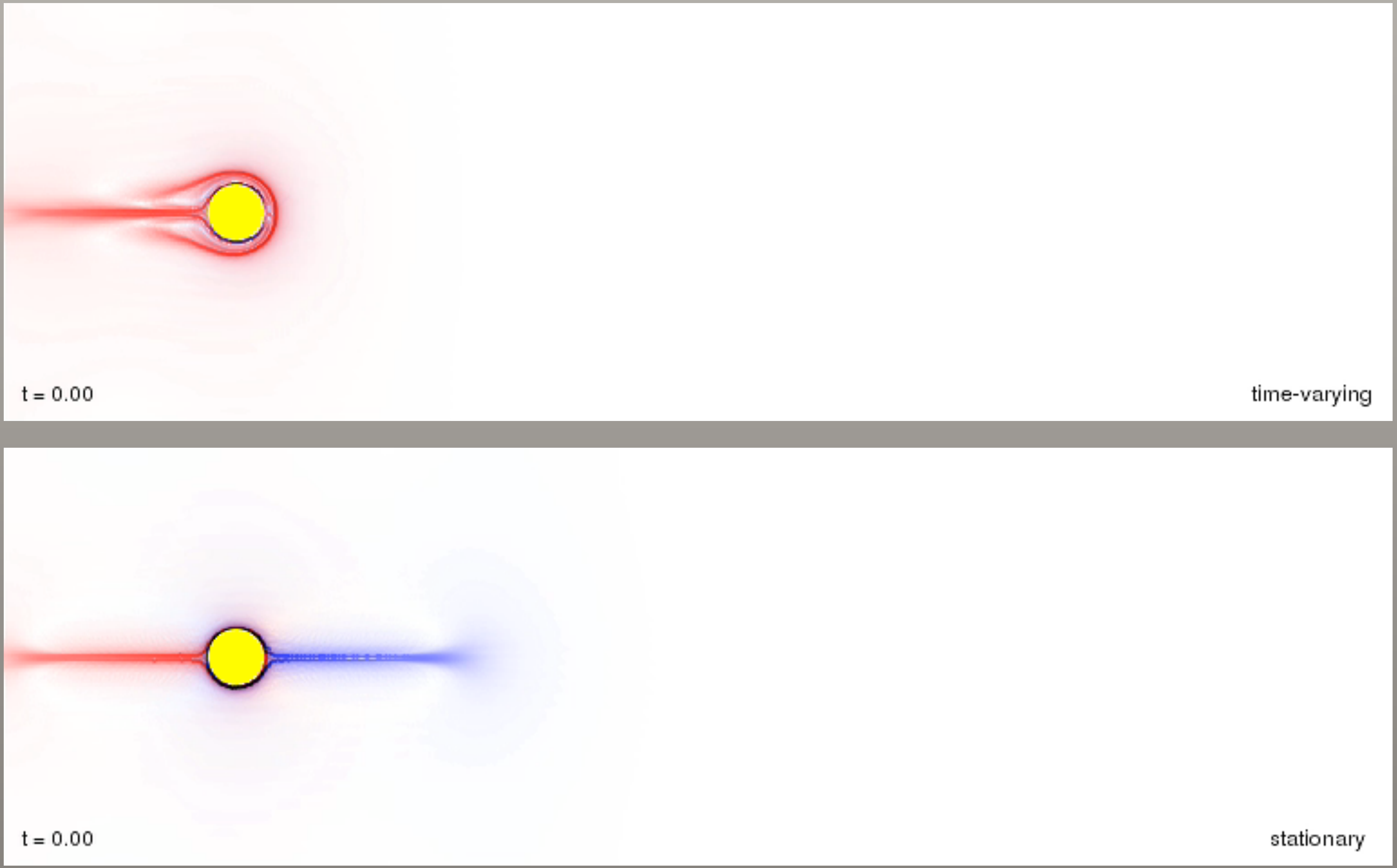
- Computation: dense particles + derivatives

- Interpretation of FTLE:
  - separation forward in time: indicates divergence
  - separation backward in time: indicates convergence

# Lagrangian Flow Visualization

Time-dependent vs. time-independent FTLE fields

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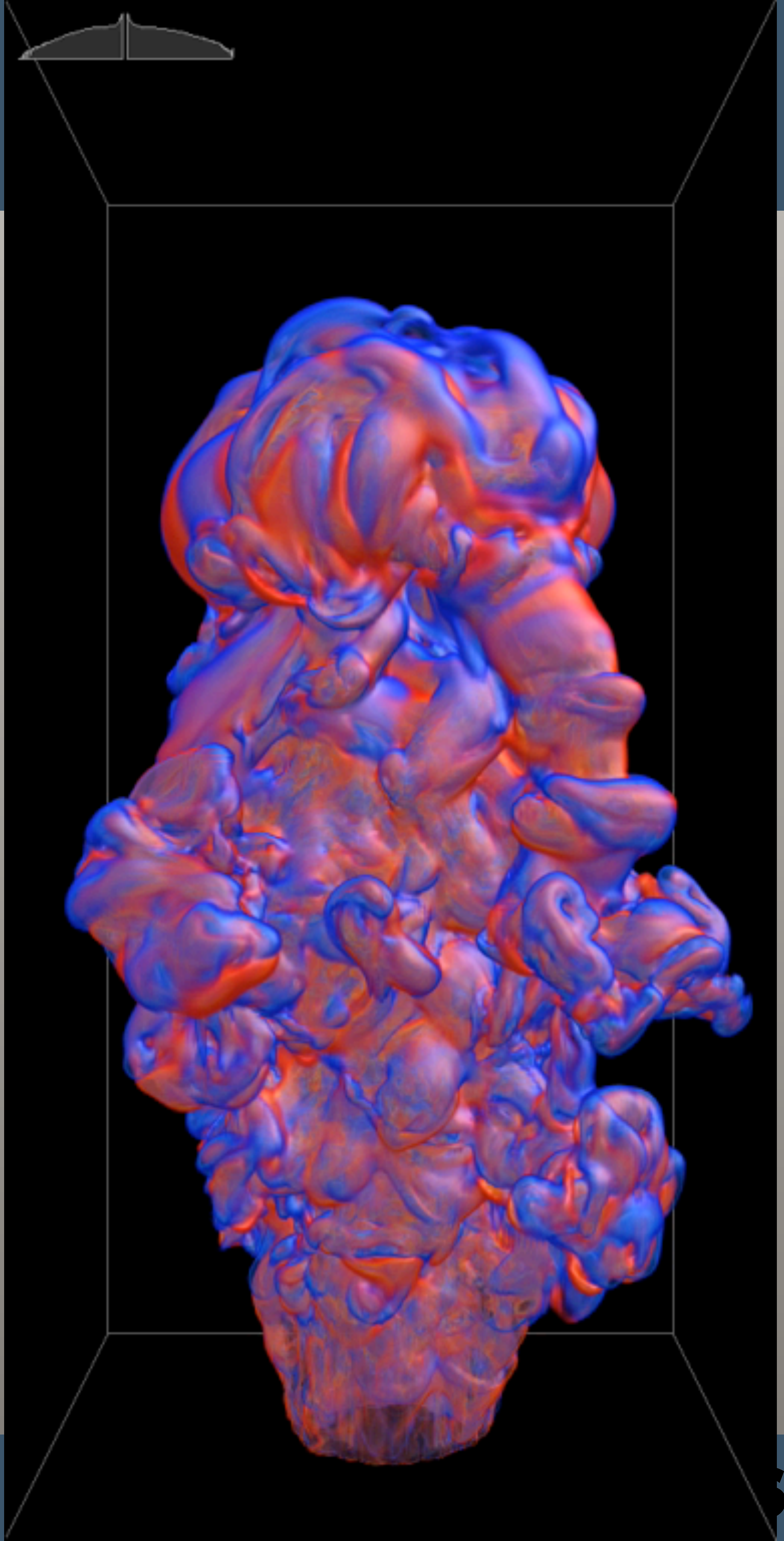
# Lagrangian Flow Visualization

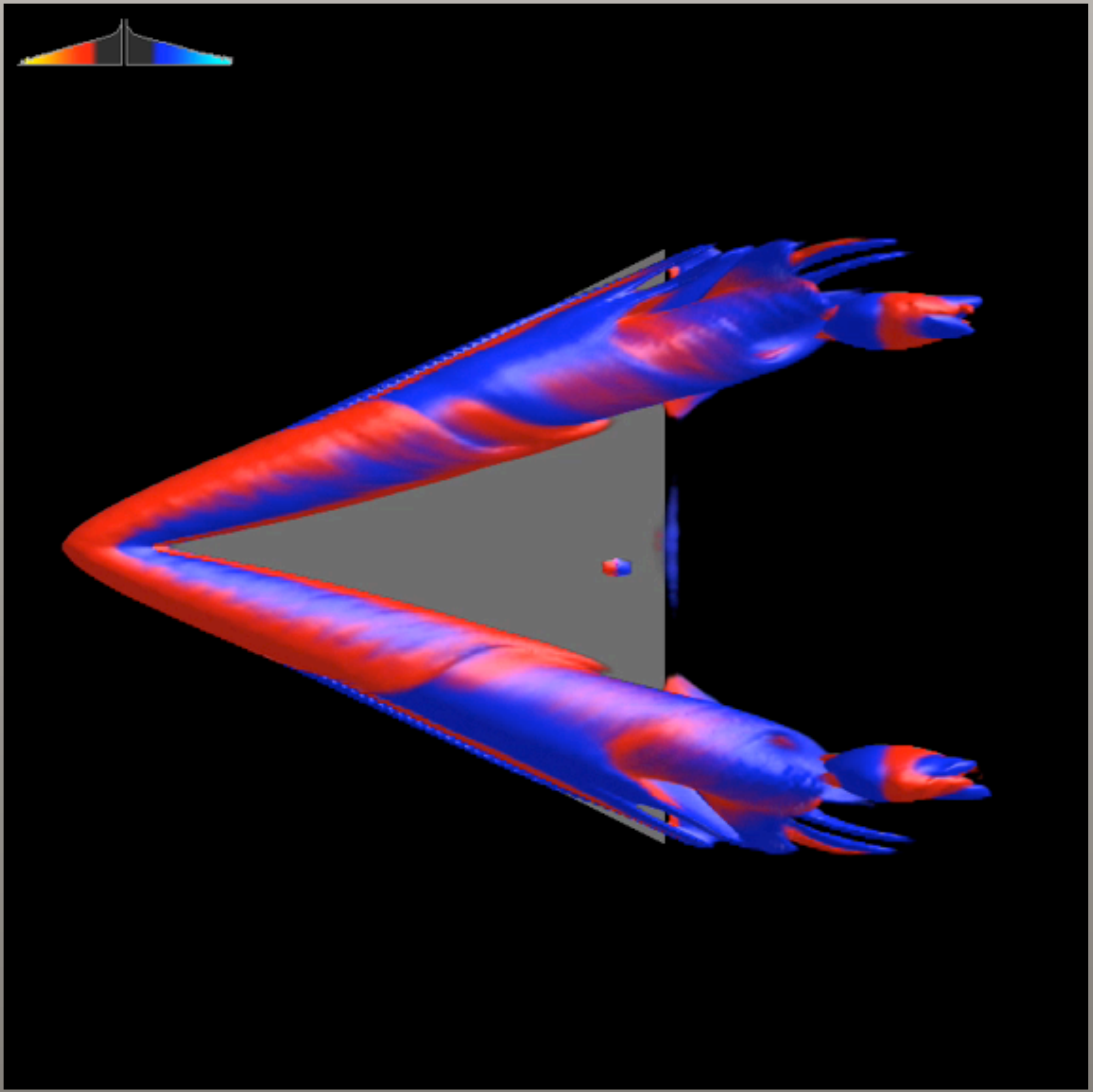
3D Visualization:
DVR of FTLE fields using a 2D transfer function

Computation is extensive, but we use GPUs for small data, and adaptive computation for medium-sized data.



# Lagrangian Flow Visualization

Often effective visualizations with relatively little application knowledge.



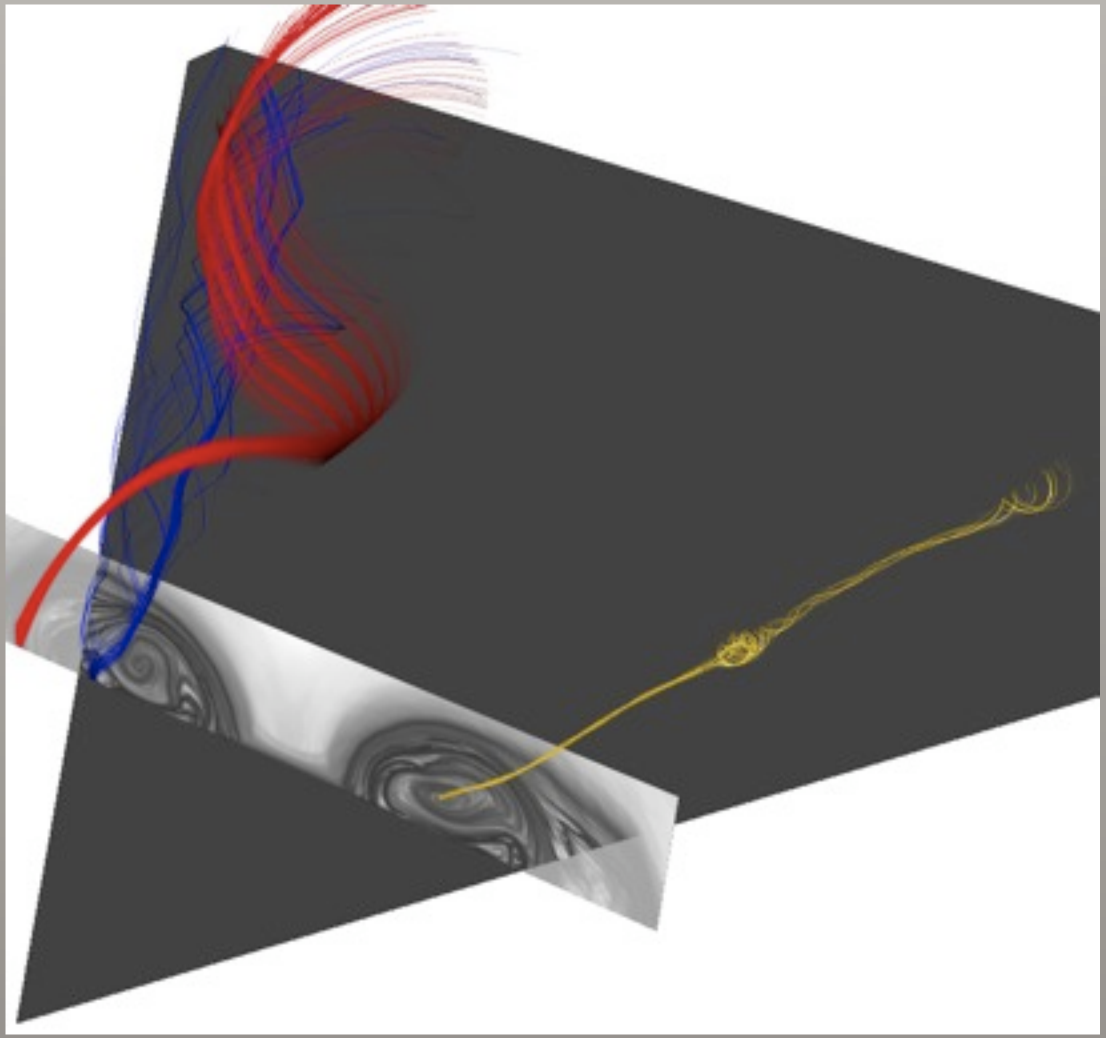
Wish list:

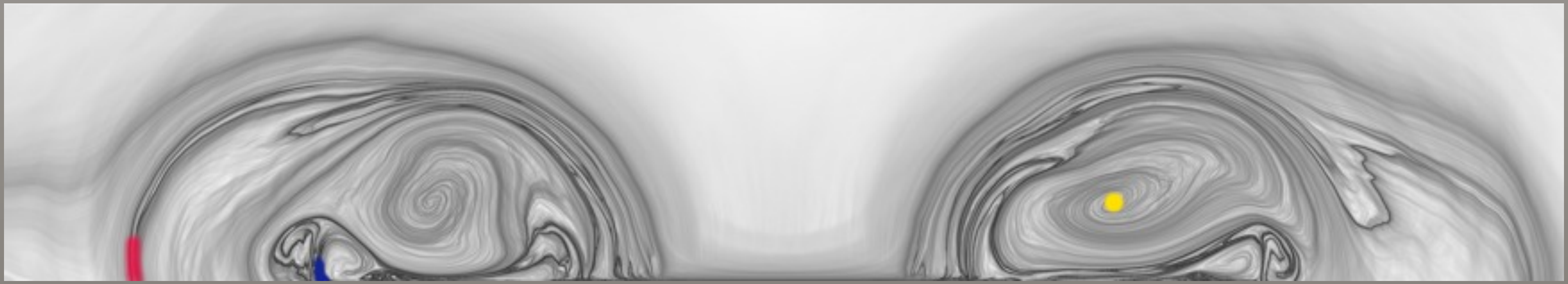
- feature identification
- feature tracking

# Lagrangian Flow Visualization

Visualization tool:
section plane FTLE +
user interaction

Pathlines seeded
according user brushing





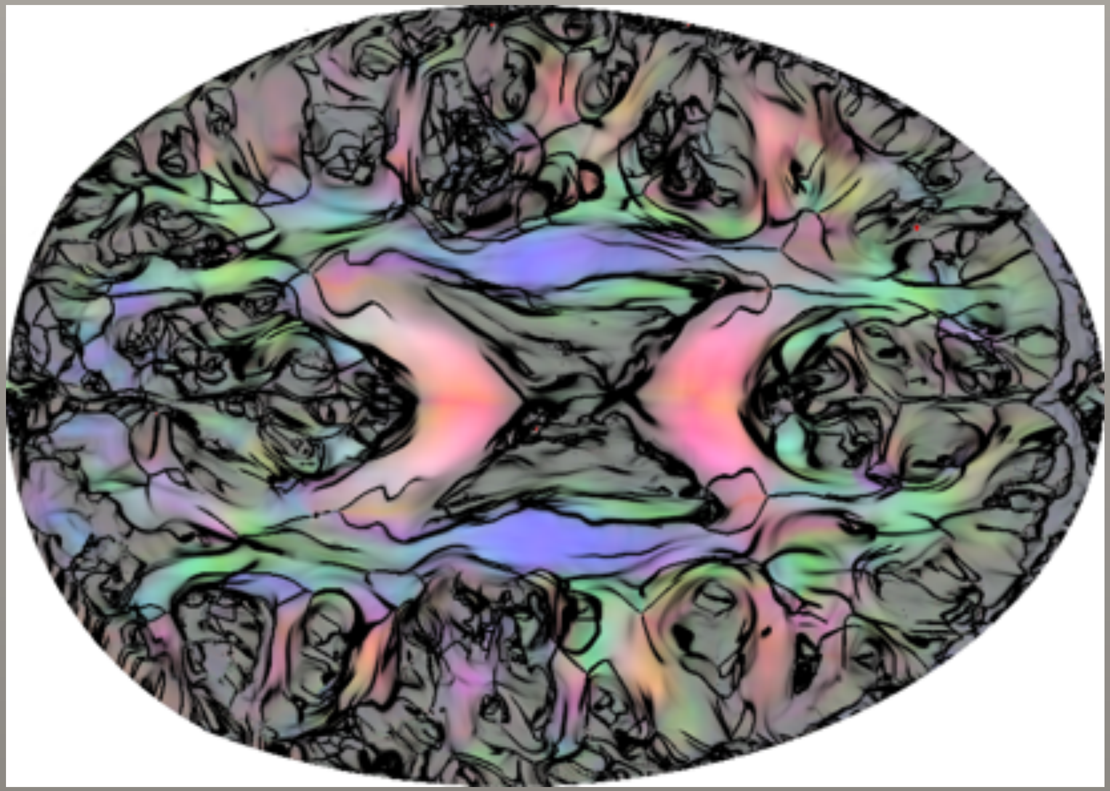
Delta Wing

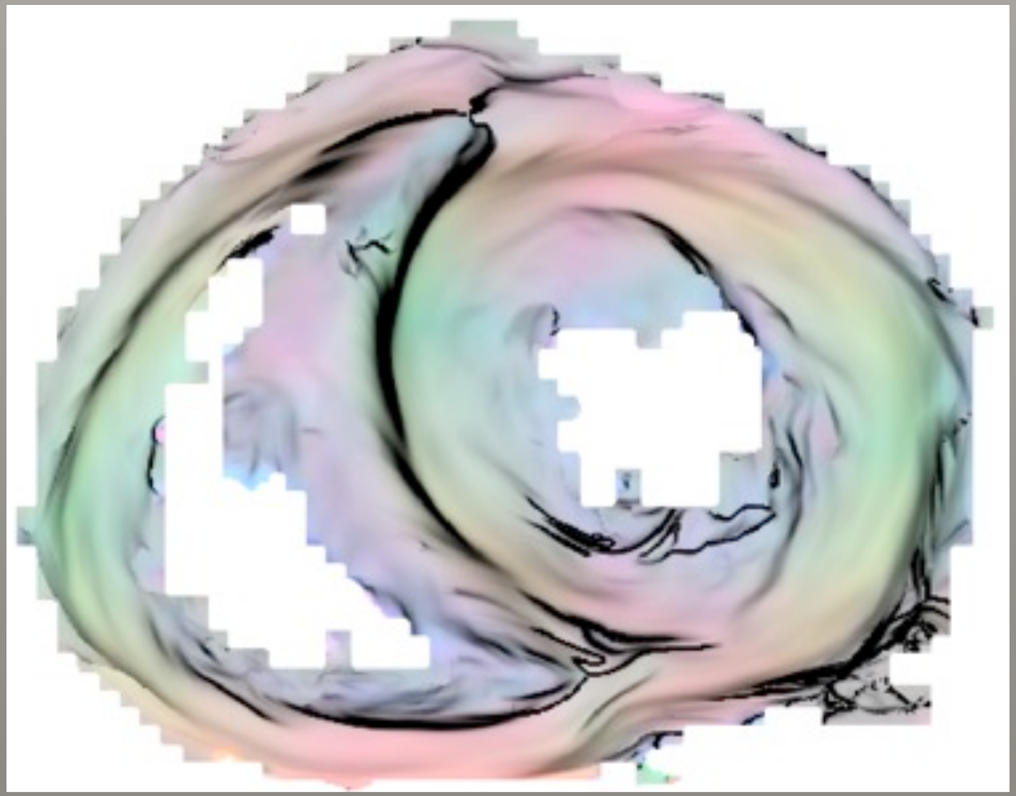
Section plane orthogonal to main flow direction

# Lagrangian Flow Visualization

- Application to DT-MRI / tensor data
- Interest in coherent fiber bundles / bundle separation

Brain Scan



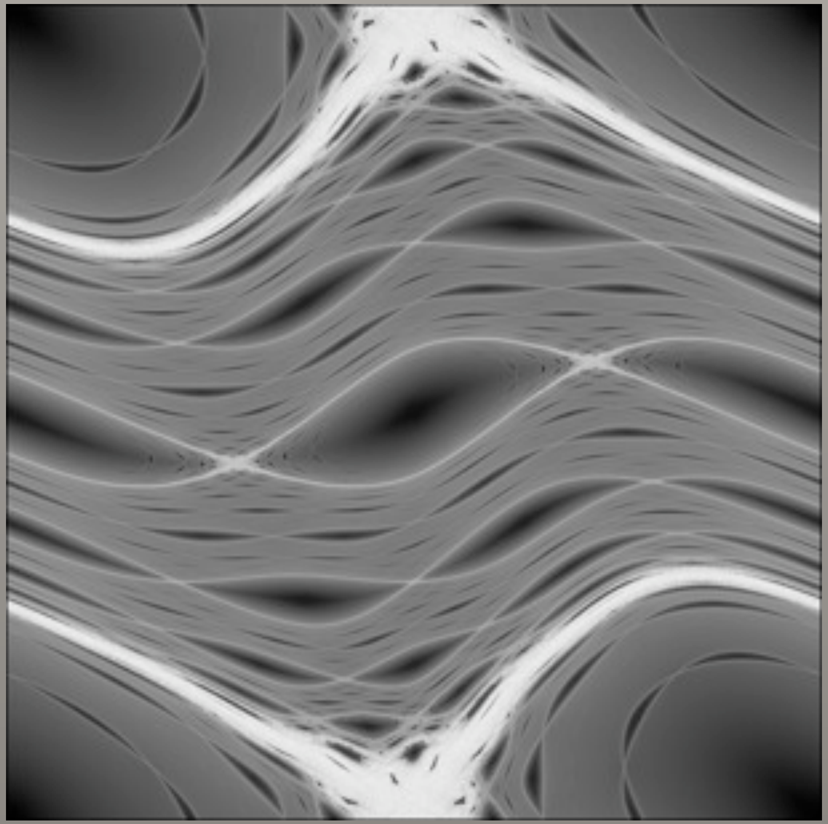


Canine Heart

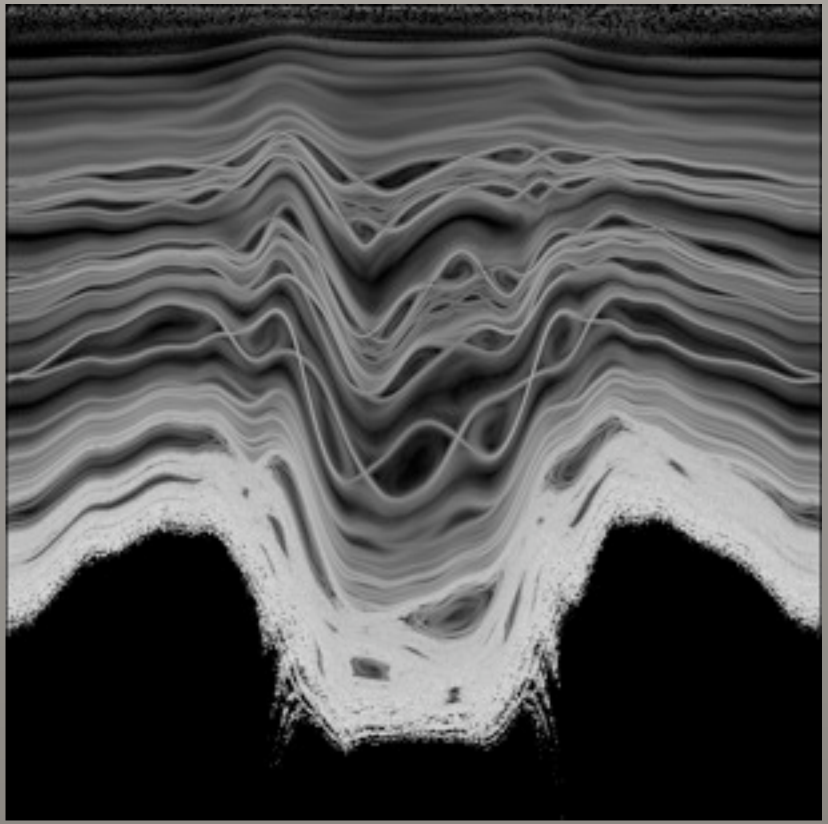
joint work with X. Tricoche (Purdue), M. Hlawitschka

# Lagrangian Flow Visualization

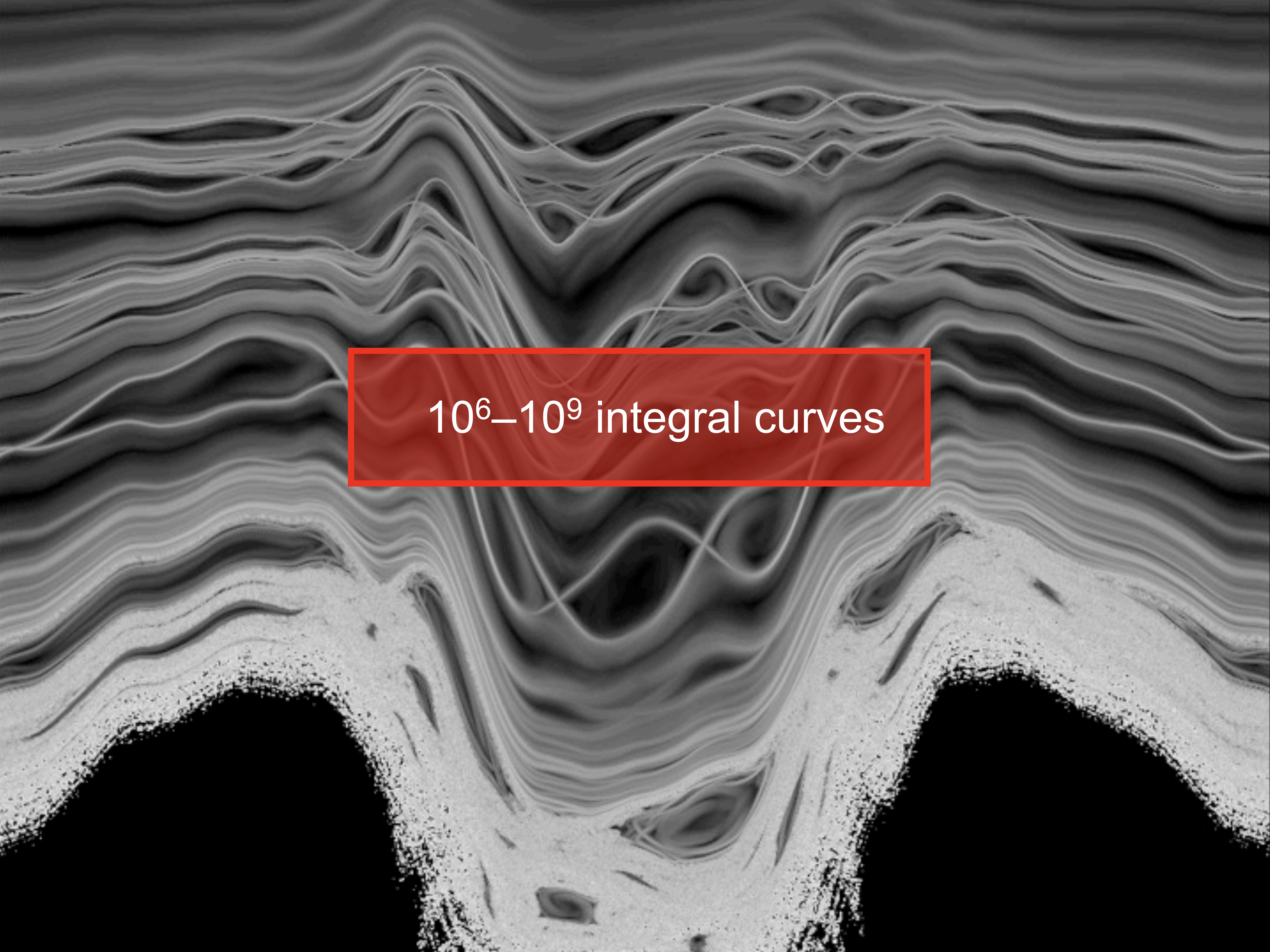
- Hamiltonian Systems (Fusion, Astrophysics, ...)
- Coherent Structures: Island Chain Boundaries



Standard Map



Tokamak Simulation


$10^6$–$10^9$ integral curves

# Improved Integration

(with Dave Pugmire, Sean Ahern, Hank Childs,
Gunther Weber, Eduard Deines)

# Improved Integration

- Integrating many curves is a hard problem
  - non-linear
  - data-dependent
  - requires fast interpolation in arbitrary meshes
- Strong need for parallelization
  - large data (petascale)
  - large seed set (millions of integral curves)
  - correct handling difficult mesh types (e.g. AMR)

# Improved Integration

- Wish list for improved integration:
  - parallelize over both data and seed point set
  - avoid bad performance in corner cases
    - large data, small seed set
    - small data, large seed set
    - precludes any kind of static partitioning
  - handle data in existing format,
    no repartitioning or expensive up-front analysis,
    general use case

- Ongoing work: adaptive load balancing using a master-slave approach and distribution heuristics
  (SC09 paper: comparison of different approaches)

# Improved Integration

Ongoing: Correct handling of AMR meshes

- Problem 1: cell-centered data
  - need good interpolation scheme
  - cell-node averaging is **not** the right thing (too much smoothing)
  - dual mesh interpolation behaves much better

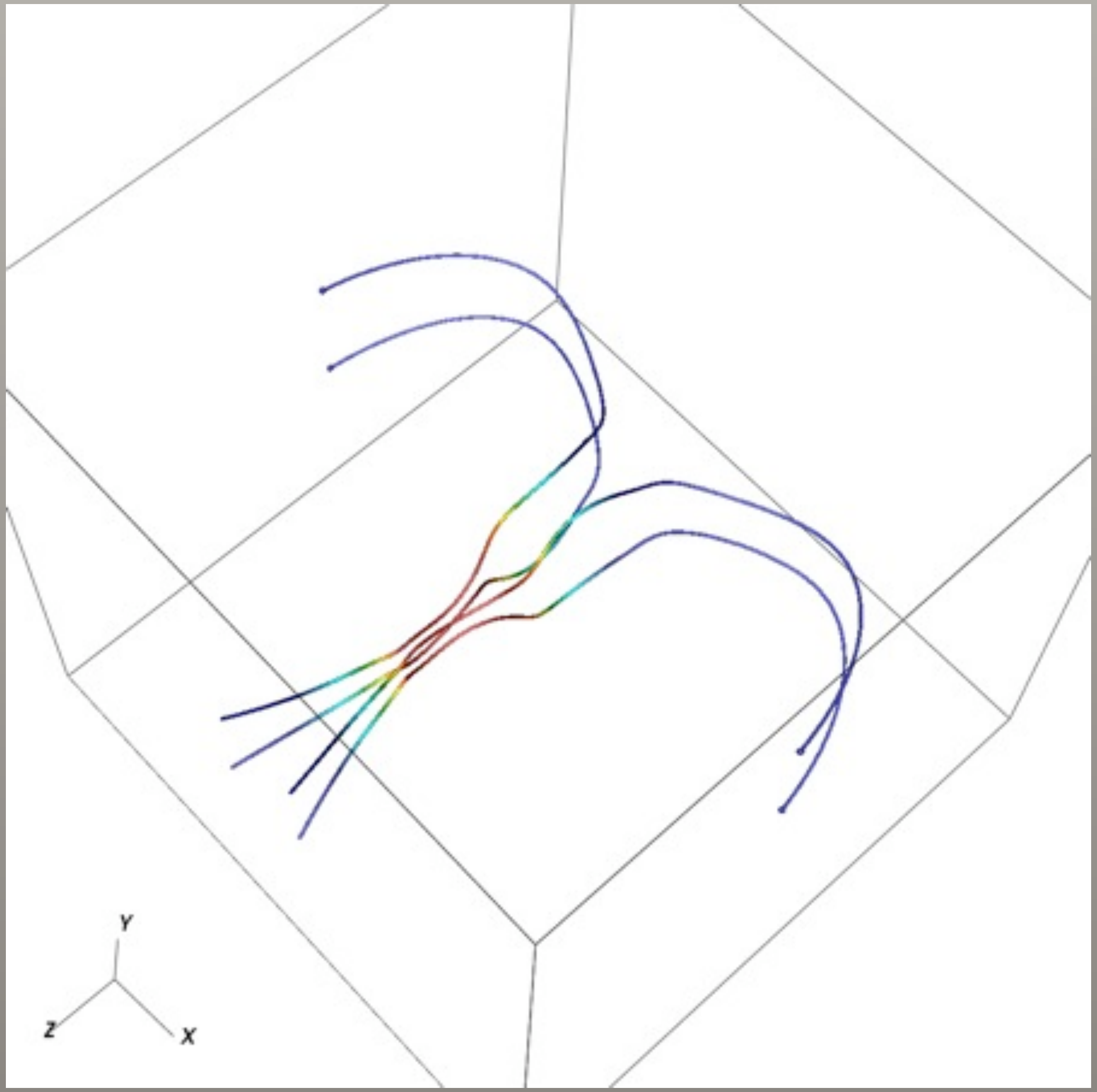
# Improved Integration

Correct handling of AMR meshes:

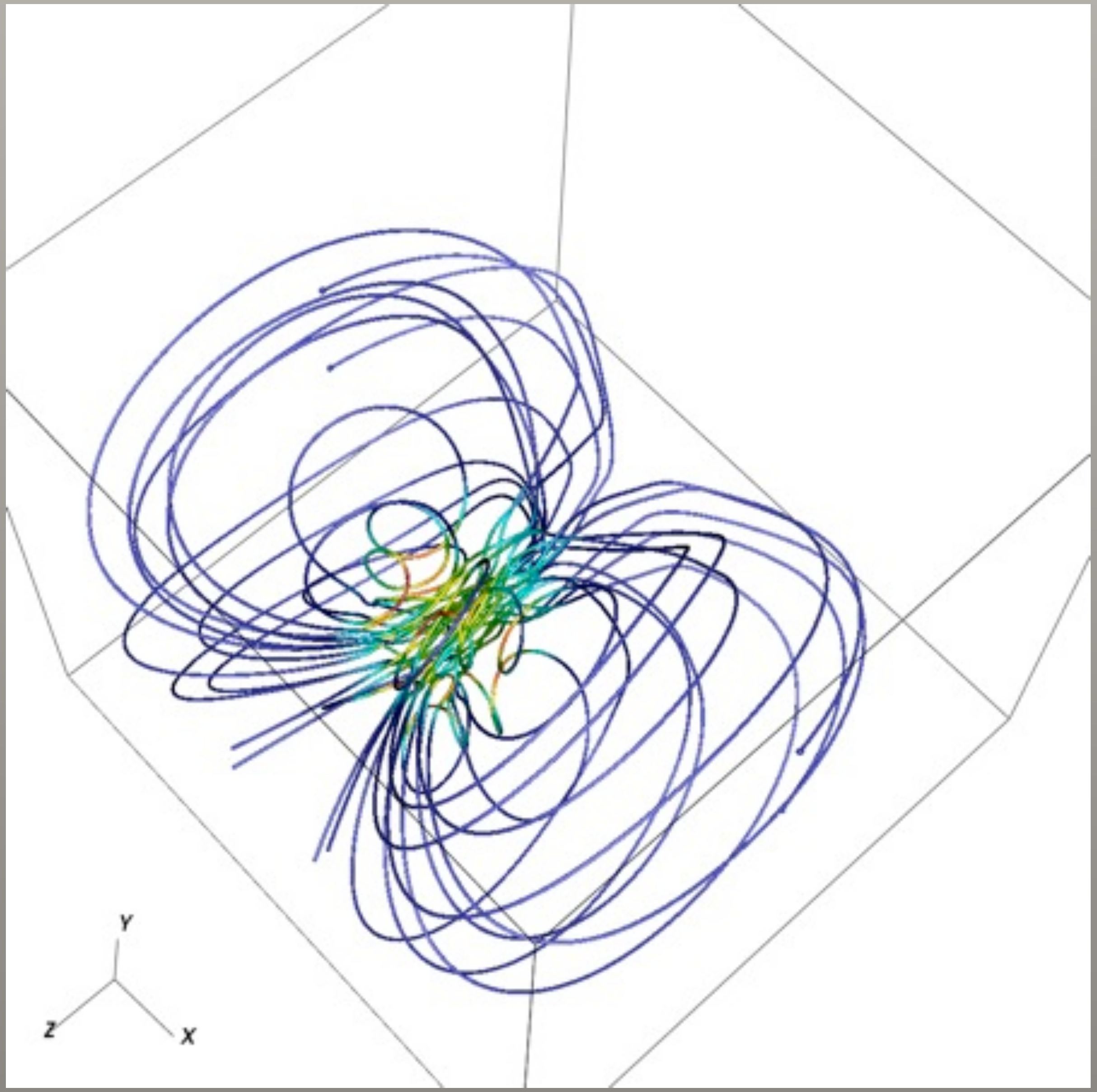
- Problem 2:
  discontinuities across AMR resolution boundaries
  - adaptive integration cannot handle this smoothly, or fails outright
  - "stopping" integration across boundary results in decreased numerical error

Integration should work out-of-the-box, without a user worrying about the details.

# Improved Integration




ignored discontinuities + averaging




explicit disc. handling + dual mesh

- Where can I download this?
  - Nowhere, yet :-(

- Integration into Visit is underway
  - Improved integration in Visit very soon
  - Integral Surfaces + FTLE visualization are being incorporated

# Acknowledgements


John Anderson,
Luke Gosink,
Hari Krishnan,
Alexy Agranovski,
Mauricio Hess-Flores,
Eduard Deines,
Ken Joy,
Markus Rütten,
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Purdue University,
University of Kaiserslautern,
University of Leipzig,
DLR Germany,
German Research Foundation,
LBNL
LLNL
ORNL

# Thanks!

Questions?