Visibility Management in Integration-based Flow Visualization

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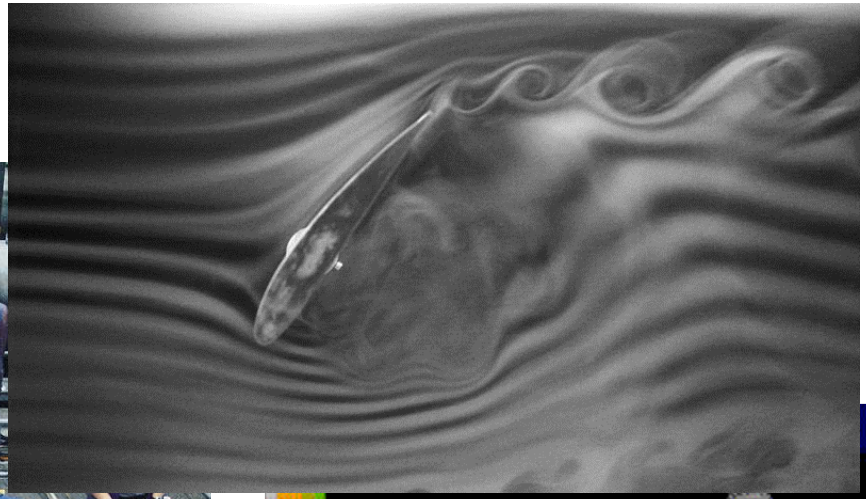
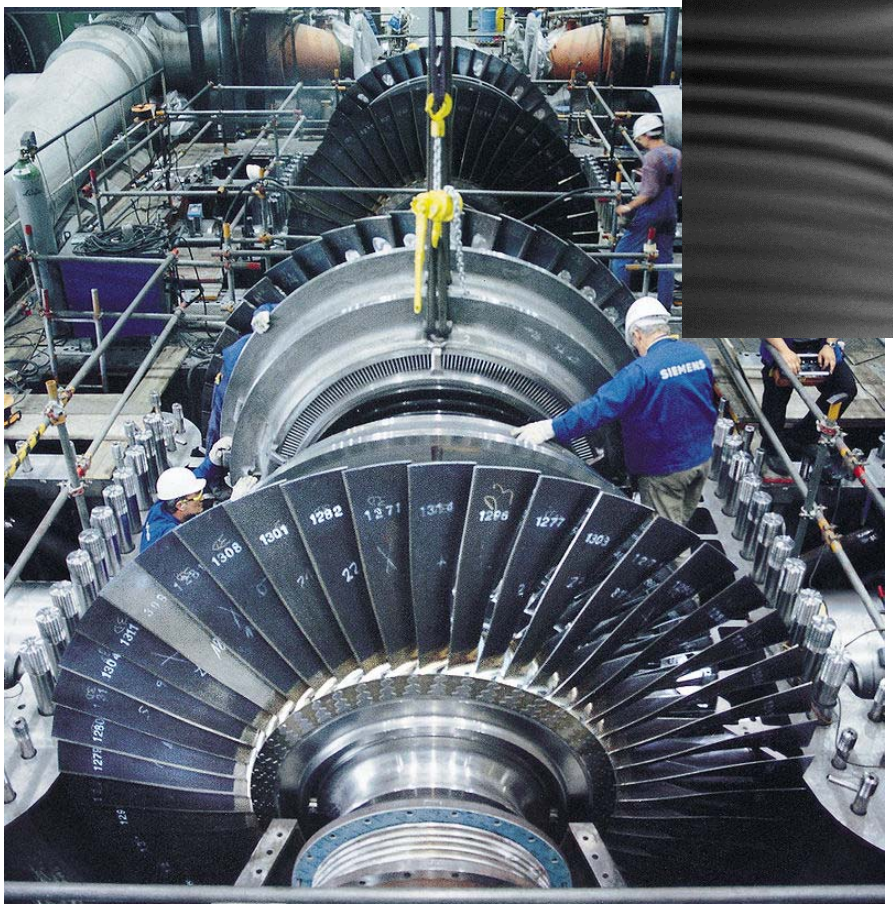
www.ii.uib.no/vis

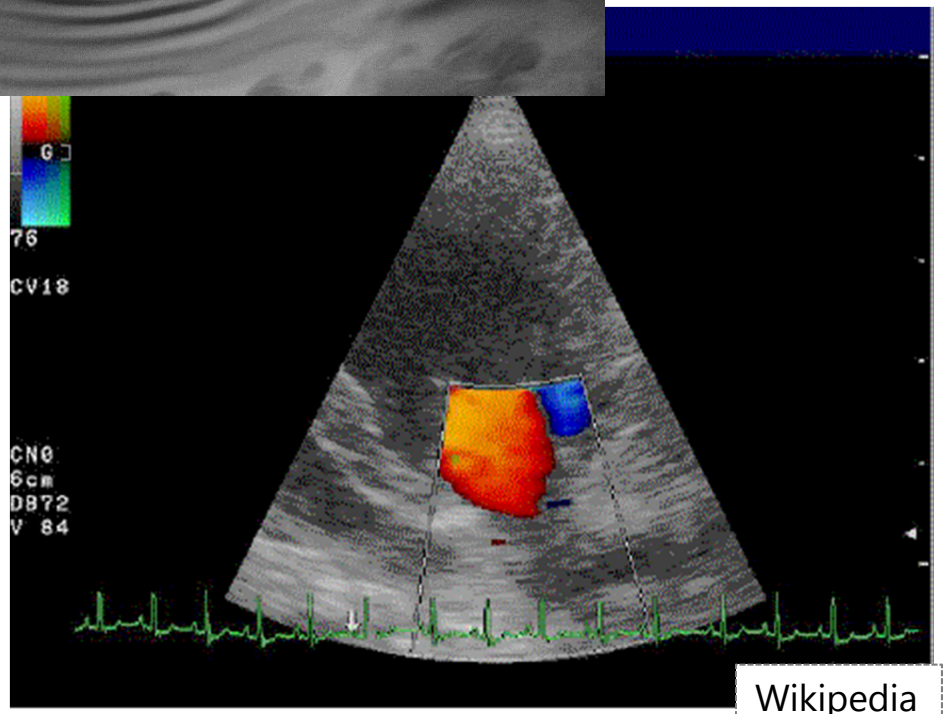
Fluid Flows

Wikipedia

Why do we care?





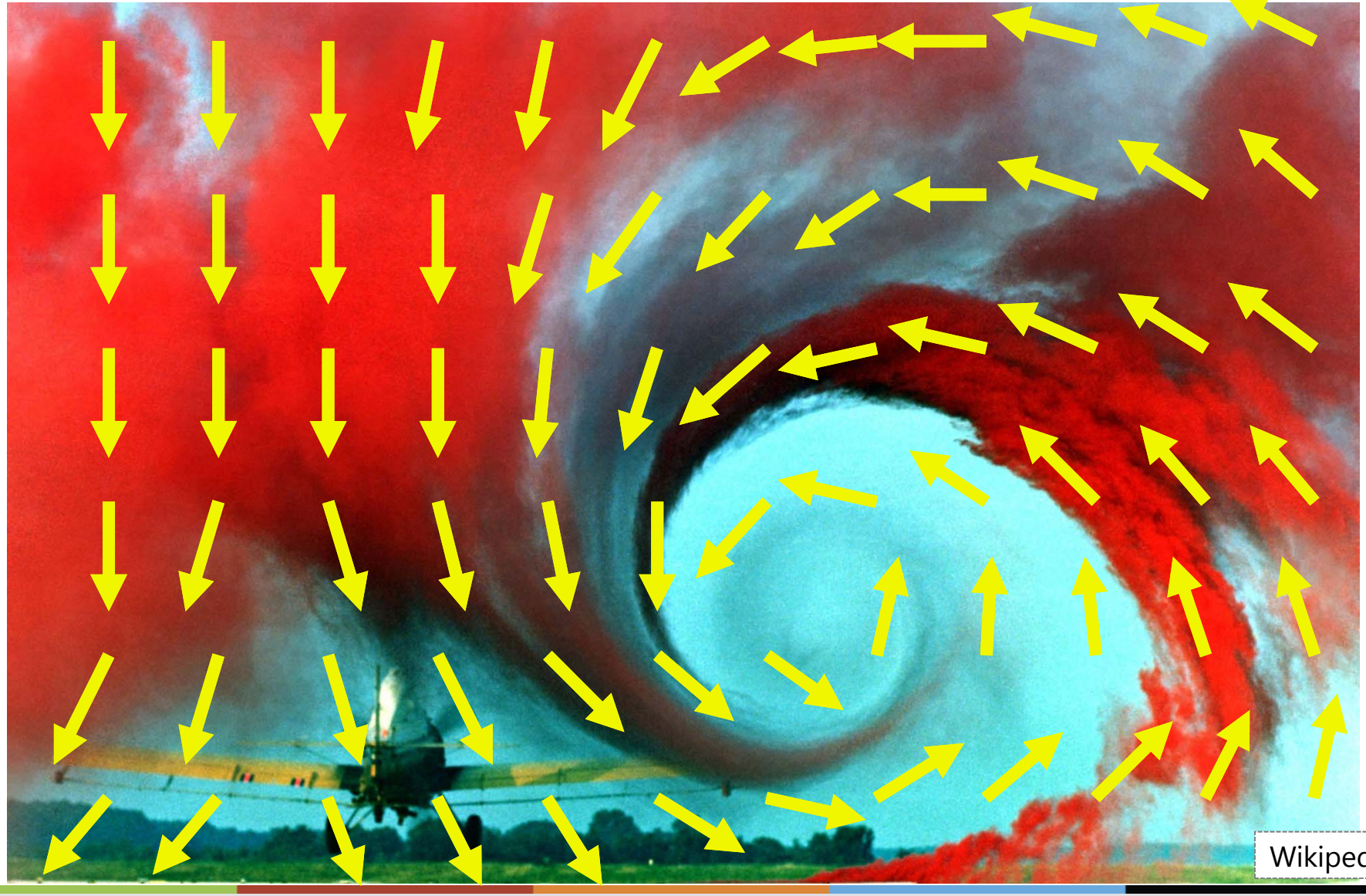


Wikipedia

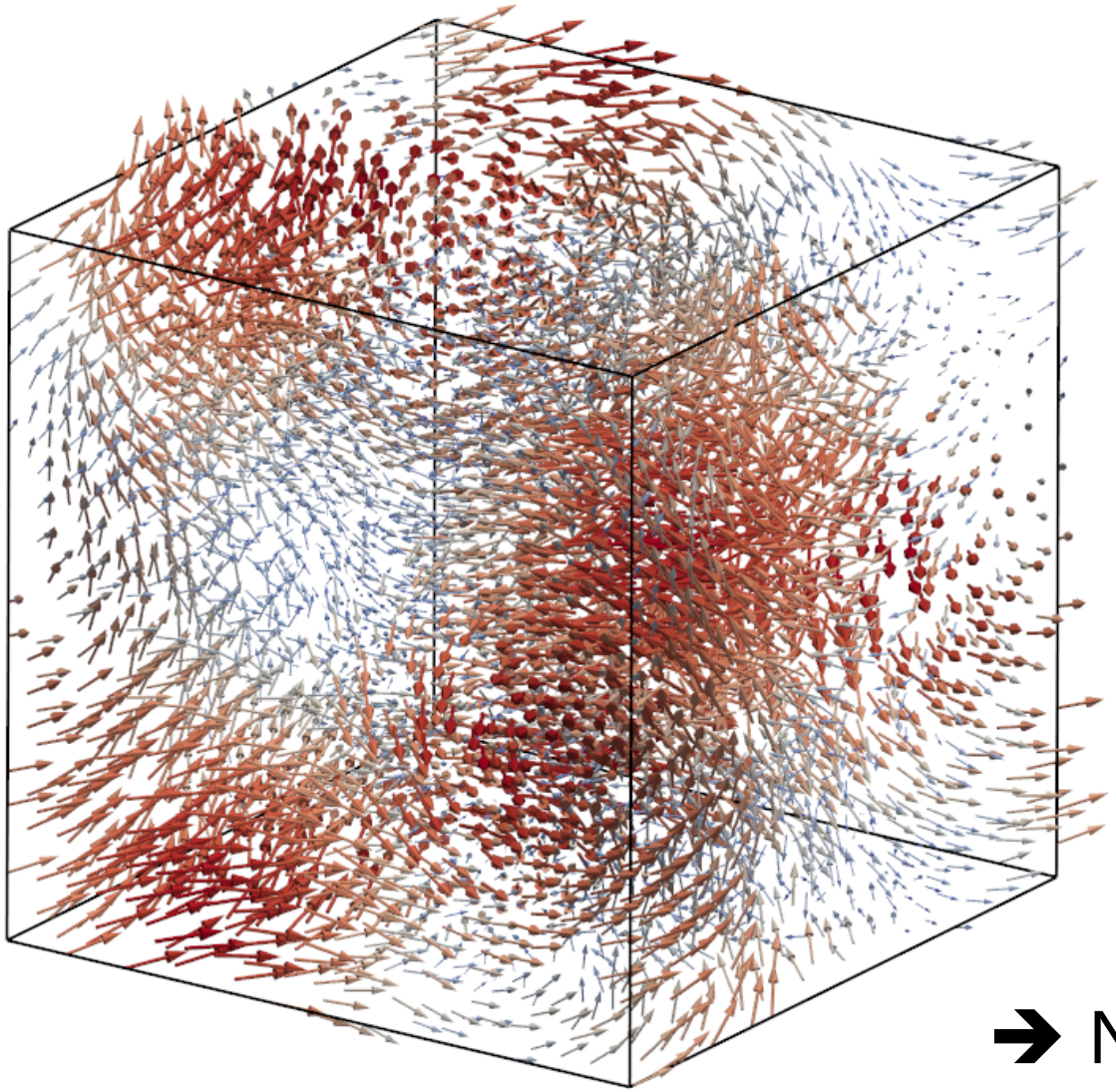
Data Representation

Wikipedia

Data representation



Fluid Flows

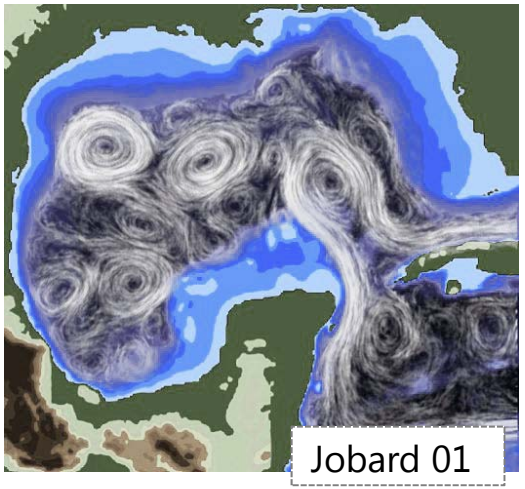


- Large
  - Up to several GB
- Time-dependent
  - Many timesteps
- Multivariate
  - Velocity
  - Pressure
  - Temperature
  - Strain
  - ...

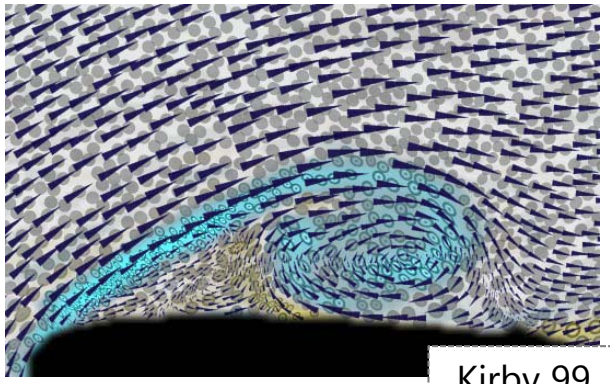
➔ Need for analysis tools

Raw Data

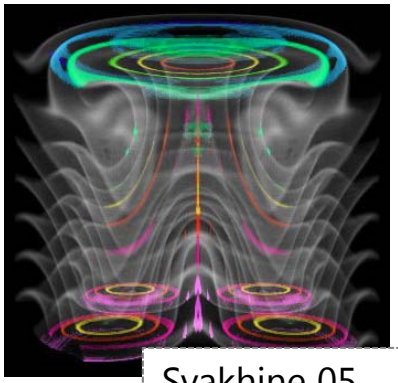
- Visualization of raw data
  - Glyphs & color coding
  - Volume rendering
  - Texture advection



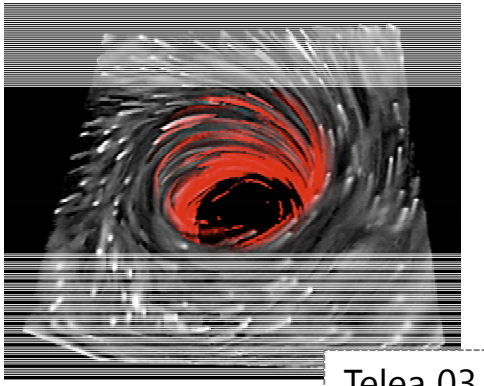
Jobard 01



Kirby 99



Svakhine 05

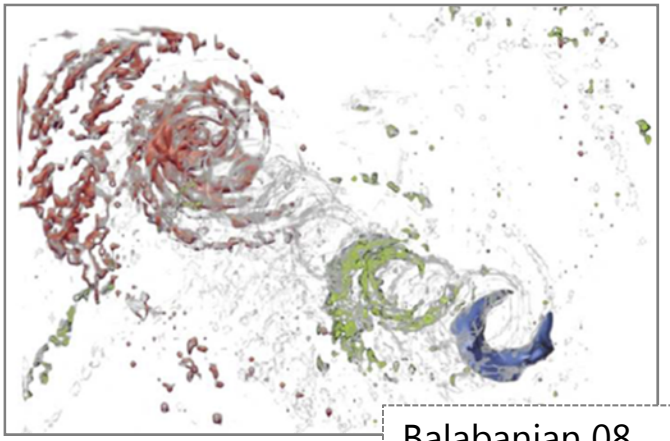


Telea 03

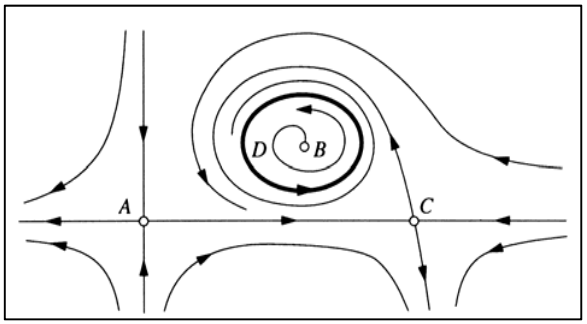
- Useful for
  - Small scale and local phenomena
  - Turbulence, shock waves, …

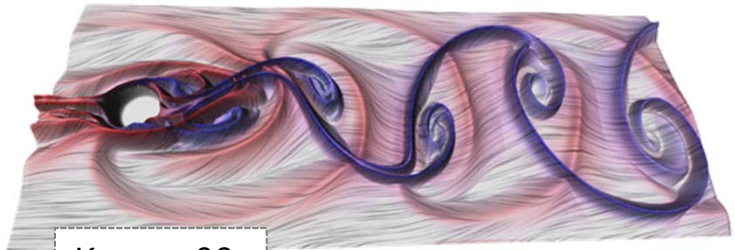
Flow Features

- Flow features
  - Vortices and shear layers
  - Vector field topology
  - …

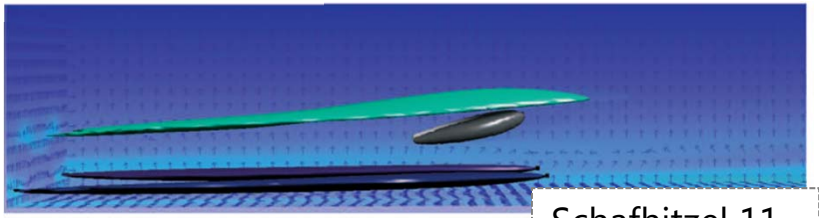


Balabanian 08





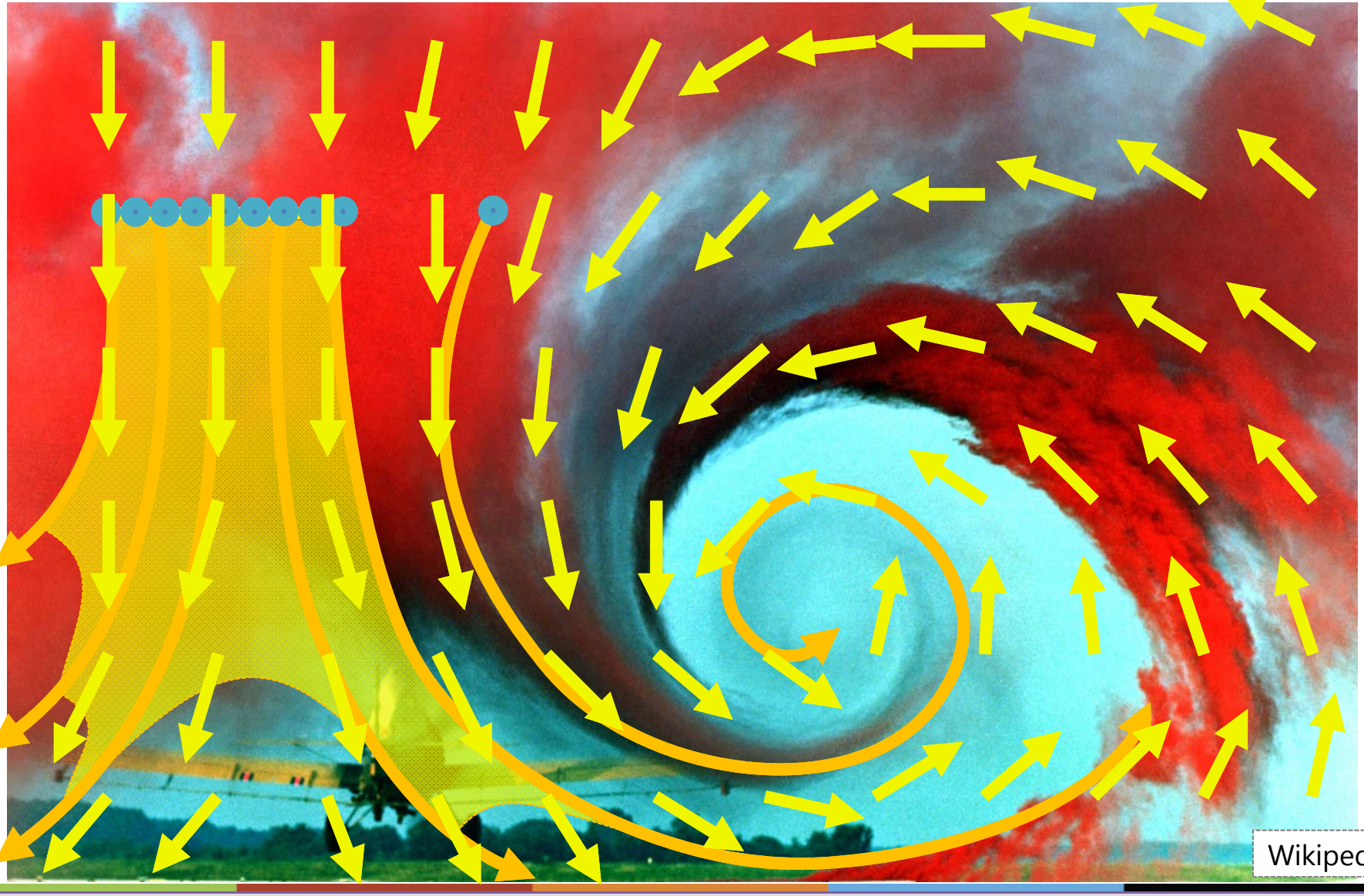
Kasten 09



Schafhitzel 11

- Useful for
  - Data overview
  - Domain-specific tasks (optimization, fault detection, …)

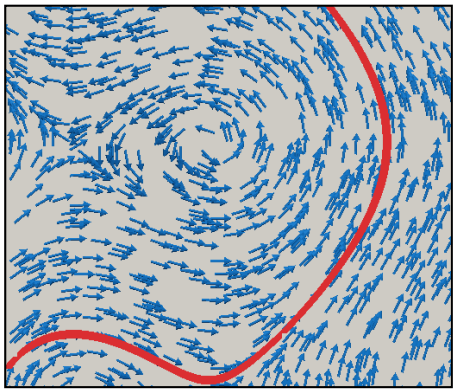
Integral structures



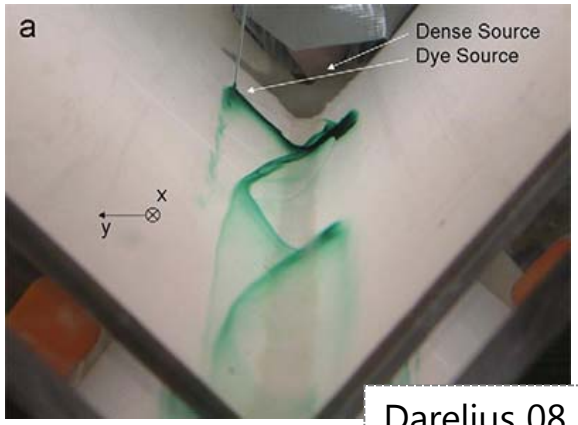
Wikipedia

Integral curves

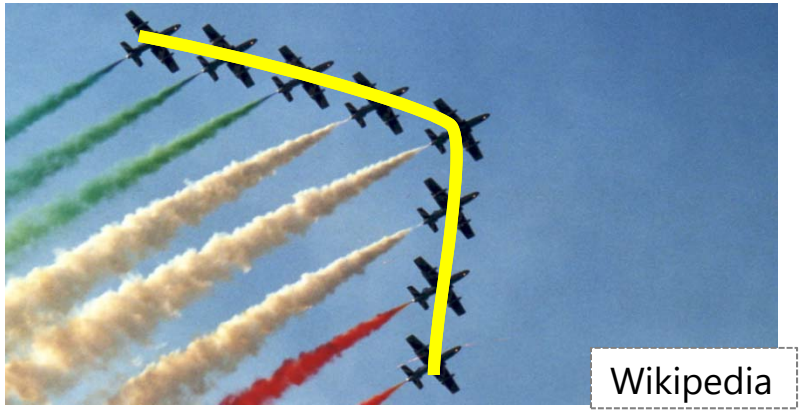
- Integral curves
  - Streamlines
  - Path lines
  - Streak lines
  - Time lines



Wikipedia



Darelius 08

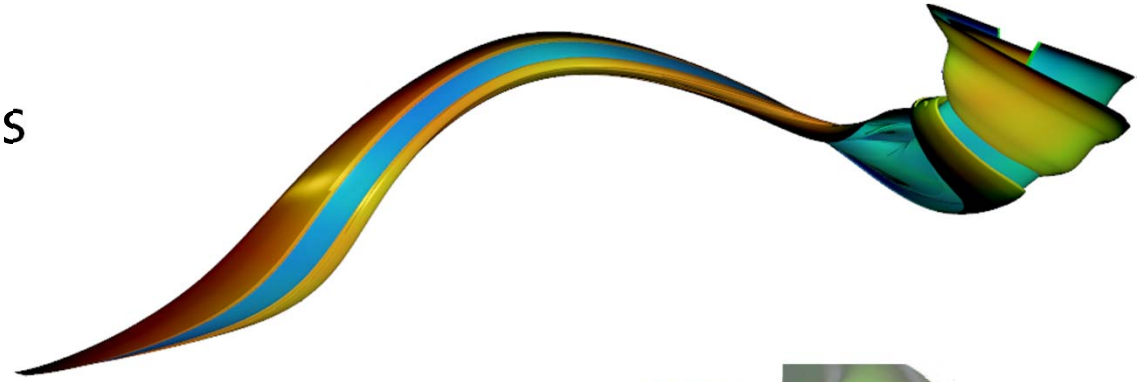


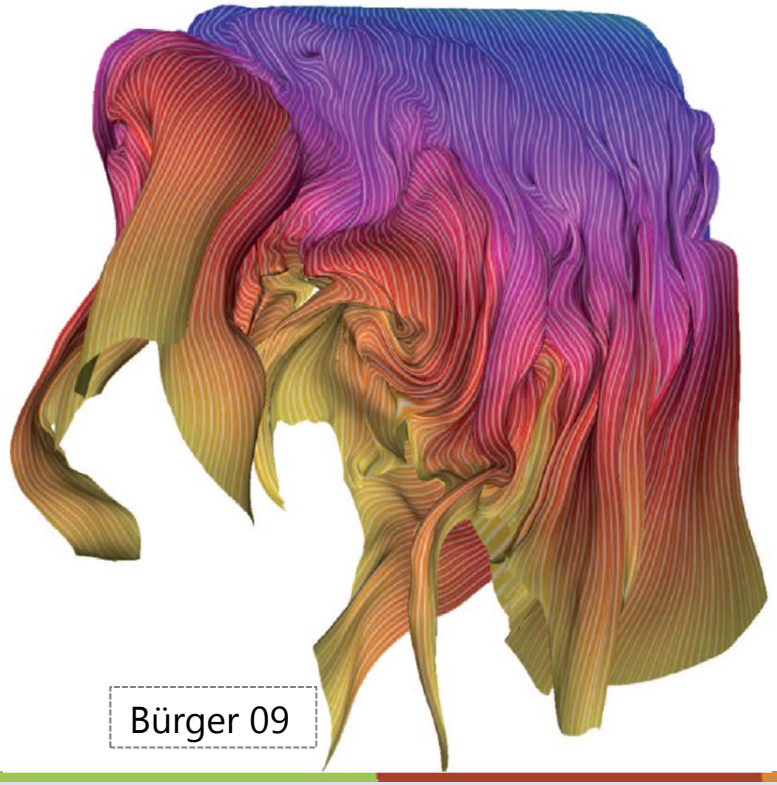
Wikipedia

- Useful for
  - Investigating time-dependent phenomena
  - Trajectories, mixing, transport, ...

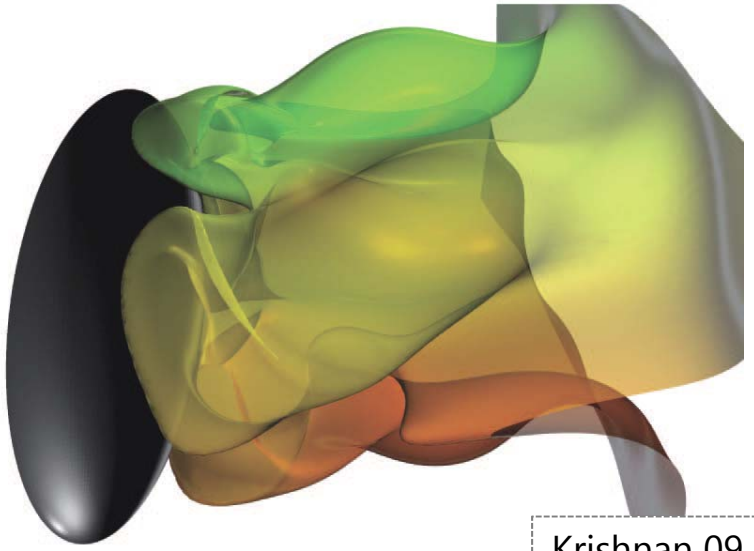
Integral surfaces

- Integral surfaces
  - Stream/path surfaces
  - Streak surfaces
  - Time surfaces





Bürger 09



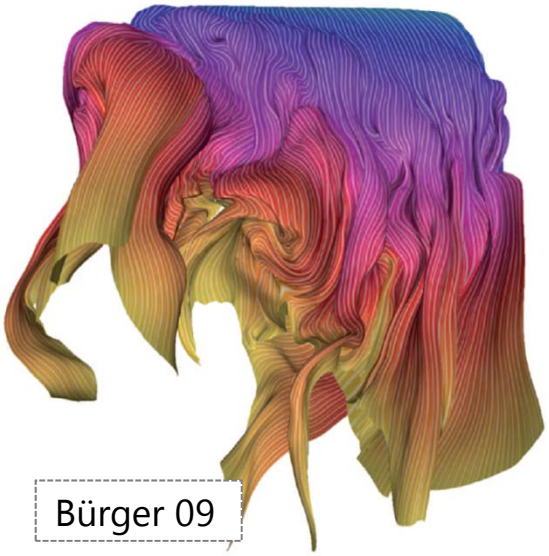
Krishnan 09

➔Improve depth & shape perception

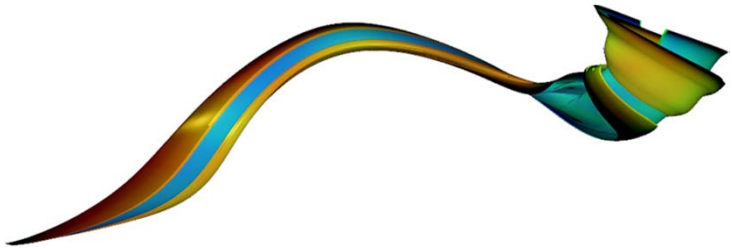
➔Emphasize relation between curves

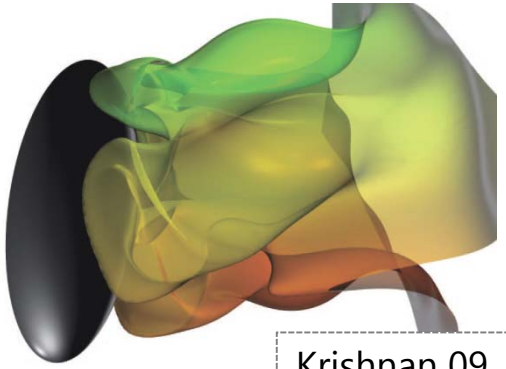
Integral surfaces

- Main problem: **cluttering** & **self occlusion**



Bürger 09

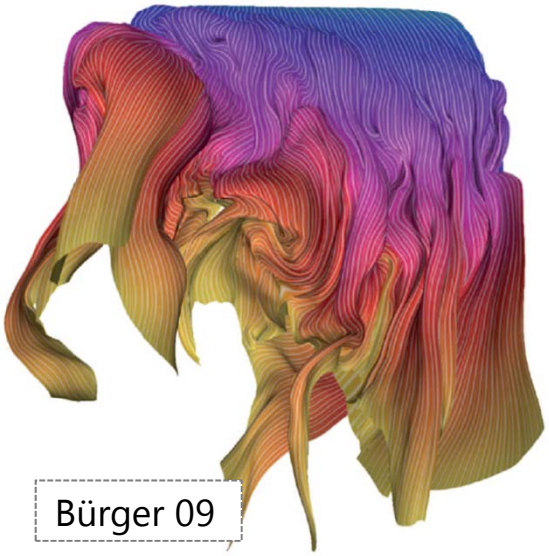




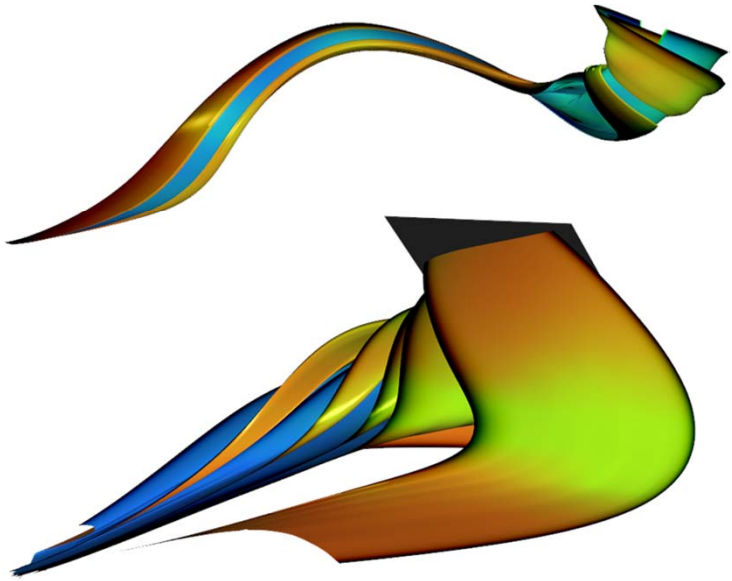
Krishnan 09

Integral surfaces

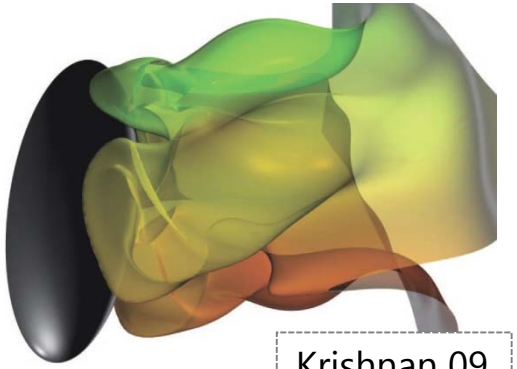
- Main problem: **cluttering** & **self occlusion**



Bürger 09



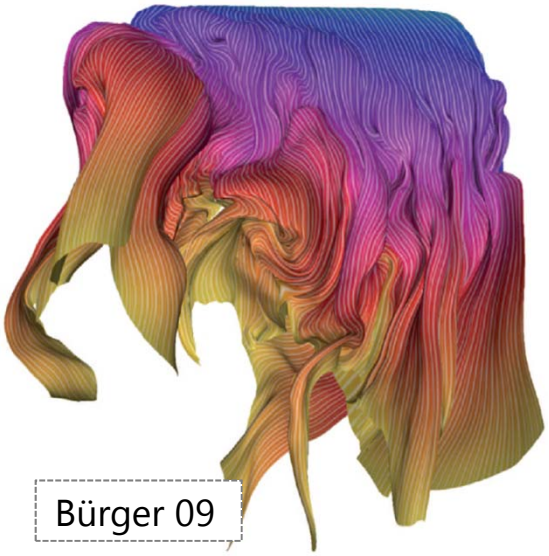
Multiple surfaces



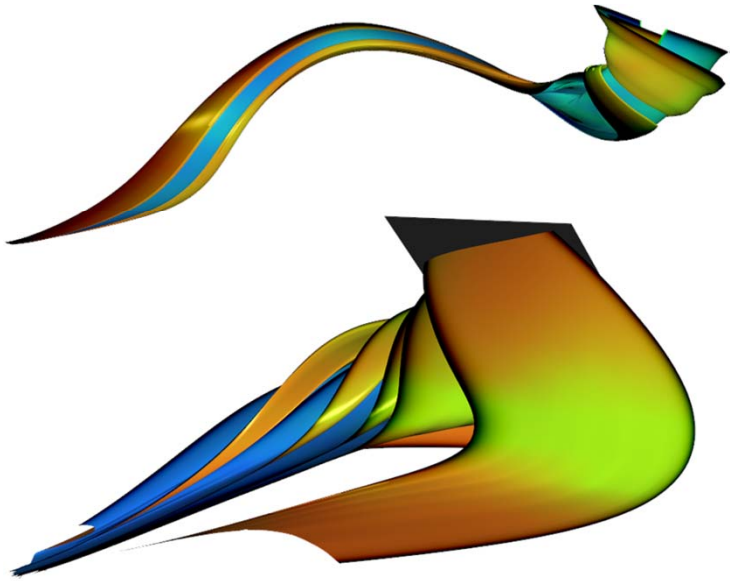
Krishnan 09

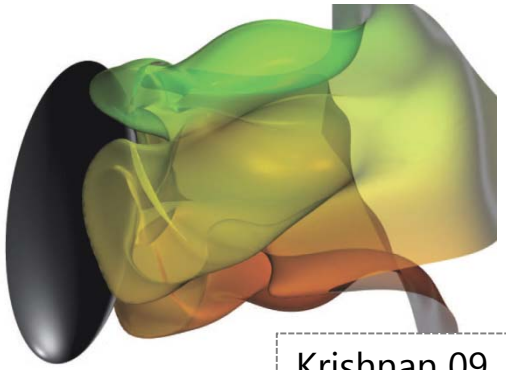
Integral surfaces

- Main problem: **cluttering** & **self occlusion**



Bürger 09



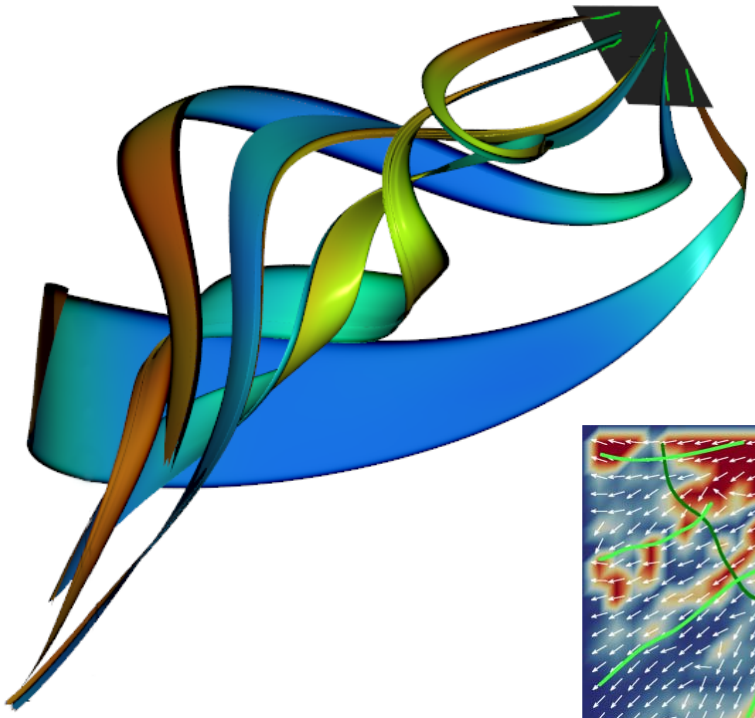


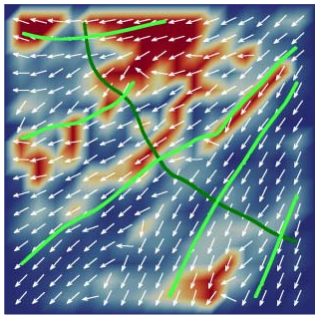
Krishnan 09

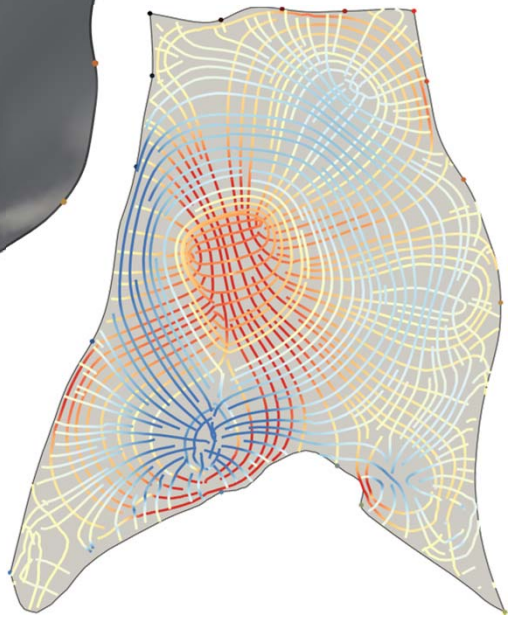
- Visibility issues can be addressed
  - Before integration -> seeding curve selection
  - After integration -> shading, cuts, deformations

Visibility Management

Similarity-based seeding



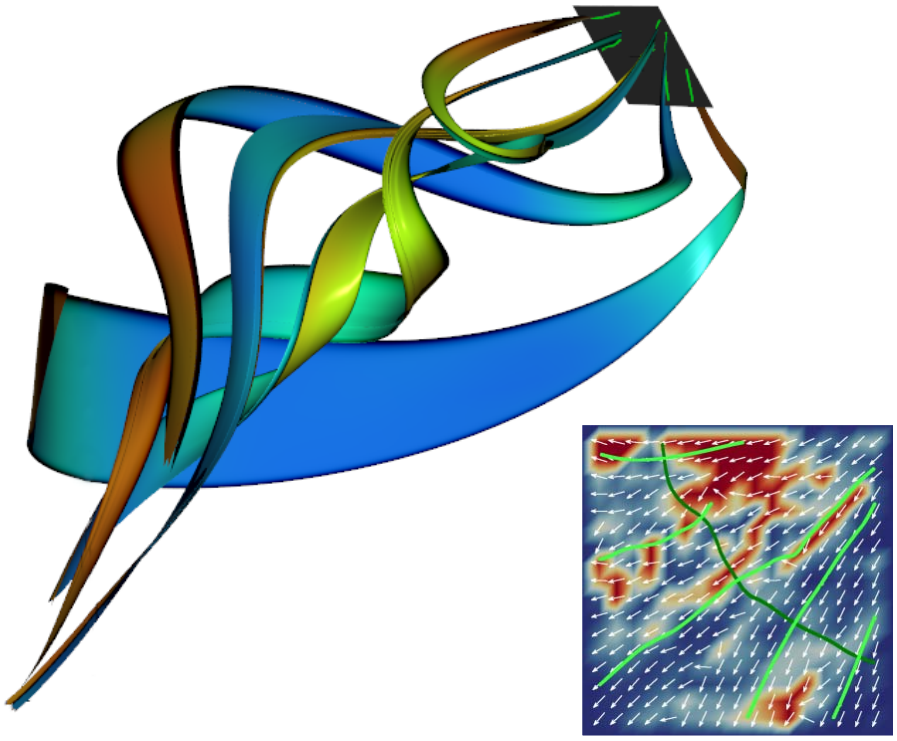




Integral surface flattening

Visibility Management

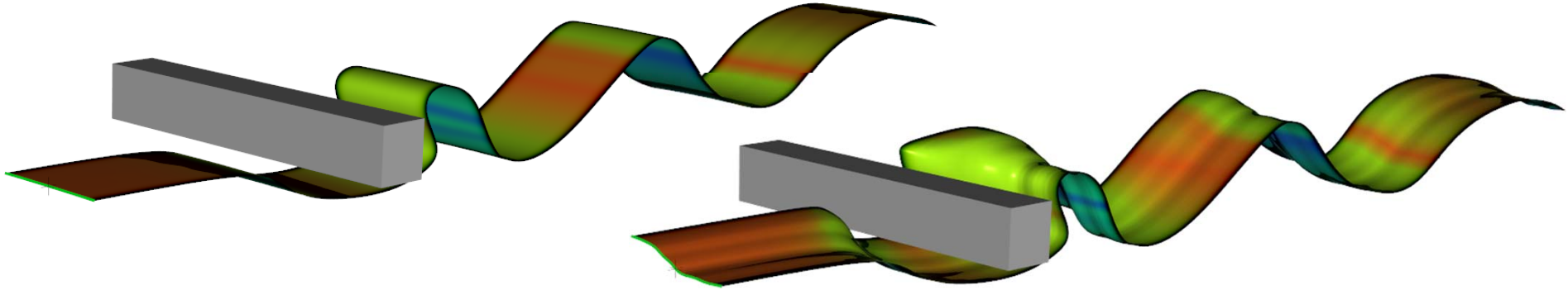
Similarity-based seeding



Integral surface flattening

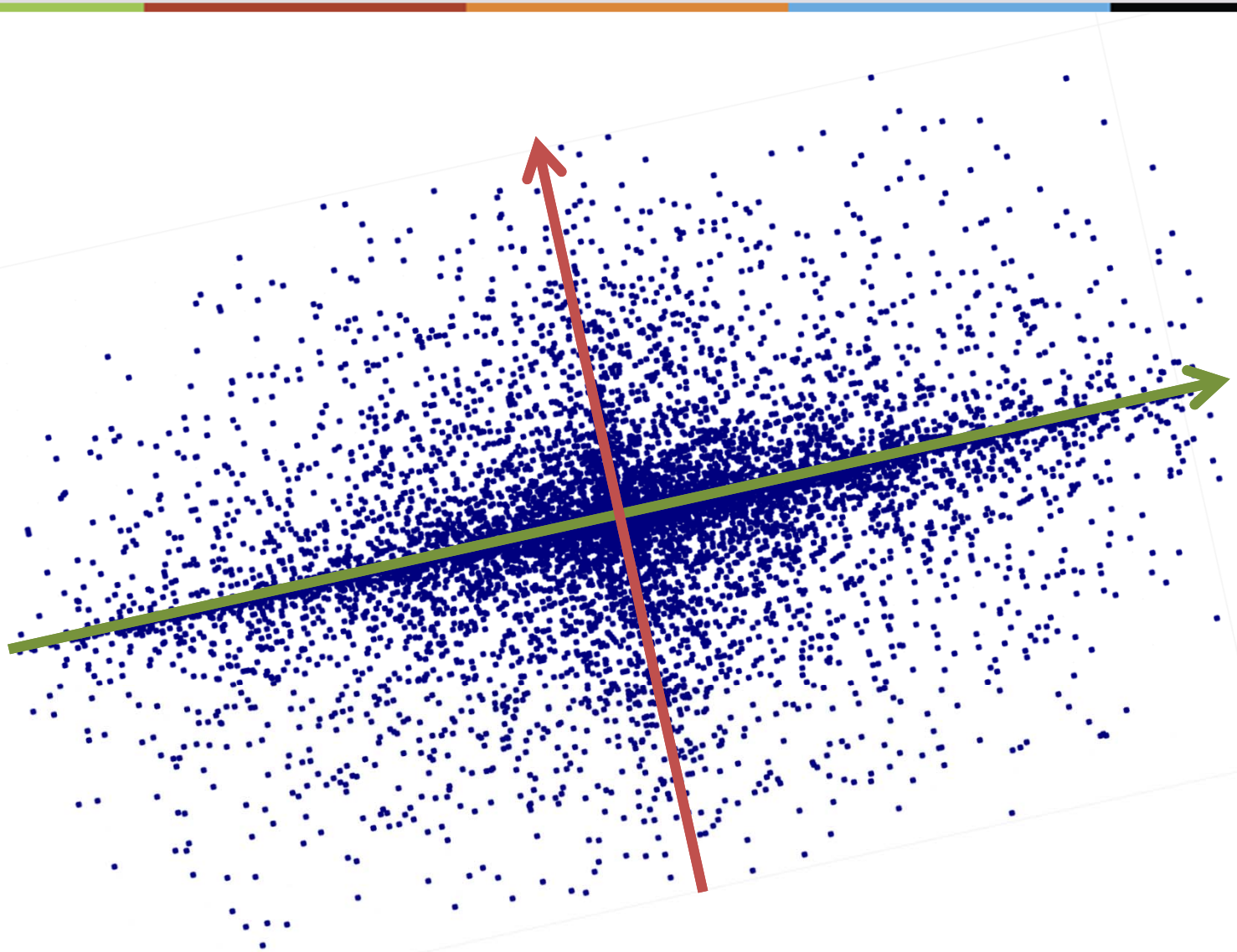
Integral Surface Placement

- How can we define a proper seeding structure?
  - Use a line segment -> 6 degrees of freedom
  - Use an arbitrary curve -> ... a lot
  - Seed multiple surfaces -> even more!

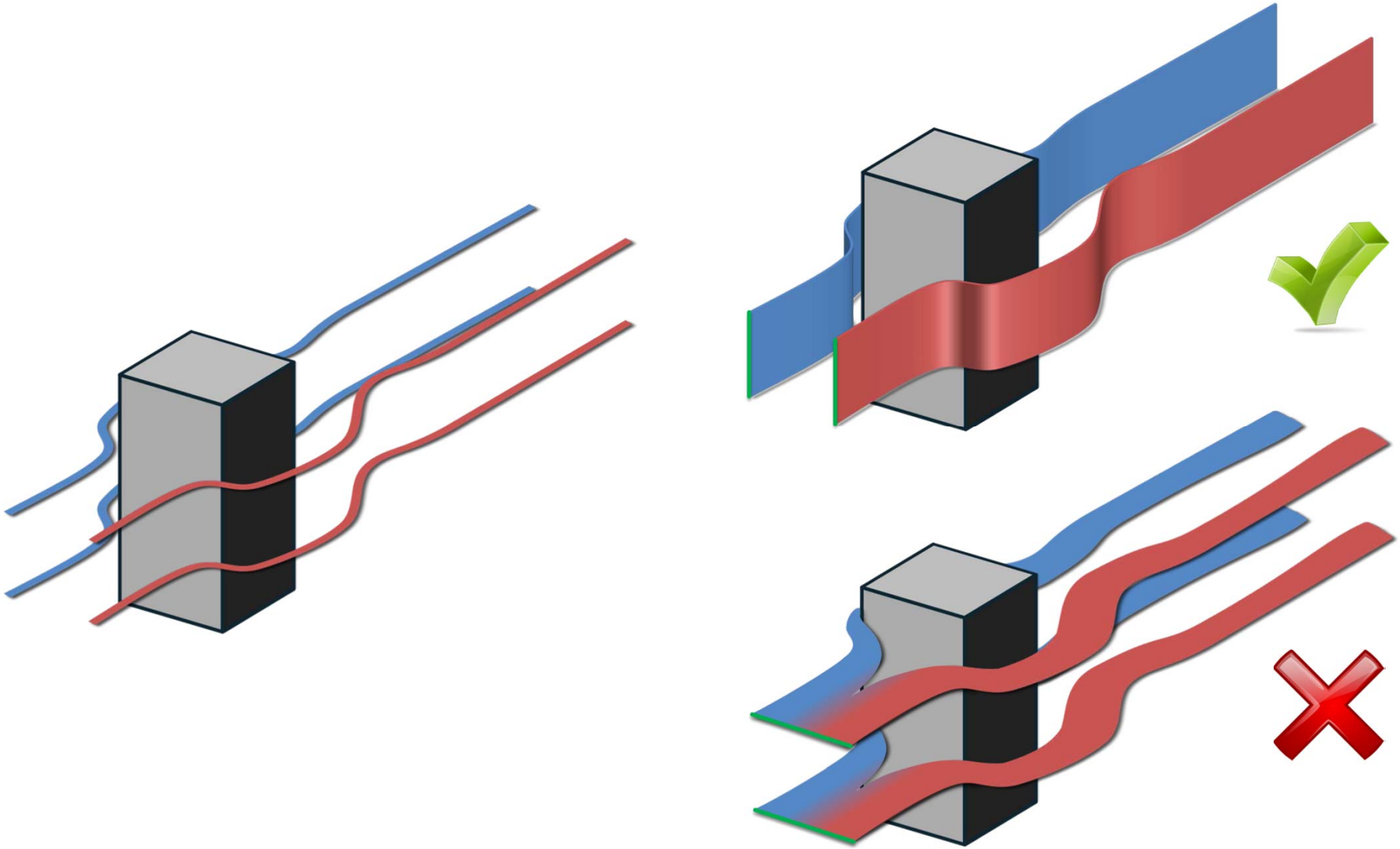


- Goal: define a semi-automatic seeding strategy s.t.:
  - Handle multiple surfaces
  - Captures the most prominent aspects of the flow
  - Each surface capture a single aspect of the flow

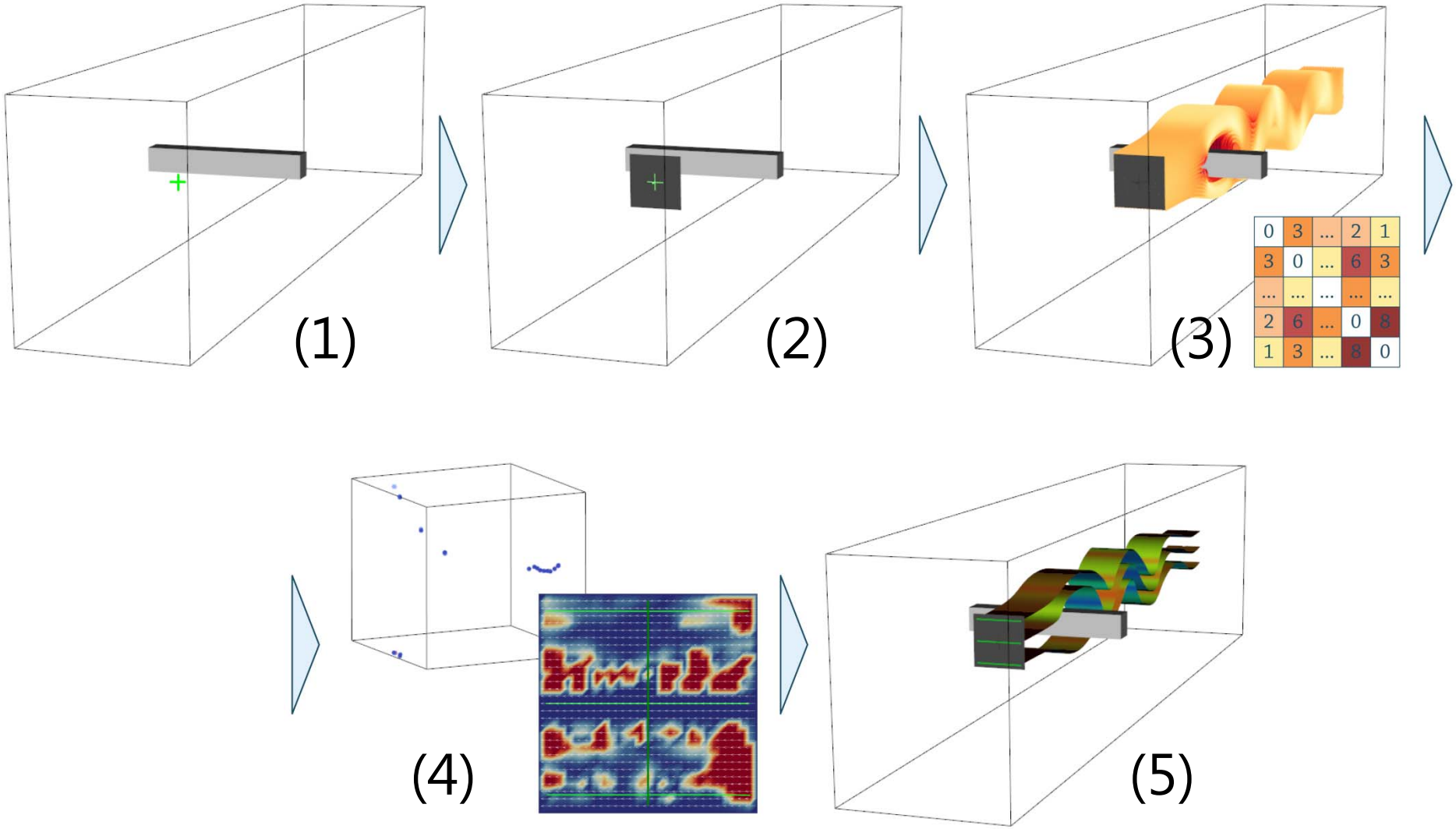
Multiple Aspects of a Flow



Multiple Aspects of a Flow

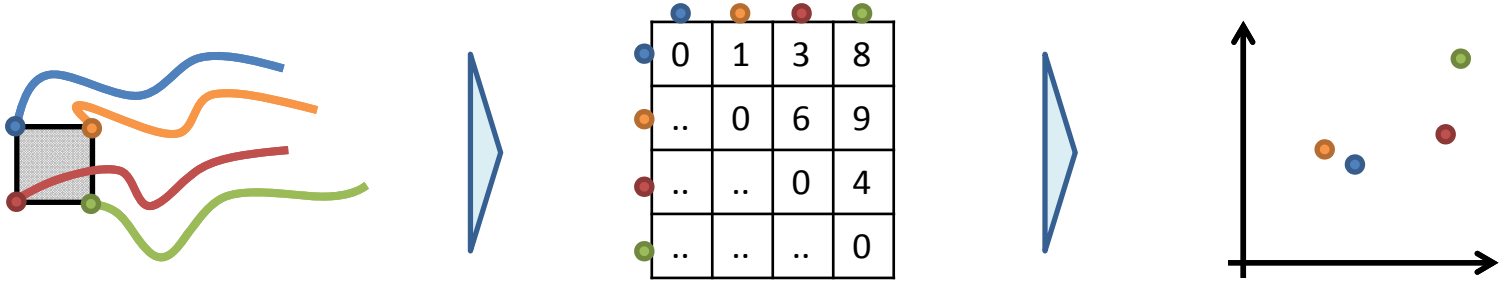


Placement Pipeline



Dissimilarity and MDS

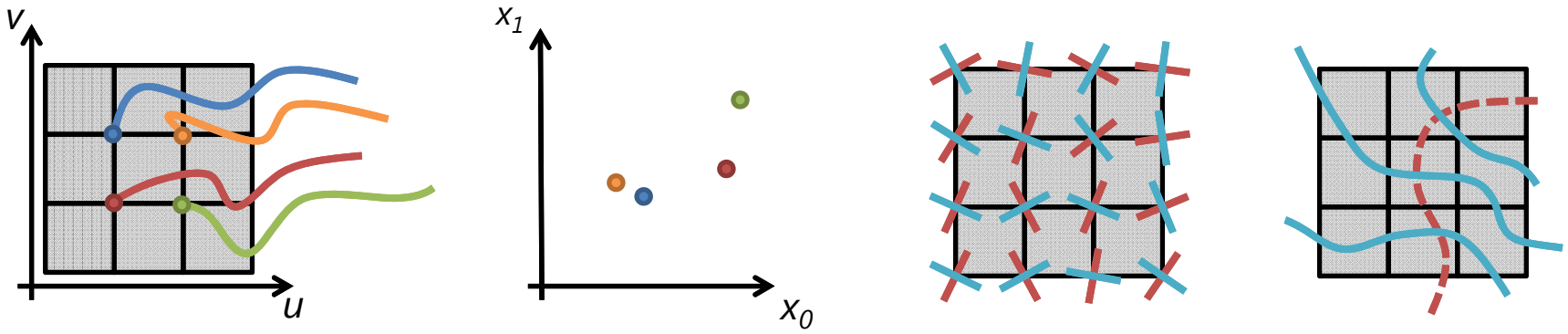
- Dissimilarity given by the Hausdorff distance
  - Expensive, so compute it on the GPU
  - Other dissimilarity measures can be used



- Multi Dimensional Scaling: embed points in R^N according to their reciprocal similarity
- Computed on the GPU using CFMDS (Park et al '12)

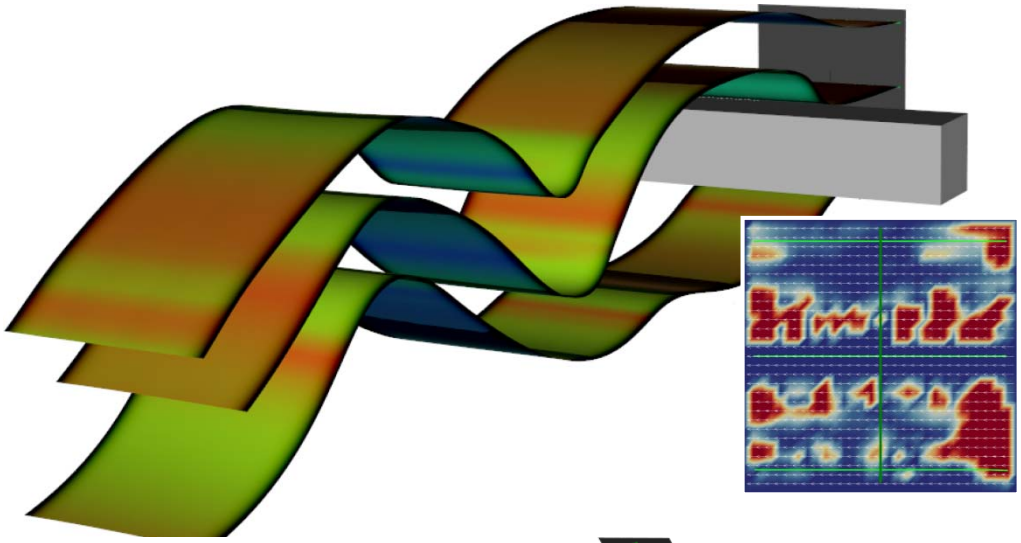
Derivatives and Seeding

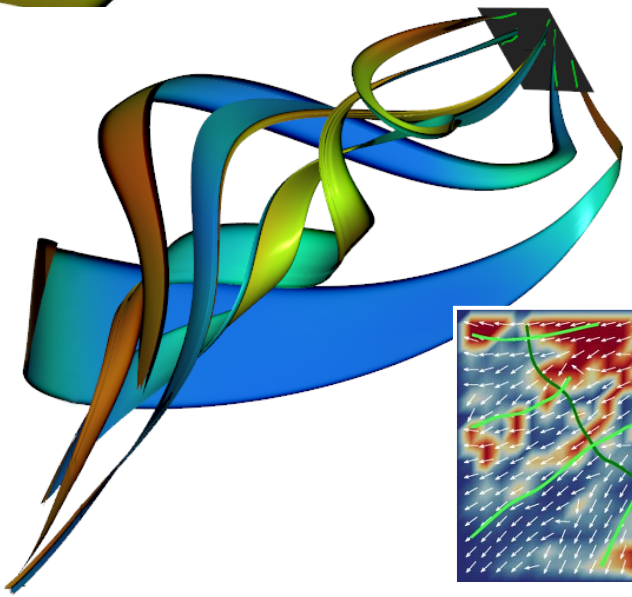
- Each point $\boldsymbol{P} = (u, v)$ is mapped by the MDS to a point $\boldsymbol{X} = (x_0, x_1, \ldots, x_N)$ in the embedding space

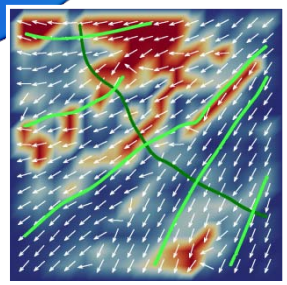


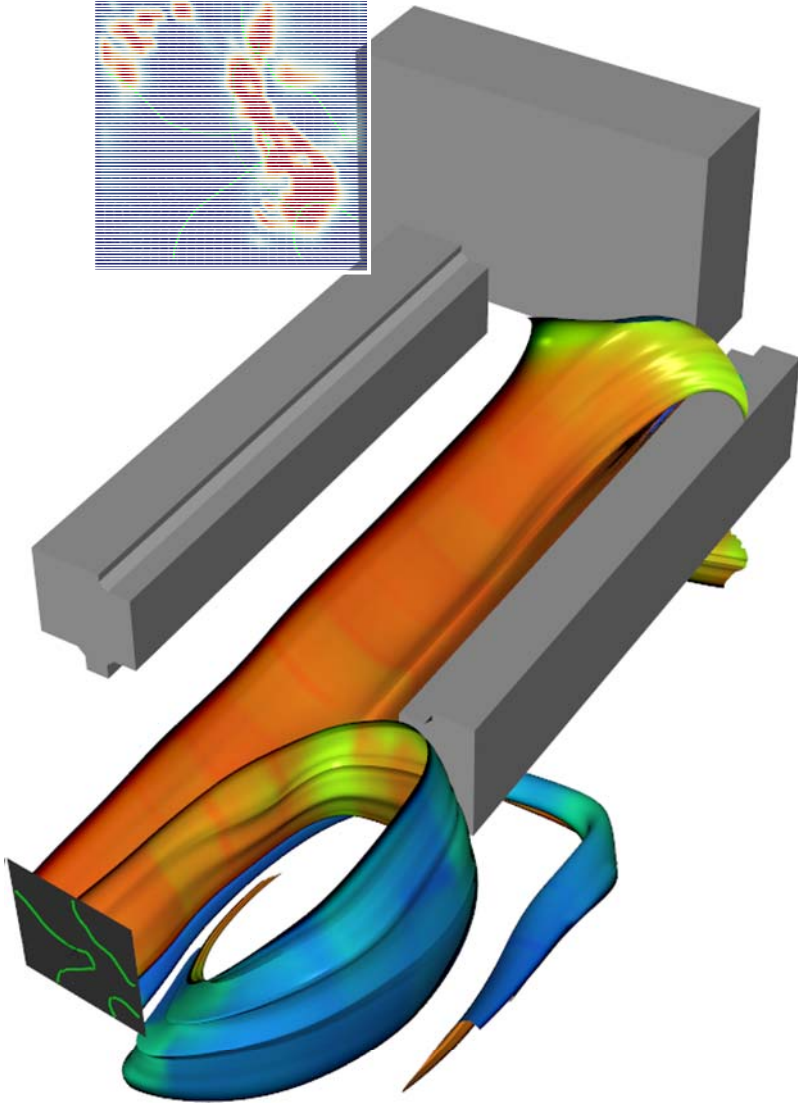
- The derivative $\boldsymbol{J} = d\boldsymbol{X} / d\boldsymbol{P}$ is a *Nx2* matrix
- We compute the eigendecomposition of $\boldsymbol{J}^T\boldsymbol{J}$
- Eigenvectors are the directions of max/min similarity
- We use tensor lines of the min eigenvector field as seeding curves

Results



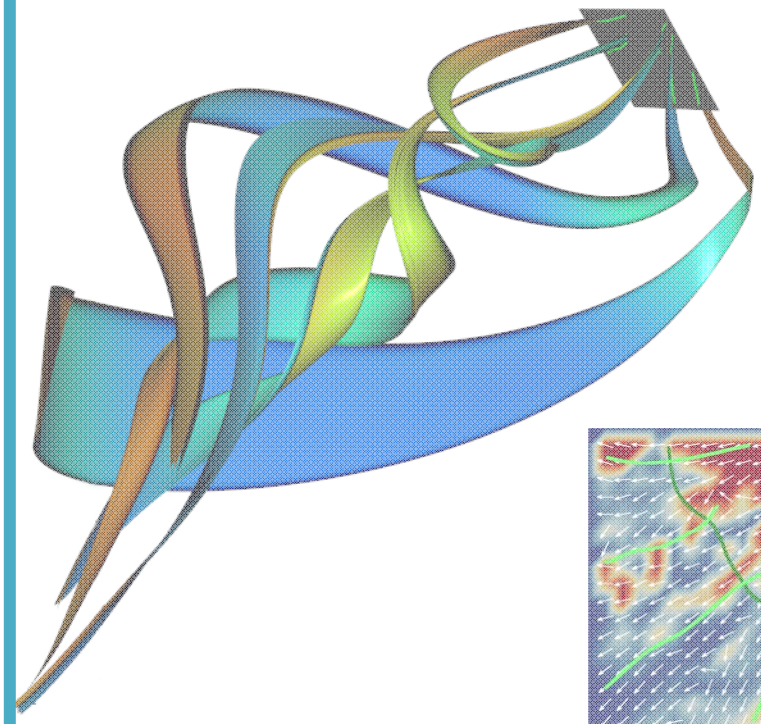


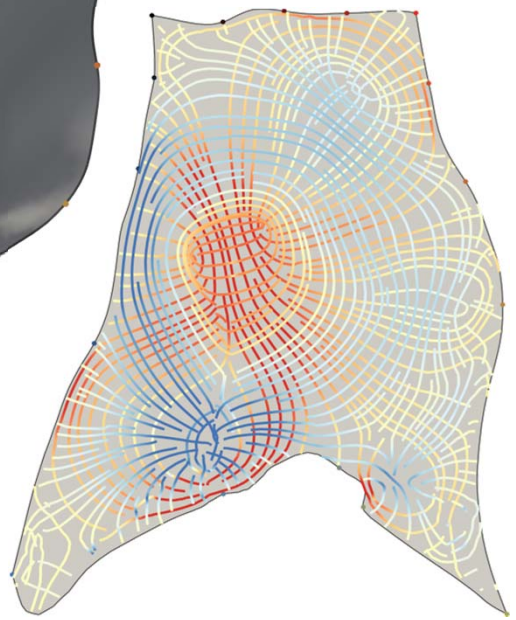




Visibility Management

Similarity-based seeding

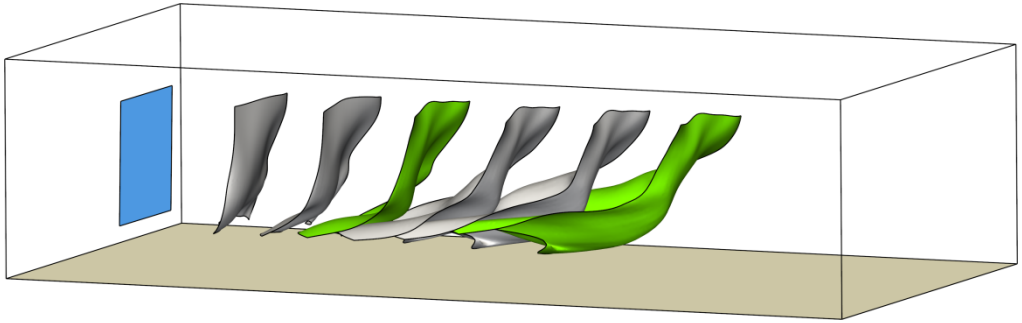


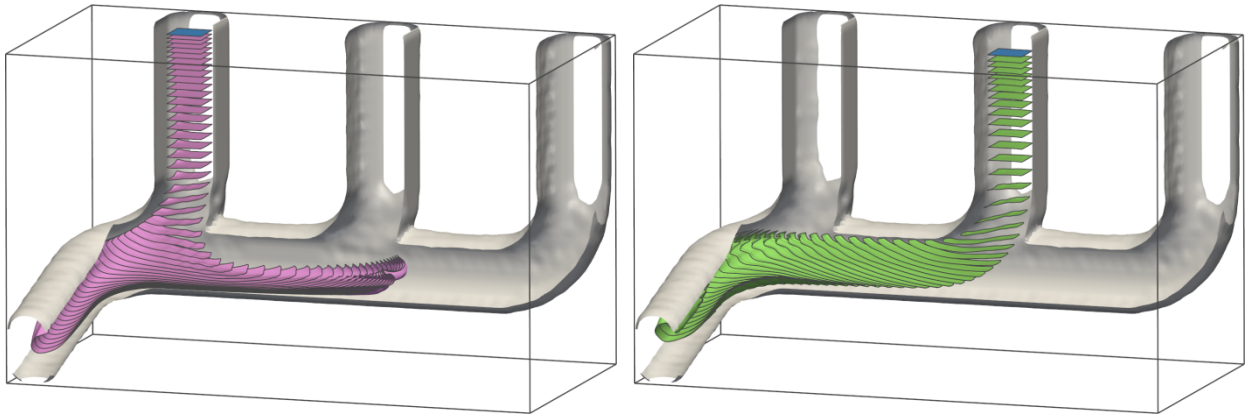


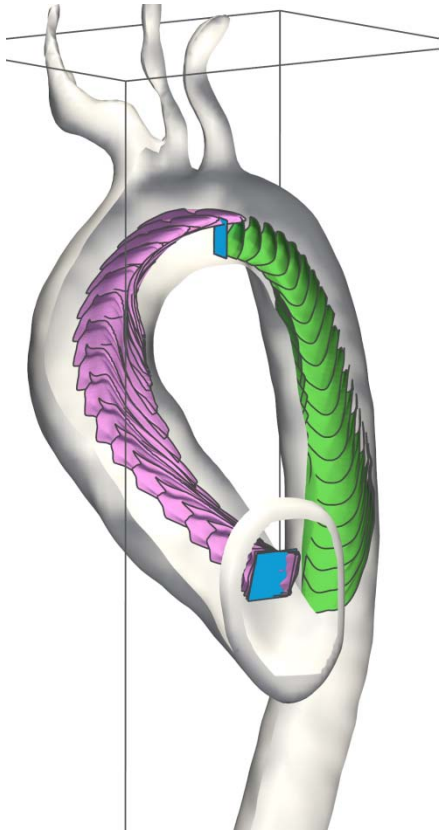
Integral surface flattening

Integral Surface Analysis

- We want to investigate the long-term flow behavior
- We adopted (families of) integral surfaces as a tool



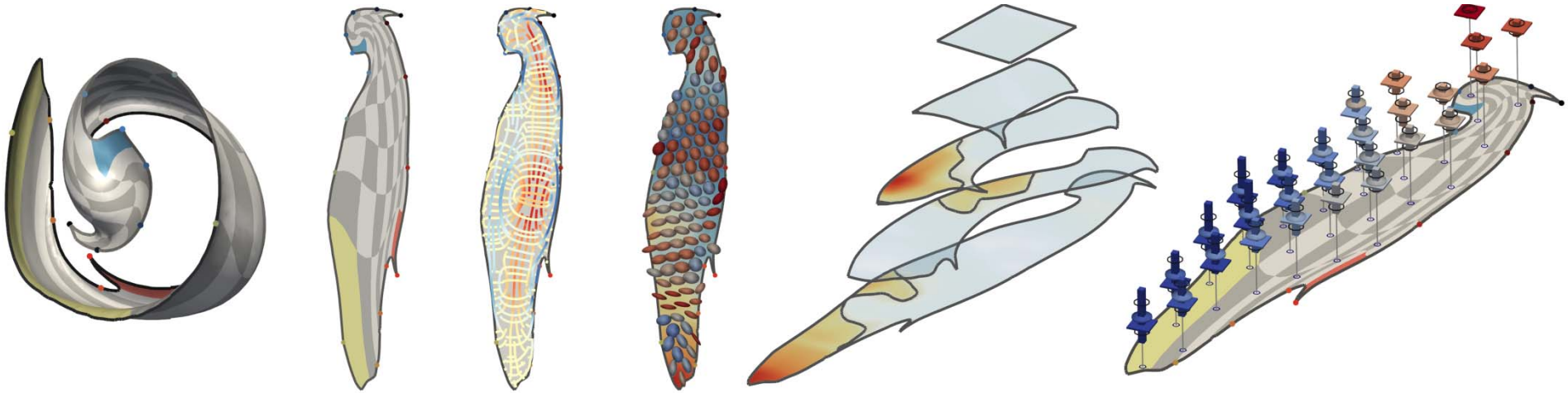




- Now we aim at easing their analysis

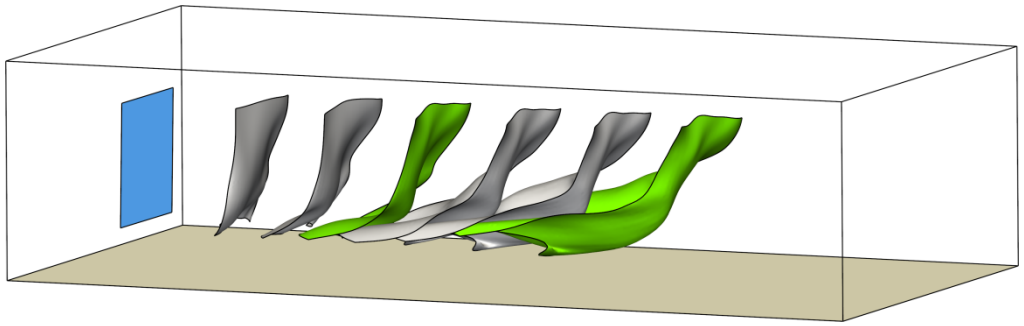
Integral Surface Analysis

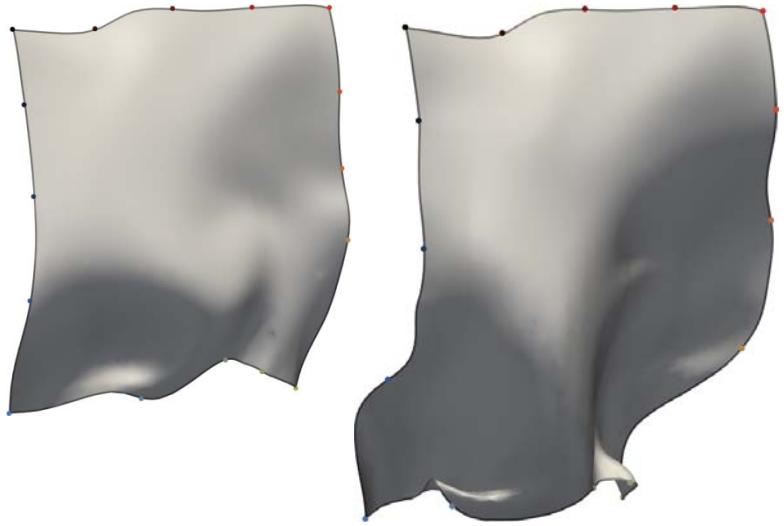
- Surfaces can have intricate shapes
  - Analysis of one surface at a time
  - Extensive user interaction / manipulation
  - Flow properties not easily conveyed
- We take advantage of **surface reformation**
- Ad-hoc visualizations in the reformed space



Surface Reformation

- As-Rigid-As-Possible flattening (Liu et al. '08)
- Maps surface points $\boldsymbol{X} = (x, y, z)$ to points $\boldsymbol{P} = (u, v)$ in the 2D reformed space
- The original shape should be still conveyed!

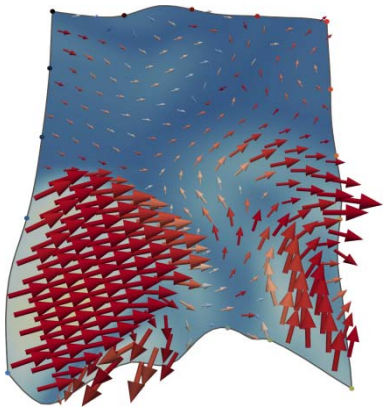




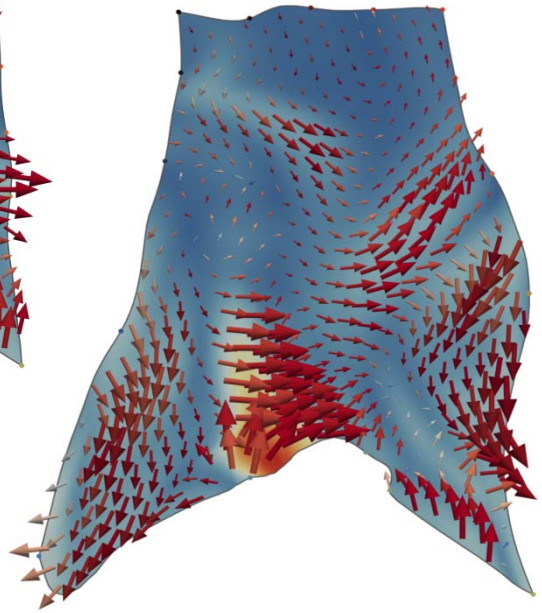
- Compute the matrix $\boldsymbol{J} = d\boldsymbol{X} / d\boldsymbol{P}$
- Compute the eigendecomposition of $\boldsymbol{J}^T\boldsymbol{J}$

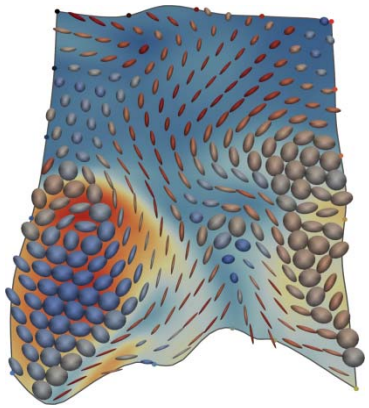
Flow Attributes on Surfaces

- Scalar attributes can be directly mapped to colors
- Vectors and tensors needs to:
  - be projected on the surface $\boldsymbol{S}_\psi = (\boldsymbol{I} - \boldsymbol{n}\boldsymbol{n}^T)\,\boldsymbol{S}\,(\boldsymbol{I} - \boldsymbol{n}\boldsymbol{n}^T)^T$
  - take flattening into account $\boldsymbol{S}_2 = \boldsymbol{J}^{-1}\,\boldsymbol{S}_\psi\,\boldsymbol{J}$

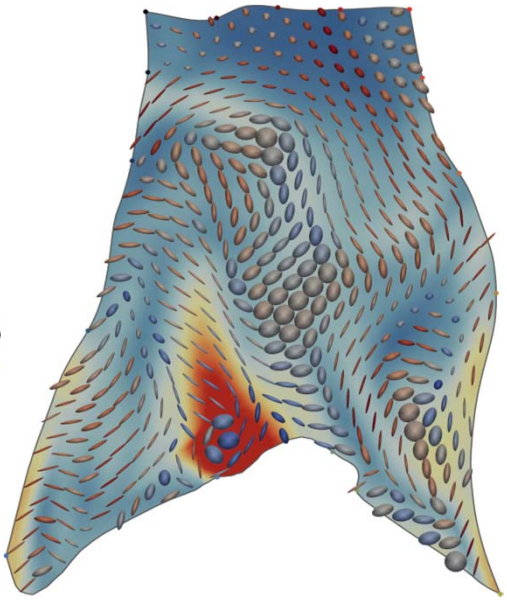


Vorticity



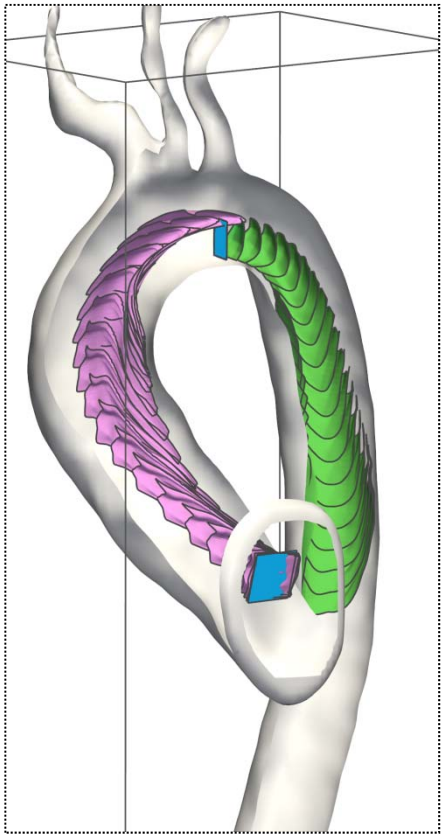


Strain rate

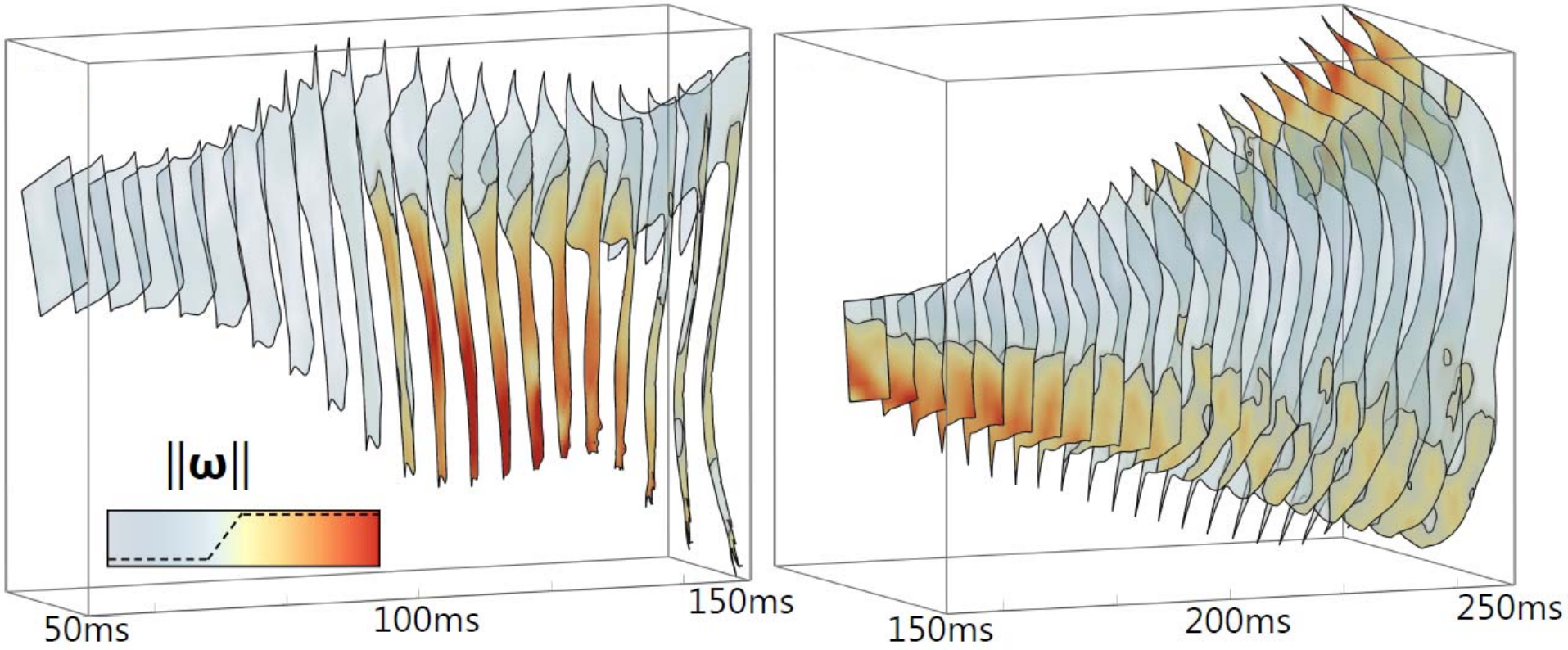


- Size <-> $\| \boldsymbol{S}_\psi \|$ Color <-> $\| \boldsymbol{S}_\psi \| / \| \boldsymbol{S} \|$

Families of Time Surfaces

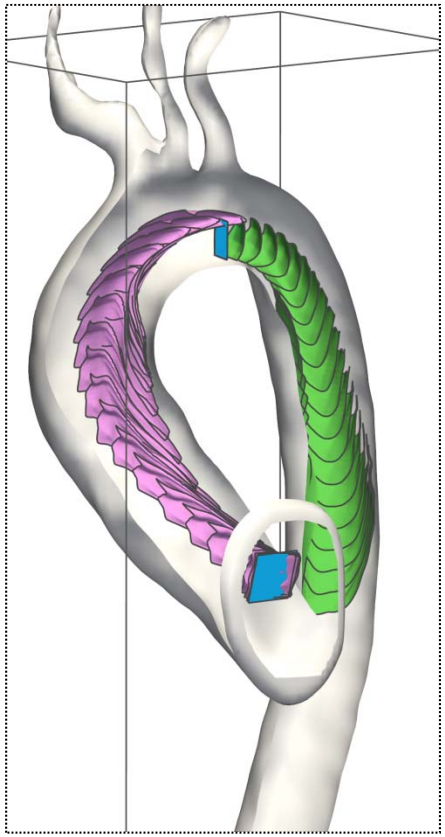


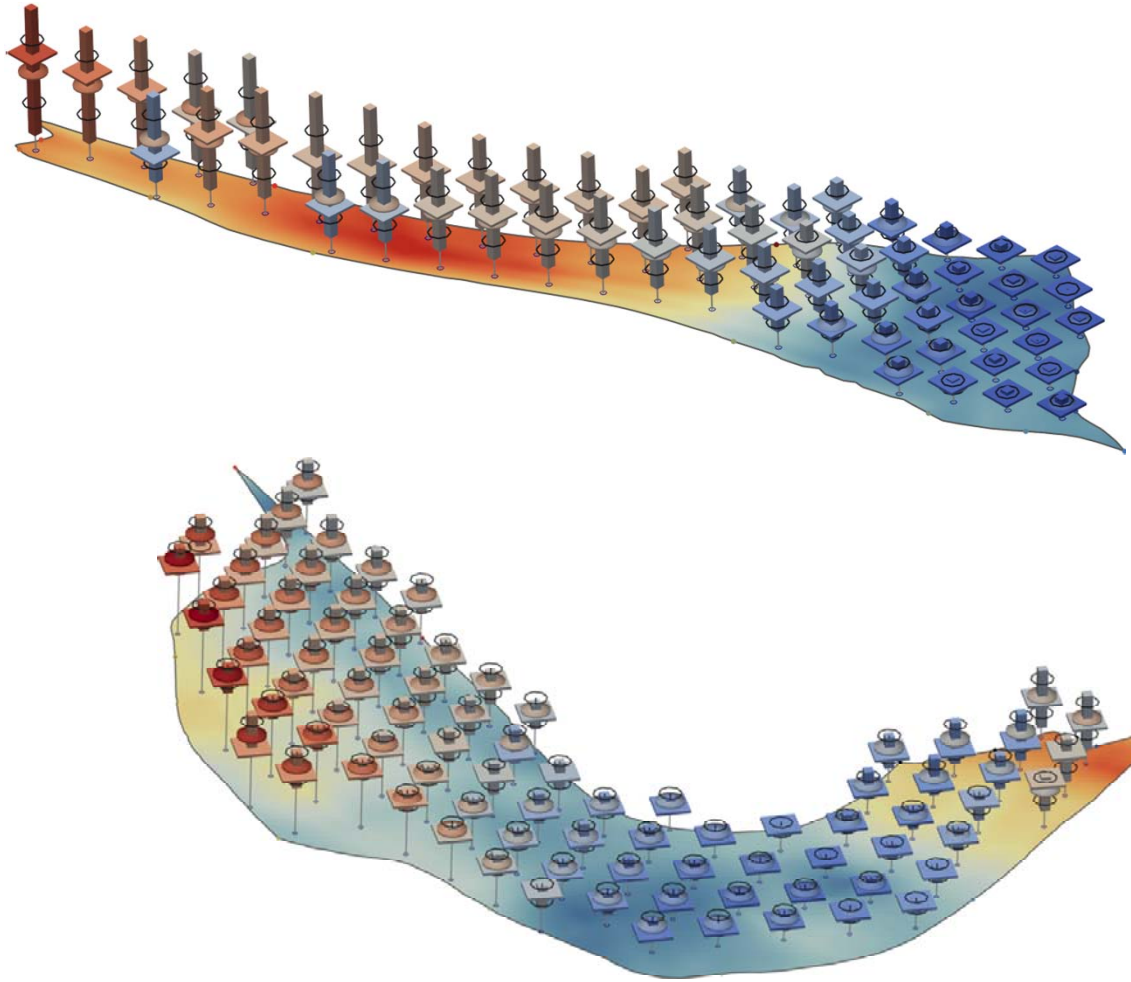
Families of Time Surfaces



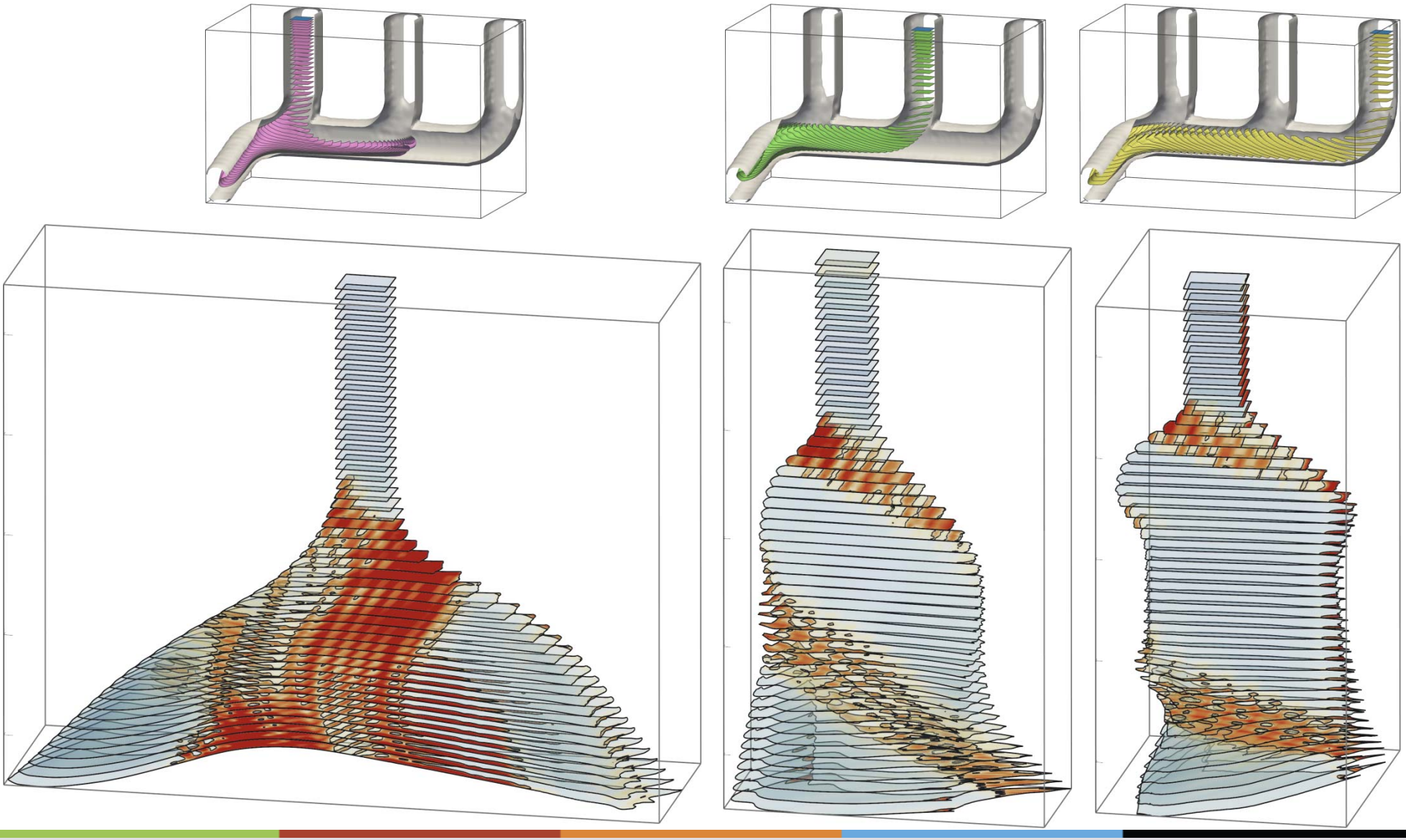
- Alignment by least square optimization
- Color & transparency depending on scalar attribute

Multiple Surface Families

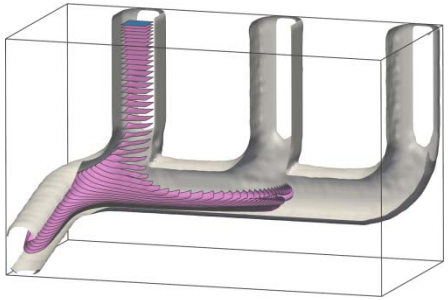


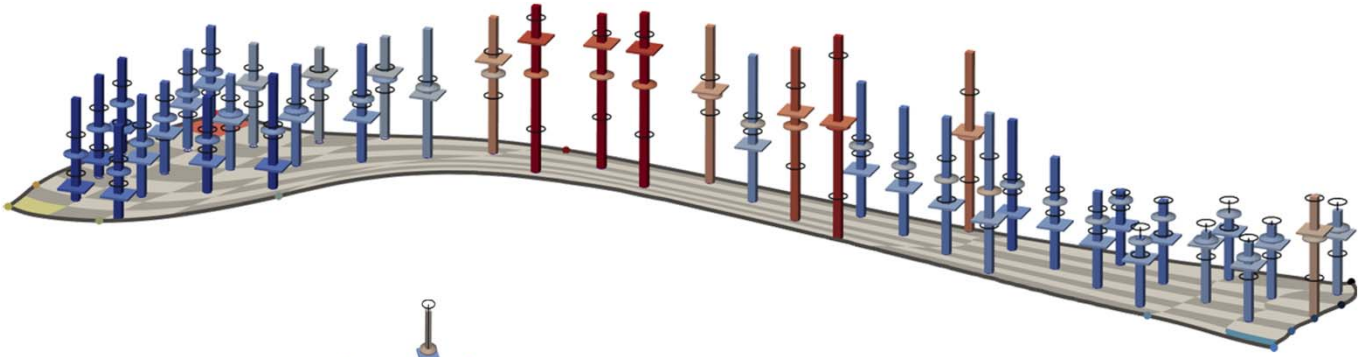


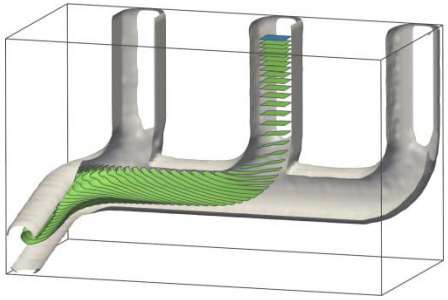
Multiple Surface Families

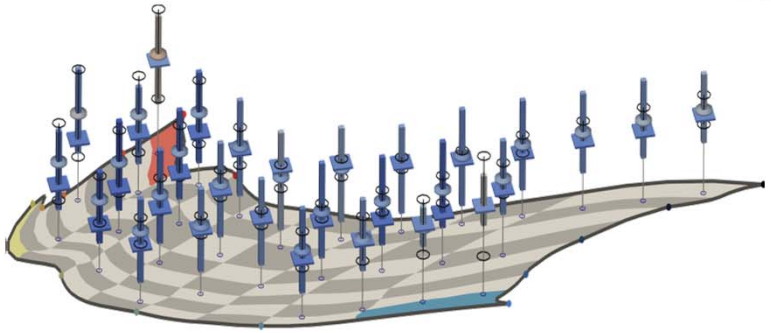


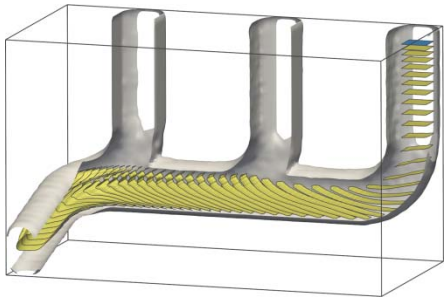
Multiple Surface Families

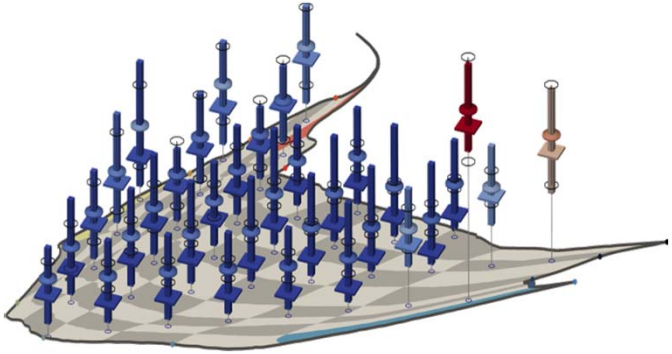






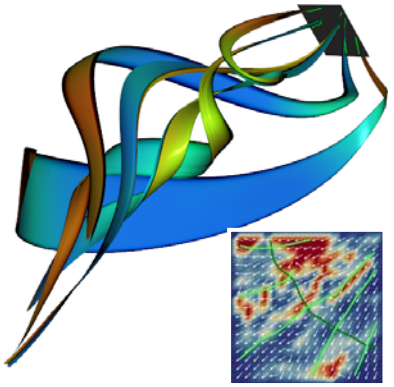


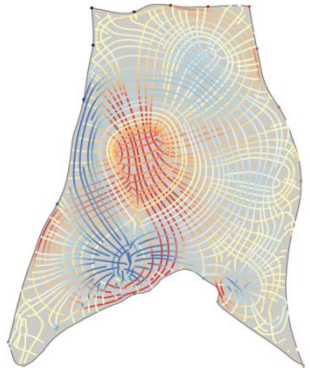


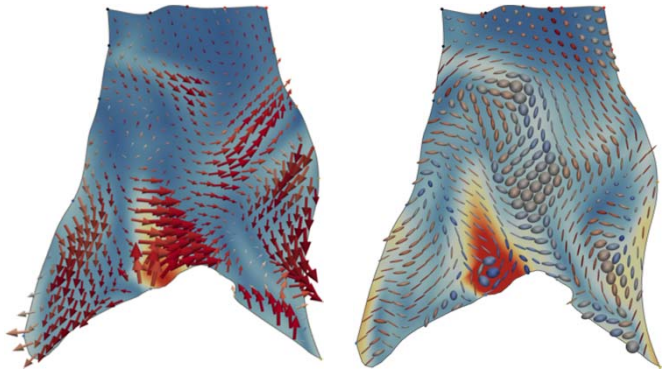


Final Remarks

- Integration-based visualization is a powerful tool for flow analysis
- Effectiveness limited by visibility issues
- Addressed visibility for either single or families of surfaces
- There is still a lot to do!
  - No approach solves all the issues
  - Integration of different analysis tools
  - Multiple spatial scales
  - …







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