Visibility Management in Integration-based Flow Visualization

Andrea Brambilla

University of Bergen (Norway)
www.ii.uib.no/vis
Fluid Flows
Why do we care?
Data representation
Fluid Flows

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

→ Need for analysis tools

Andrea Brambilla
Raw Data

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

- Useful for
  - Small scale and local phenomena
  - Turbulence, shock waves, ...
Flow Features

• Flow features
  • Vortices and shear layers
  • Vector field topology
  • ...

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

Andrea Brambilla

Balabanian 08
Kasten 09
Schafhitzel 11
Integral structures
Integral curves

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

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

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

→ Improve depth & shape perception
→ Emphasize relation between curves

Bürger 09

Krishnan 09
Integral surfaces

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

Bürger 09

Krishnan 09
Integral surfaces

• Main problem: cluttering & self occlusion
Integral surfaces

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

• 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

(1) 

(2) 

(3) 

(4) 

(5)
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 $\mathbf{P} = (u, v)$ is mapped by the MDS to a point $\mathbf{X} = (x_0, x_1, ..., x_N)$ in the embedding space.

- The derivative $\mathbf{J} = \frac{d\mathbf{X}}{d\mathbf{P}}$ is a $N \times 2$ matrix.
- We compute the eigendecomposition of $\mathbf{J}^T \mathbf{J}$.
- 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 $\mathbf{X} = (x, y, z)$ to points $\mathbf{P} = (u, v)$ in the 2D reformed space
- The original shape should be still conveyed!

- Compute the matrix $\mathbf{J} = d\mathbf{X} / d\mathbf{P}$
- Compute the eigendecomposition of $\mathbf{J}^T \mathbf{J}$
Flow Attributes on Surfaces

• Scalar attributes can be directly mapped to colors
• Vectors and tensors need to:
  • be projected on the surface
  • take flattening into account

\[ S_\psi = (I - nn^T) S (I - nn^T)^T \]
\[ S_2 = J^{-1} S_\psi J \]

Vorticity

Strain rate

• Size <-> \( \| S_\psi \| \)
• Color <-> \( \| S_\psi \| / \| S \| \)
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
  • ...
Acknowledgements

• Raimondo Schettini

• My supervisors
  • Helwig Hauser (University of Bergen)
  • Ivan Viola (TU Wien)
  • Øyvind Andreassen
    (Norwegian Defence Research Council)

• Visualization Group in Bergen

Datasets:
• AVL Gmbh (Graz)
• Cardiovascular MRI, Group, Univ. Medical, Center (Freiburg)
• Tino Weinkauf
• GexCon AS (Bergen)