The State of the Art in Flow Visualization: Partition-based Techniques

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Flow Visualization: Classification

- Direct visualization: arrows, color coding, etc.
- Texture-based visualization: spot noise, line integral convolution, etc.
- Geometric visualization: computation of streamline, streakline, pathlines, etc.
- Feature-based visualization: extraction of relevant structures, e.g., vortex, singularity

Data acquisition:

Visualization

User perception
1. Direct Visualization

Colormap

Hedgehogs
2. Texture-based Visualization

right: Spot noise [de Leeuw '95]

bottom: Line integral convolution
3. Geometric Visualization

Stream-/Path-lines

Streak-lines
4. Feature-based Visualization

- Vortex core-lines (Sujudi-Haimes)
- Separation and attachment lines [Tricoche '05]
- Surface topology
Why do we need another category?
Features

- conifer
- edges
- flowers
- grass
- hedge
Problems

cars? dogs? mountains?

similar structures

unknown structures
Partitioning
Classification

unknown
Visualization Pipeline

Original Field → Attribute Field → Partition/Segmentation → Classification

Heike Jänicke  Partition-based Flow Visualization Techniques
### Flow Visualization: New Classification

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<th>Direct Visualization</th>
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<td>arrows, color coding, etc.</td>
<td>spot noise, line integral convolution, etc.</td>
<td>computation of streamline, streakline, pathlines, etc.</td>
<td>extraction of relevant structures, e.g. vortex, singularity</td>
<td>partitioning of domain using clustering, topology, line-predicates</td>
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**Heike Jänicke**  **Partition-based Flow Visualization Techniques**
Partition-based Visualization

- Cluster-based Methods
- Integral-line-based Methods
- New Directions
Partition-based Visualization

Partition-based Techniques

Cluster-based Methods  Integral-line-based Methods  New Directions
Cluster-based Techniques

- Similarity-based Methods
  - Hierarchical: HWH99, Tvw99
  - Fixed Size: DW04, MLD05

- Physical Processes
  - GPR+00, GPR+01, GPR+04

- Topology-related Methods
  - CPPBY04, CBBL03, LCS06
Cluster-based Techniques
Clustering: Similarity-based

Hierarchical [Telea '99]

(a) Vector Field
(b) Directionality clustering
(c) Gradient tensor clustering
(d) Vorticity clustering

Fixed-size [McKenzie '05]
Clustering: Physical Models

Cluster Extraction (classification + thresholding)

Scalar field \( u \)

Skeletonization

Clusters \( C \)

Skeletons points

Connection

Skeletons polylines

Center Computation

Skeletons centers

Streamline Tracing

Streamlines

Iconification

Curved arrows

Garcke '00
Partition-based Visualization

Partition-based Techniques

- Cluster-based Methods
- Integral-line-based Methods
- New Directions
Integral-line-based Techniques

- Topology-based Methods
  - 2D, 2.5D, 3D + steady/ unsteady
  - Topology Simplification

- General integral-line-based Methods
  - Streamline Predicates
  - Pathline Predicates
Flow Topology 2D

Saddle Point: $R_1 < 0$, $R_2 > 0$, $I_1 = I_2 = 0$
Repelling Focus: $R_1 = R_2 > 0$, $I_1 = -I_2 <> 0$
Attracting Focus: $R_1 = R_2 < 0$, $I_1 = -I_2 <> 0$
Repelling Node: $R_1, R_2 > 0$, $I_1 = I_2 = 0$
Attracting Node: $R_1, R_2 < 0$, $I_1 = I_2 = 0$

Critical points

Flow topology [Helman & Hesselink '89]

Closed Streamlines [Wischgoll '02]
Flow Topology 2.5D

Poincare sections [Löffelmann '97]  Morse decomposition [Chen '07]
Flow Topology 3D

Saddle connectors [Theisel '03]  Boundary switch connectors [Weinkauf '04]
Unsteady Flow Topology

Topology tracking 2D [Tricoche '02]
Topology Simplification

Skin friction field of square cylinder [deLeeuw '99]

Swirling jet [Tricoche '00]
General Integral-Line-based Approaches
Stream-/Path-line Predicates

Regions influenced by a vortex
[Salzbrunn '06]

Particle times
[Salzbrunn '08]
Pathline Attributes
Finite-Time Lyapunov Exponent

left: FTLE [Garth '07]
top: FLTE ridge surface [Sadlo '07]
Local Statistical Complexity

Streamlines

LSC of $|\text{velocity}| > 10$

LSC of $|\text{velocity}| > 14$

[Jänicke '07]
Conclusion

- Subdivide feature-based flow visualization.
- Image processing and computer vision as guiding examples.
- Essential steps:
  - Attribute fields
  - Partitioning
  - Classification
- Several partitioning methods exist.
- Further research needed for
  - attribute fields and
  - partitioning.
Thank you for your attention!

Questions?