The State of the Art in Flow Visualization

Armin Pobitzer
Department of Informatics
UiB
Visualization – What for?

- The data shows details, but (usually) fails to convey overview

- **To visualize**: to form a mental image of s.th.
  (from Oxford dictionary)

- Aims at insight, not pictures!

- Used for
  - Exploration
  - Analysis
  - Presentation
Visualization – What for?

Example: algebraic equations

- Data:
  \[ x^2 + y^2 z - z^2 = 0 \]

- Questions:
  - Surface?
  - Self intersections?
  - Singularities?
Visualization – What for?

Example: algebraic equations

- **Data:**
  \[ x^2 + y^2 z - z^2 = 0 \]

- **Questions:**
  - Surface?
  - Self intersections?
  - Singularities?
Visualization – What for?

Example: algebraic equations

Data:

\[ x^2 + y^2 z - z^2 = 0 \]

Questions:
- Surface ✓
- Self intersections ✗
- Singularities ✓
Flow visualization – Beyond vectors

- Usually velocity vectors on discrete grid (possibly time dependent)

- Direct visualization usually fails to convey insight

Example: Arnold-Beltrami-Childress flow

\[
\begin{align*}
\dot{x} &= A \sin(z) + C \cos(y) \\
\dot{y} &= B \sin(x) + A \cos(z) \\
\dot{z} &= C \sin(y) + B \cos(x)
\end{align*}
\]

\[A = B = \sqrt{3}, \quad C = 1\]
Flow Visualization – Classical approaches

- Feature extraction: derivation of a characteristic numerical value, based on local velocities

- Limitations to “local” phenomena
Vector field topology: segmentation of flow in regions of different behavior

Limitations: only for steady velocity field!
Flow Visualization – New Directions

- Reformulation of theory for unsteady vector fields
  - E.g., for tracking of features over time

[Theisel et al., 2005]

- Alternatives for transport barriers in unsteady flow
  - Finite-time Lyapunov exponents

[Kourentis and Konstantinidis, 2011]
UiB involved in an European project in Flow visualization:
SemSeg - 4D Space-Time Topology for Semantic Flow Segmentation

A collaboration with:
- ETH Zürich, Switzerland
- University of Magdeburg, Germany
- VRVis research center Vienna, Austria
Research directions

- Interactive Visual Analysis for flow visualization: framework to incorporate domain experts more closely
- Feature extraction on different scales: method to distinguish between features that act at different scales of motion/energy
- Lagrangian Methods: based on particle movement, related to investigation of transport, mixing,…
- Incorporation of uncertainty: vector field topology-like segmentation for uncertain velocity data
IVA for flow visualization

- Large number of measured or computable variables to describe the flow
  - e.g., $\lambda_2$, vorticity, …
  - both on grid or particle

- Depict multiple dimensions in multiple views
  - e.g., scatter plots, histograms, function plots, …

- Views are linked to each other and a 3D view of the flow domain
  - Highlighting interesting data ranges can reveal correlation of different fields and the spatial location of this interplay
Example: exhaust manifold \cite{Lez, Pobitzer}

- Examination of exhaust gas flow
  - Design goal: higher power/less fuel consumption
  - Analysis goal: Detect back pressure

- Compute path lines and descriptors of their behavior (curvature, torsion, average velocity,...)
Example: exhaust manifold (Lež et al., Pobitzer et al.)

- Examine particles that originate in or close to middle pipe

- Discard particles that leave domain immediately

The State of the Art in Flow Visualization

14
Example: exhaust manifold (Lež et al., Pobitzer et al.)

- Look at shape descriptors

- Discard particles that leave domain immediately
Example: exhaust manifold (Lež et al., Pobitzer et al.)

- Investigate different branches

- Change 3D view from path lines to particles
IVA in other settings

- simulations: detection of bugs
  - areas with wrong gridding
  - problems with boundary conditions
  - …
- tool for the expert to detect undesired / unexpected flow behavior
Feature extraction on different scales (Pobitzer et al.)

- Velocity fields are composed of different energy scales (turbulence cascade)
Feature extraction on different scales (Pobitzer et al.)

- The scales can be calculated by *proper orthogonal decomposition*

- Extracting features at different scales gives physically correct simplification
Uncertain vector fields (Otto et al.)

- Velocity fields can be affected by uncertainty, e.g., multiple samples, measurement accuracy, ...
- Uncertainty is accumulated along particle paths
- New method to compute stream lines taking uncertainty in account

The State of the Art in Flow Visualization
Acknowledgements

- R. Fuchs, R. Peikert, B. Schindler (ETH Zürich, Switzerland)
- A. Kuhn, M. Otto, H. Theisel (University of Magdeburg, Germany)
- A. Lež, K. Matković (VRVis Research Center, Austria)
- Ø. Andreassen (Norwegian Defence Research Establishment)
- M. Tutkun (Norwegian Defence Research Establishment & Université Lille - Nord de France, France)
- H. Hauser (University of Bergen, Norway)
- AVL GmbH (Graz, Austria)
- SimVis GmbH (Vienna, Austria)
- SemSeg (www.SemSeg.eu)

The project SemSeg acknowledges the financial support of the Future and Emerging Technologies (FET) programme within the Seventh Framework Programme for Research of the European Commission, under FET-Open grant number 226042.
Further information...

- All discussed papers can be found at www.SemSeg.eu
- Two survey articles (http://www.ii.uib.no/vis/publications)