Visualizing Time-Dependent Flows – introduction

Helwig Hauser (Univ. of Bergen)
et al.

Overview

- **Flows**, vector fields, time-dependent flows
- **Flow visualization**
  - direct flow visualization
  - texture-based flow visualization
  - integration-based flow visualization
  - feature-based / topological flow visualization
- From visualizing steady flow fields
  to visualizing time-dependent flow fields

Flows (first steady, *i.e.*, time-independent flows)

- **Something moving**,
  usually some matter (a liquid or gas),
  but also dynamical systems, *etc*.
- Usefully **understood as differential wrt. time**

$$\mathbf{v} = \mathrm{d}\,\mathbf{p} \,/\, \mathrm{d}\,t \qquad \mathbf{p} \in \Omega \subseteq \mathcal{R}^n,\ \mathbf{v} \in \mathcal{R}^n,\ t \in \mathcal{R}$$

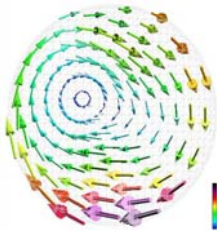
- Often represented as **vector field**, *i.e.*,
  as set of vector samples $\mathbf{v}(\mathbf{p}_i)$ over a certain grid $\{\mathbf{p}_i\}$
- **Flow data** origin in
  - **measurements**, *e.g.*, with PIV (particle image velocimetry)
  - **simulation**, *e.g.*, from CFD (computational fluid dynamics)
  - **modeling**, *e.g.*, as ODEs (ordinary differential equations)

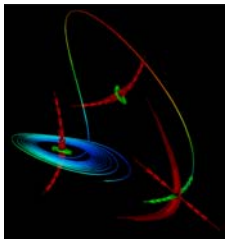
Unsteady Flows

- Steady flows: motion that does not change over time
  unsteady flow: **also the flow changes** over time
- Steady flow: $\mathbf{v}(\mathbf{x})$: $R^n \rightarrow R^n$
  unsteady flow: $\mathbf{v}(\mathbf{x},t)$: $R^n \times R \rightarrow R^n$
- Steady flows rare in nature,
  most gas/liquid flows are unsteady
- Unsteady flows usually **given for some time** "only":
  one vector field per time step t_i
- Often significantly larger than steady flow fields,
  more challenging to analyze

Flow Visualization Methods

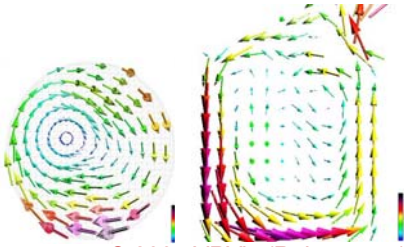
- From Post *et al.*:
  Feature Extraction and Visualisation of Flow Fields
  (Eurographics 2002 State-of-the-Art Report):
  - Direct flow visualization
  - Texture-based flow visualization
  - Integration-based flow visualization
  - Feature-based / topological FlowViz



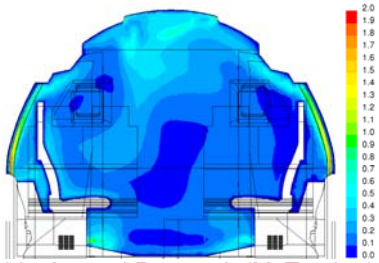


Direct Flow Visualization (1)

- One-to-one mapping of **v** into vis. space
- Classical approaches:
  - arrows (hedgehog plot)
  - color coding



© 2005 VRVis (R. Laramee)



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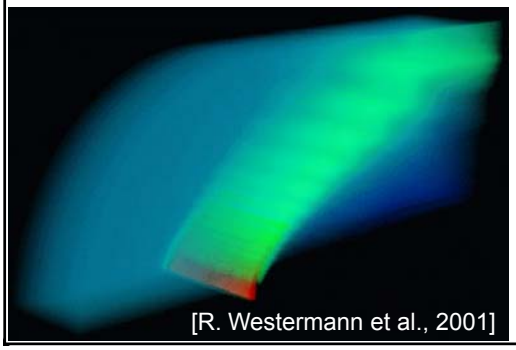
- Naturally intuitive ☺, long-term behavior ☹

Volume Rendering

- Truly 3D rendering of scalar values
  + less selective
  – hard to read



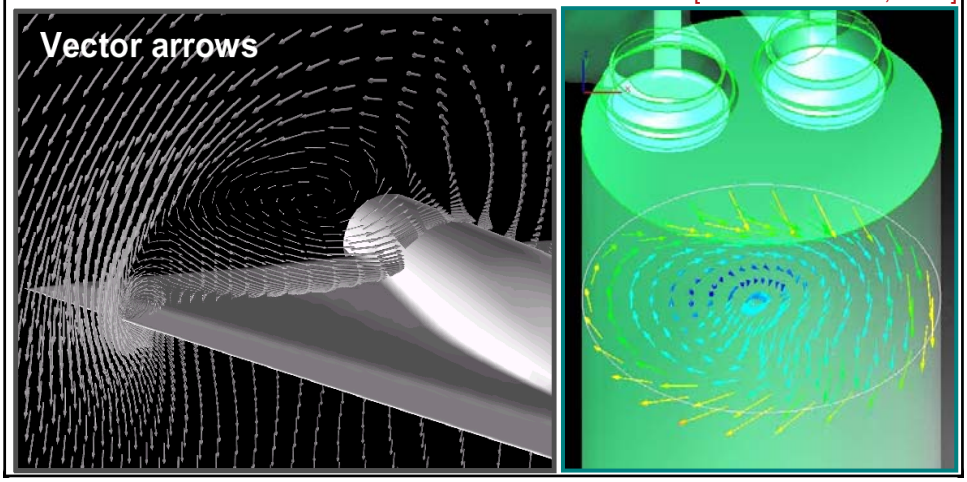
[R. Westermann et al., 2001]

[K. Ono et al., 2001]

Hedgehog Plots

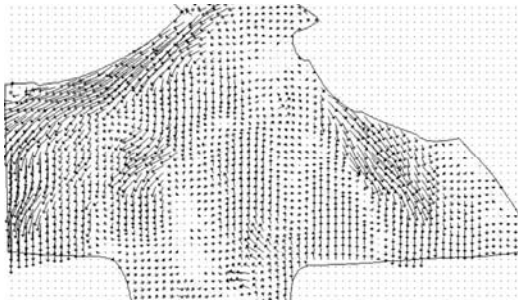
- Mapping flow vectors to geometric arrows
- Issues: seeding, perception

[R. Laramee et al., 2003]

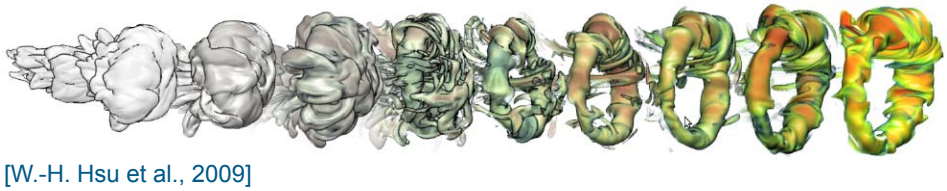


Direct Visualization of Unsteady Flows

- Usually:
  - animated color plots
  - animated hedgehog plots

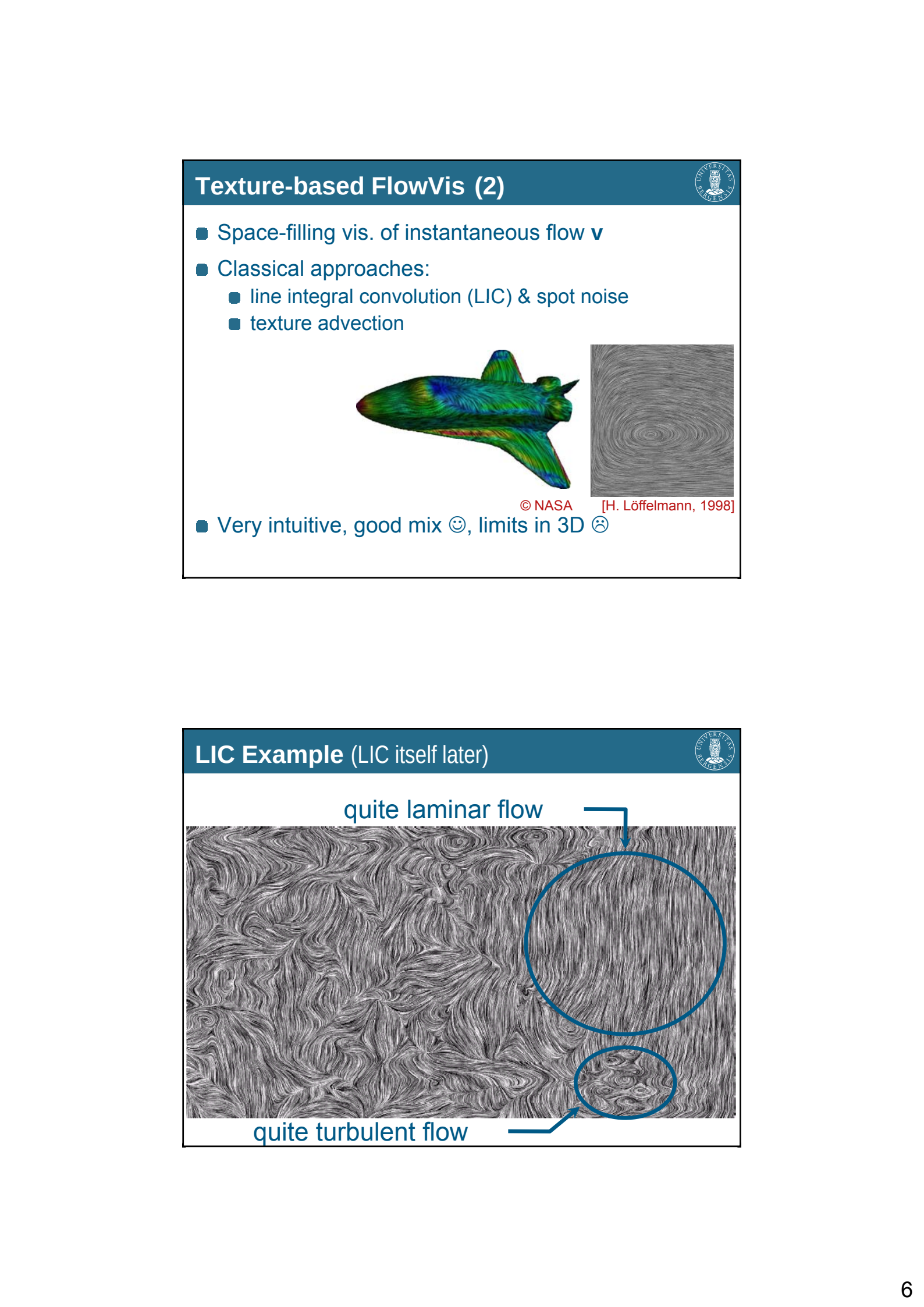


- Occasionally:
  - more advanced solutions, *e.g.*, illustrative FlowViz



[W.-H. Hsu et al., 2009]

Texture-based FlowVis (2)



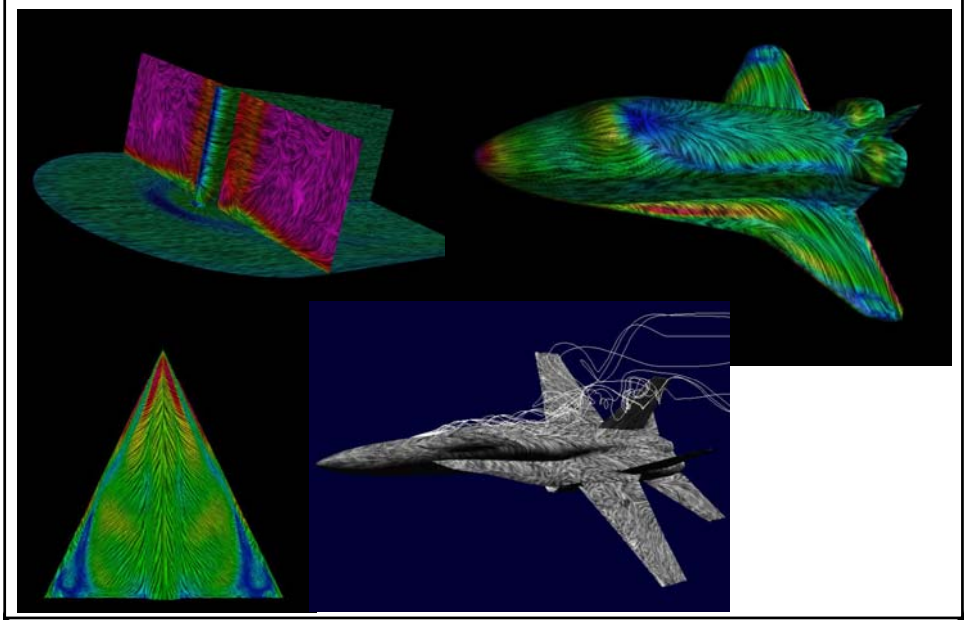
- Space-filling vis. of instantaneous flow **v**
- Classical approaches:
  - line integral convolution (LIC) & spot noise
  - texture advection

© NASA [H. Löffelmann, 1998]

- Very intuitive, good mix ☺, limits in 3D ☹

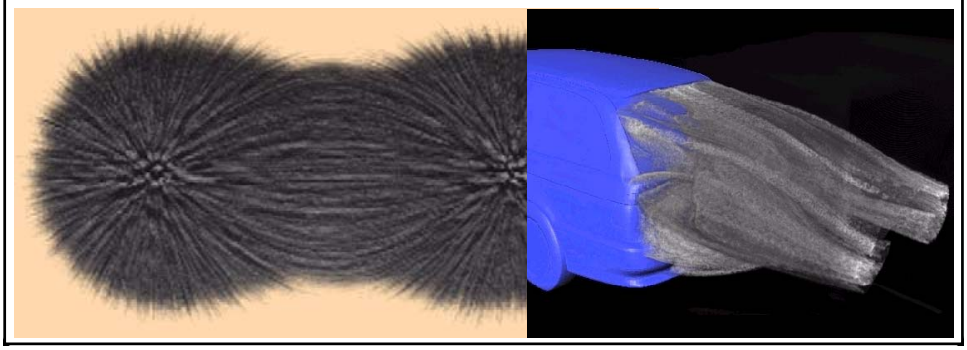
LIC Example (LIC itself later)

LIC – Examples on Surfaces



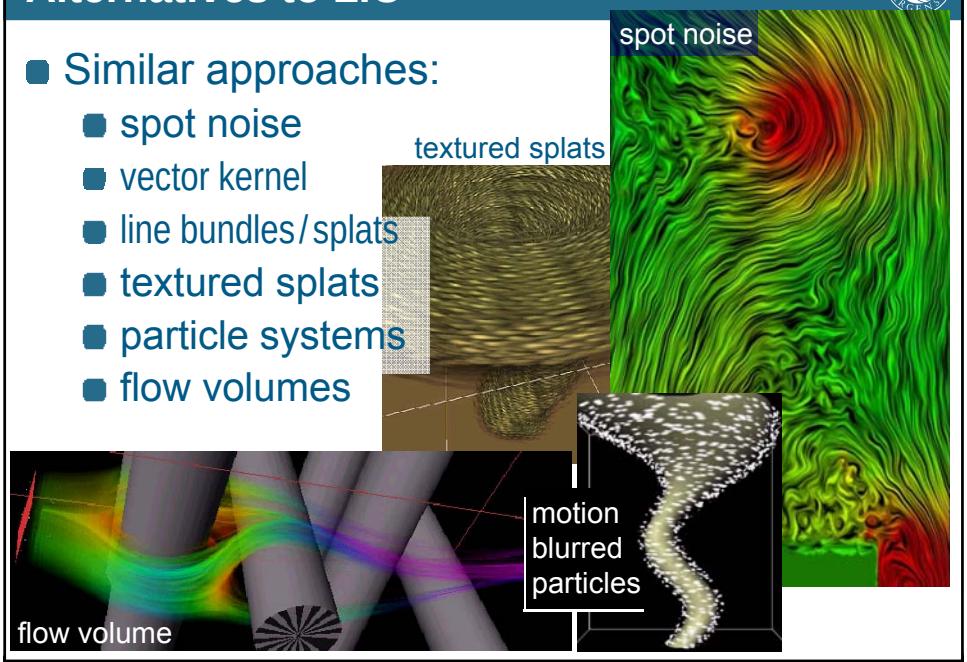
LIC in 3D(?)

- Correlation also possible in 3D:
  - problem of rendering: DVR of 3D LIC ⇒ Destruction of correlational information!
  - Hence: selective use



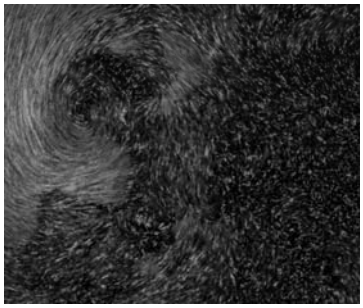
Alternatives to LIC

- Similar approaches:
  - spot noise
  - vector kernel
  - line bundles / splats
  - textured splats
  - particle systems
  - flow volumes

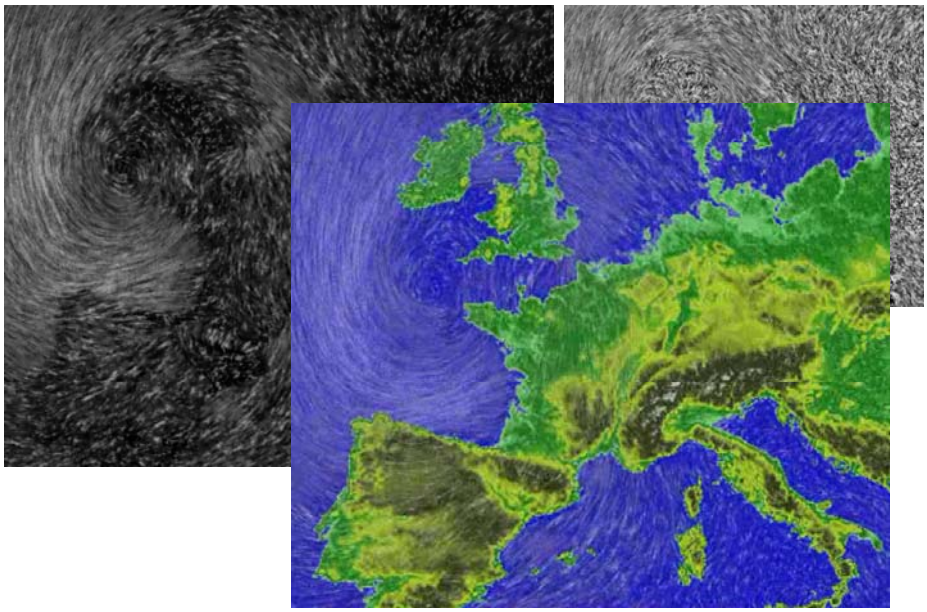


Texture-based Vis. of Unsteady Flows

- Extensions to LIC, *e.g.*,
  - unsteady LIC [Forseel & Cohen, 1995]
  - UFLIC [Shen & Kao, 1997]
    & AUFLIC [Liu & Moorhead, 2002]
  - DLIC [Sunquist, 2003]
- Texture advection [Jobard et al., 2002; …]

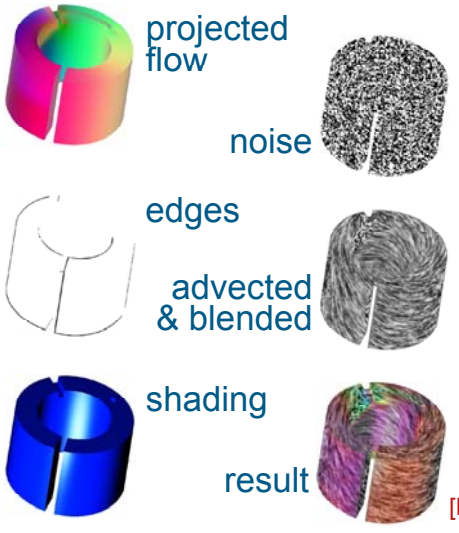


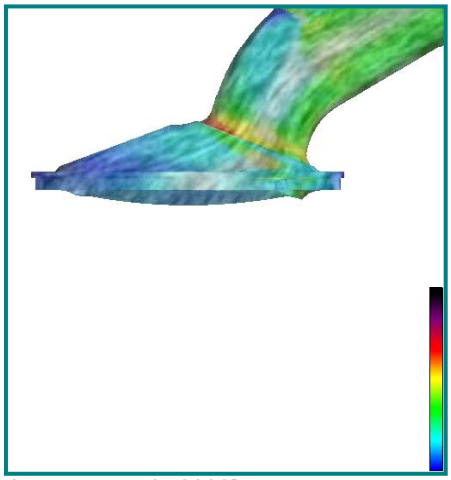
Texture Advection – Unsteady Flows



Texture Advection on Surfaces

- Image space based advection on surfaces

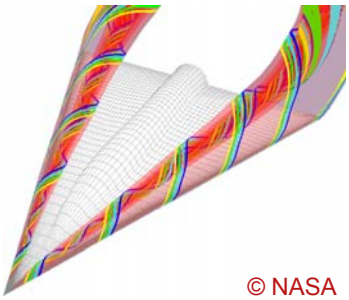




[R. Laramee et al., 2003]

Integration-based FlowVis (3)

- Utilization of integration paths for FlowVis
- Classical approaches:
  - streamlines
  - stream-surfaces



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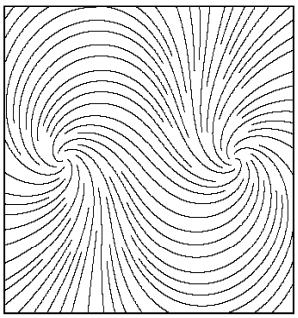


[Br. Jobard et al., 1997]

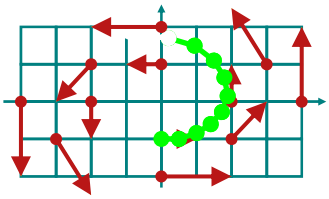
- Very intuitive wrt. long-term behavior, issue of selective visualization

Flow Integration

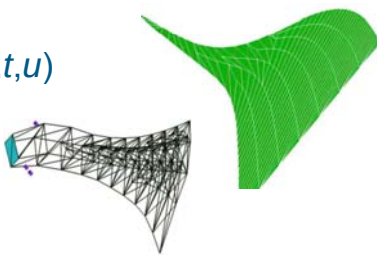
- Integrating the flow

$$\mathbf{p}(s) = \mathbf{p}_0 + \int_{\tau=0}^{s} \mathbf{v}(\mathbf{p}(\tau),\, t_0+\tau)\, \mathrm{d}\,\tau$$

from $\mathbf{p}_0$ along $\mathbf{v}$ (parameterized in s)

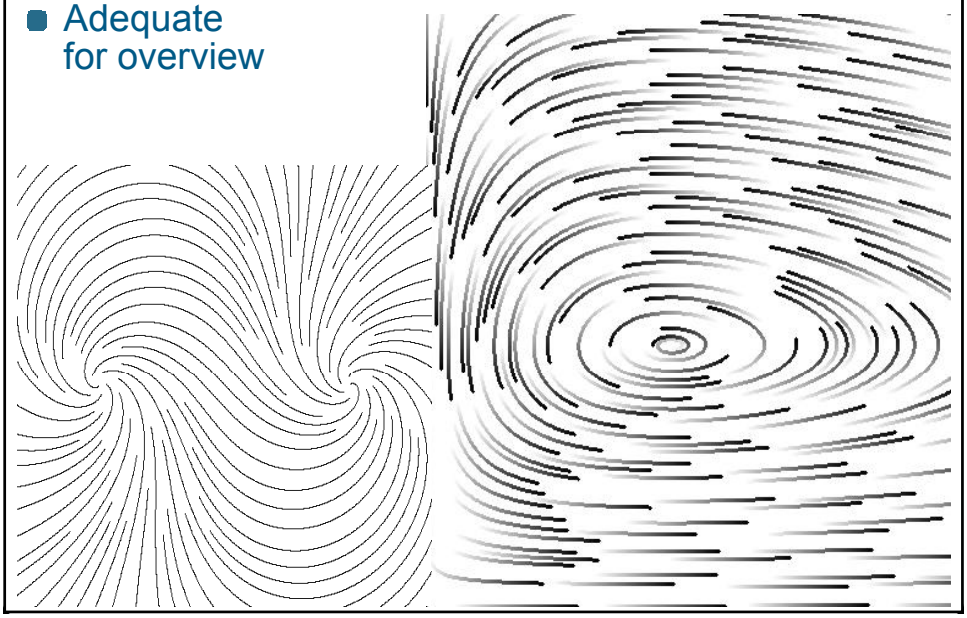


- Generates:
  - point $\mathbf{p}_0 \Rightarrow$ pathline $\mathbf{p}(s)$
  - curve $\mathbf{p}_0(t) \Rightarrow$ surface $\mathbf{p}(s,t)$
  - surface $\mathbf{p}_0(t,u) \Rightarrow$ volume $\mathbf{p}(s,t,u)$



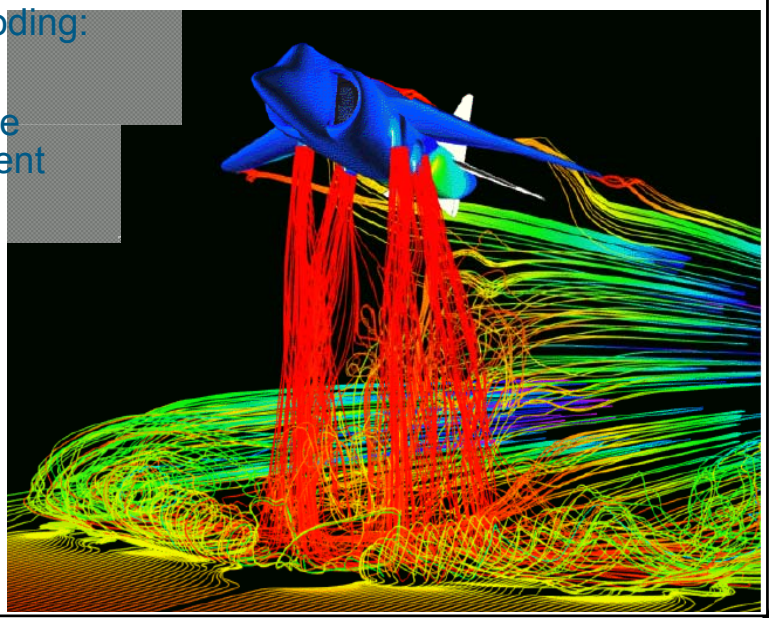
Streamlines in 2D

- Adequate for overview



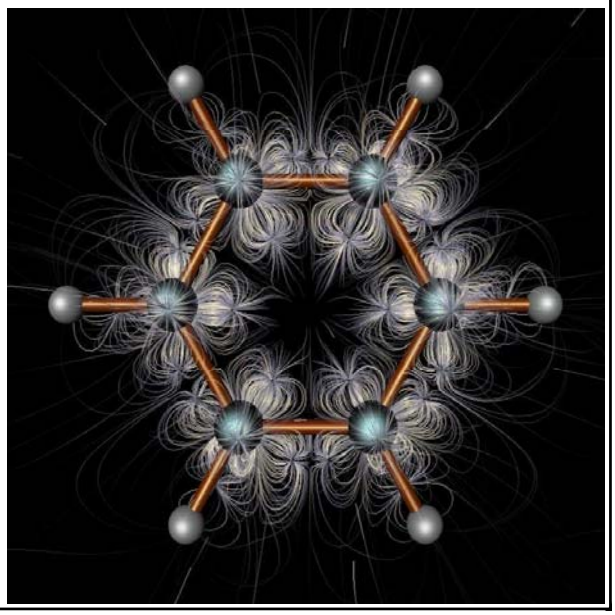
Streamlines in 3D

- Color coding: Speed
- Selective Placement



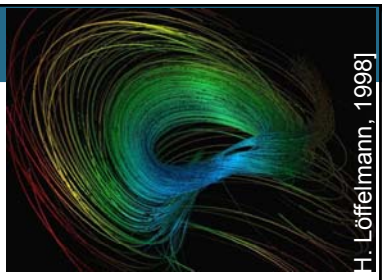
Illuminated Streamlines

- Illuminated 3D curves ⇒ better 3D perception!



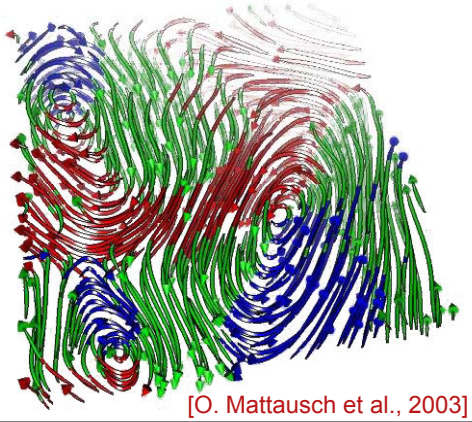
Issue: Seeding

- Seeding/placement
- Approaches:
  - interactive
  - feature-based
  - evenly-spaced



H. Löffelmann, 1998]

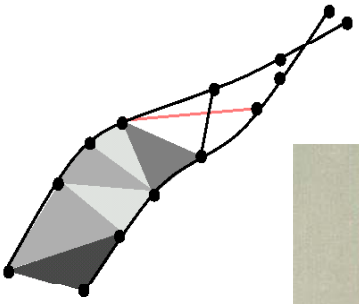
[G. Zachmann, 2003]

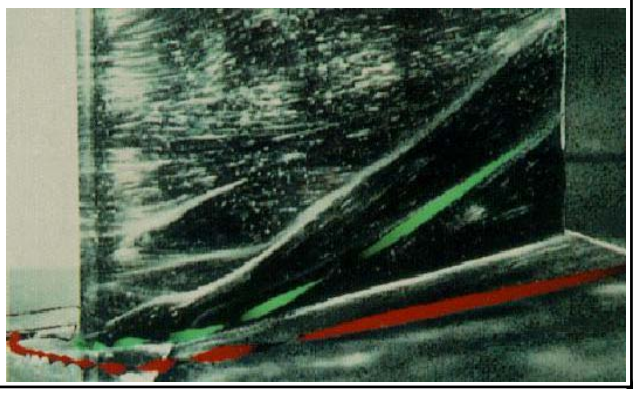


[O. Mattausch et al., 2003]

More Integral Objects in 3D (1/3)

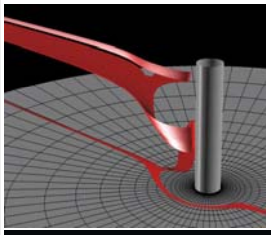
- Streamribbons

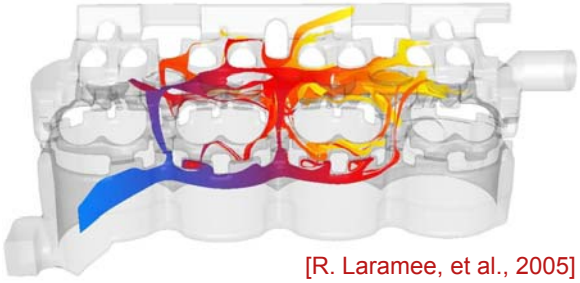




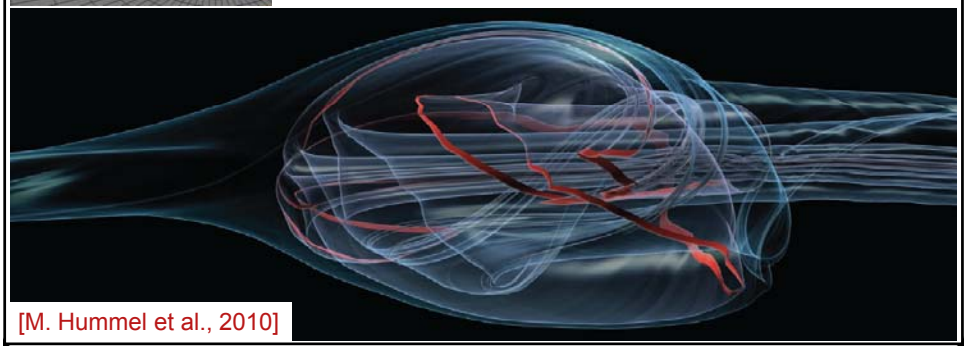
More Integral Objects in 3D (2/3)

- Streamsurfaces





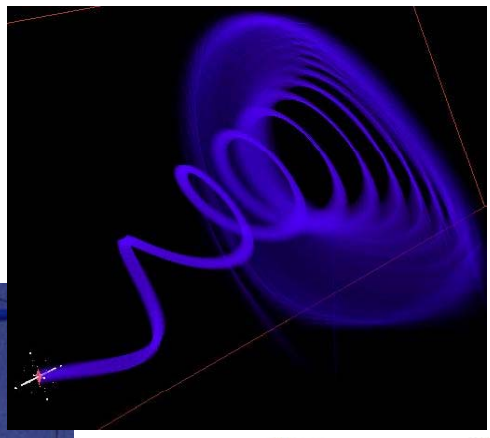
[R. Laramee, et al., 2005]



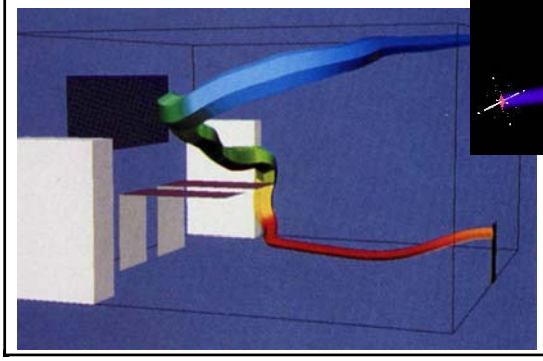
[M. Hummel et al., 2010]

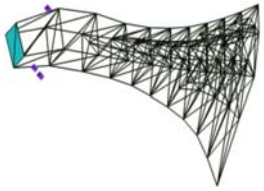
More Integral Objects in 3D (3/3)

- Flow volumes …



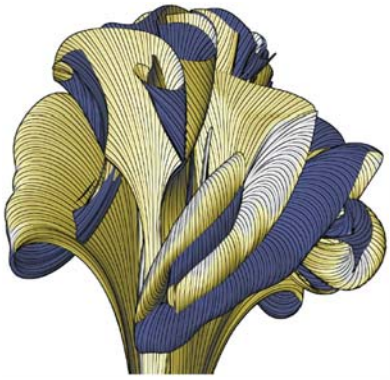
- vs. streamtubes
  (similar to streamribbon)



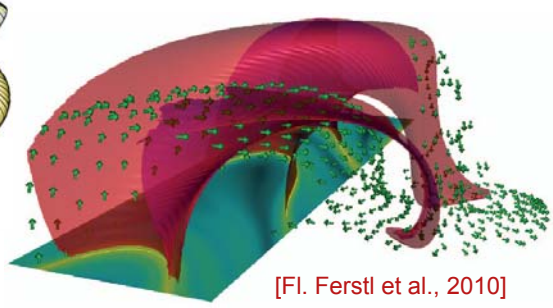


Integration-based Vis. of Unsteady Flows

- From streamlines
  to pathlines and streaklines
- Pathsurfaces and streaksurfaces

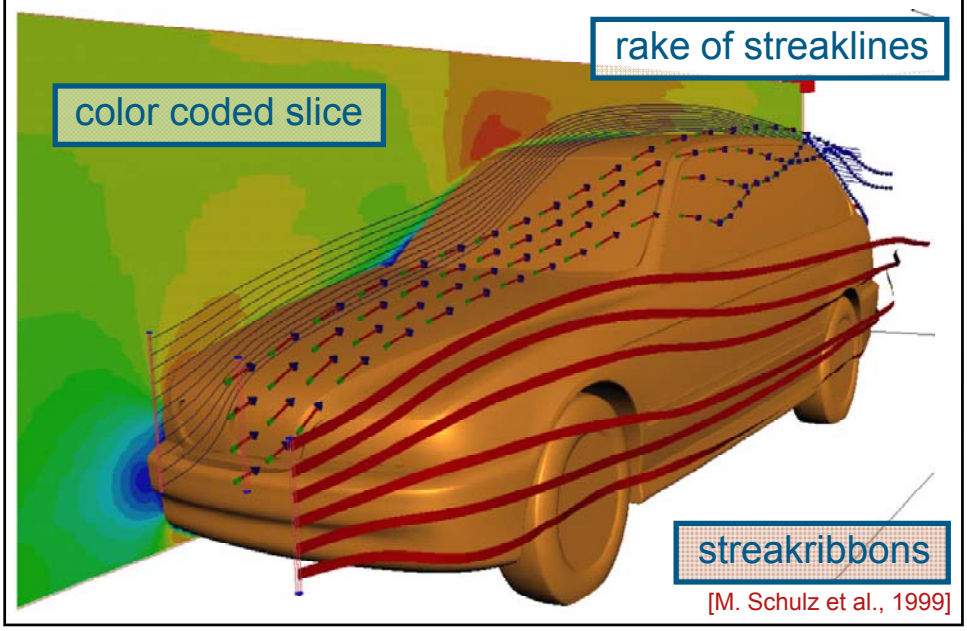


[M. Hummel et al., 2010]



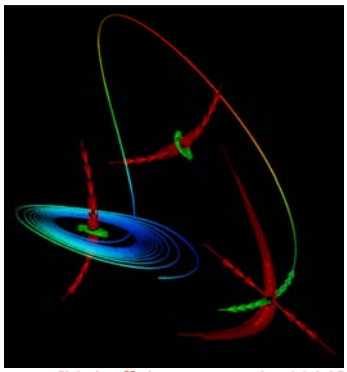
[Fl. Ferstl et al., 2010]

Air Flow around a Car



[M. Schulz et al., 1999]

Feature-based / Topological FlowVis (4)



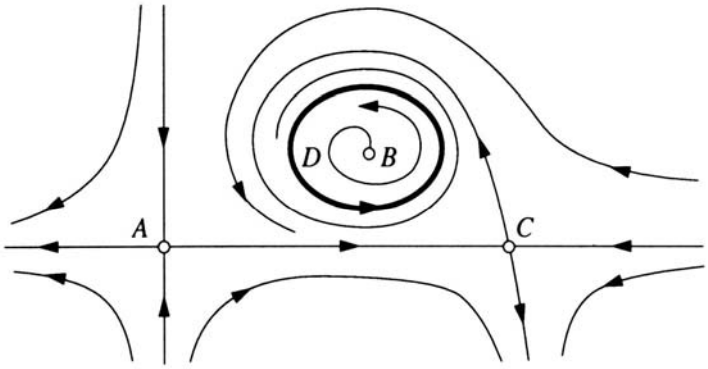
- Use of computational analysis for FlowVis
- Classical approaches:
  - topology-based FlowVis
  - utilization of vortex extraction for FlowVis

[H. Löffelmann et al., 1998]

- Informative ☺, limits wrt. intuitiveness ☹

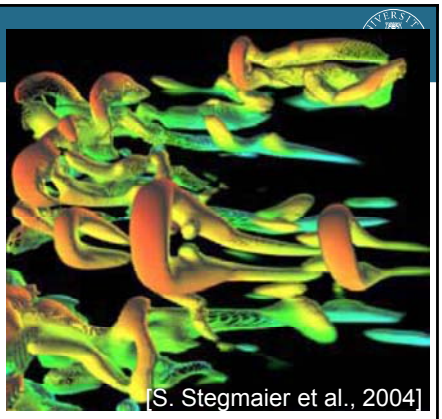
Topology-based FlowVis

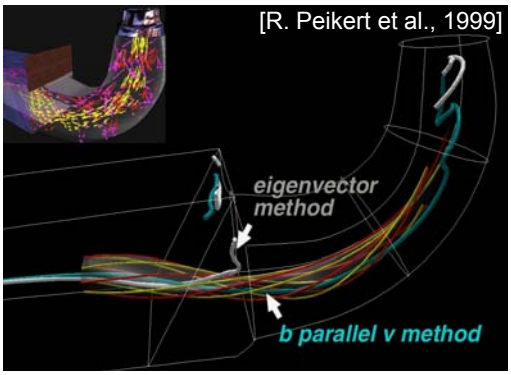
- FlowVis based on flow topology (steady flows)
- Extraction & visualization

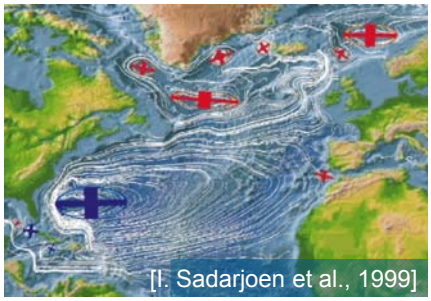


Flow Features

- Extr. & vis.
  - vortical regions
  - vortex core lines
  - rotating flow

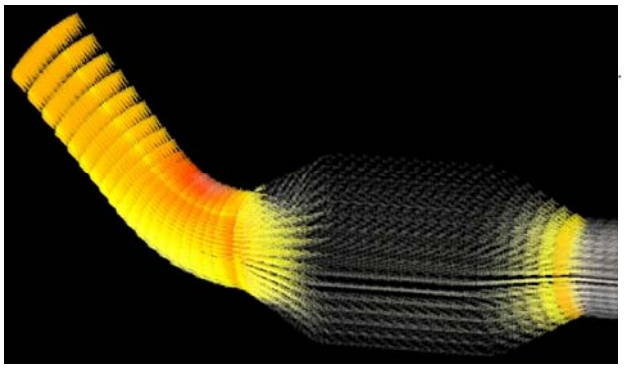

[S. Stegmaier et al., 2004]

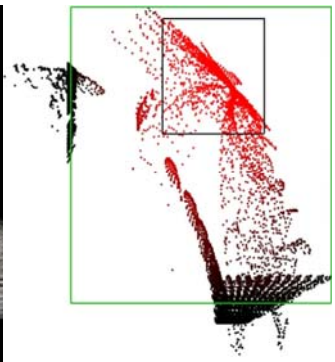



[I. Sadarjoen et al., 1999]

Interactive Visual Feature Specification

- Interaction
- Specification & visualization





[H. Doleisch et al., 2000–]

Tutorial Overview

- Part 1
  - Opening & Introduction (HH et al.)
  - General Methods (AP & AK)
- Part 2
  - Lagrangian Methods (AP & AK)
  - Space-time Methods (MSch)
- Part 3
  - Interactive Visual Analysis (HH)
  - Wrap-up (all)

Acknowledgements

- **You** – thank you for your attention!
  Question?

- SemSeg project (funded in the context of the FET-Open scheme of FP7, #226042)