# Visualization, Lecture #2d

Flow visualization,
Part 3 (of 3)

# Retrospect: Lecture #2c

- Flow Visualization, Part 2:
  - FlowVis with arrows
  - numerical integration
    - Euler-integration
    - Runge-Kutta-integration
  - streamlines
    - in 2D
    - particle paths
    - in 3D, sweeps
    - illuminated streamlines
  - streamline placement

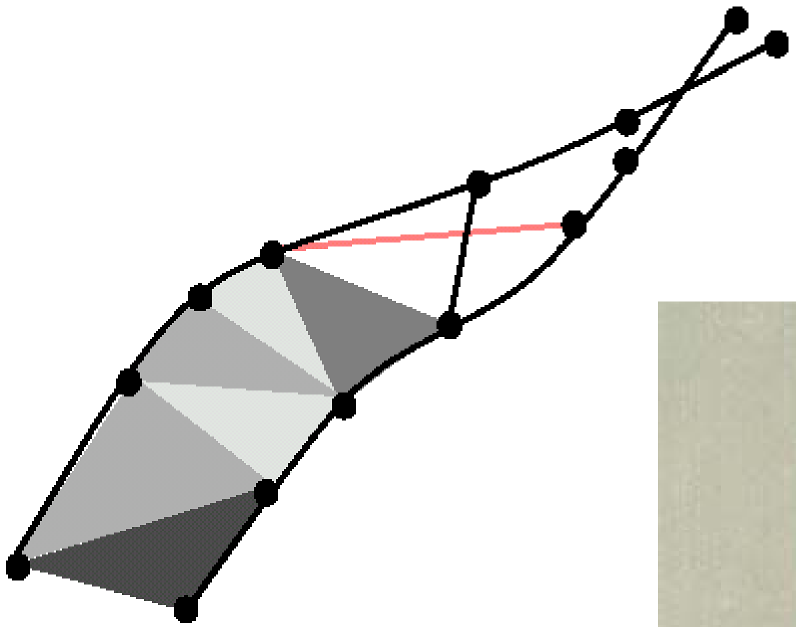
# Overview: Lecture #2d

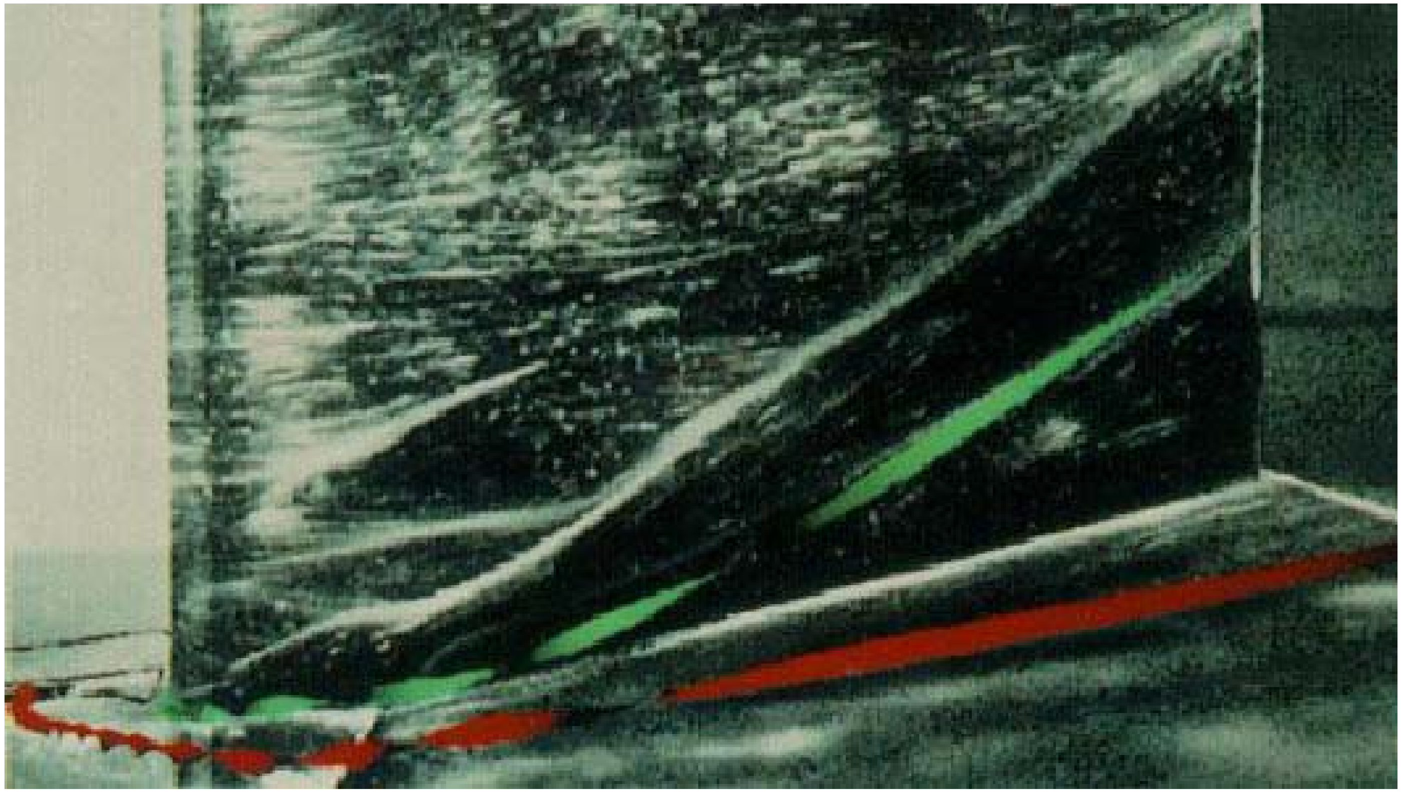
- Flow Visualization, Part 3:
  - flow visualization with integral objects
    - streamribbons,
    - streamsurfaces, stream arrows
  - line integral convolution
    - algorithm
    - examples, alternatives
  - glyphs & icons, flow topology
  - summary

# Flow Visualization with Integral Objects

Streamribbons,
Streamsurfaces,
etc.

- Streamribbons



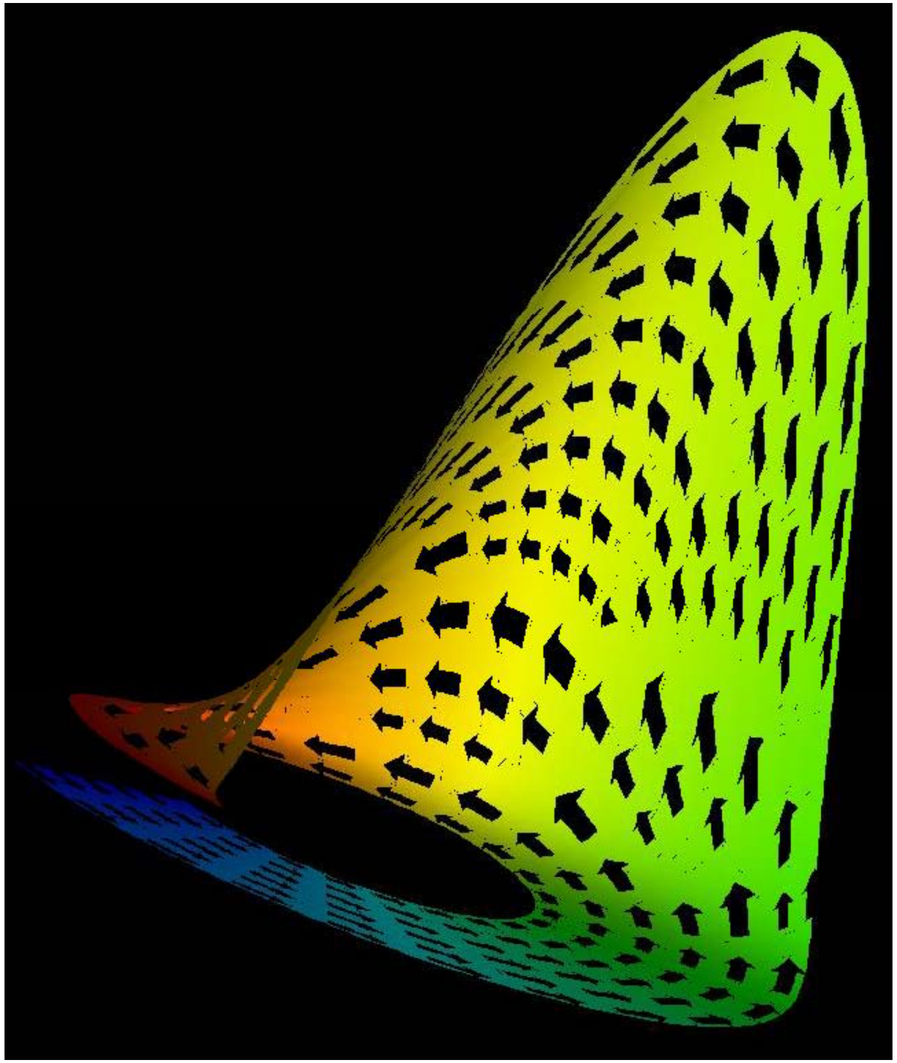


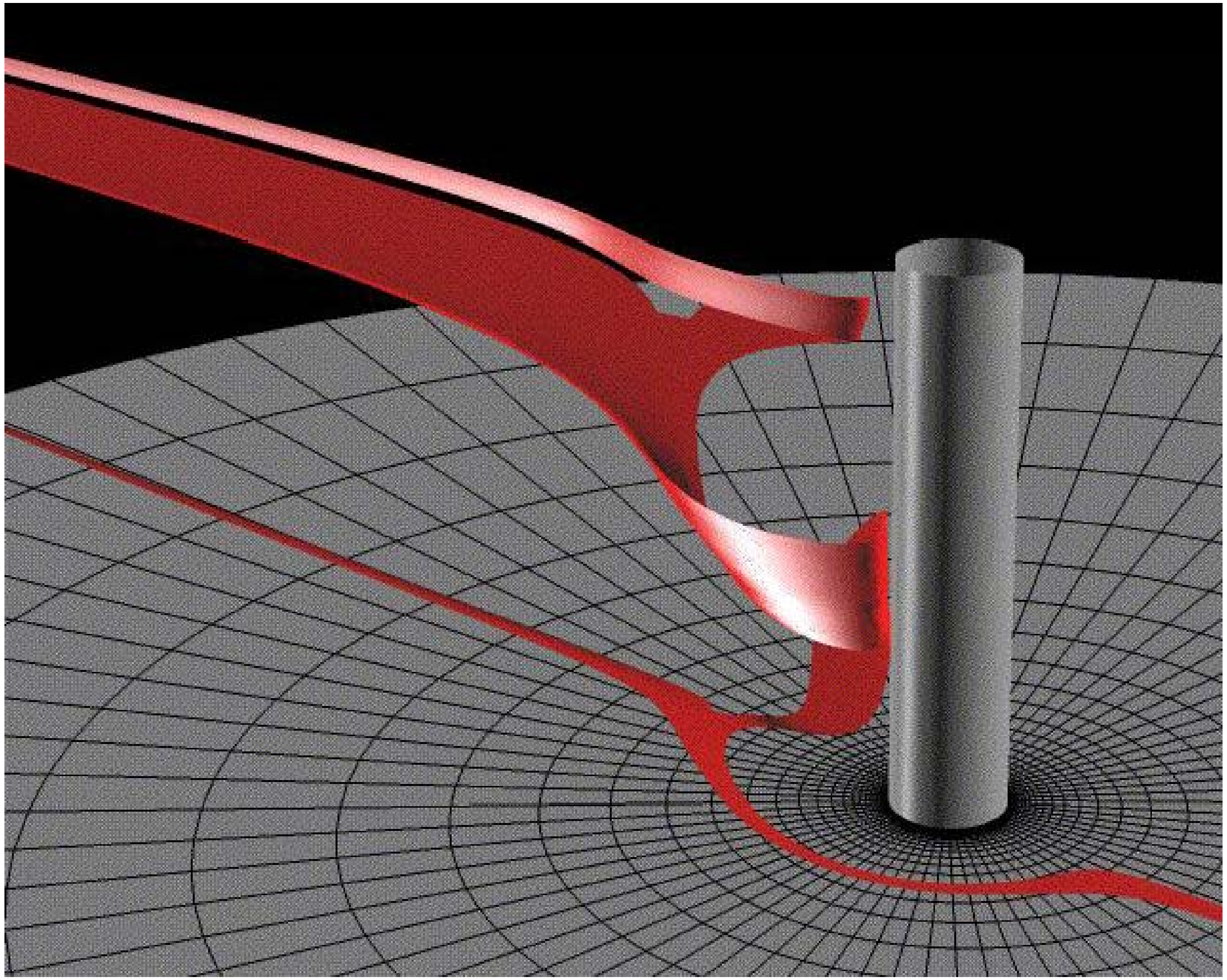
# Streamribbon Generation

- Start with a 3D point $\mathbf{x}_{i=0}$ and a 2nd one $\mathbf{y}_{i=0}$ in a particular dist. $d$, i.e. $(\mathbf{x}_i-\mathbf{y}_i)^2=d^2$
- Loop:
  Do an integration step from $\mathbf{x}_i$ to yield $\mathbf{x}_{i+1}$
- Do an integration step from $\mathbf{y}_i$ to yield $\mathbf{z}$ renormalize the dist. between $\mathbf{x}_{i+1}$ & $\mathbf{z}$ to $d$, i.e. $\mathbf{y}_{i+1}=\mathbf{x}_{i+1}+d\cdot(\mathbf{z}-\mathbf{x}_{i+1})/|\mathbf{z}-\mathbf{x}_{i+1}|$
- End streamribbon integration if wanted

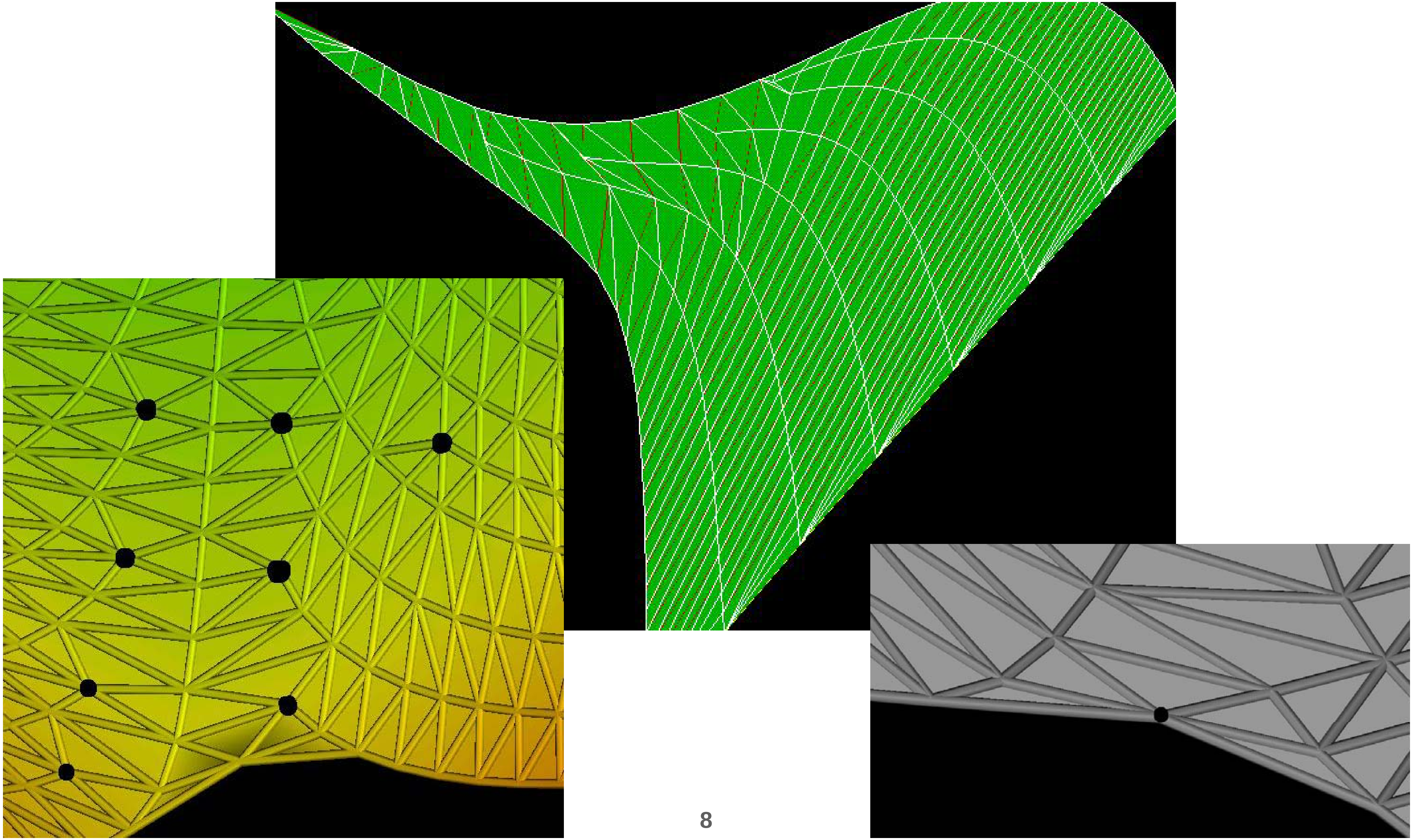
# Integral Objects in 3D 2/3

- Streamsurfaces

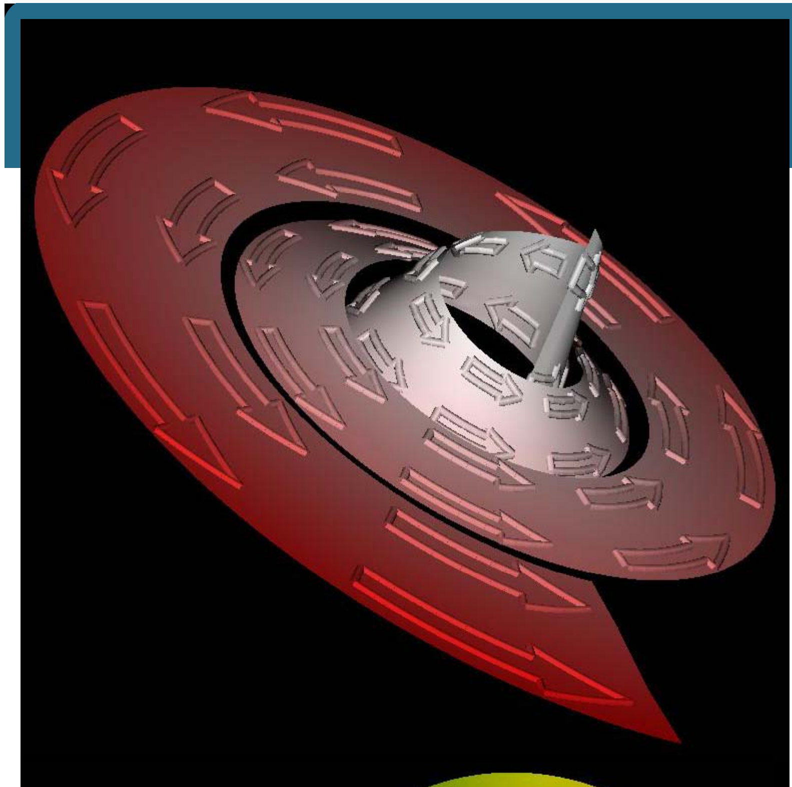


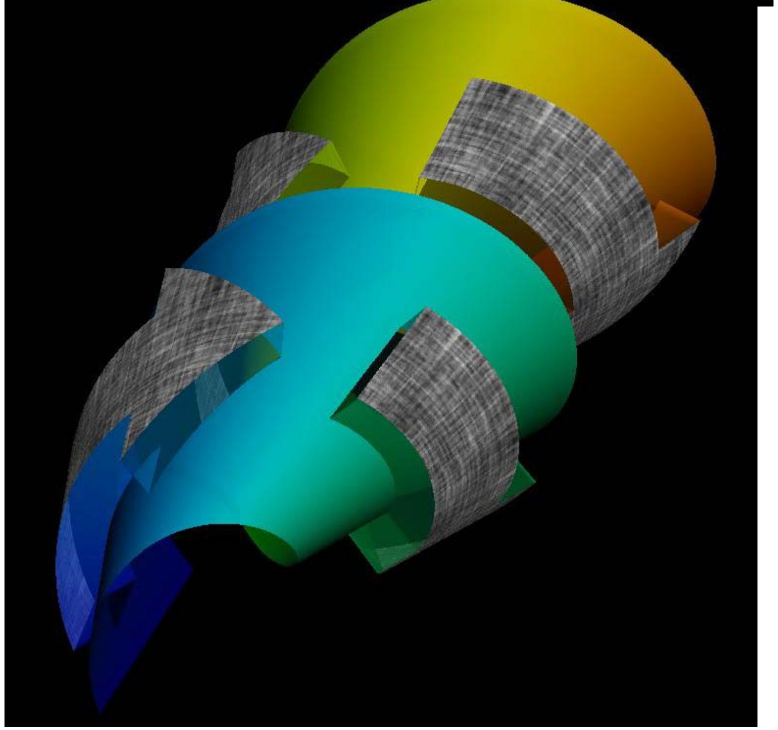


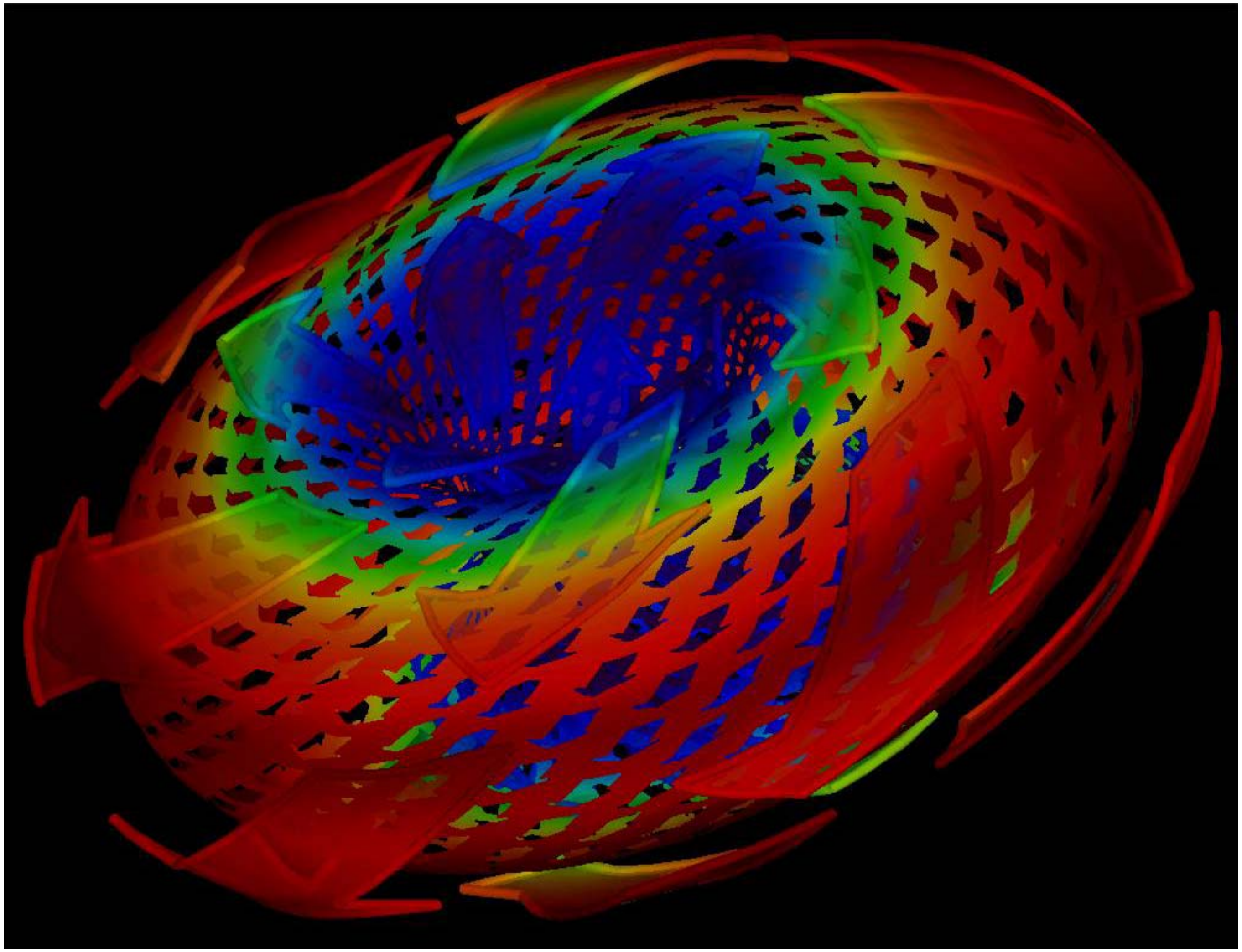
# Streamsurfaces – split / merge



# Stream Arrows

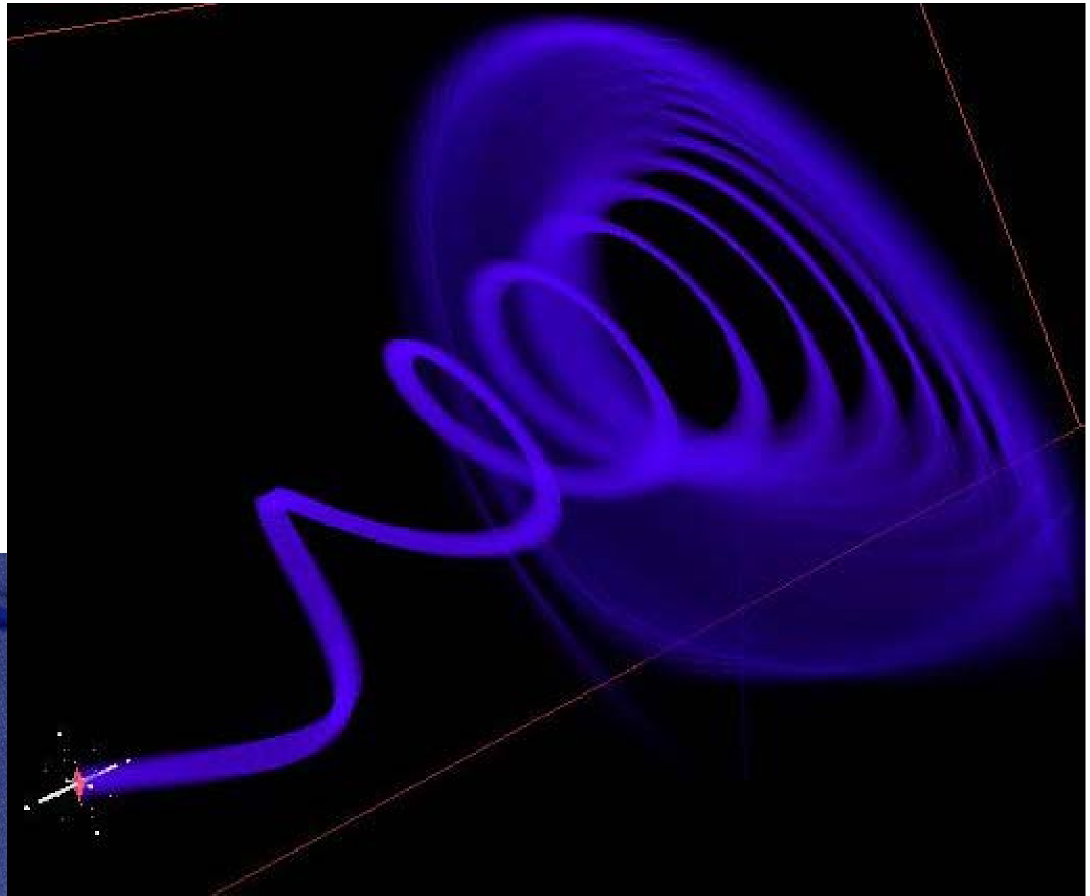




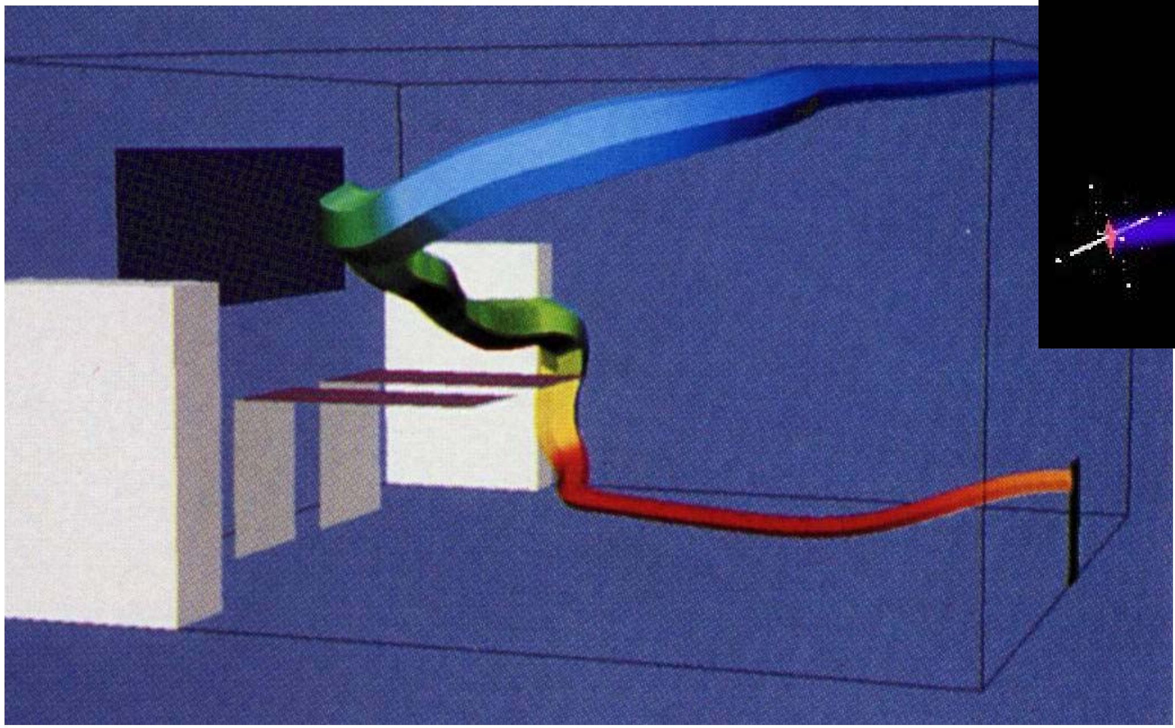


# Integral Objects in 3D 3/3

- Flow volumes …



- vs. streamtubes
  (similar to streamribbon)



# Relation to Seed Objects

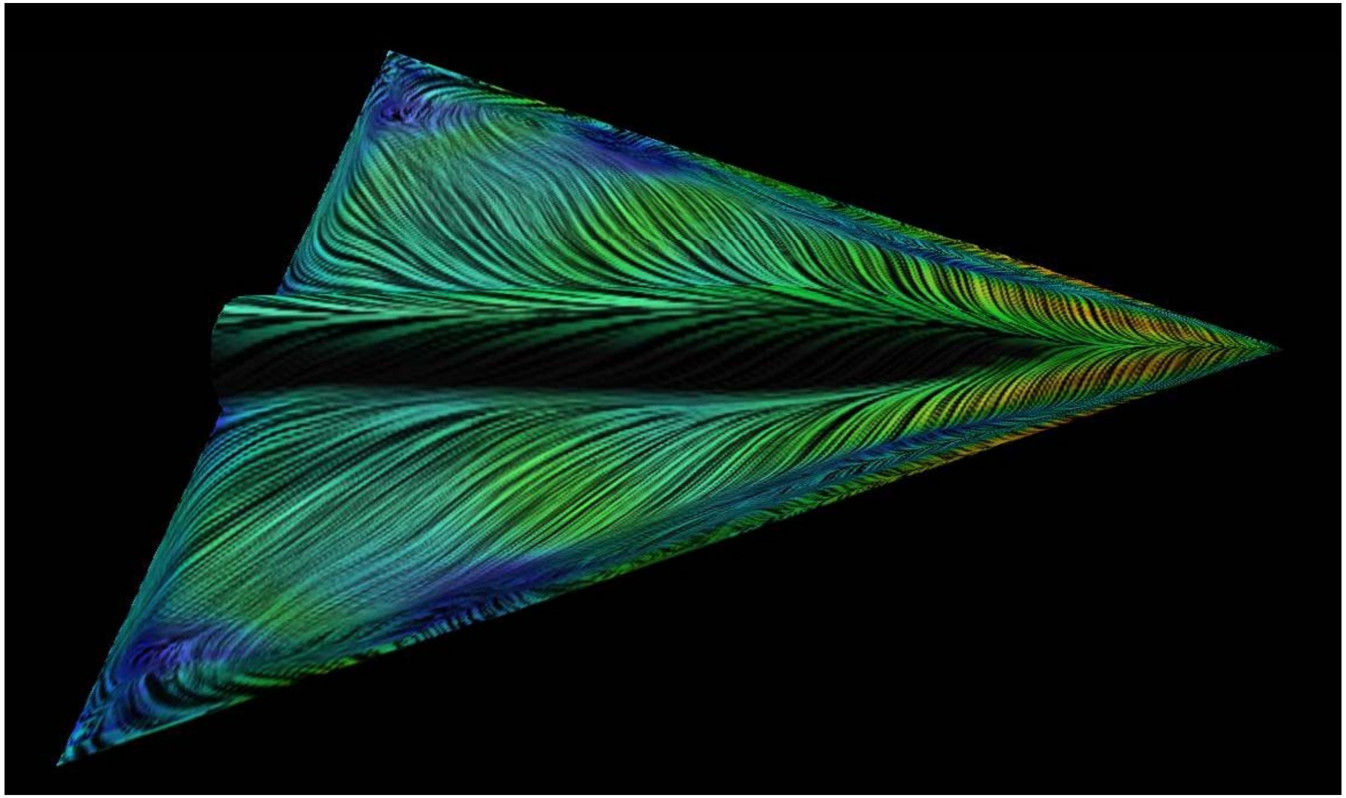
| IntegralObj. | Dim. | SeedObj. | Dim. |
|---|---|---|---|
| Streamline,… | 1D | Point | 0D |
| Streamribbon | 1D++ | Point+pt. | 0D+0D |
| Streamtube | 1D++ | Pt.+cont. | 0D+1D |
| Streamsurface | 2D | Curve | 1D |
| Flow volume | 3D | Patch | 2D |

# Line Integral Convolution

Flow Visualization
in 2D or on surfaces

# LIC – Introduction

- Aspects:
  - goal: general overview of flow
  - Approach: usage of textures
  - Idea: flow $\Leftrightarrow$ visual correlation
  - Example:

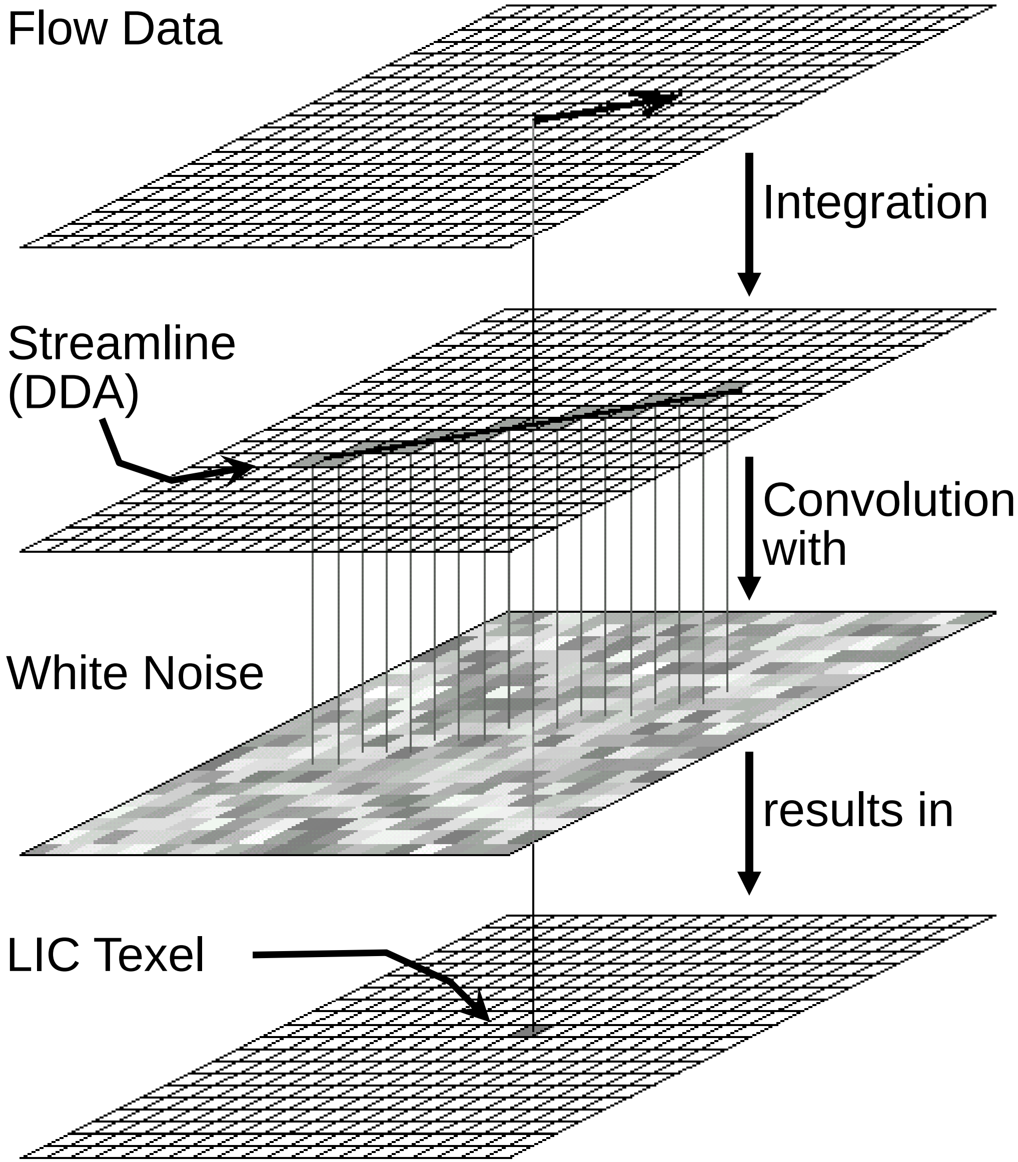


# LIC – Approach

- LIC idea:
  - for every texel: let the texture value…
    - … correlate with neighboring texture values along the flow (in flow direction)
    - … *not* correlate with neighboring texture values across the flow (normal to flow dir.)
  - result:
    along streamlines the texture values are correlated ⇒ visually coherent!
  - approach: “smudge” white noise (no a priori correlations) along flow

# LIC – Steps

- Calculation of a texture value:
  - look at streamline through point
  - filter white noise along streamline



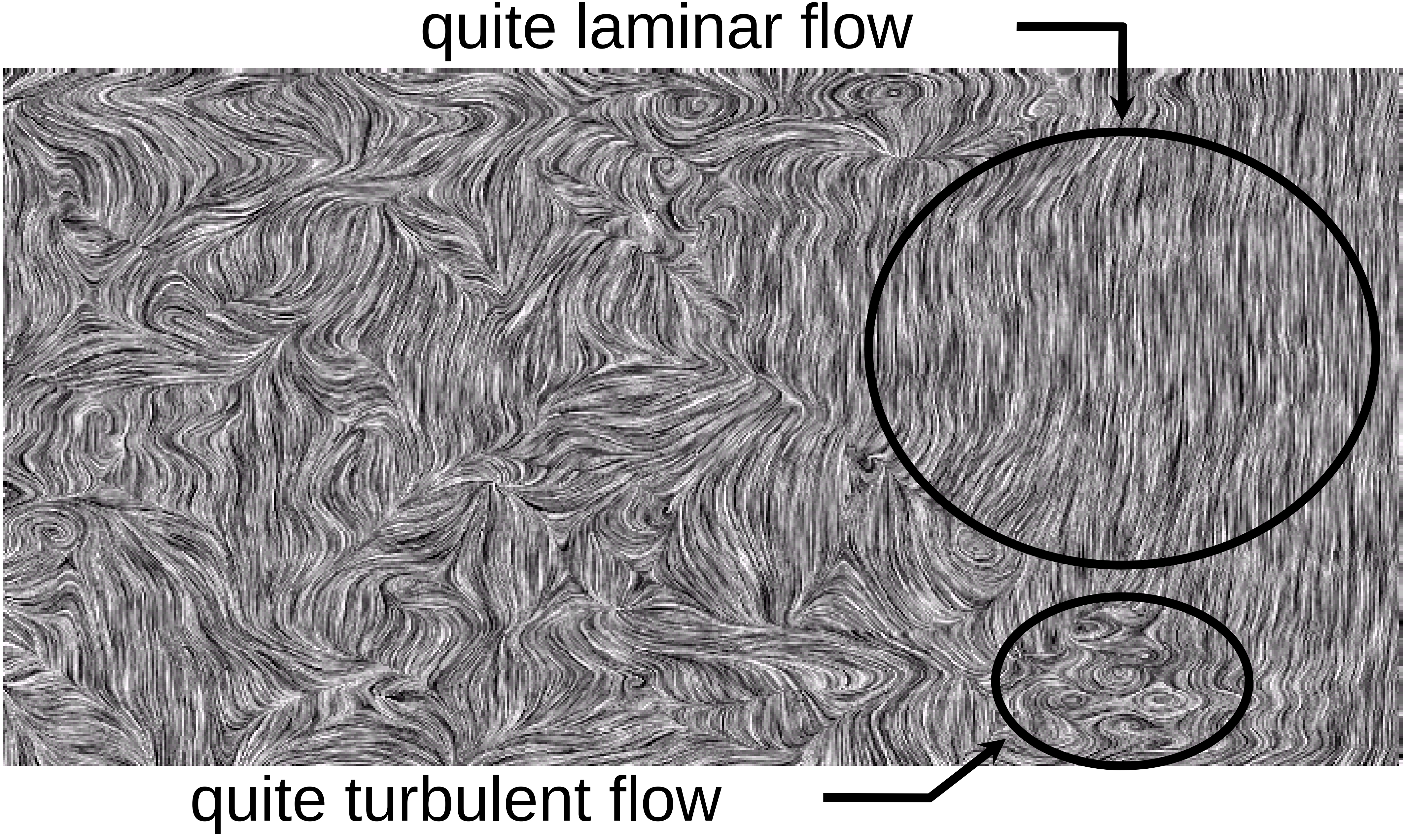
# LIC – Convolution with Noise

- Calculation of LIC texture:
  - input 1: flow data $\mathbf{v}(\mathbf{x})$: $R^n \rightarrow R^n$, analytically or interpolated
  - input 2: white noise $n(\mathbf{x})$: $R^n \rightarrow R^1$, normally precomputed as texture
  - streamline $\mathbf{s_x}(u)$ through $\mathbf{x}$: $R^1 \rightarrow R^n$, $\mathbf{s_x}(u) = \mathbf{x} + \mathrm{sgn}(u) \cdot \int_{0 \le t \le |u|} \mathbf{v}(\mathbf{s_x}(\mathrm{sgn}(u) \cdot t))\,dt$
  - input 3: filter $h(t)$: $R^1 \rightarrow R^1$, e.g., Gauss
  - result: texture value $\mathrm{lic}(\mathbf{x})$: $R^n \rightarrow R^1$, $\mathrm{lic}(\mathbf{x}) = \mathrm{lic}(\mathbf{s_x}(0)) = \int n(\mathbf{s_x}(u)) \cdot h(-u)\,du$

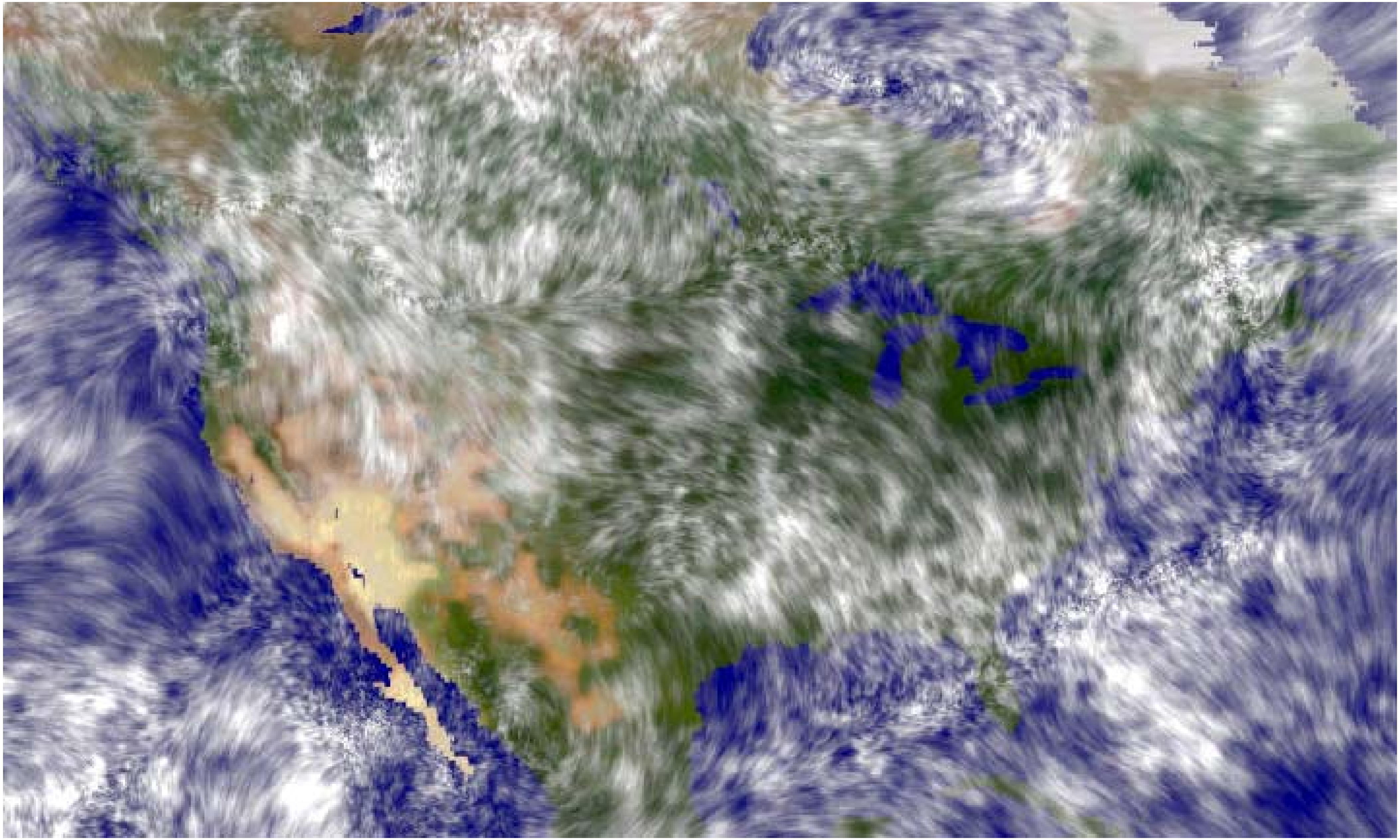
# More Explanation

- So:
  - LIC – lic($\mathbf{x}$) – is a convolution of
    - white noise *n* (or …)
    - and a smoothing filter *h* (e.g. a Gaussian)
  - The noise texture values are picked up along streamlines $\mathbf{s}_\mathbf{x}$ through $\mathbf{x}$

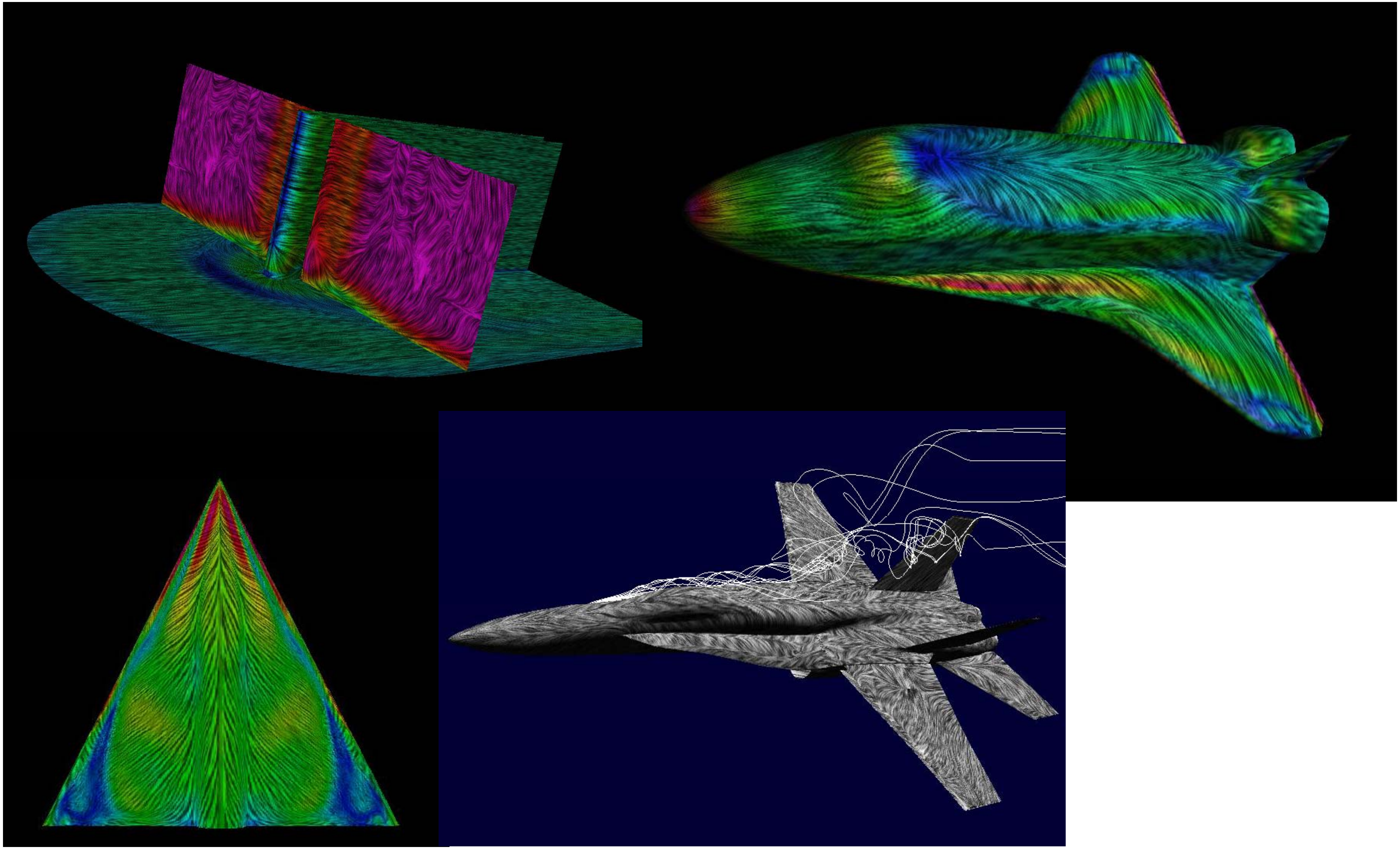
# LIC – Example in 2D



# LIC in 2D – Further Example

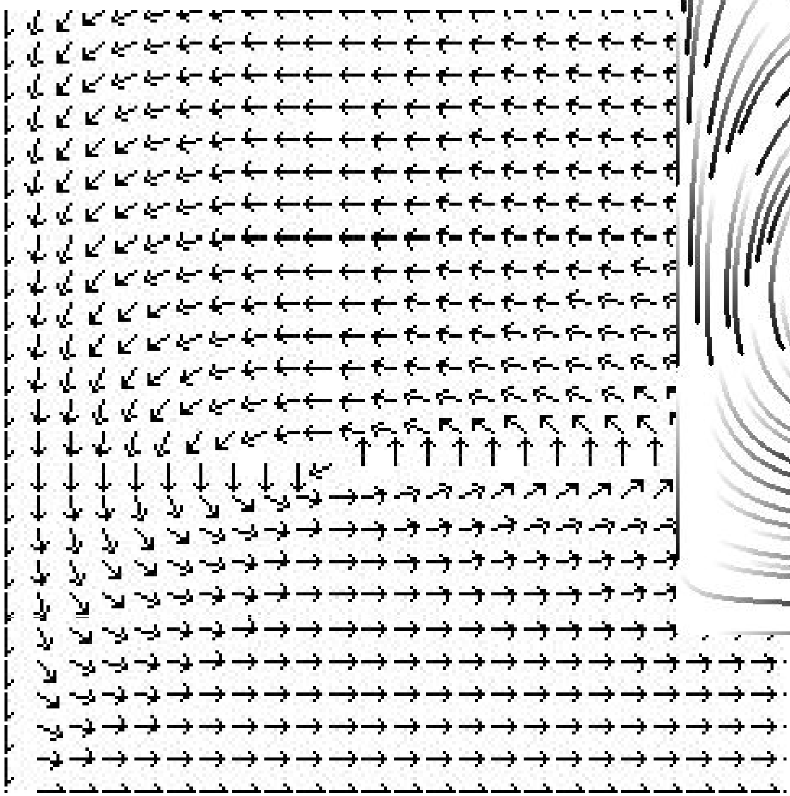


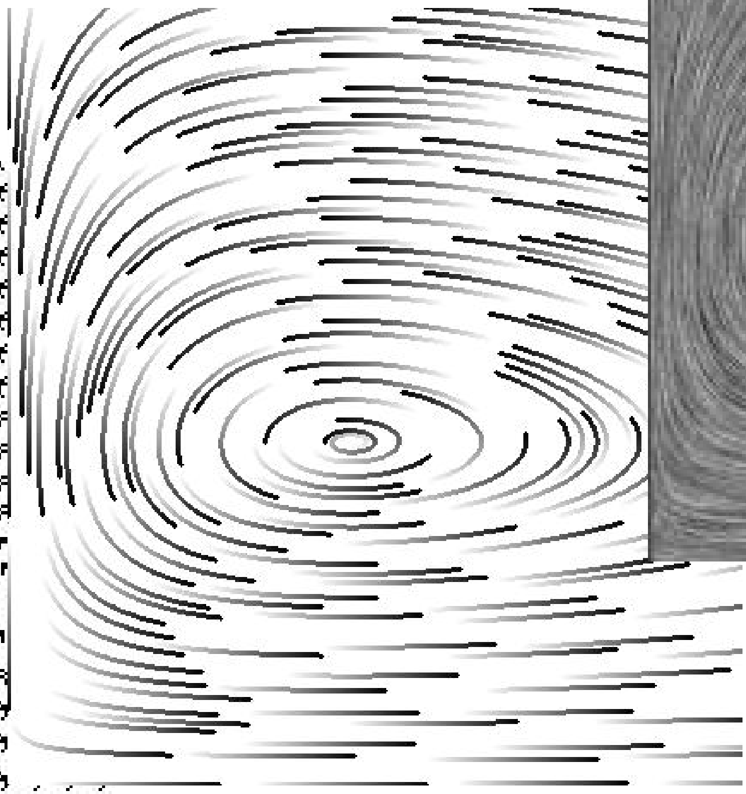
# LIC – Examples on Surfaces

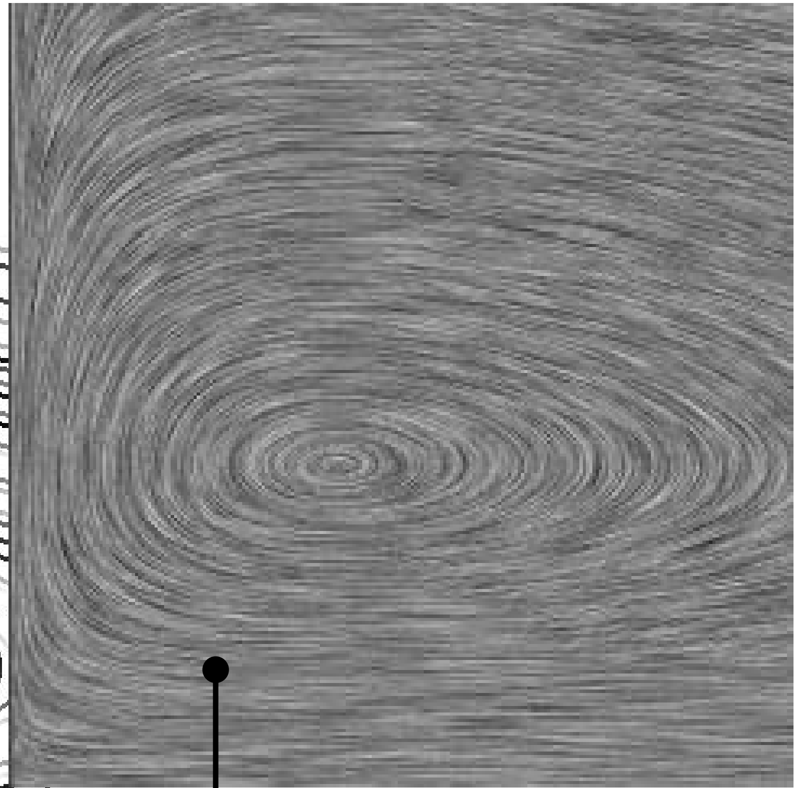


# Arrows vs. StrLines vs. Textures

- Streamlines: selective
- Arrows: well..



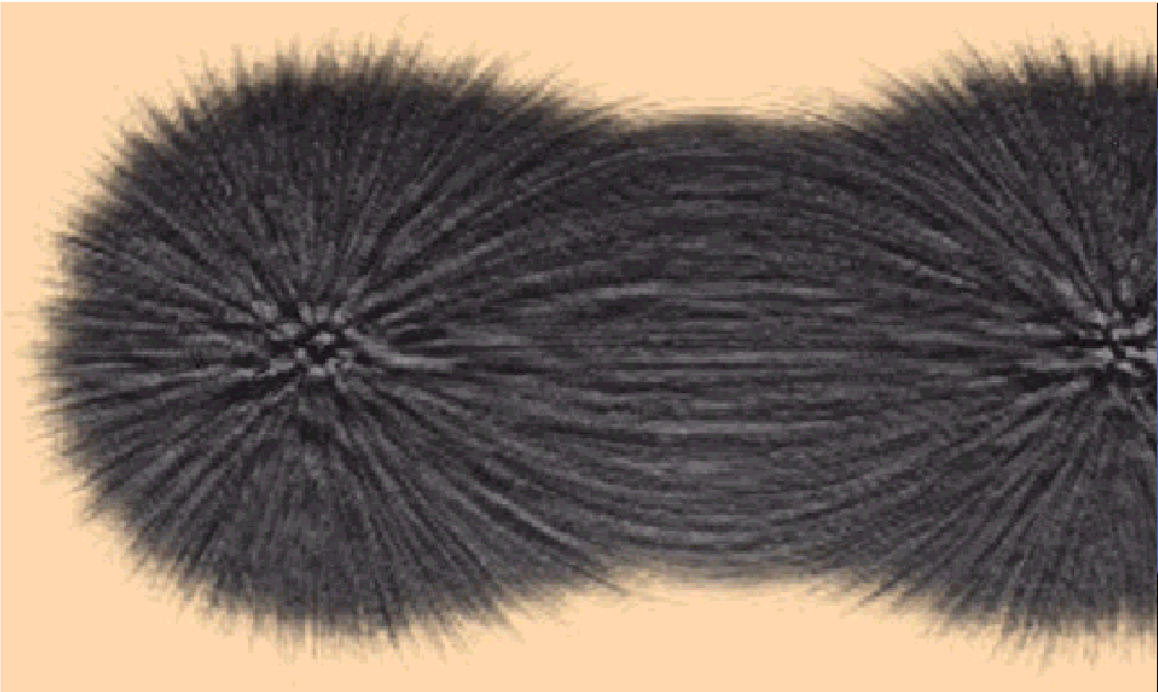
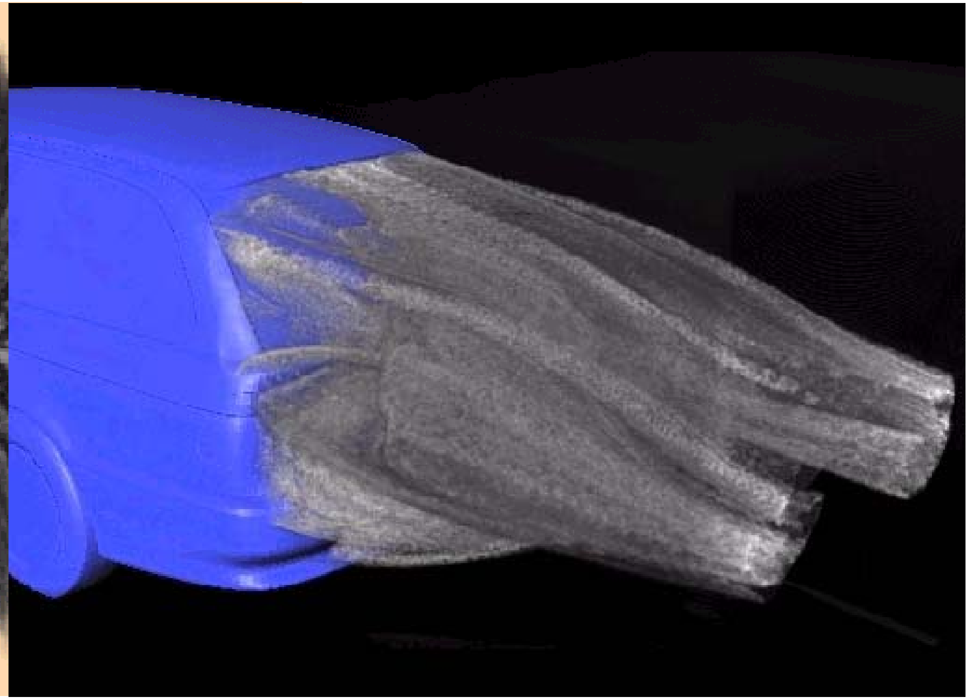




Textures:
2D-filling

# LIC in 3D??!

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

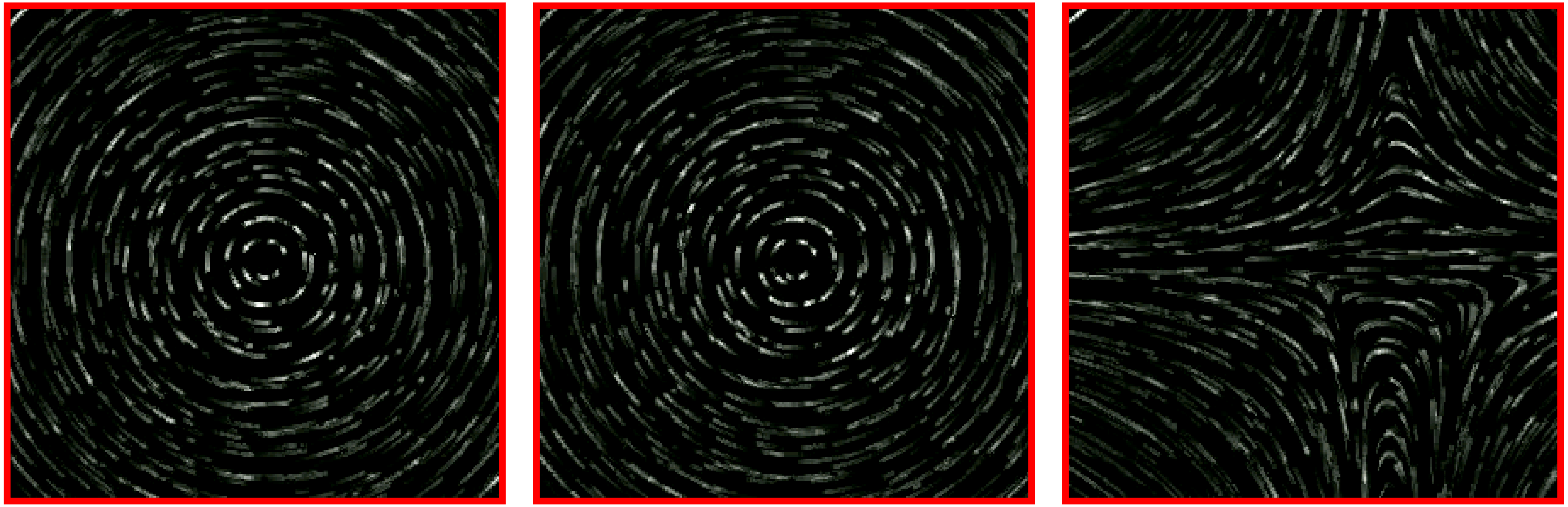



# Literature

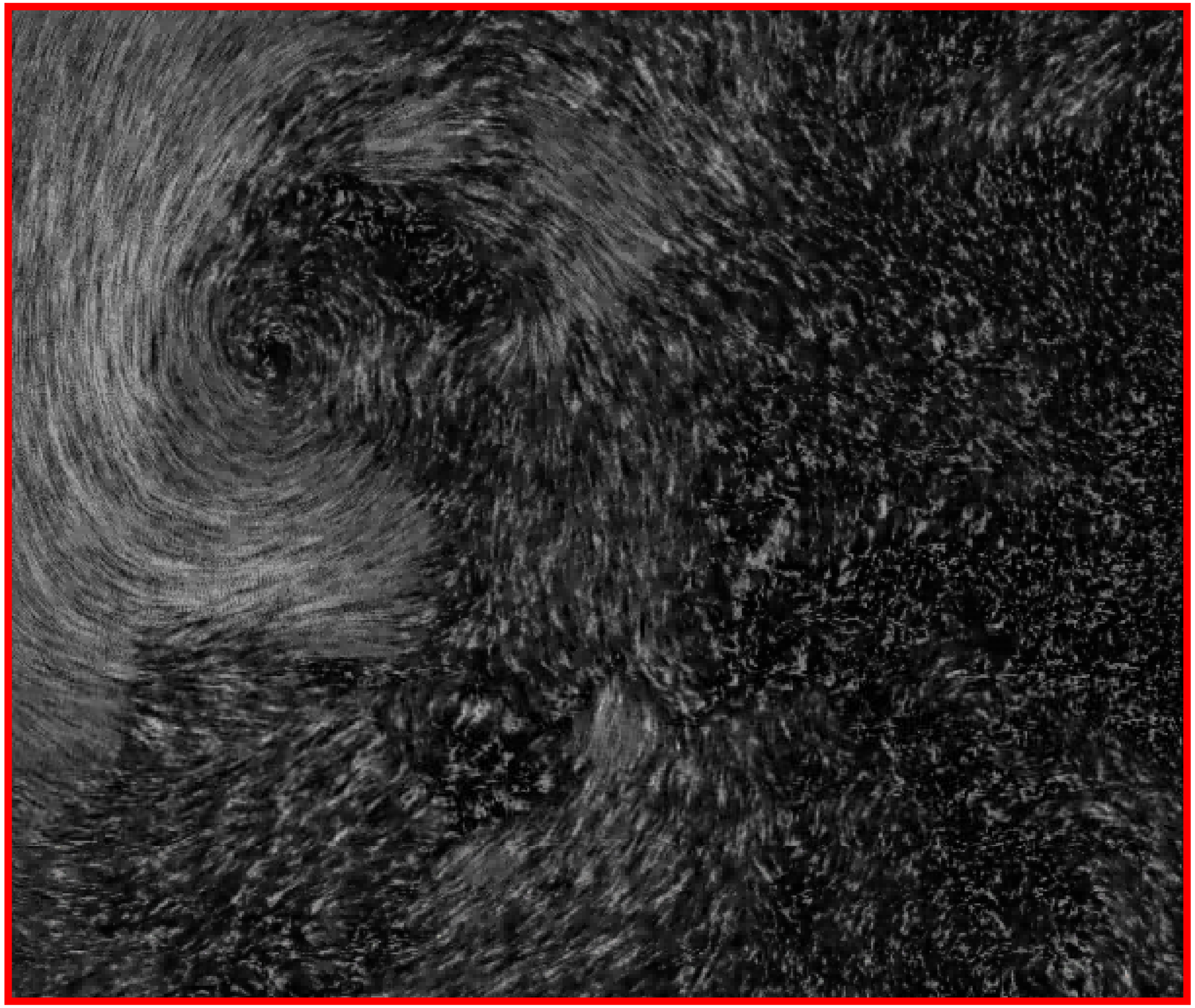
- Papers (more details):
  - B. Cabral & L. Leedom: "**Imaging Vector Fields Using Line Integral Convolution**" in *Proceedings of SIGGRAPH '93* = Computer Graphics 27, 1993, pp. 263-270
  - D. Stalling & H.-C. Hege: "**Fast and Resolution Independent Line Integral Convolution**" in *Proceedings of SIGGRAPH '95* = Computer Graphics 29, 1995, pp. 249-256

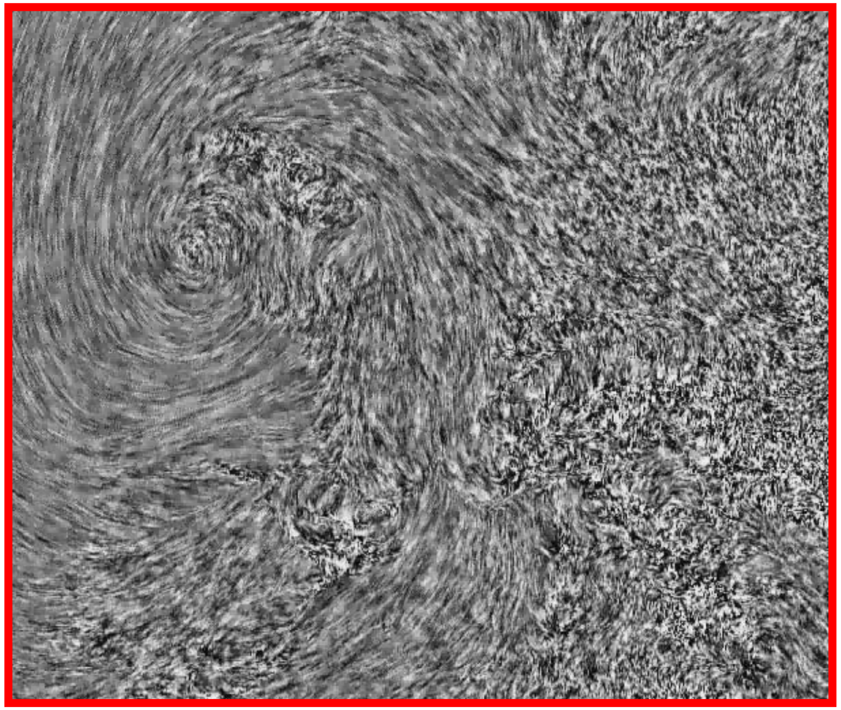
# LIC-Variants

- OLIC = Oriented Line Integral Convolution
  - visualization of directional information

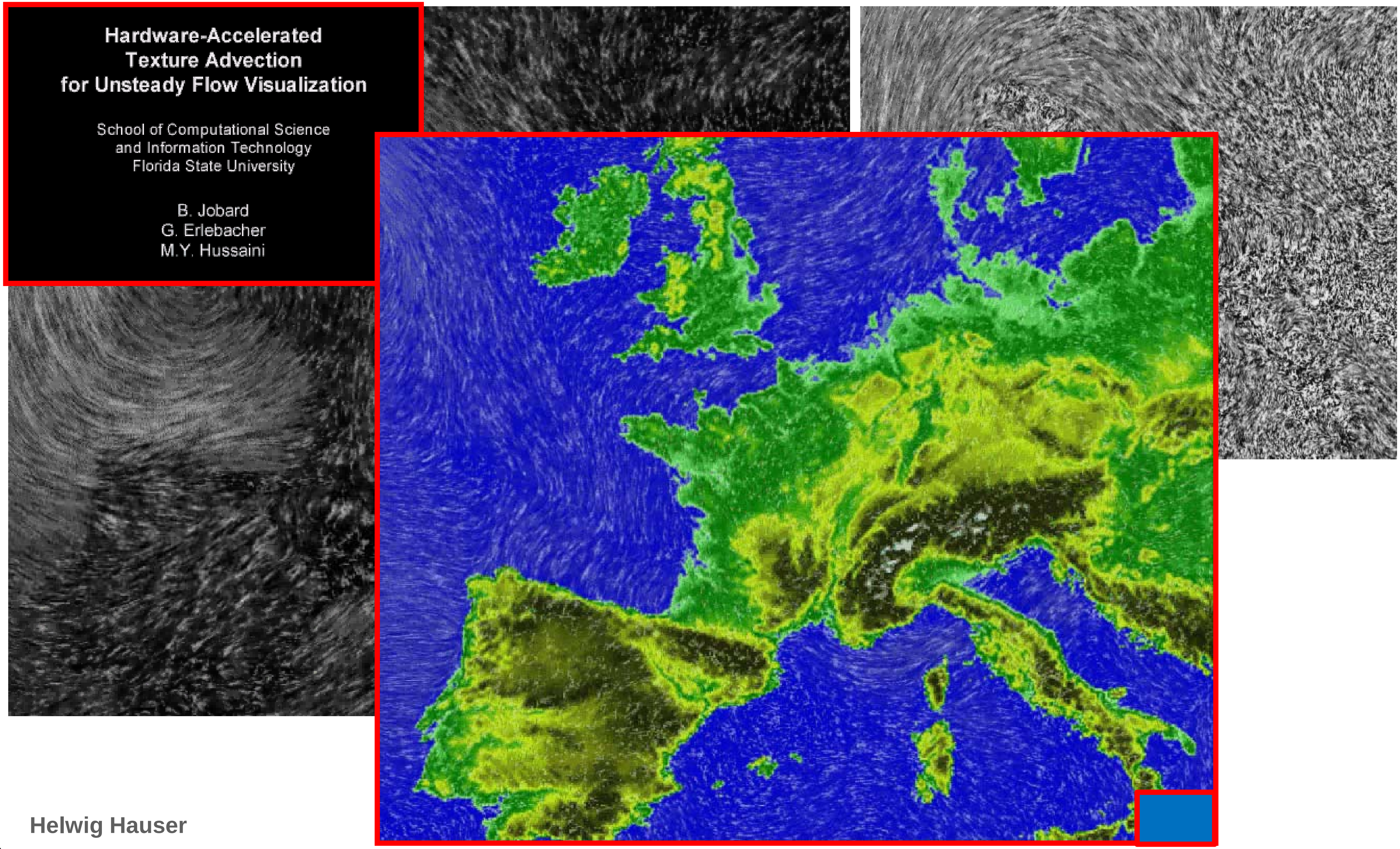


# Texture Advection – Steady Flows





# Texture Advect. – Unsteady Flows

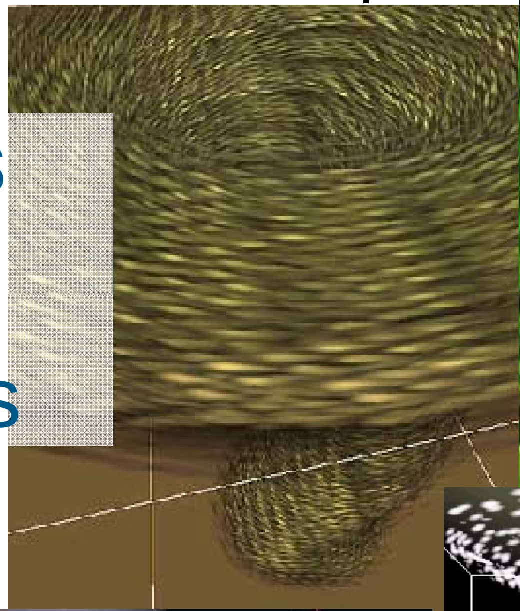


# Alternatives to LIC

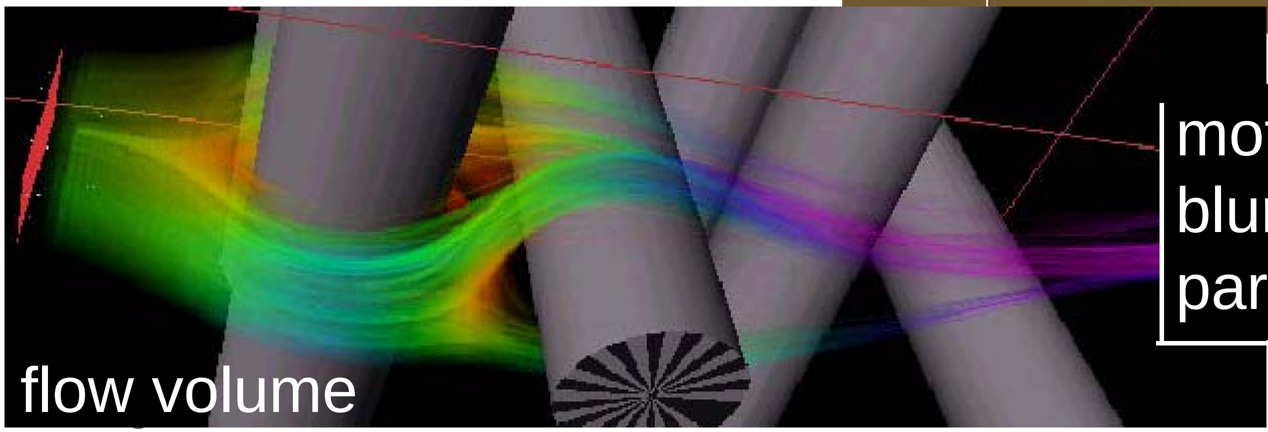
- Similar approaches:
  - spot noise
  - vector kernel
  - line bundles / splats
  - textured splats
  - particle systems
  - flow volumes

spot noise

textured splats



motion blurred particles



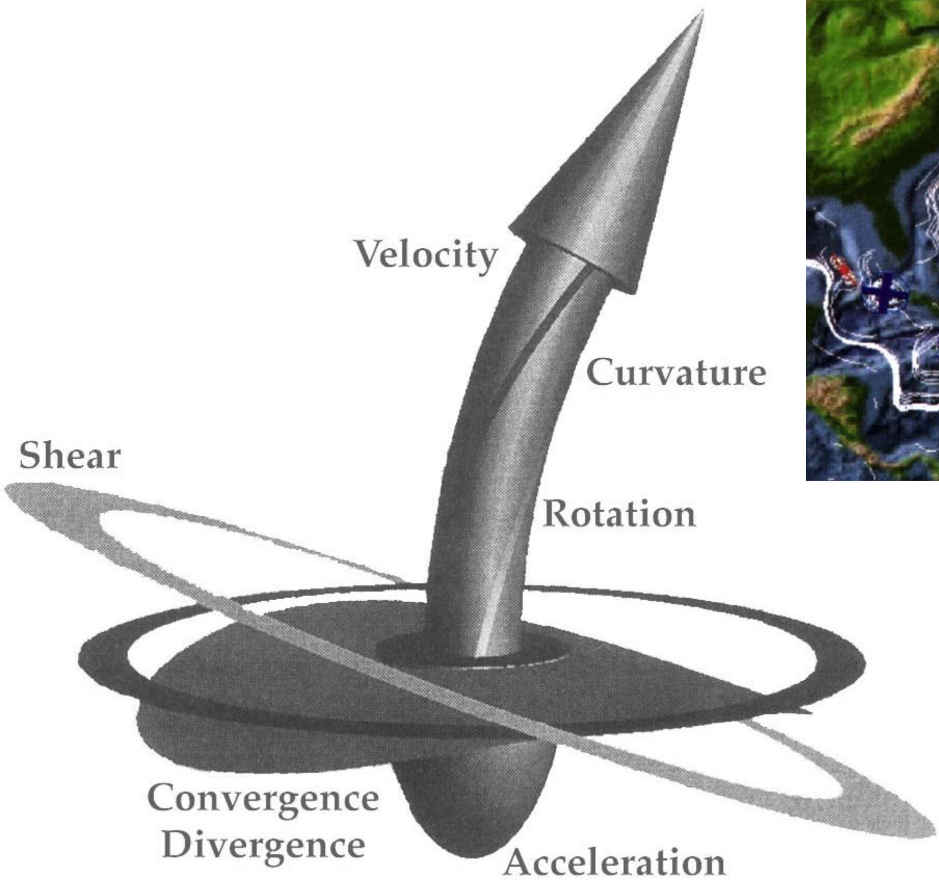
flow volume

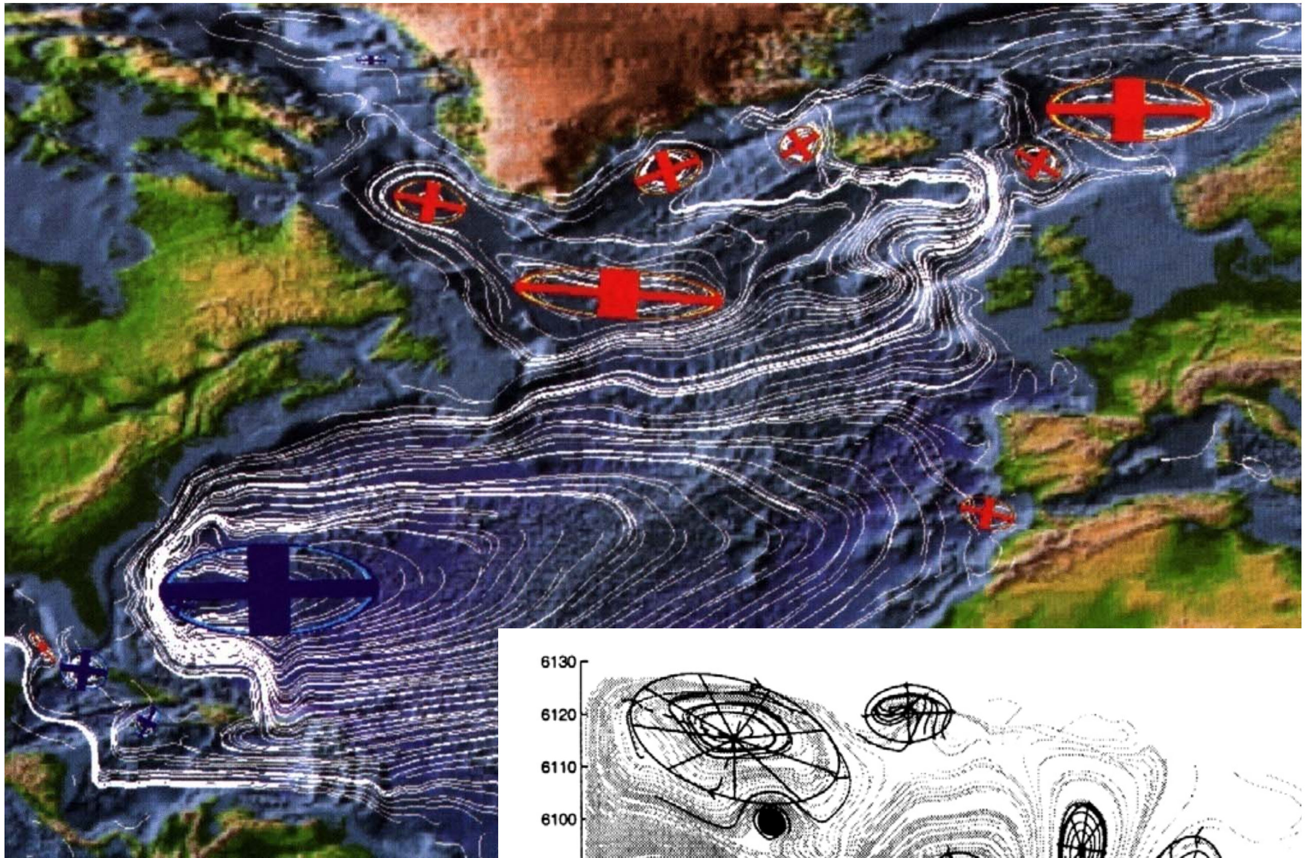
# Flow Visualization
## dependent on local props.

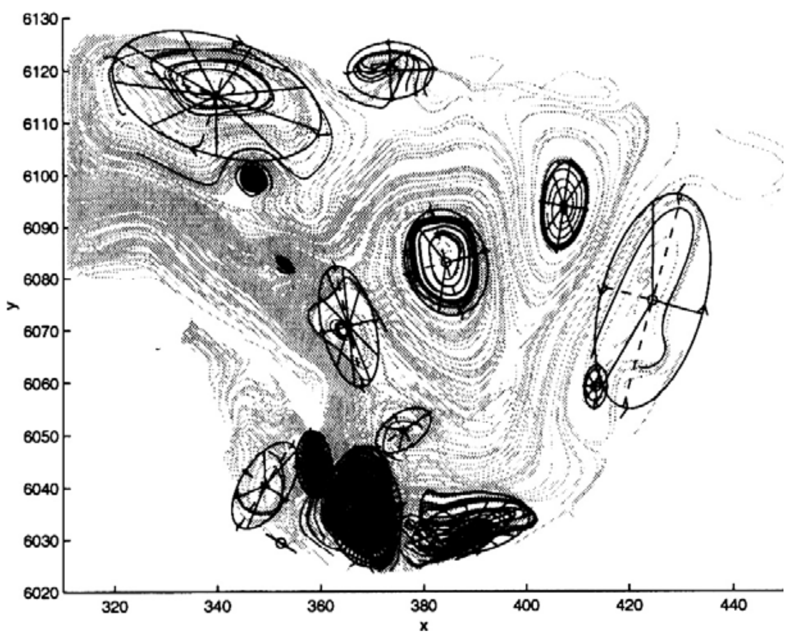
Visualization of $\nabla \mathbf{v}$

# Glyphs resp. Icons

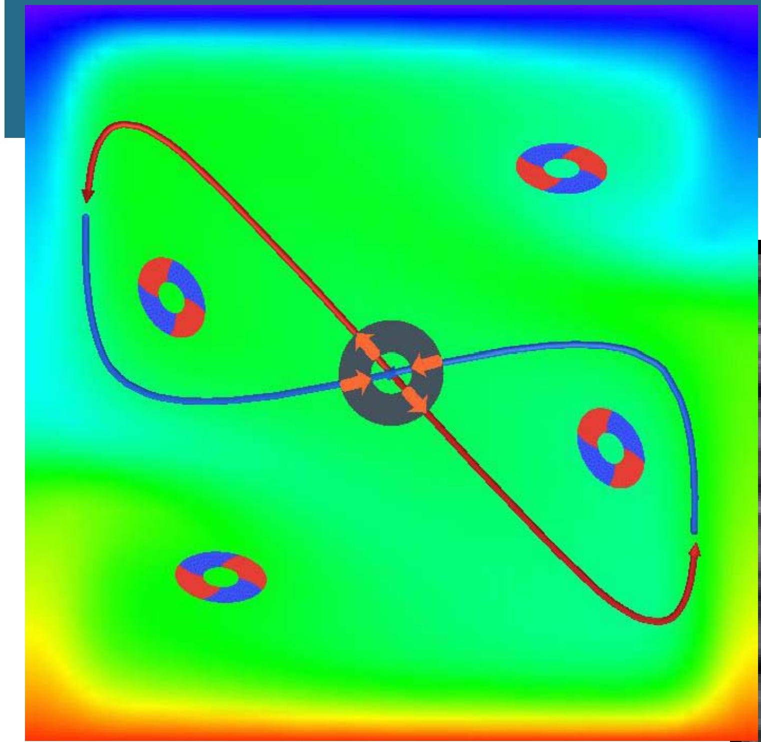
- Local / topological properties

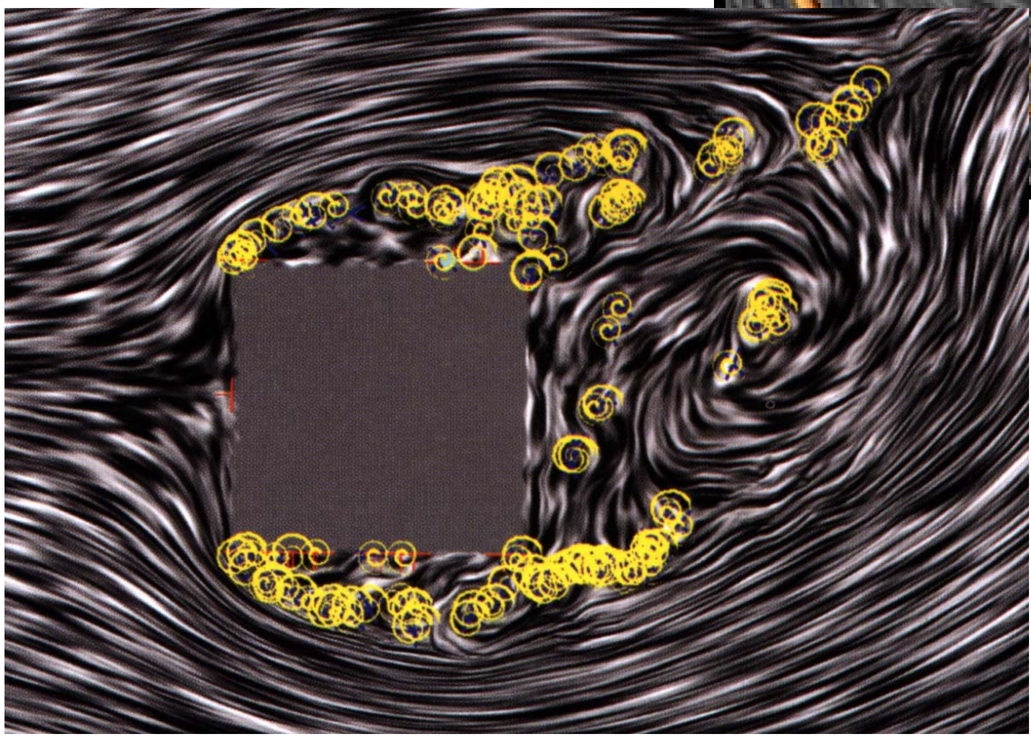


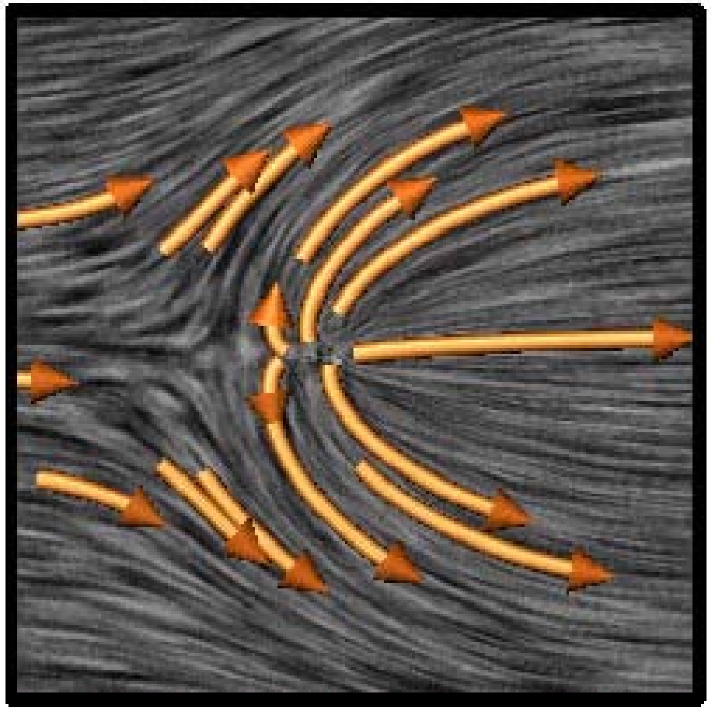



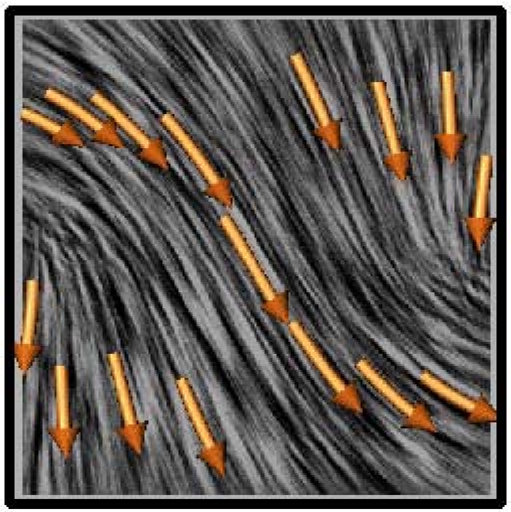


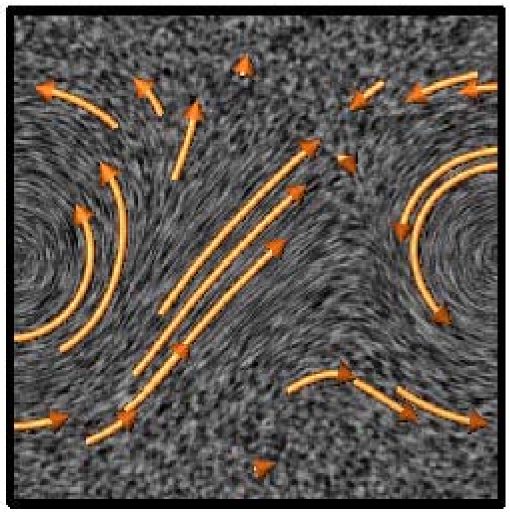
# Icons in 2D



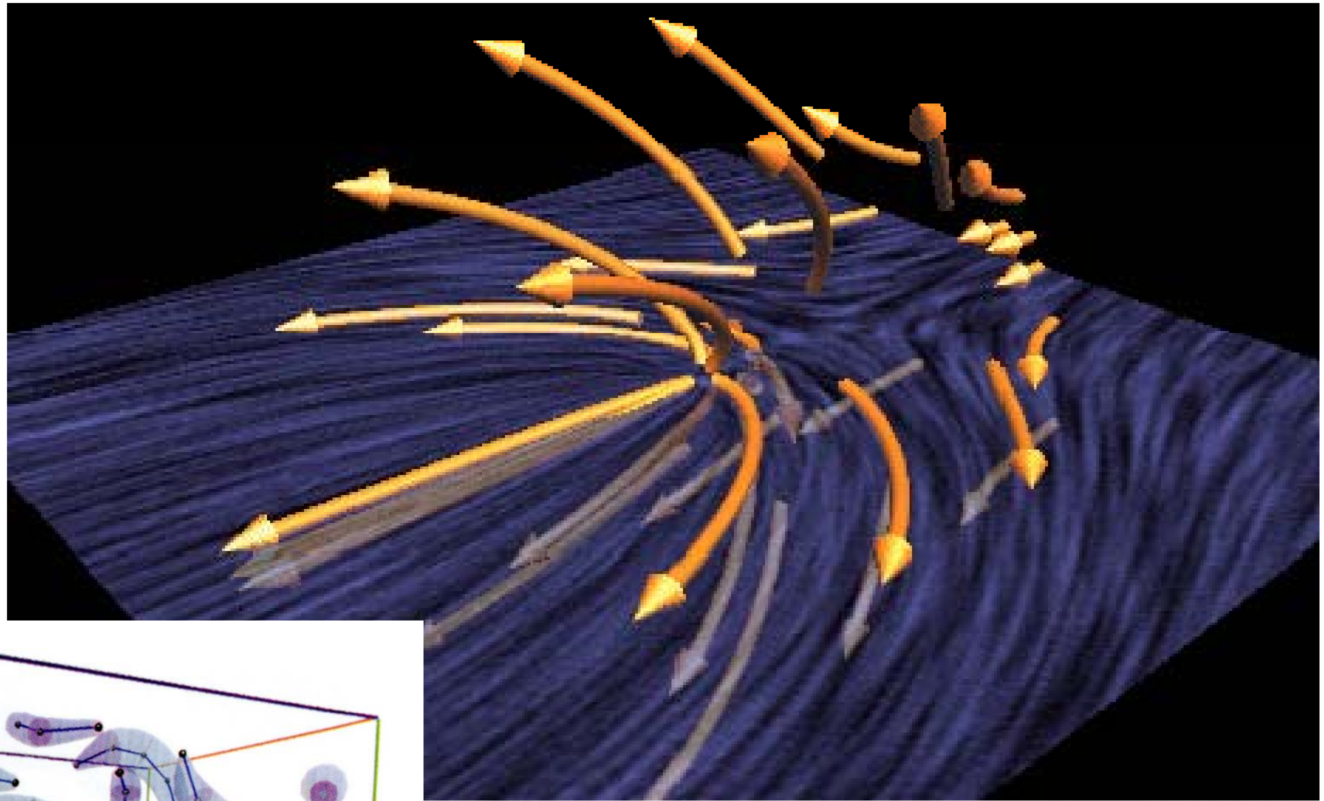


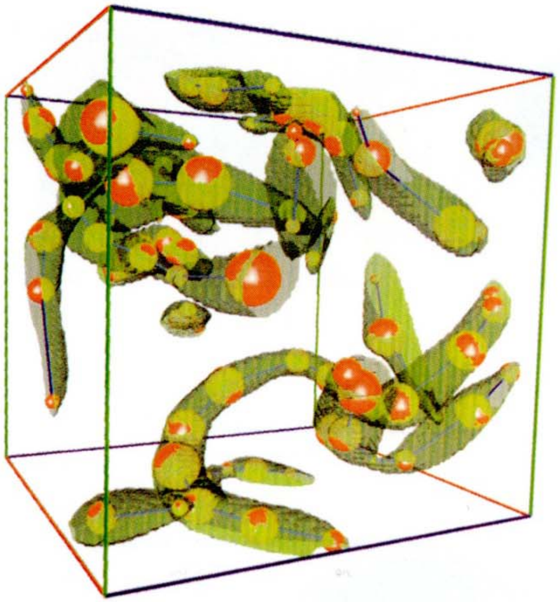


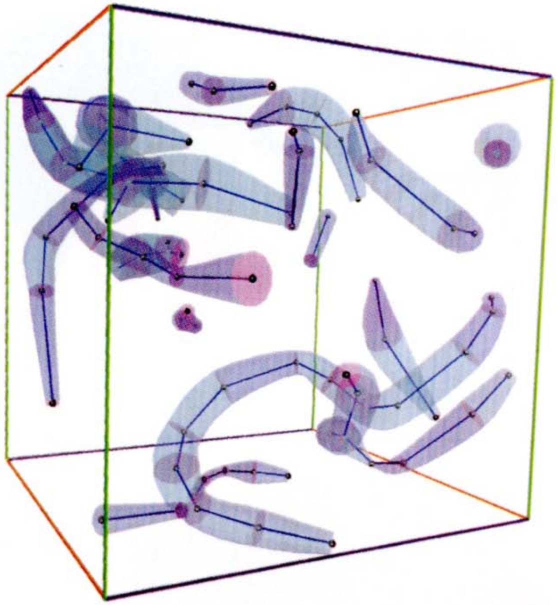


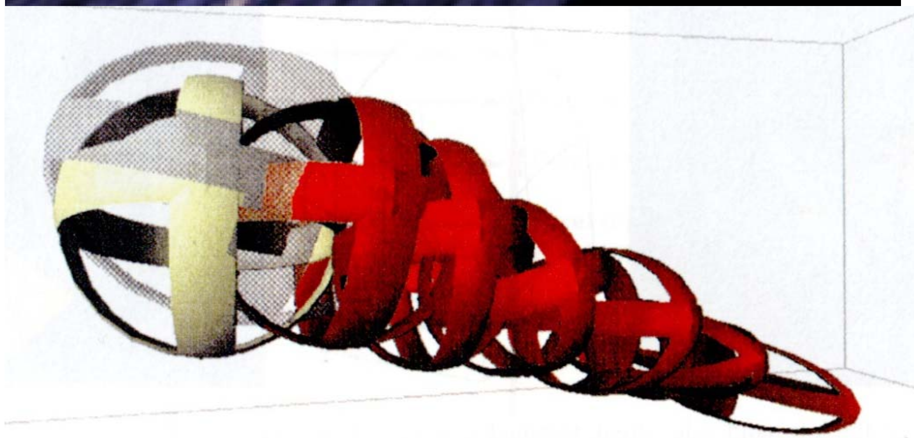


# Icons & Glyphs in 3D



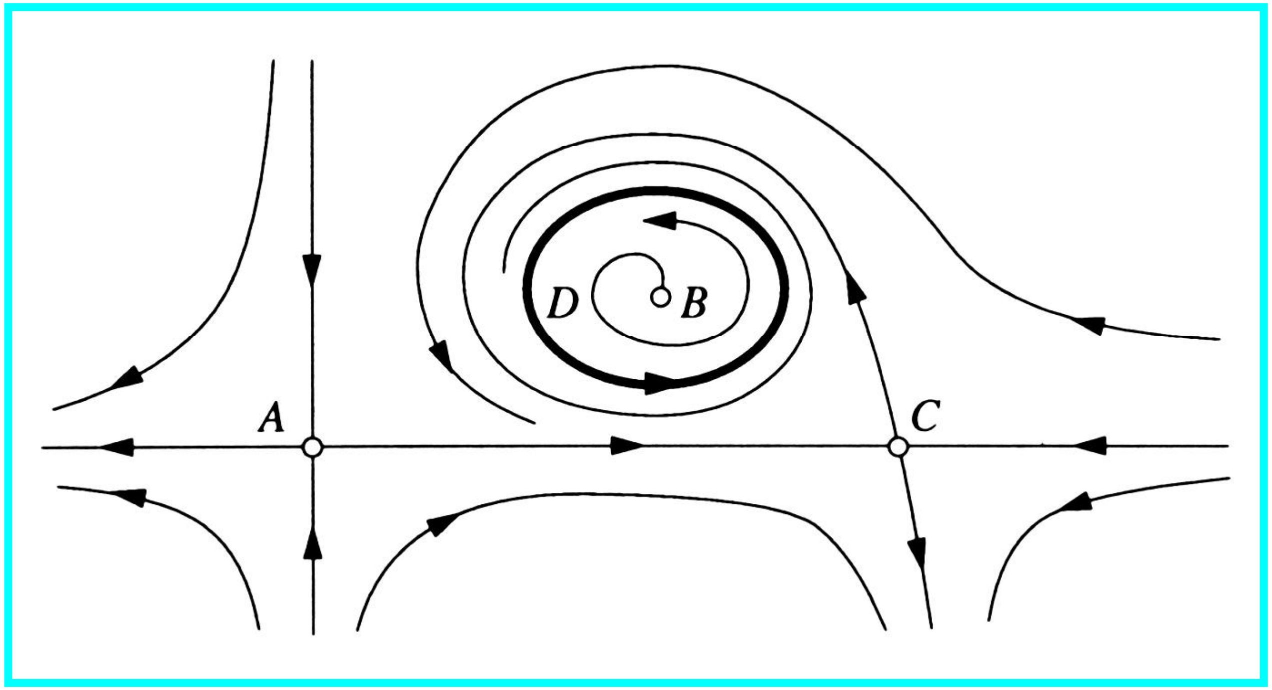






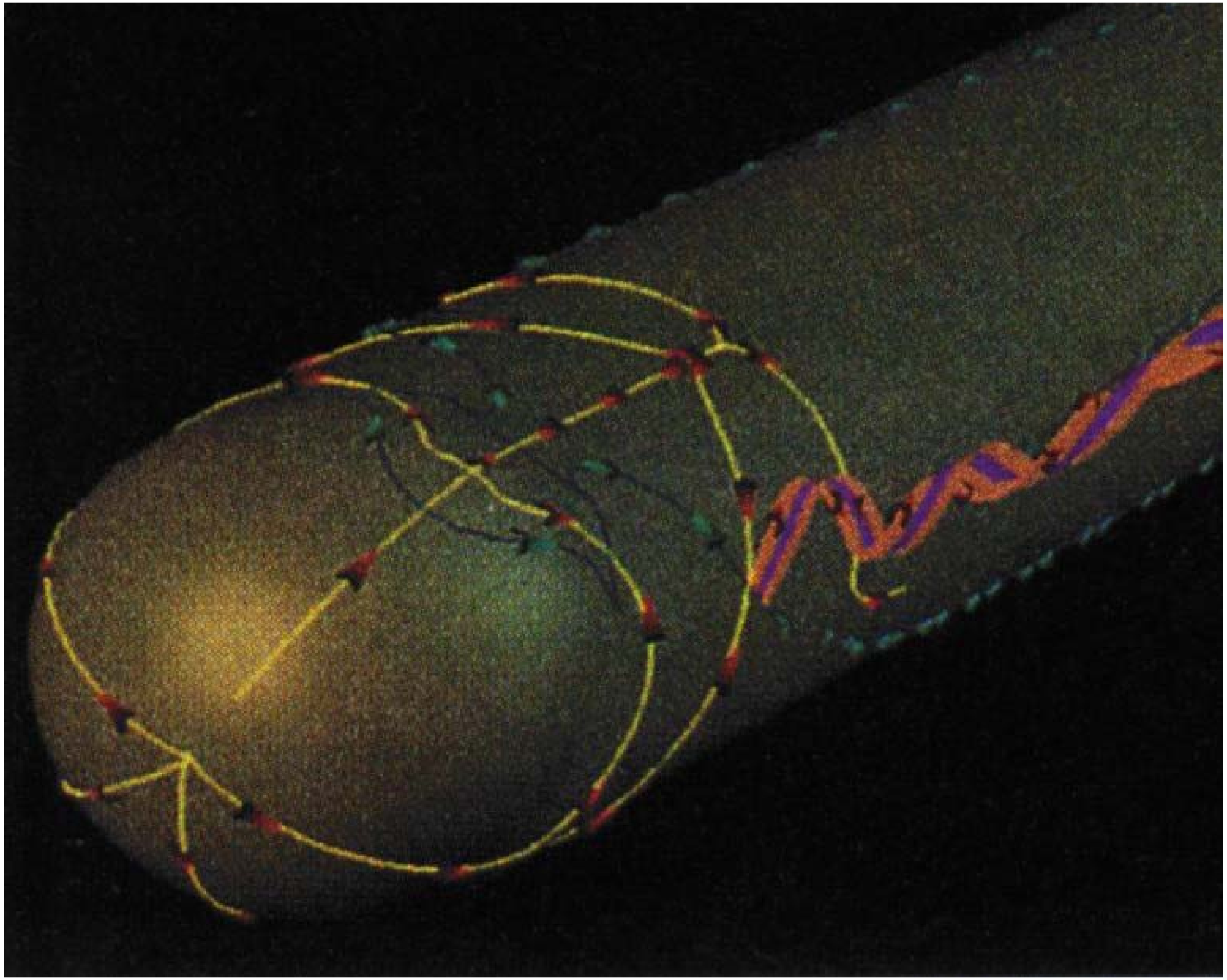
# Flow Topology

- Topology:
  - abstract structure of a flow
  - different elements, e.g.:
    - checkpoints, defined through $\mathbf{v}(\mathbf{x})=\mathbf{0}$
    - cycles, defined through $\mathbf{s}_\mathbf{x}(t+T)=\mathbf{s}_\mathbf{x}(t)$
    - connecting structures (separatrices, etc.)



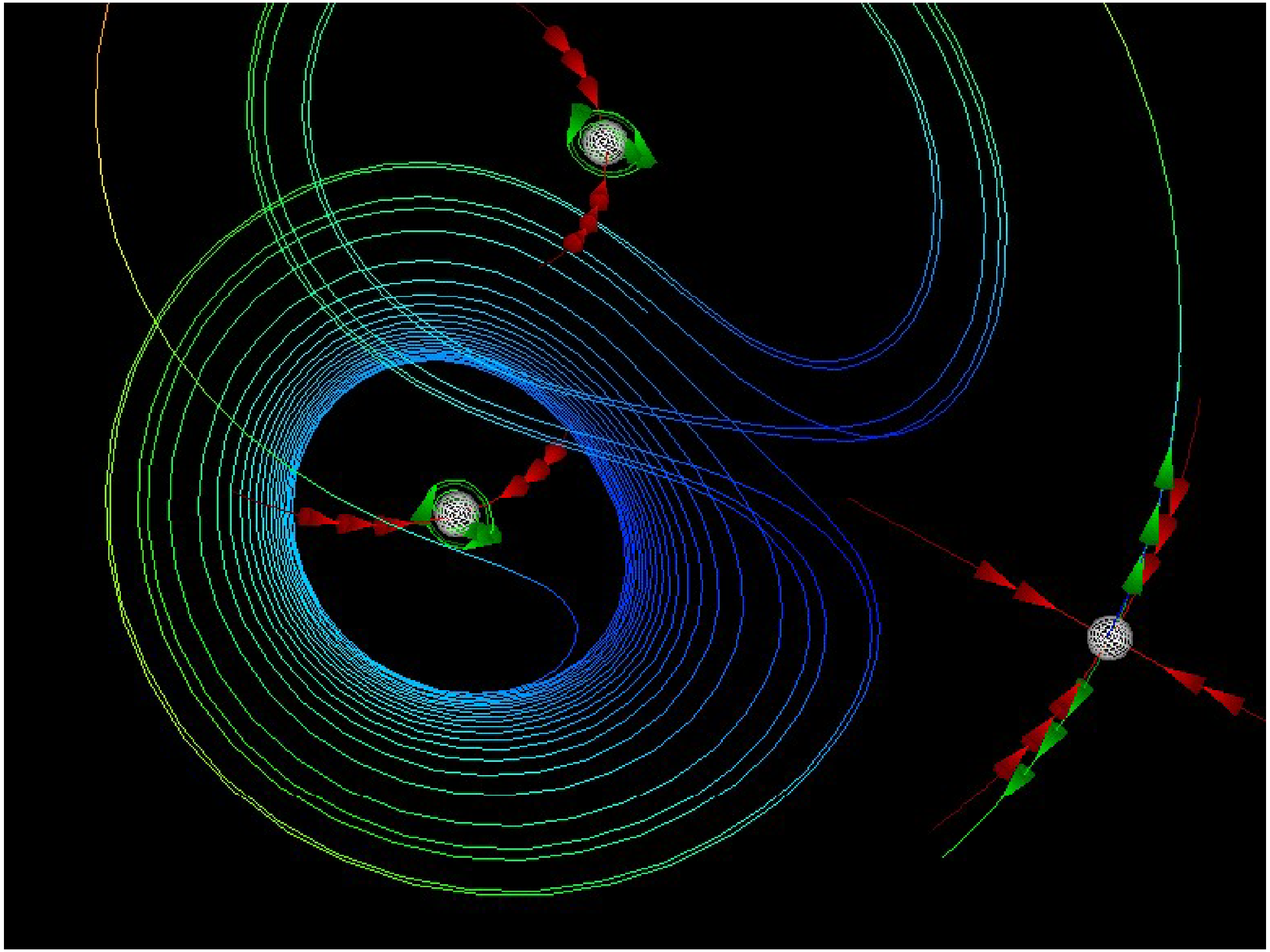
# Flow Topology in 3D

- Topology on surfaces:
  - fixed points
  - separa-trices



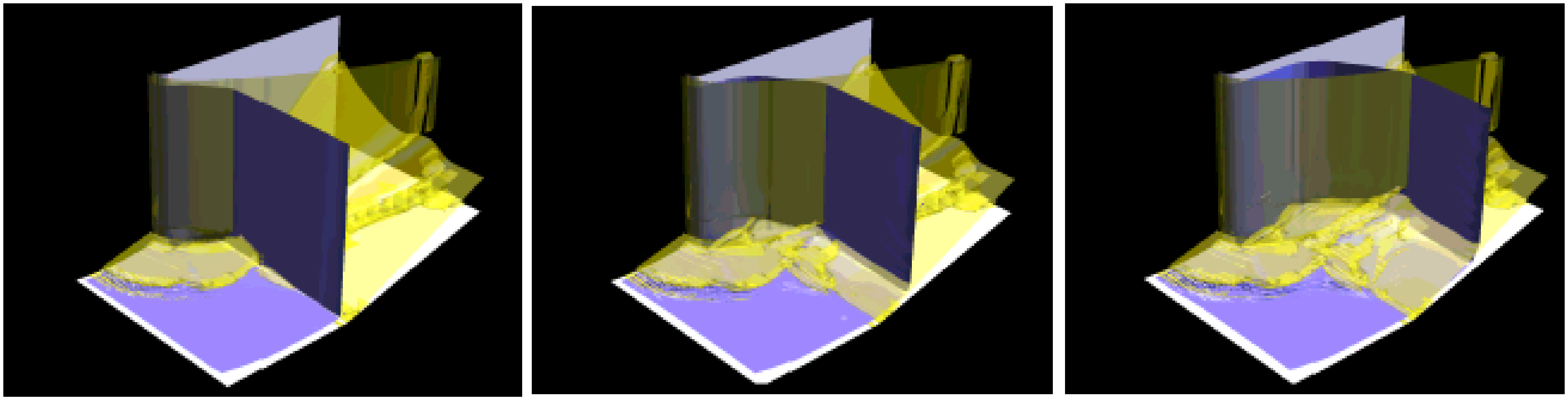
# Flow Topology in 3D

- Lorenz system:
  - 1 saddle
  - 2 saddle foci
  - 1 chaotic attractor



# Timesurfaces

- Idea:
  - start surface, e.g. part of a plane
  - move whole surface along flow over time
  - time surface: surface at one point in time



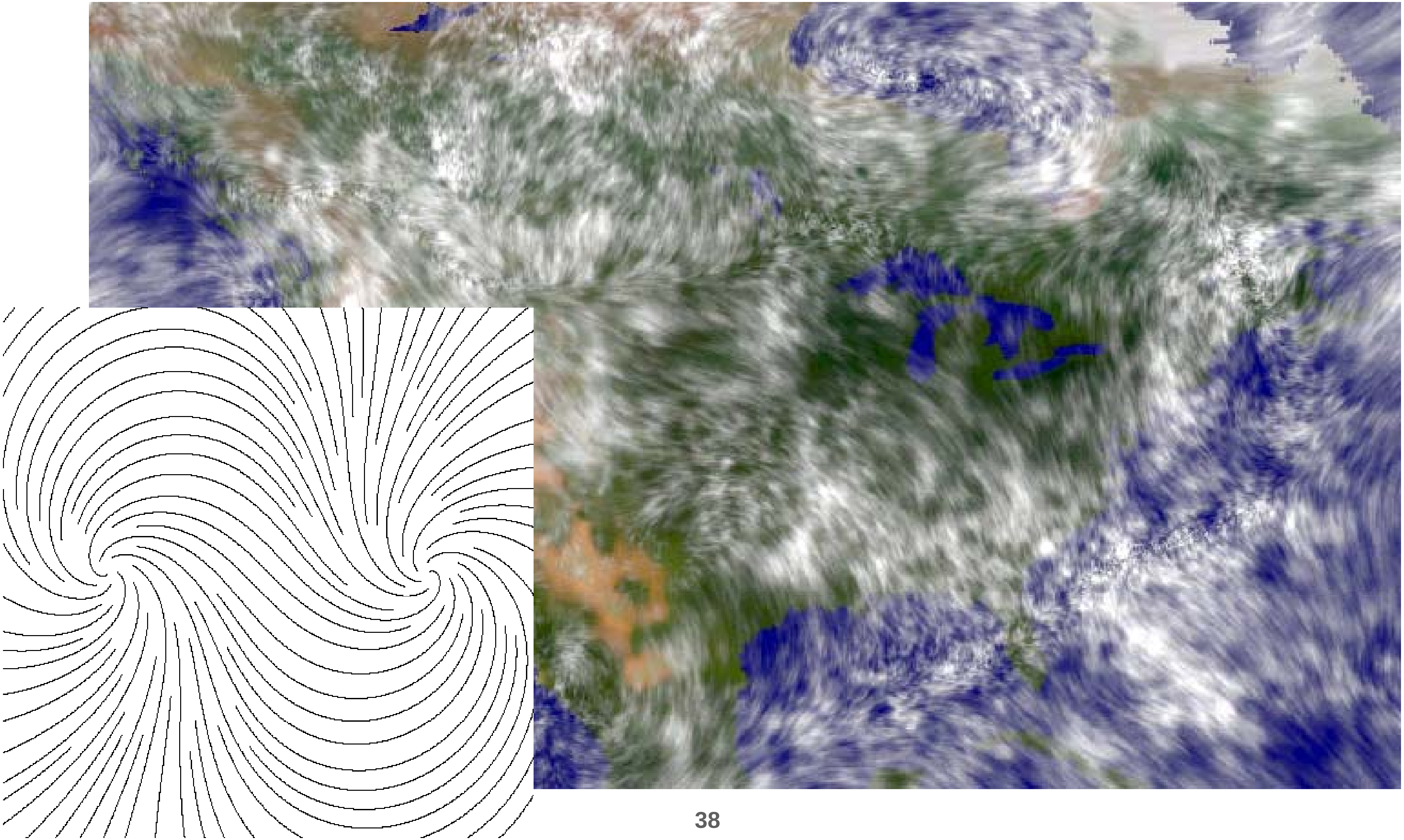
# Flow Visualization – summary

Overview, Solutions

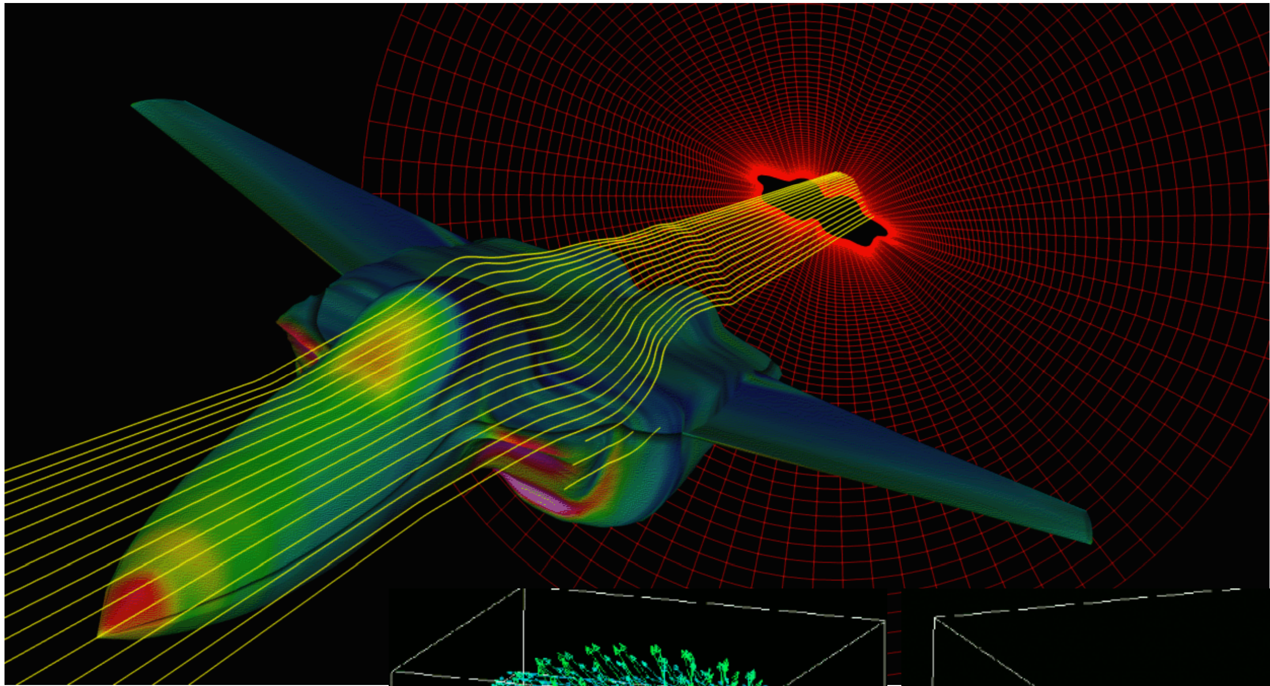
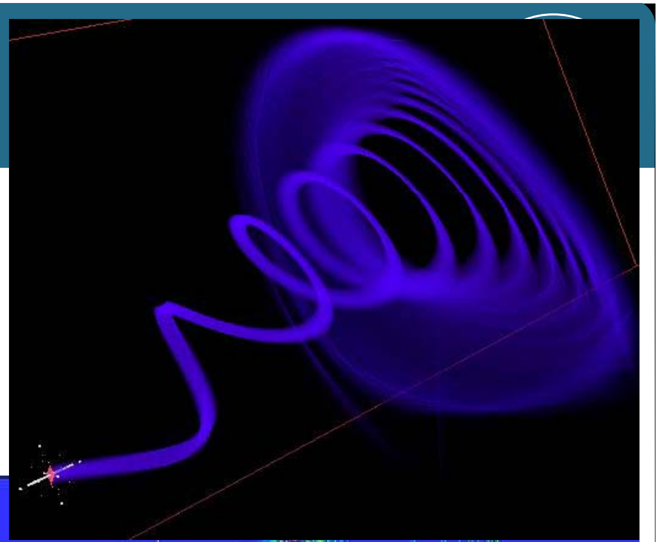
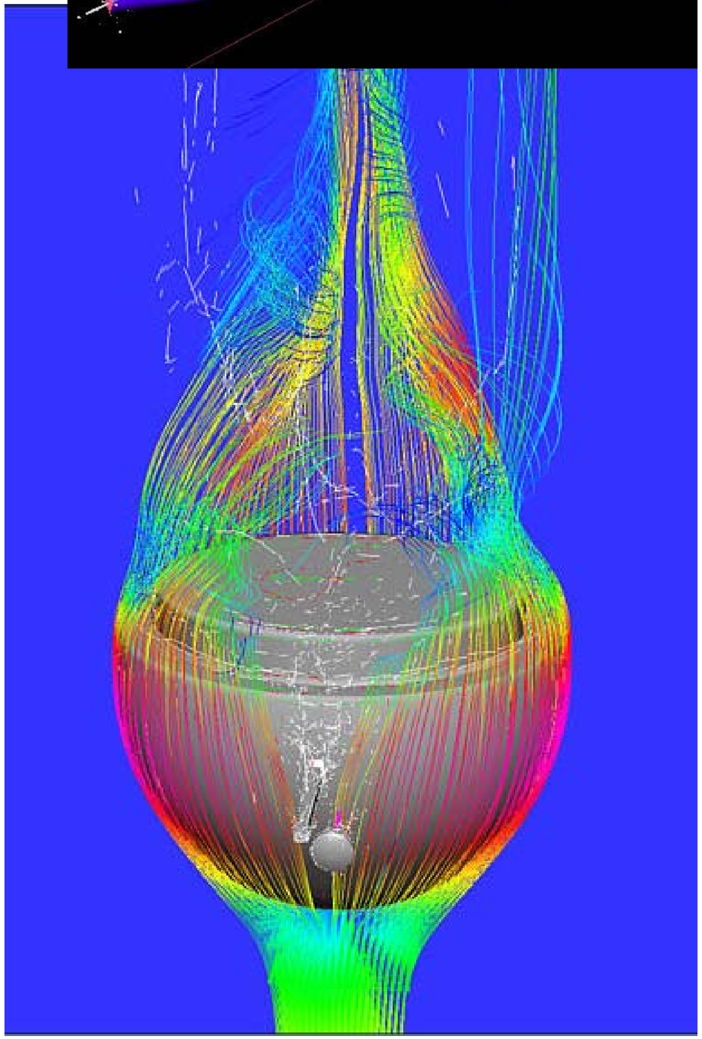
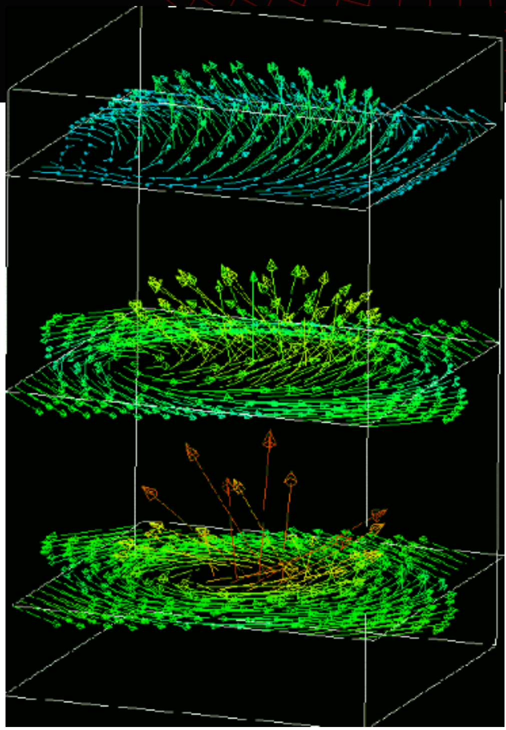
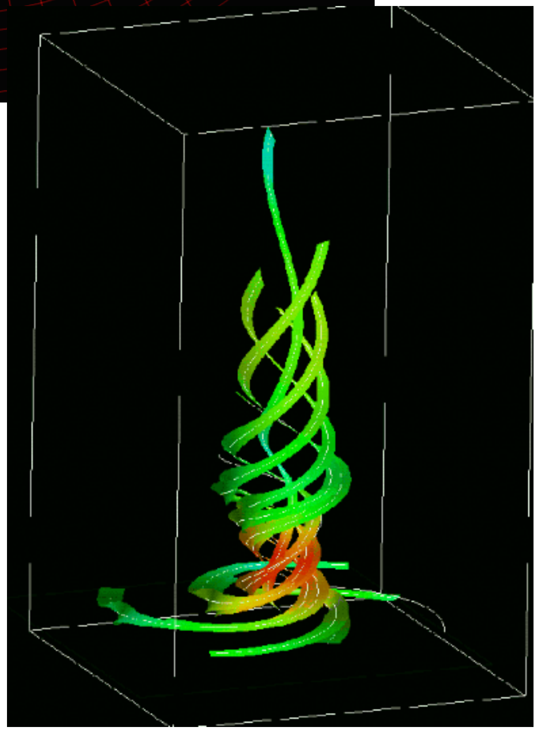
# Important Questions

- Dimensionality? 2D, Surface, 3D?
- User-Goal? overview, details?
- Examples:
  - 2D/surfaces+overview ⇒ LIC (or…), evenly-placed streamlines, hedgehog plots
  - 3D+exemplary ⇒ selected streamlines, streamsurfaces, etc., 3D arrows on slices
  - unsteady/2D+overview ⇒ animated texture advection, etc.
  - unsteady/3D+idea ⇒ animated particles

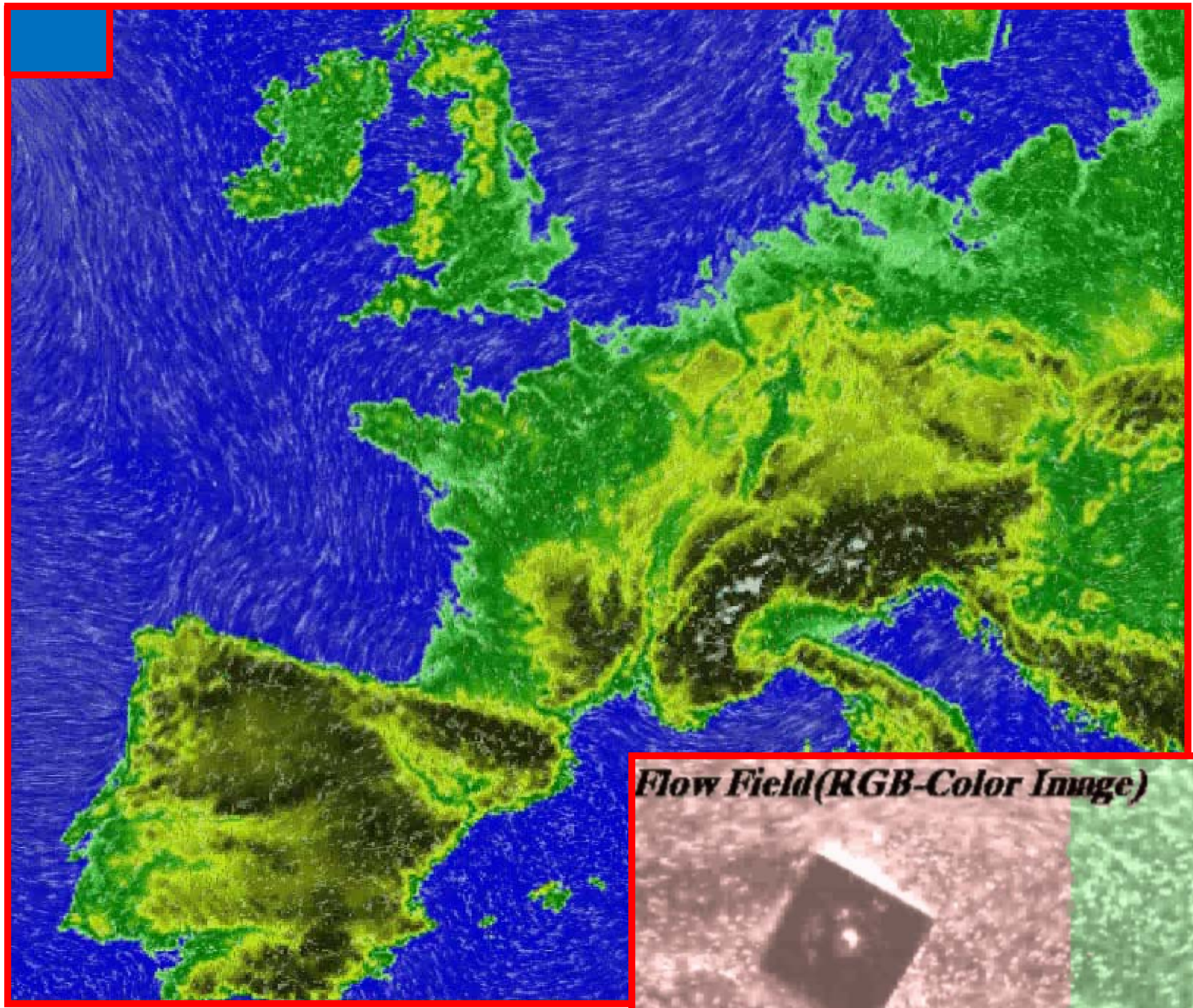
# 2D+Overview

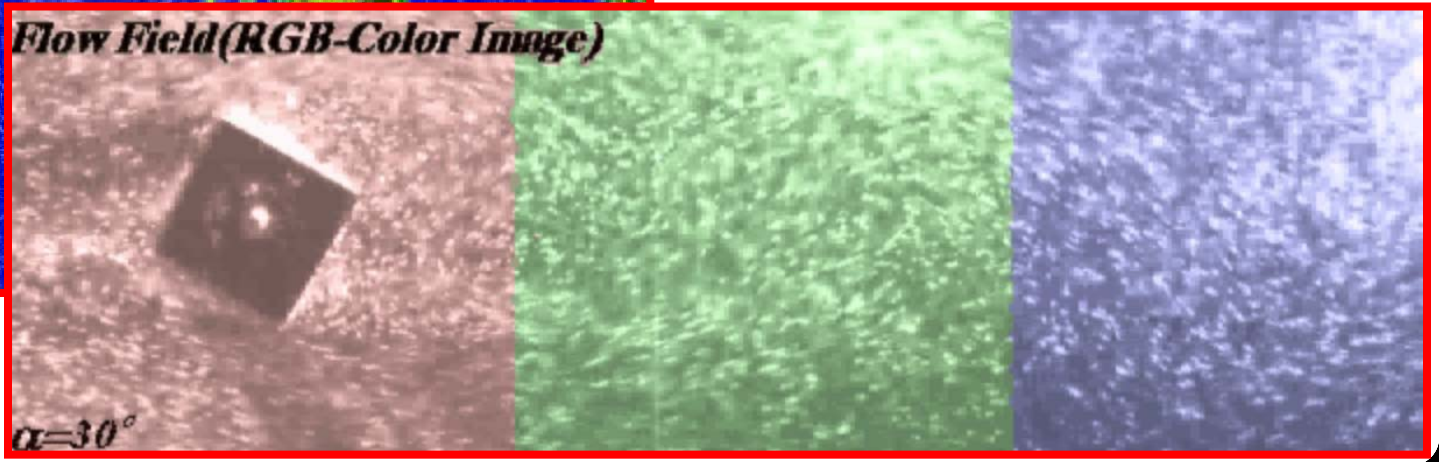


# 3D exemplary

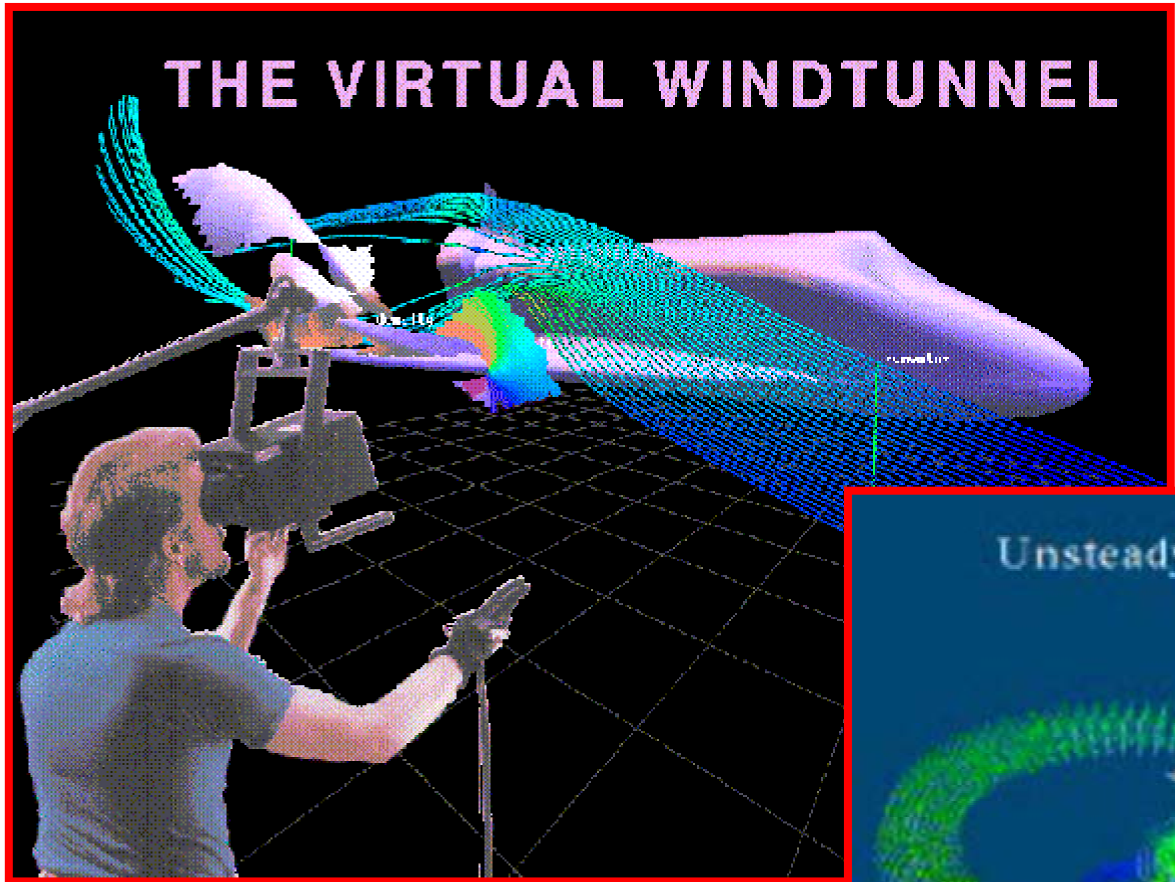






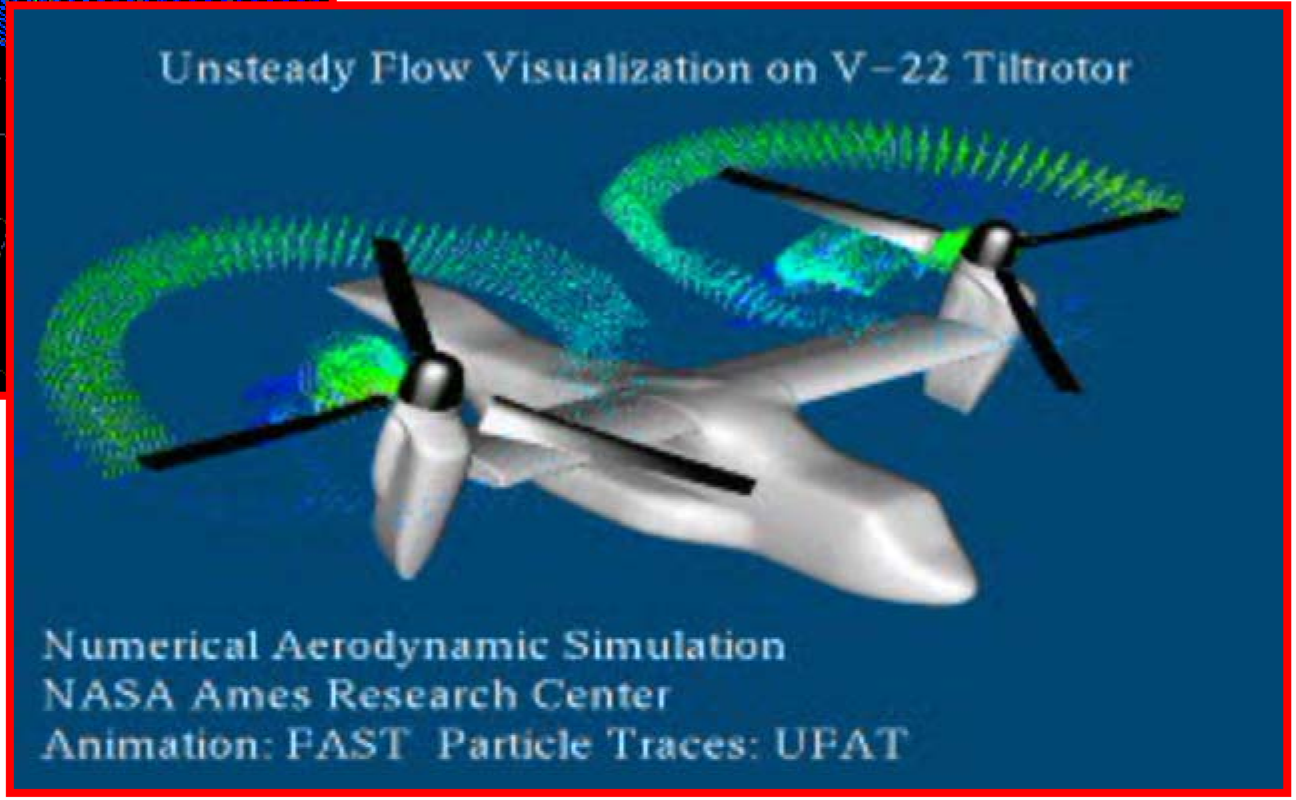
# Unsteady/2D+Overview





# Unsteady/3D+Idea



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  - Nelson Max, Will Schroeder et al.
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  - David Kenwright
  - Rüdiger Westermann
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