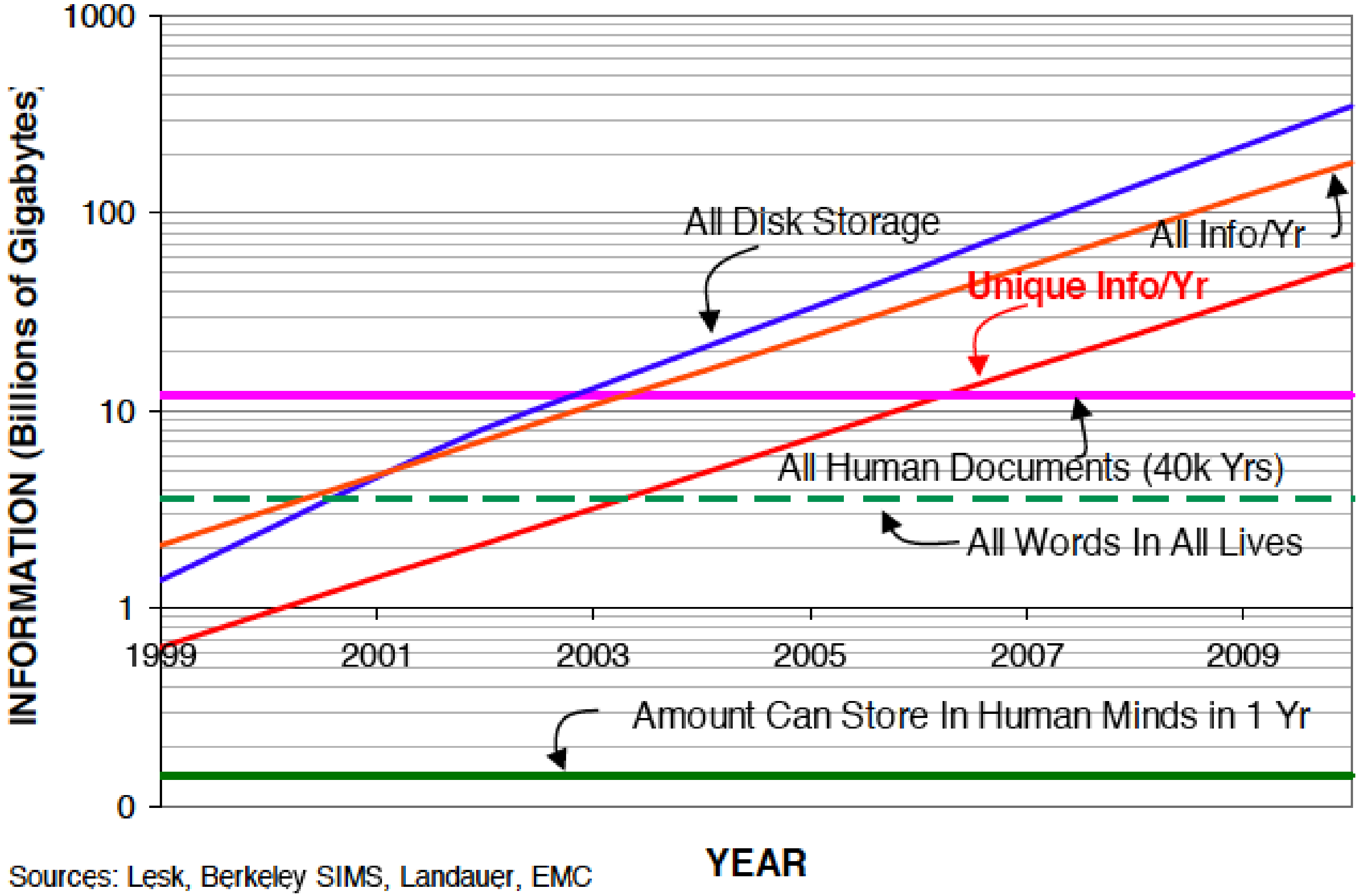
CS434

Visualizing Flows

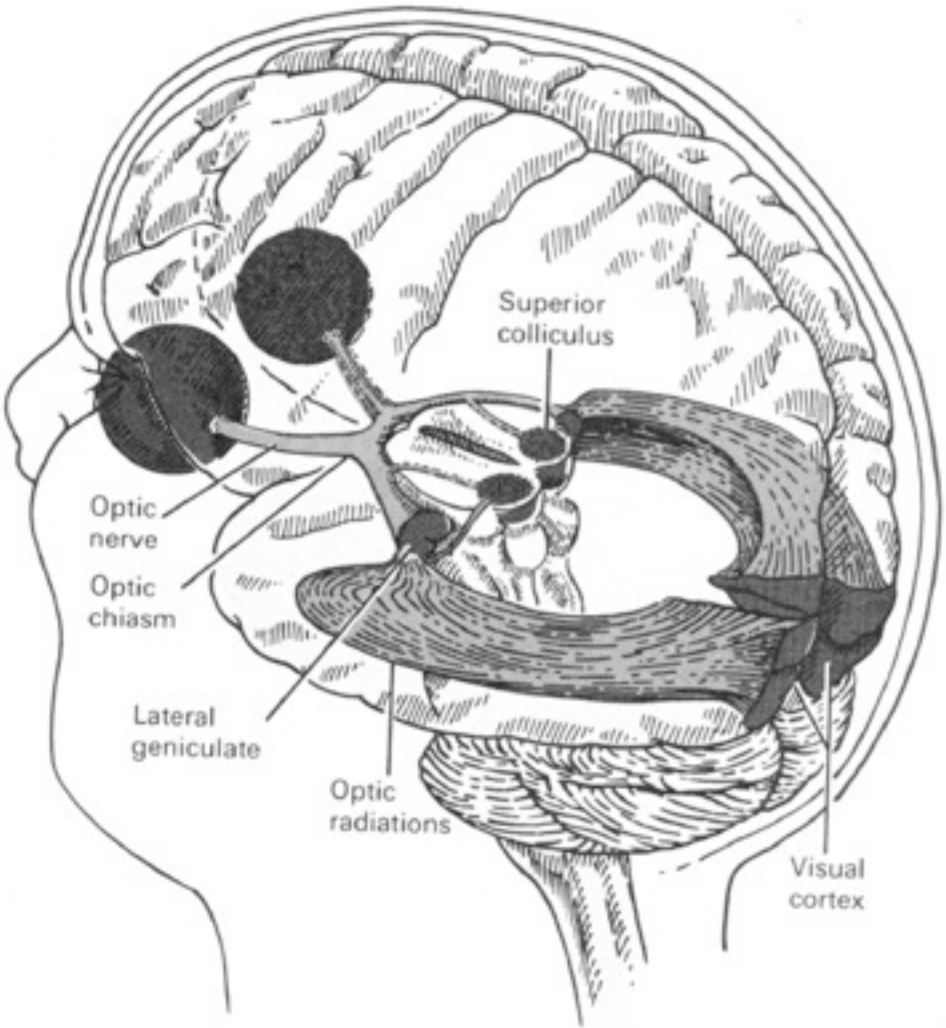
Xavier Tricoche

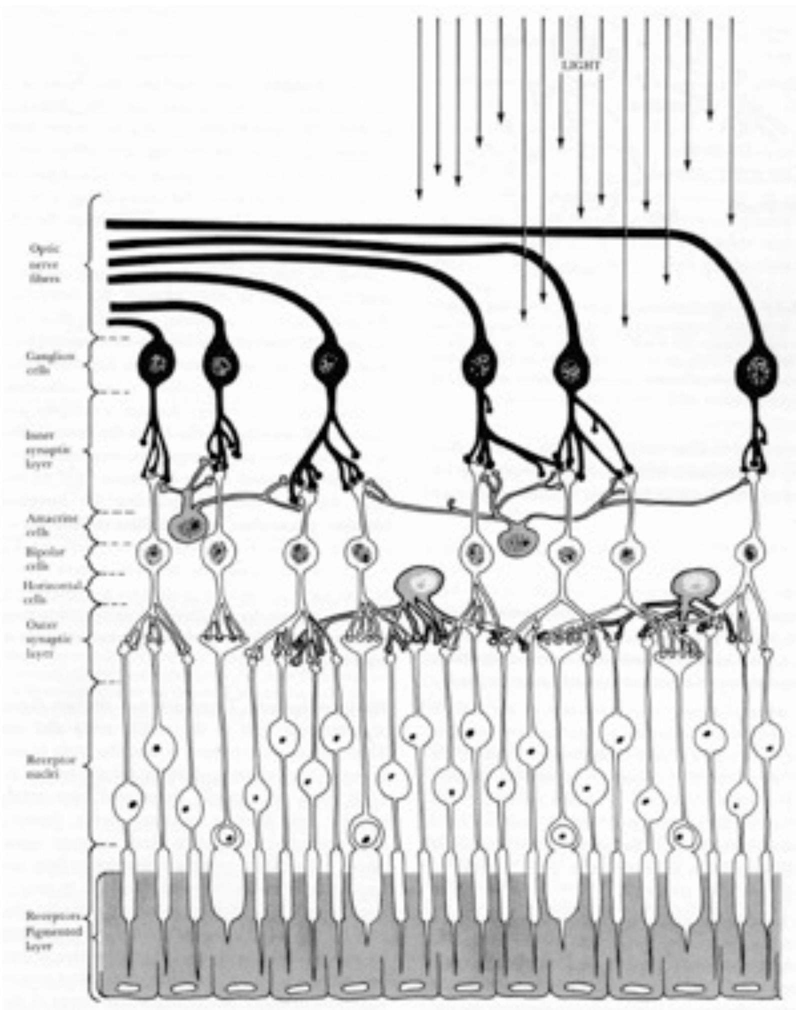
04/10/2013

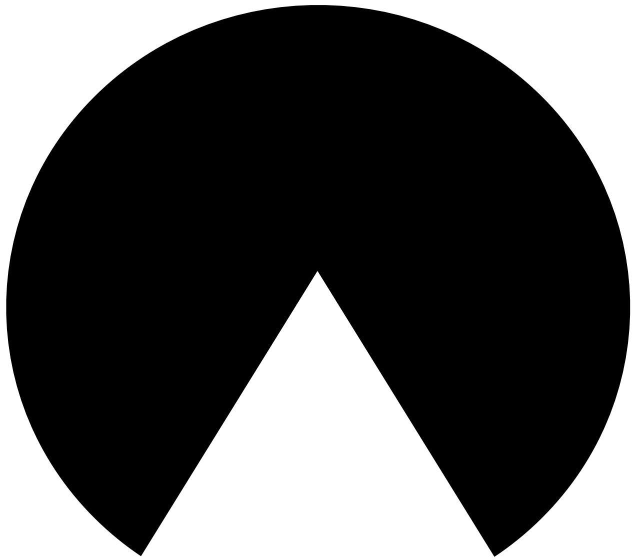


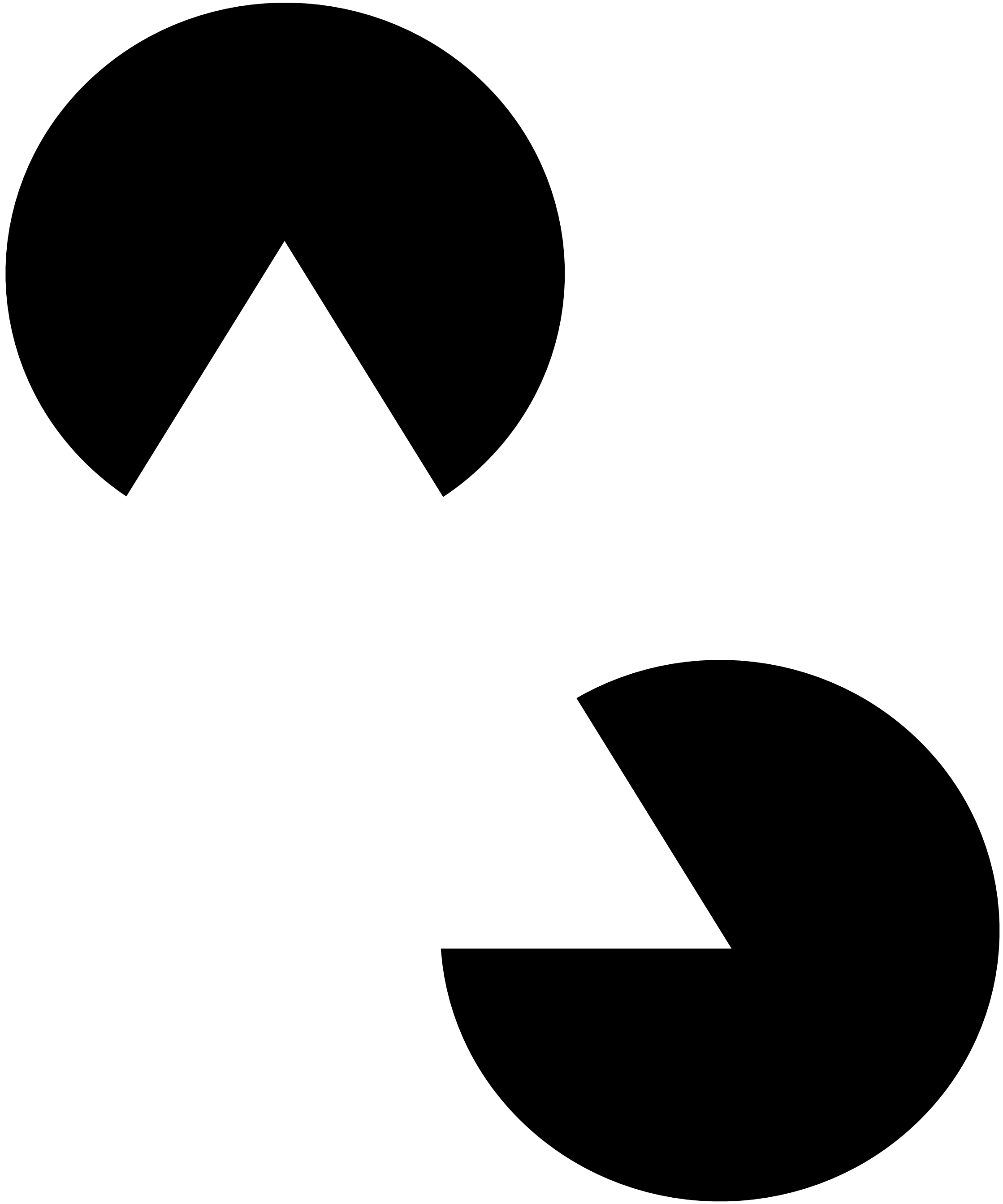
INFORMATION (Billions of Gigabytes)
1000
100
10
1
0
1999
2001
2003
2005
2007
2009
All Disk Storage
All Info/Yr
Unique Info/Yr
All Human Documents (40k Yrs)
All Words In All Lives
Amount Can Store In Human Minds in 1 Yr
YEAR
Sources: Lesk, Berkeley SIMS, Landauer, EMC

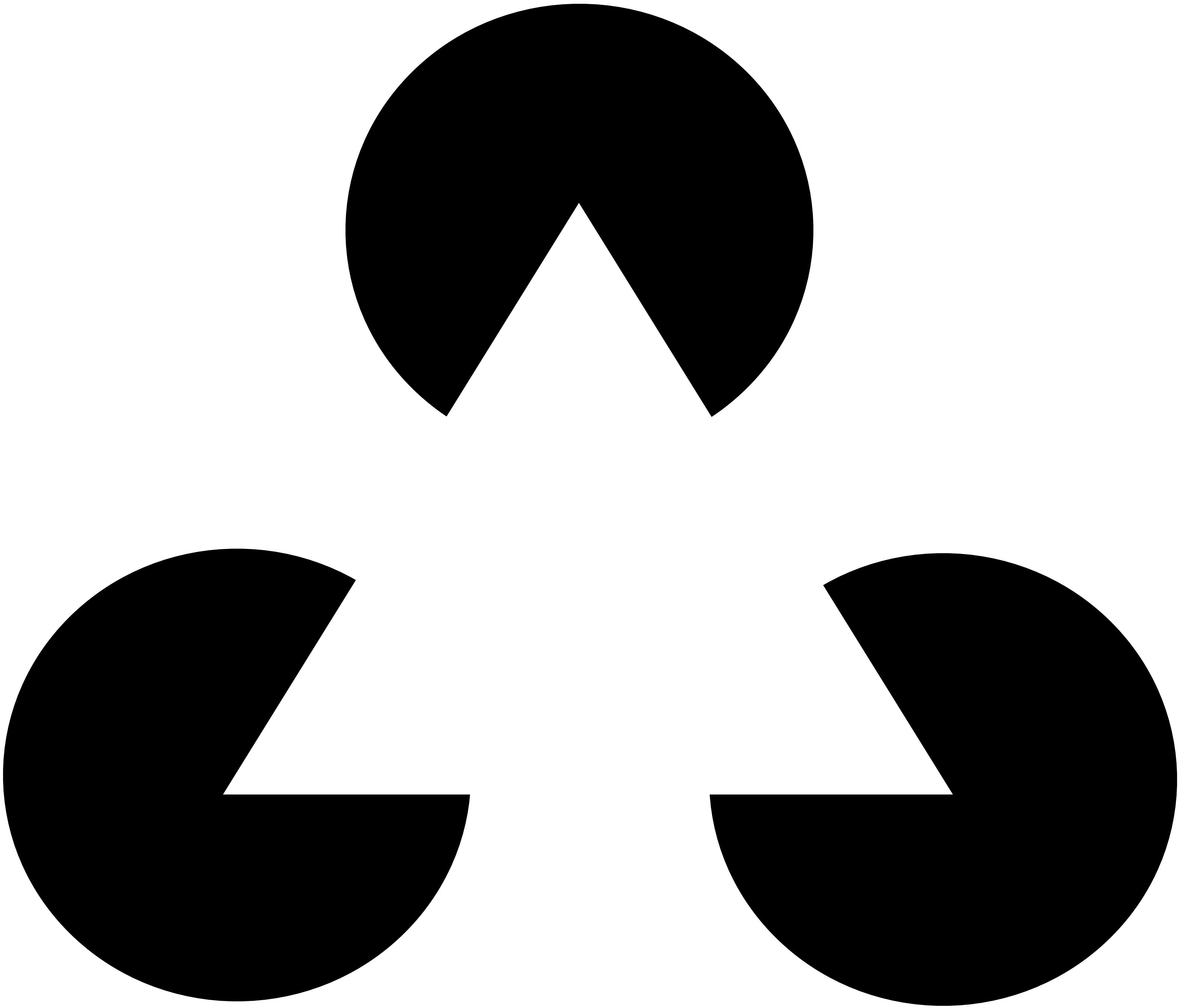
Visual System

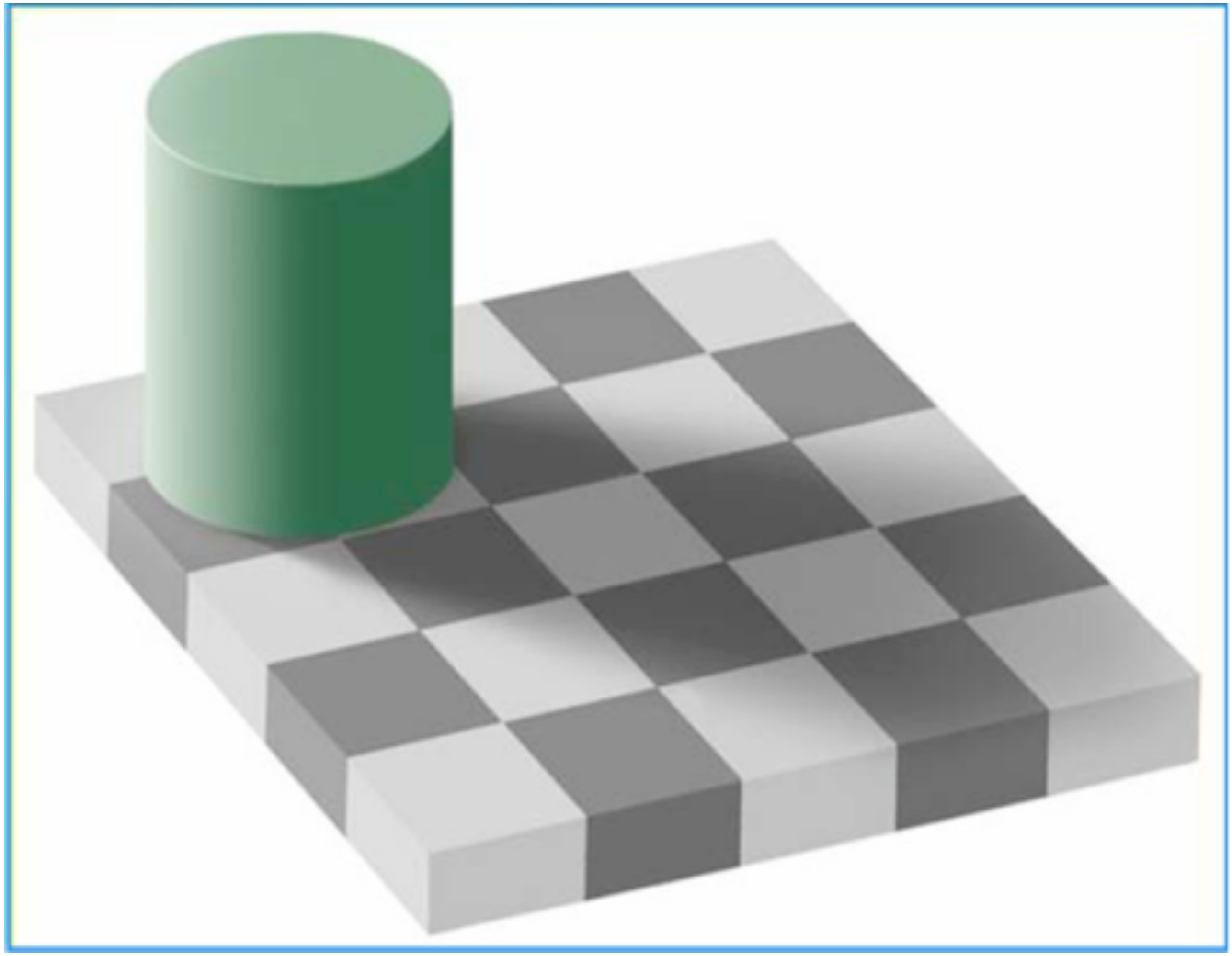


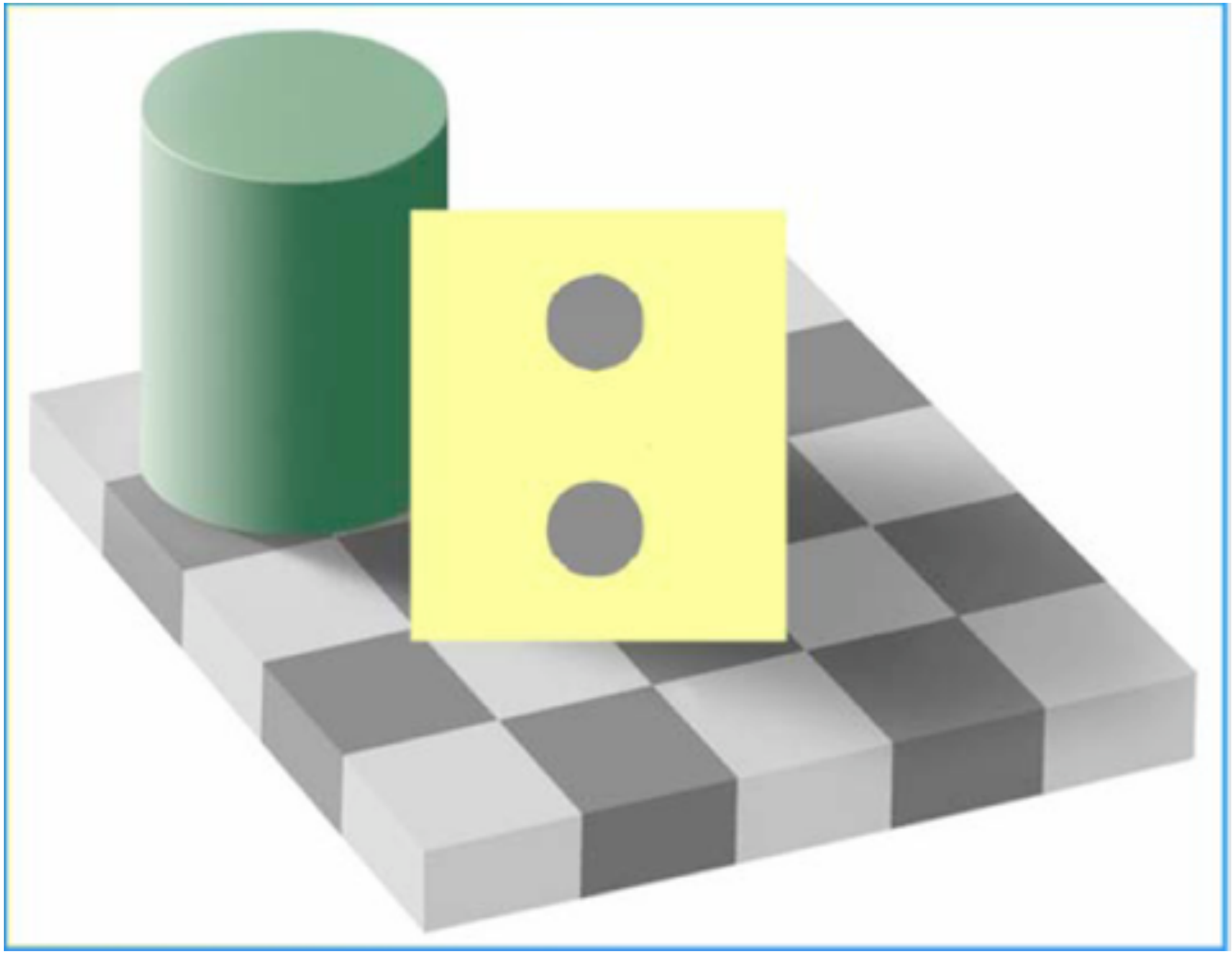


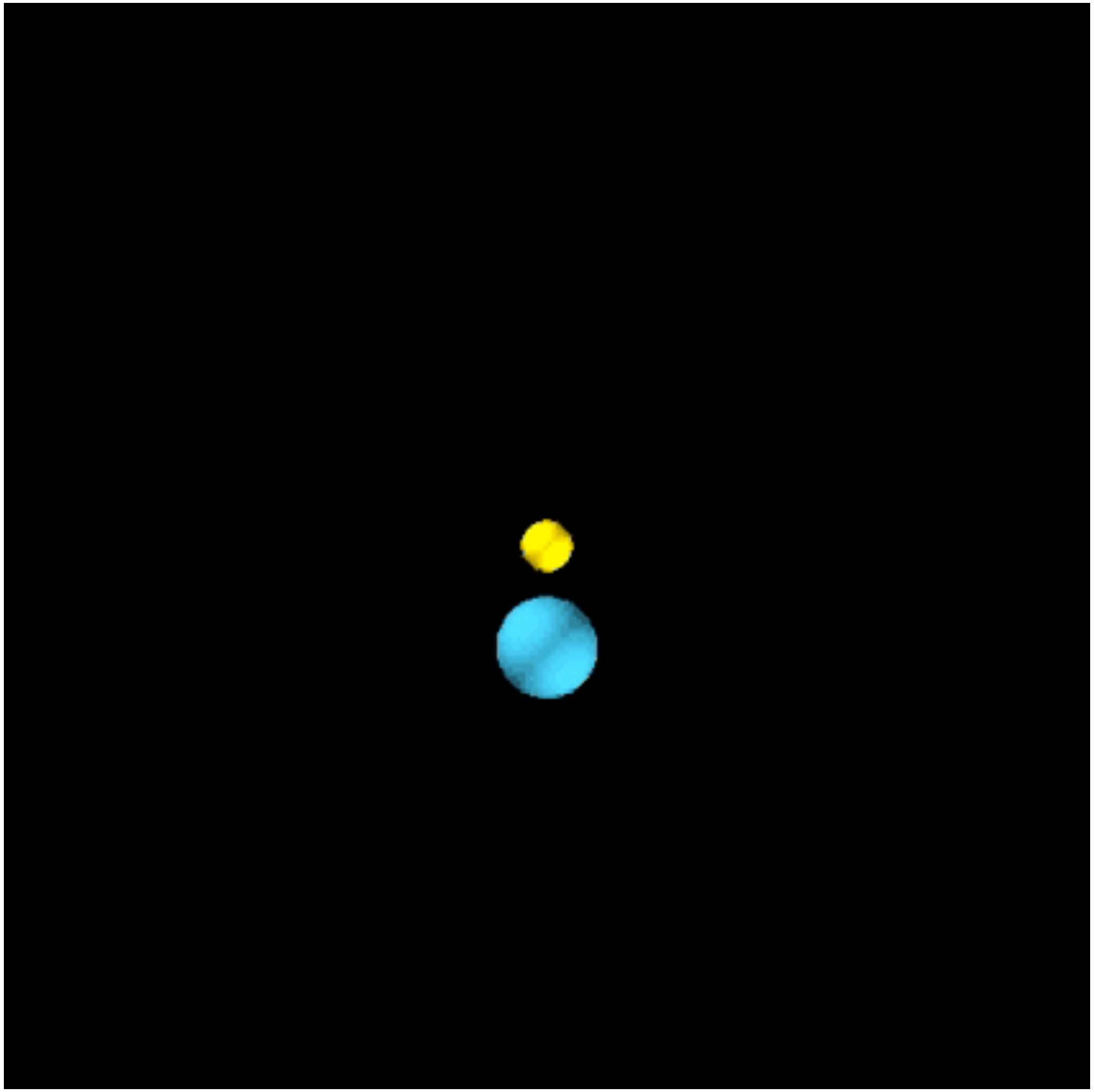


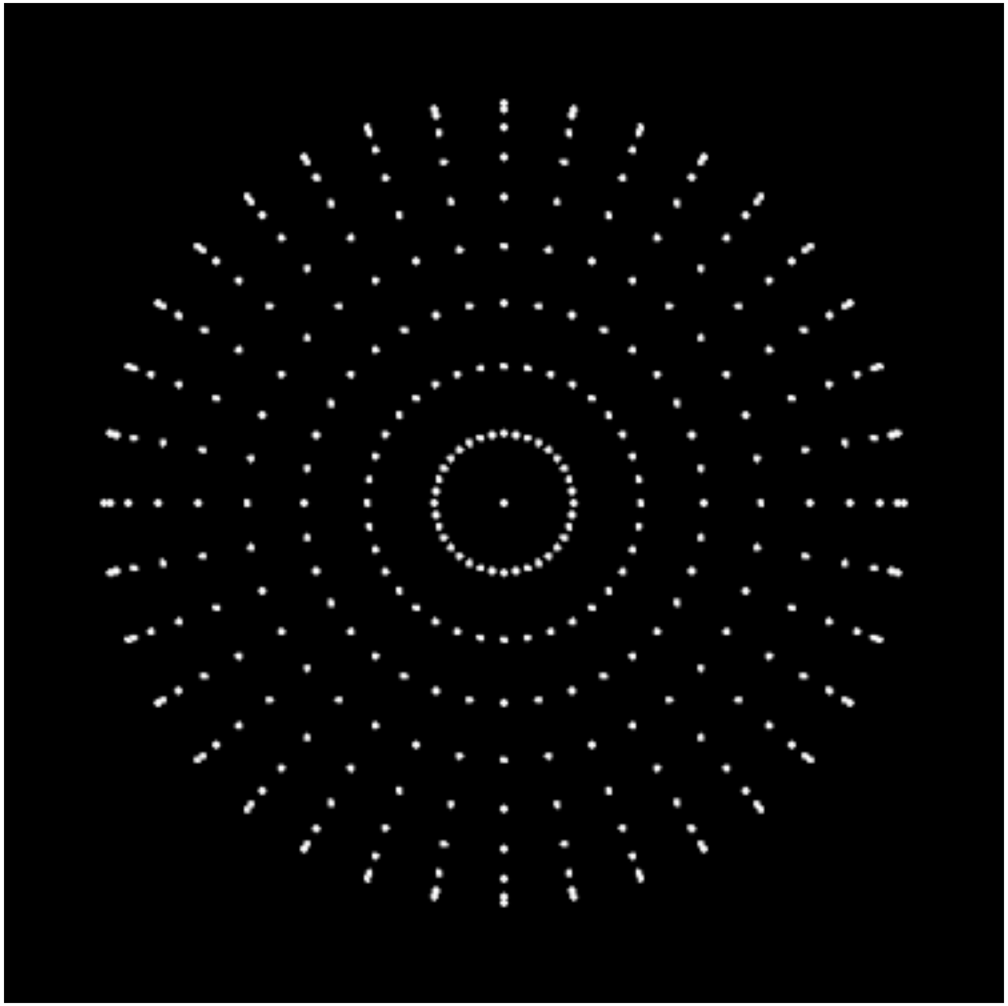


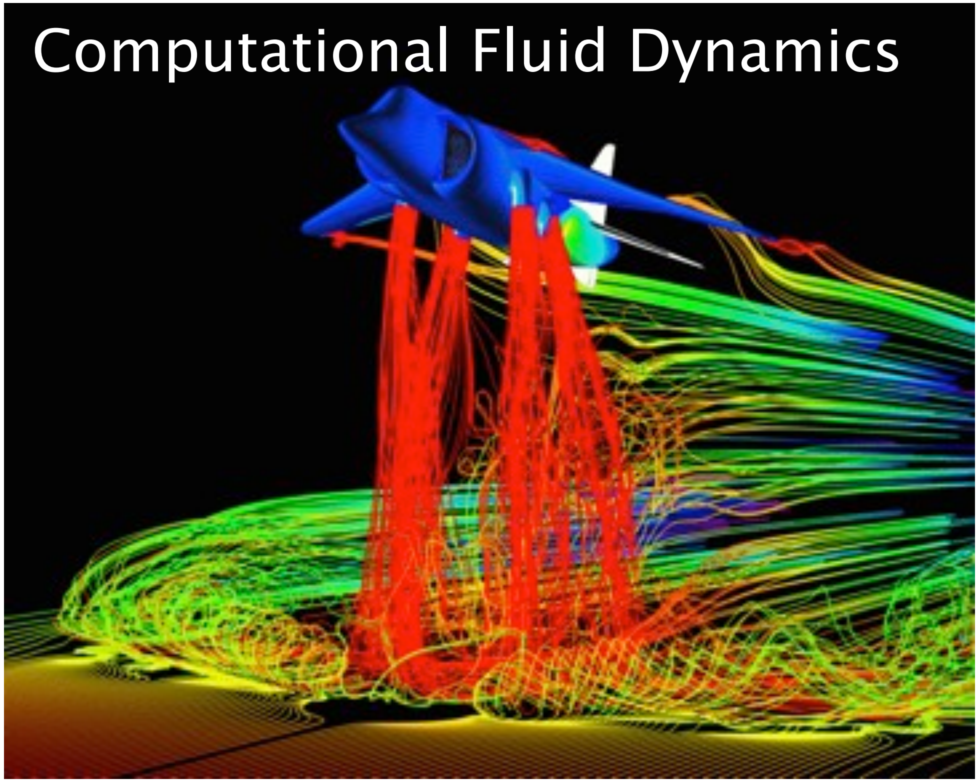


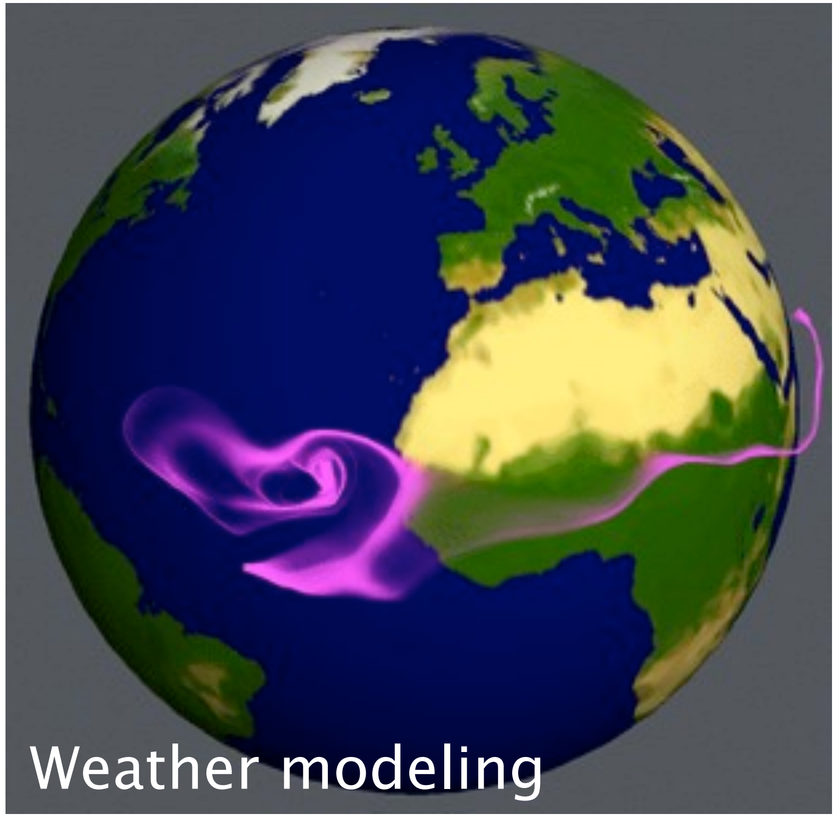






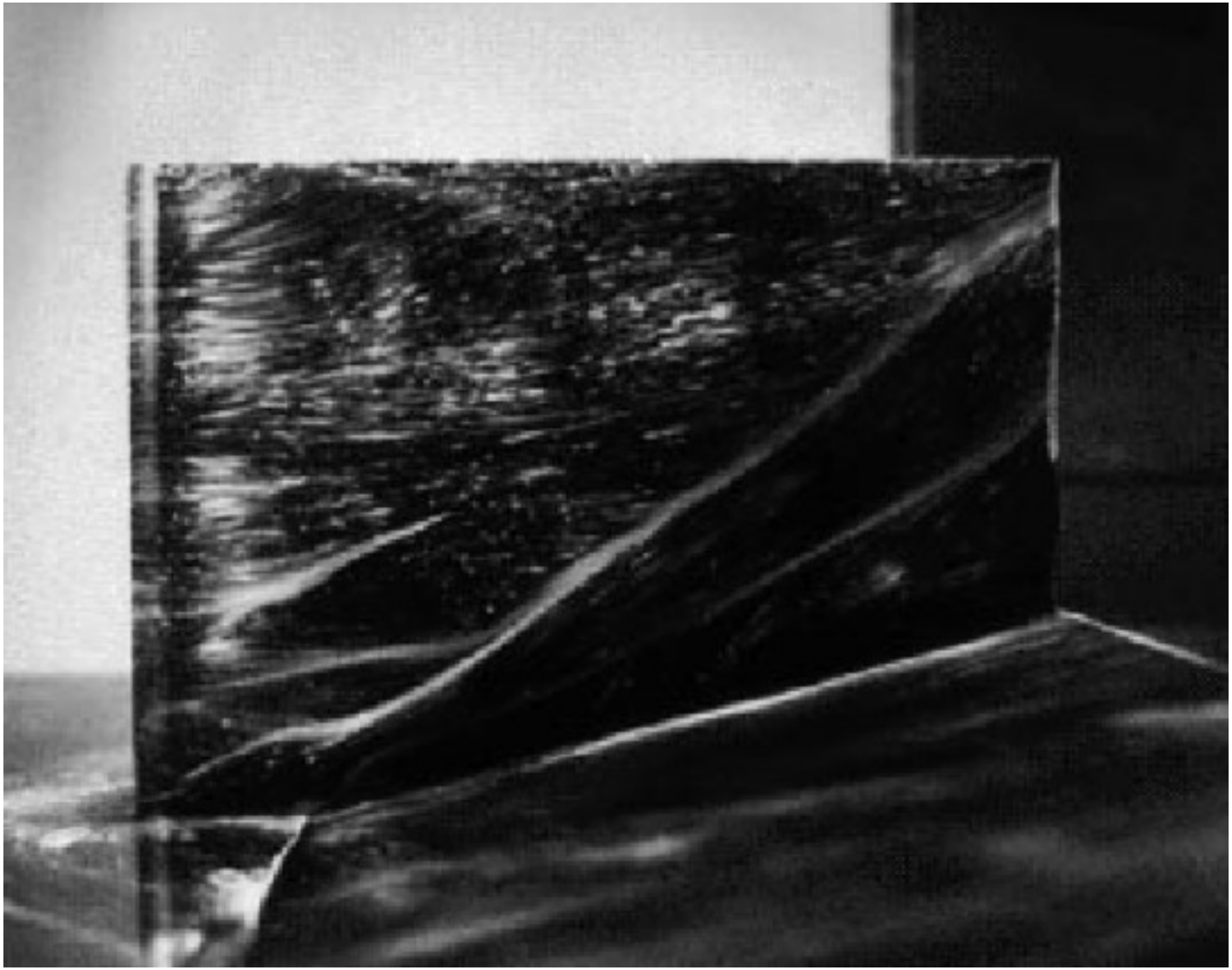



Computational Fluid Dynamics

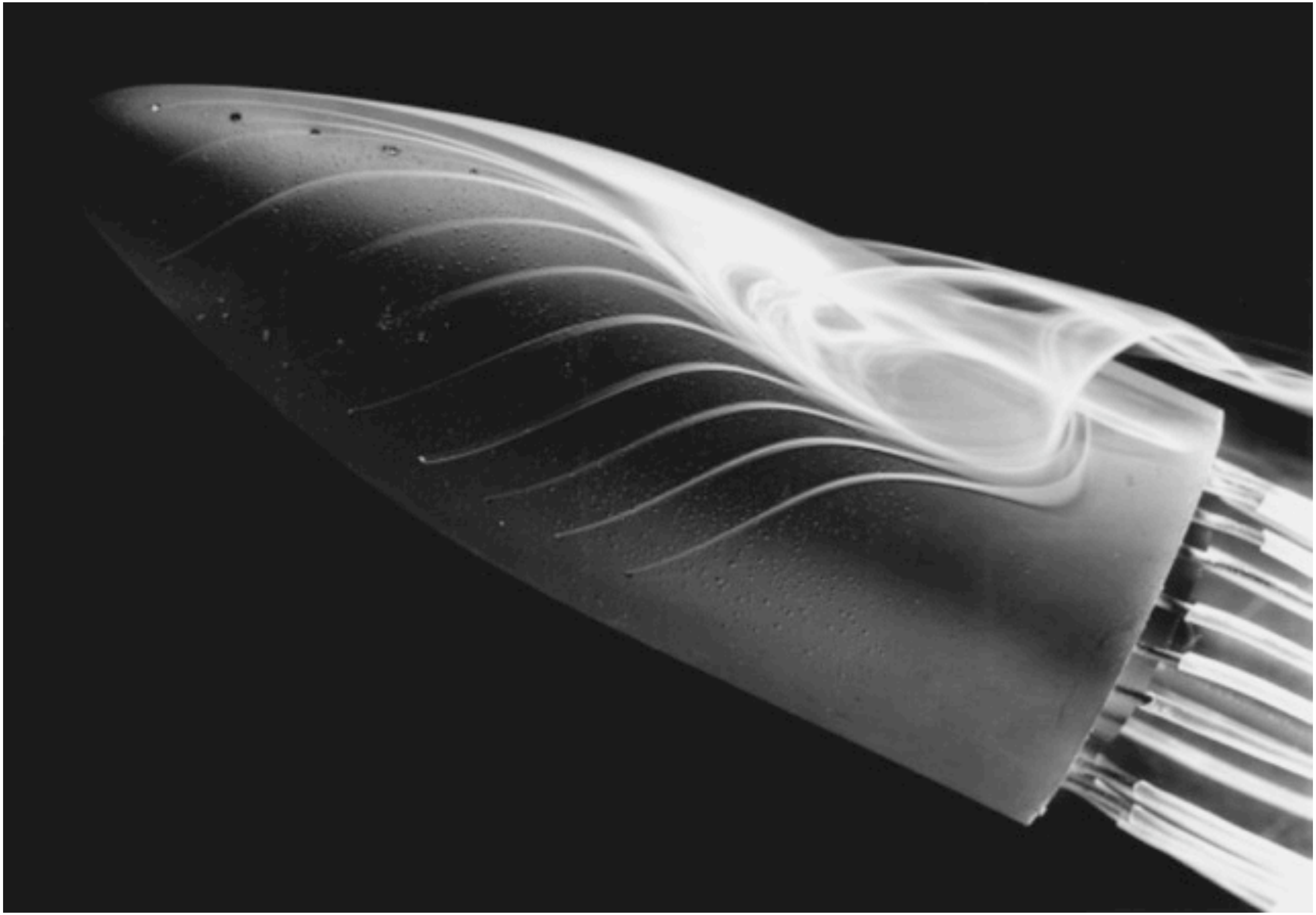

Weather modeling

Flow Visualization - Origins

Experimental Flow Visualization

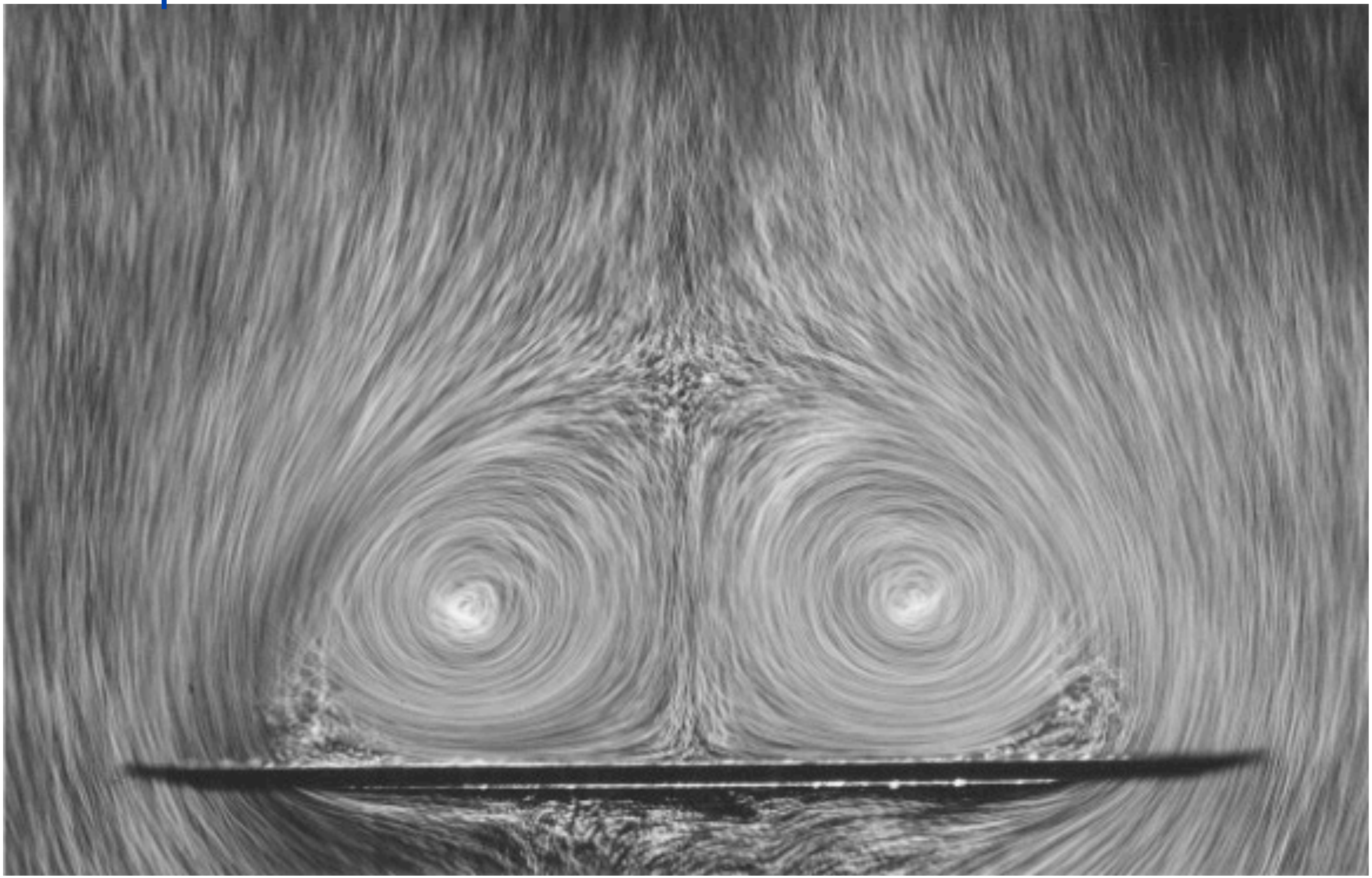


Experimental Flow Visualization

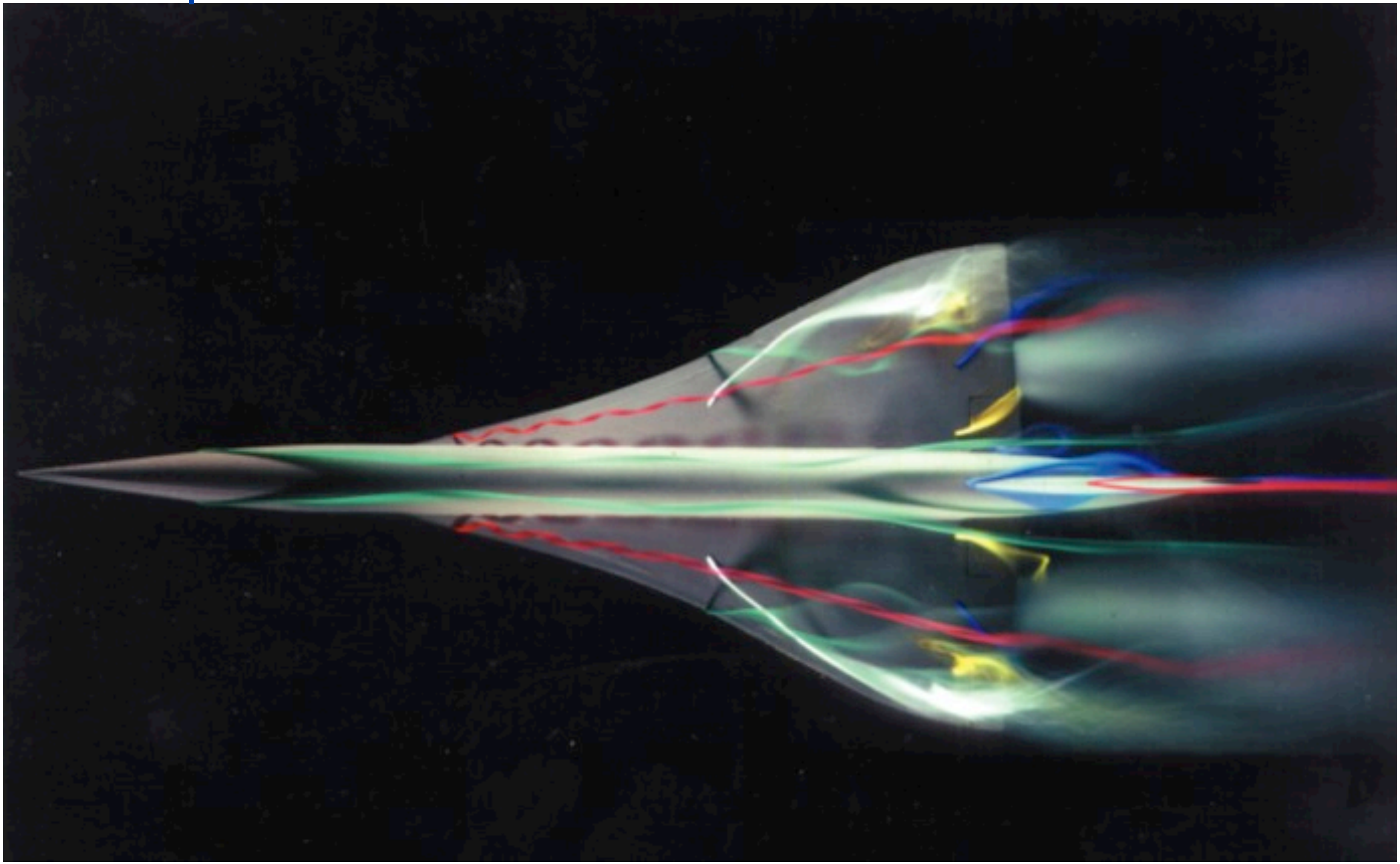


Experimental Flow Visualization

Experimental Flow Visualization



Experimental Flow Visualization



Experimental Flow Visualization

A Little Bit of Math

flow velocity at x at time t

- Differential equation associated with smooth vector field

$$\boxed{\frac{d\mathbf{x}}{dt} = \vec{v}(t, \mathbf{x})}$$

position of particle at time t

- with $\mathbf{x} : I\!R \rightarrow I\!R^n$: trajectory (or streamline)
- Steady: $\vec{v}$ does not depend on time vs. unsteady ("time-dependent", "transient")
- Initial conditions: $\mathbf{x}(0) = \mathbf{x_0}$

Streamline Computation

- Previous equation is an ordinary differential equation (ODE)
- Closed form solutions (analytic) are not available in general
- Numerical ODE solvers are needed

Runge Kutta 4 (RK4)

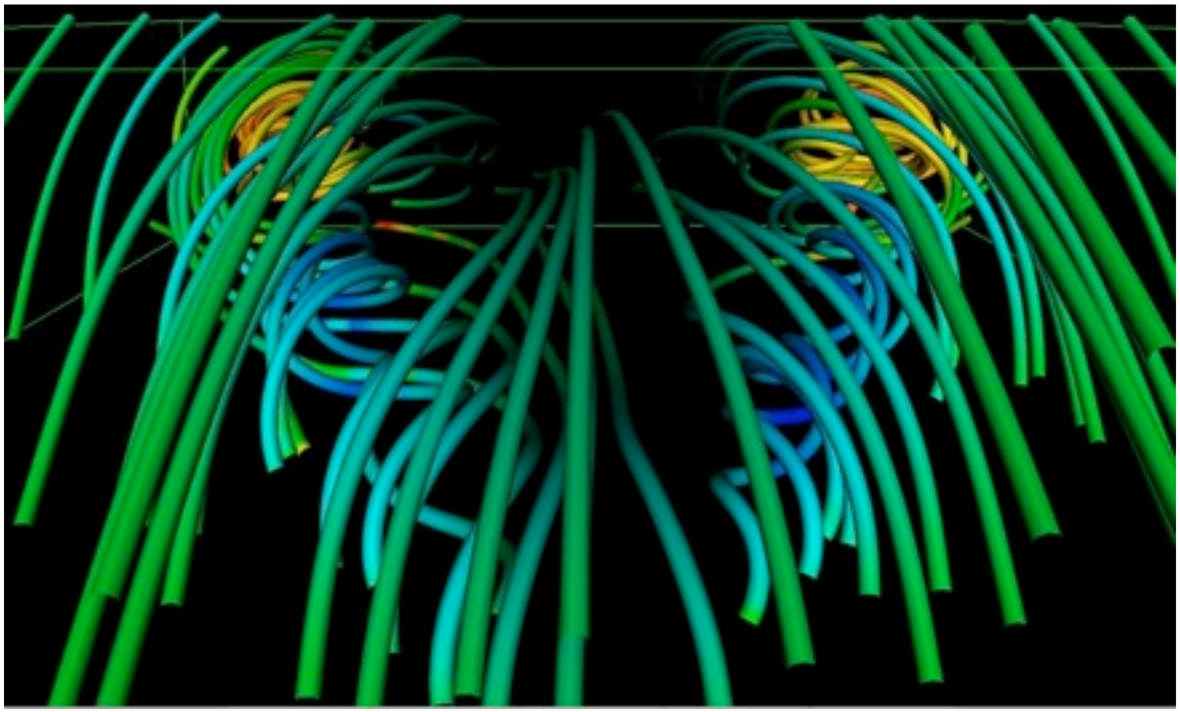
- Multiple intermediate steps to achieve higher accuracy

$$\vec{k}_1 = h\vec{v}(\mathbf{x}_n, t_n)$$
$$\vec{k}_2 = h\vec{v}(\frac{1}{2}\vec{k}_1, t_n + \frac{1}{2}h)$$
$$\vec{k}_3 = h\vec{v}(\mathbf{x}_n + \frac{1}{2}\vec{k}_2, t_n + \frac{1}{2}h)$$
$$\vec{k}_4 = h\vec{v}(t_n + h, \vec{x}_n + \vec{k}_3)$$

$$\boxed{\vec{x}_{n+1} = \vec{x}_n + \frac{1}{6}\vec{k}_1 + \frac{1}{3}\vec{k}_2 + \frac{1}{3}\vec{k}_3 + \frac{1}{6}\vec{k}_4 + O(h^5)}$$

Streamlines

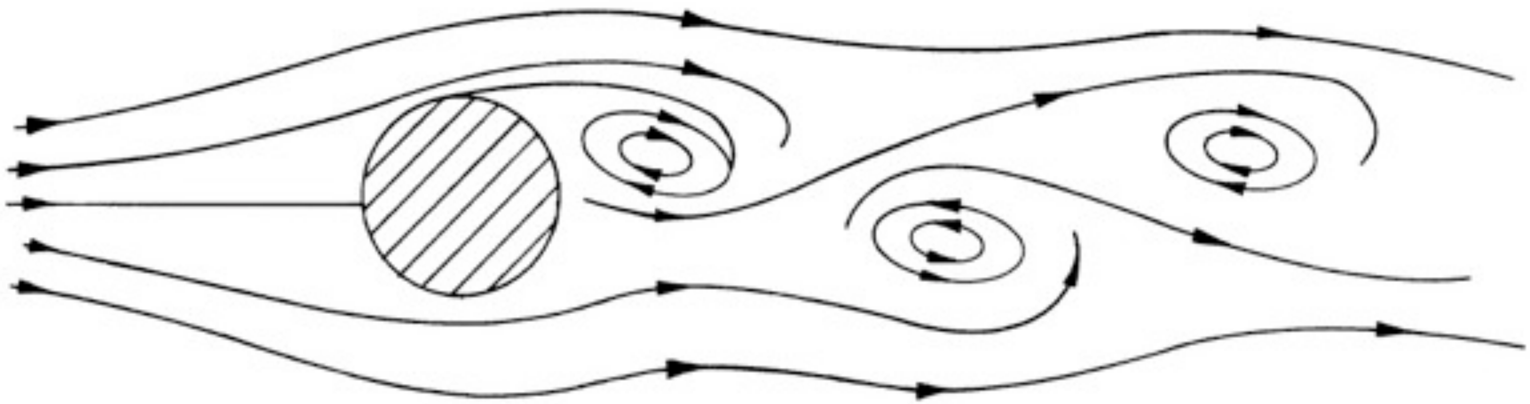
Basic idea: visualizing the flow directions by releasing particles and calculating a series of particle positions based on the vector field



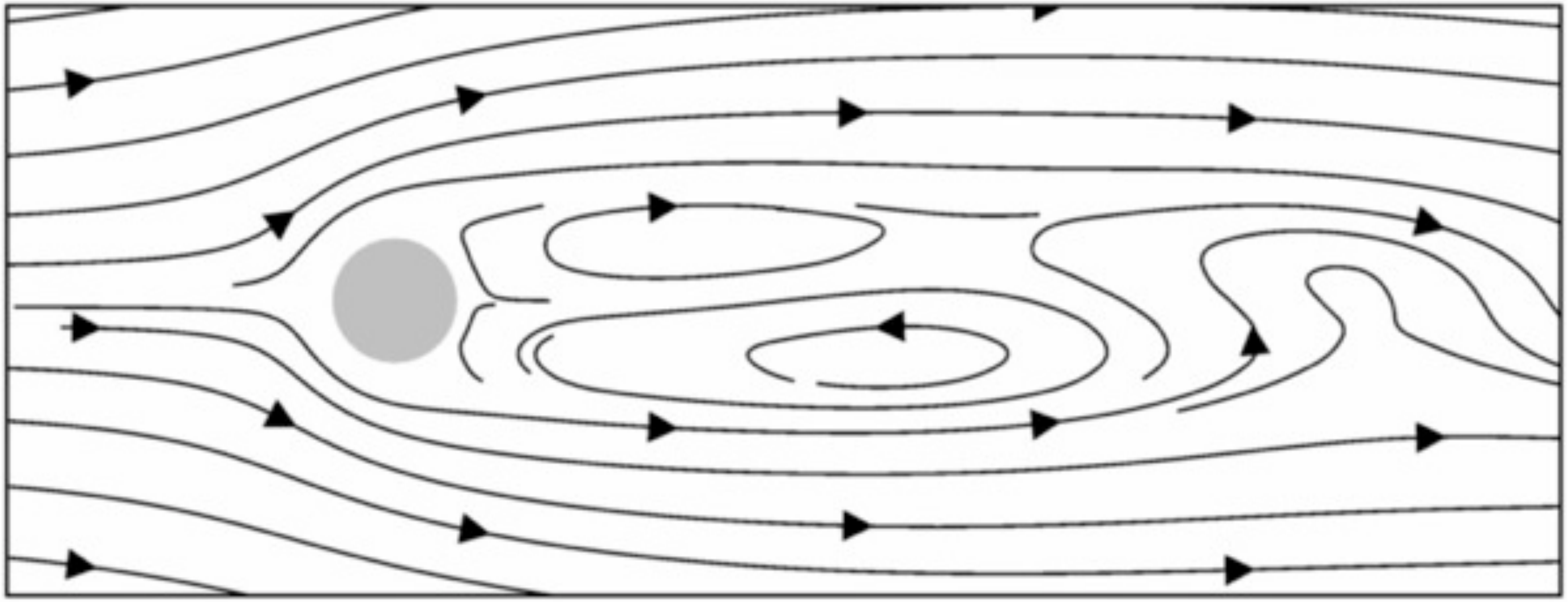
Streamline Seeding

- Isolated streamlines provide poor picture of the flow continuum
- Large number of streamlines create visual clutter
- Seeding strategy is important to effectively leverage streamlines in visualization

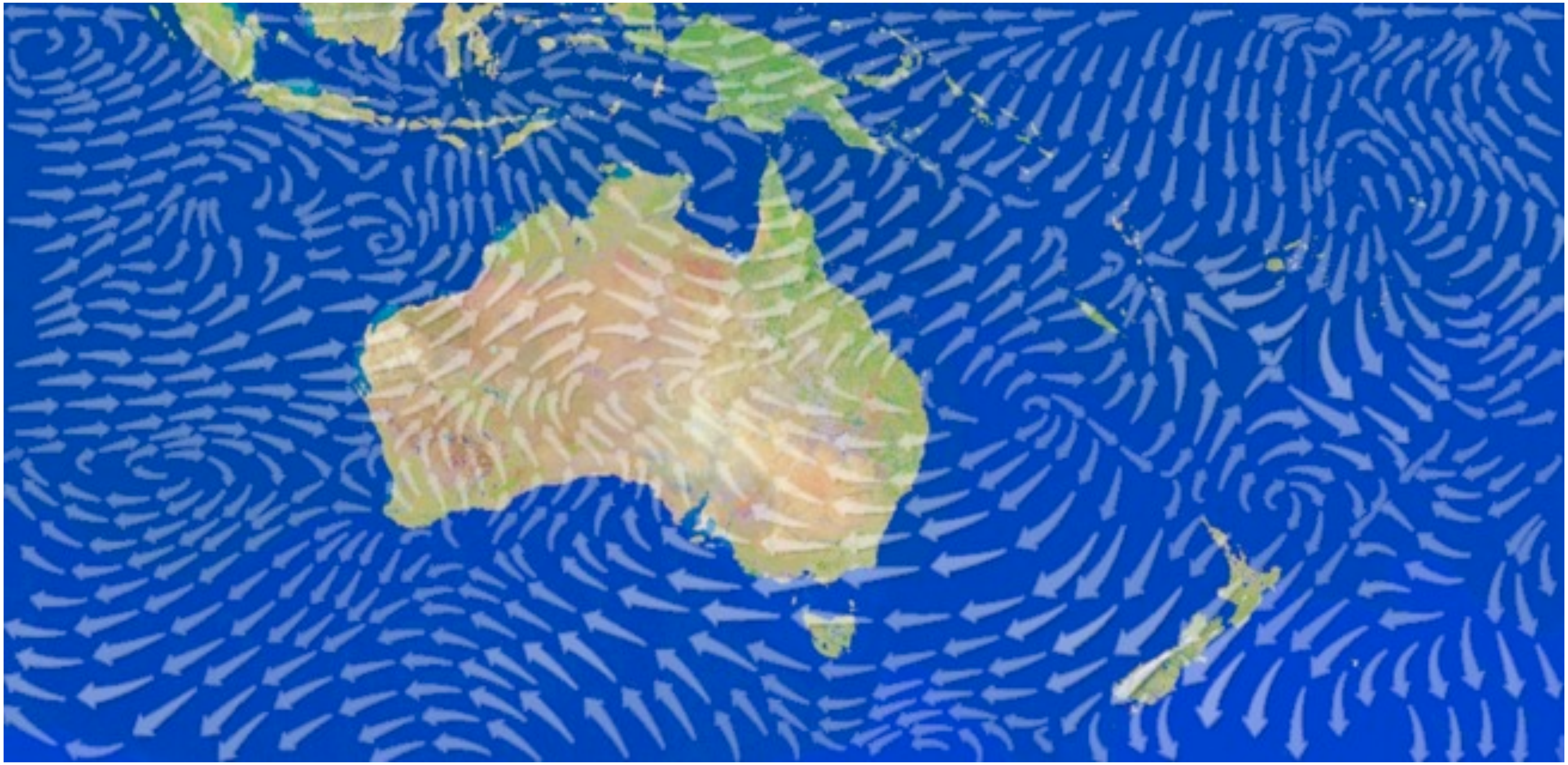
Hand Drawn Flows



Automated Results

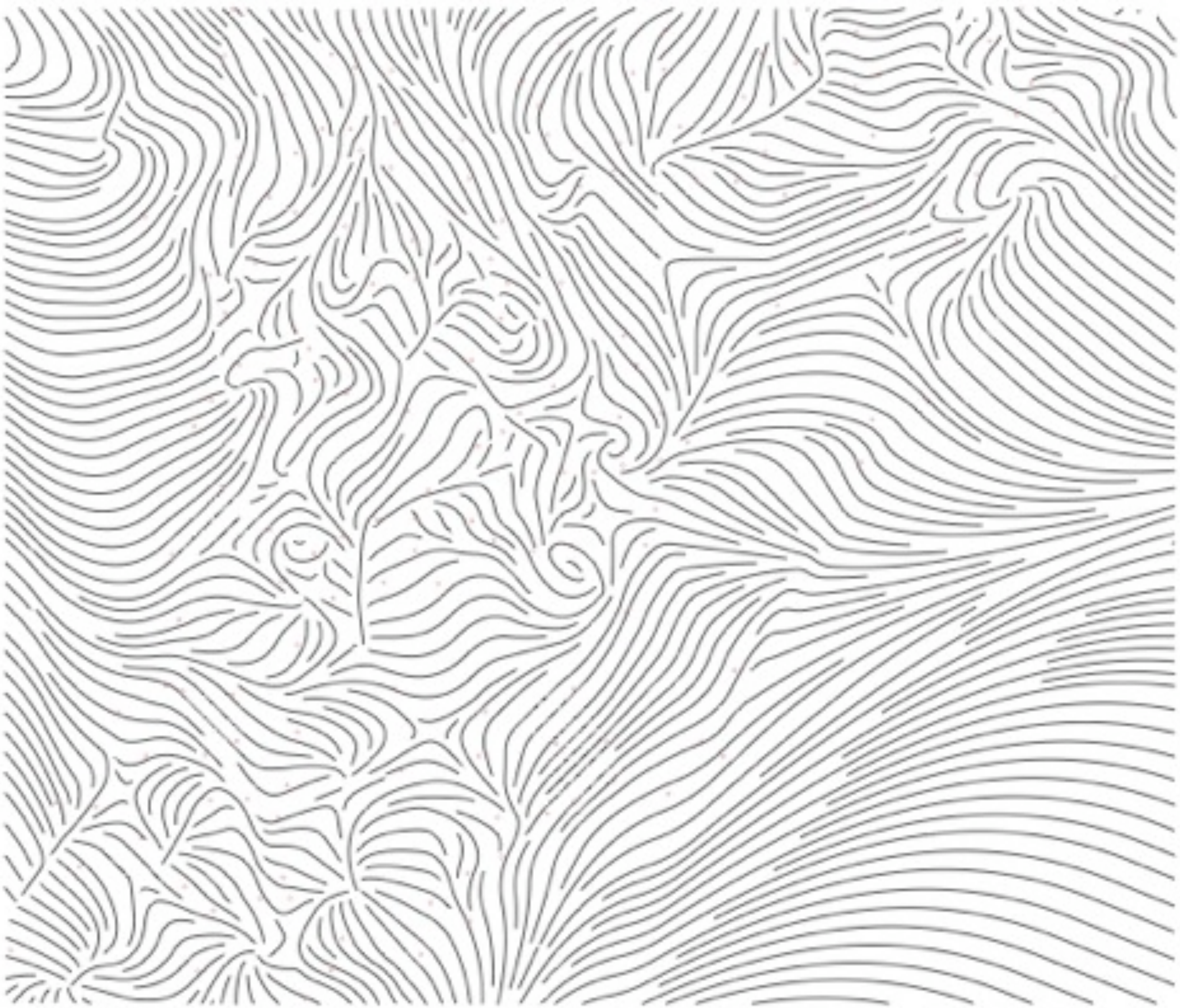


Streamline Seeding



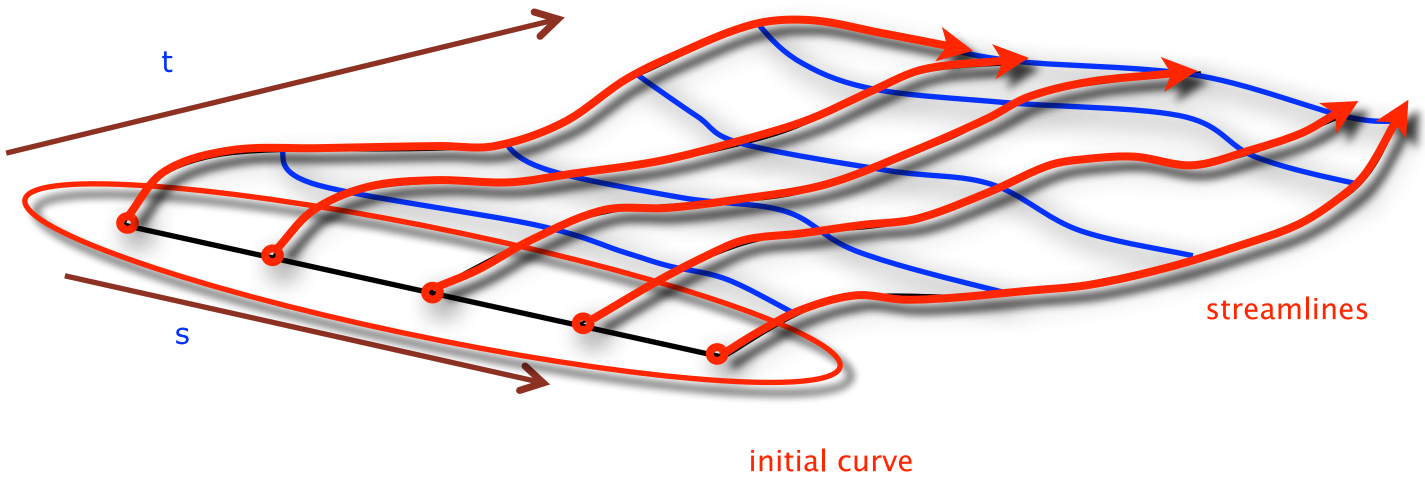
Turk and Banks, SIGGRAPH 1996

Streamline Seeding



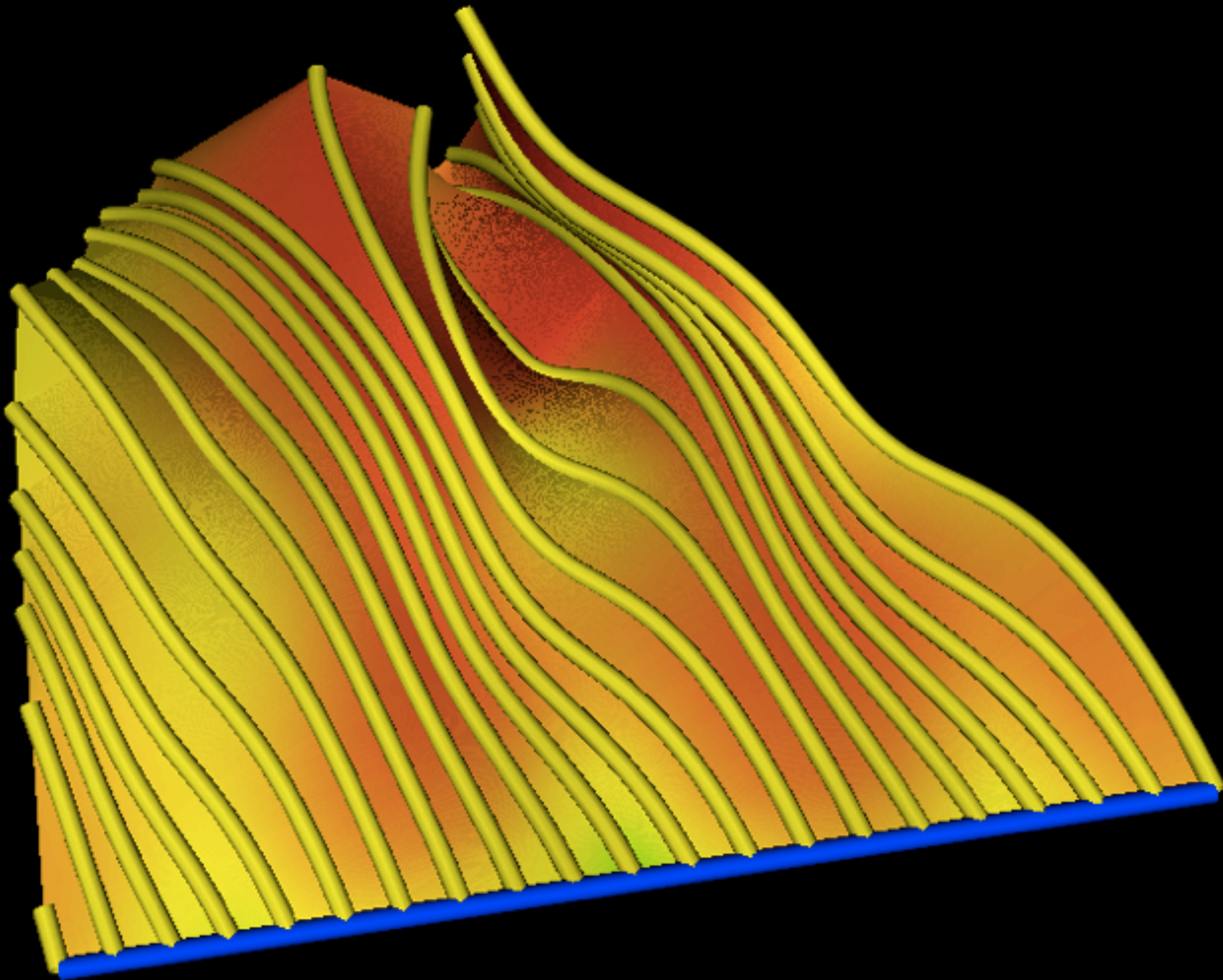
Stream Surface

- Surface spanned by union of infinite many streamlines integrated from a curve
- Everywhere tangential to the flow
- “Natural” extension of streamlines in 3D

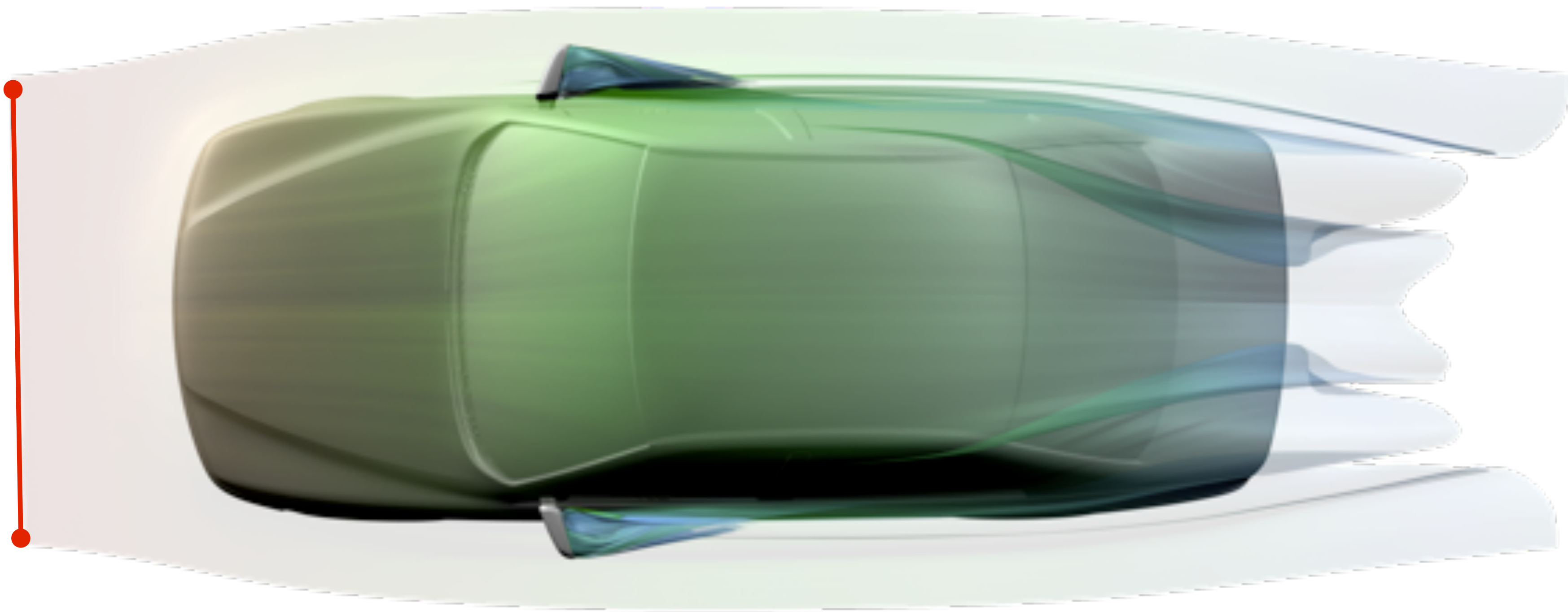


(Naïve) Implementation

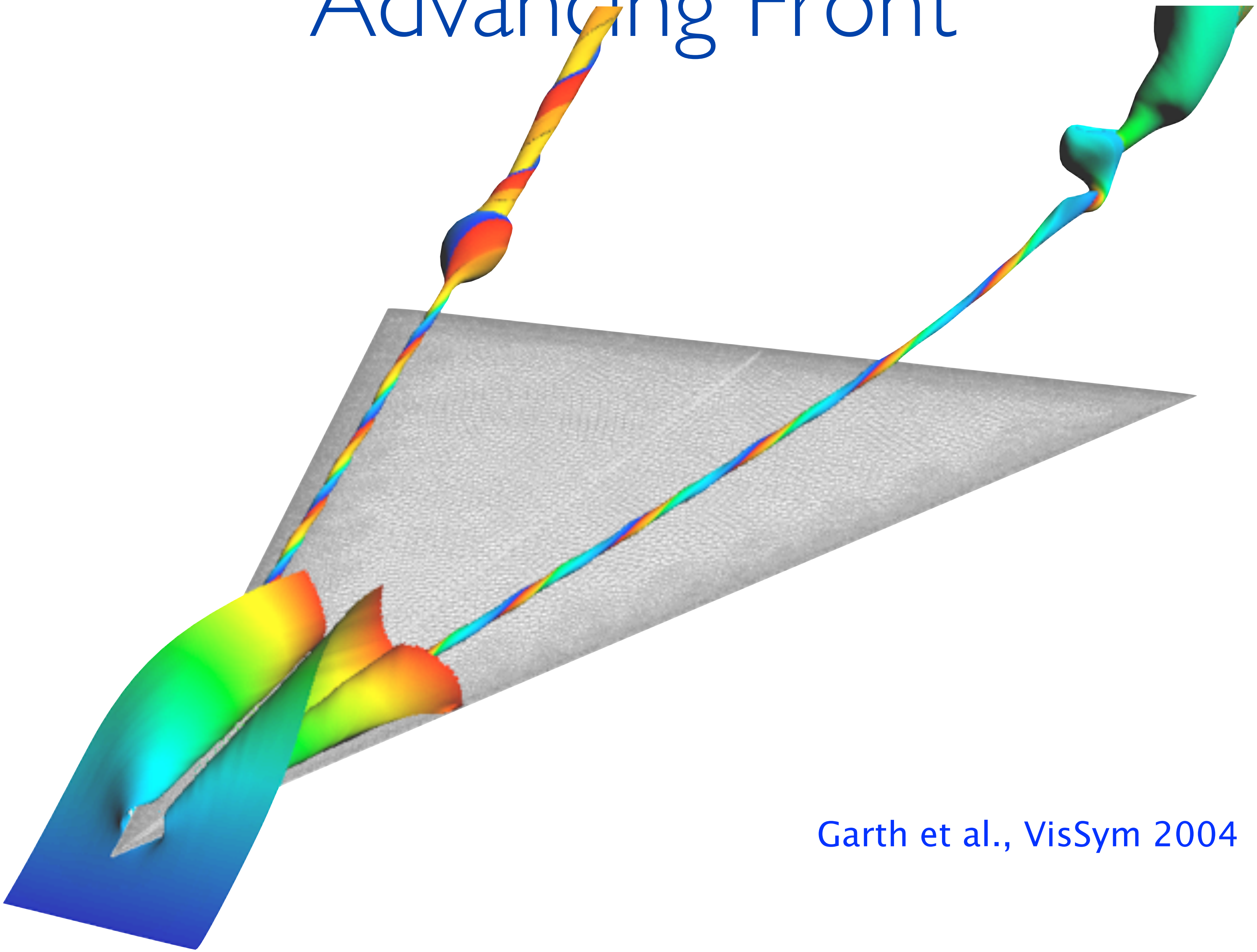
- Sparse set of streamlines integrated independently
- Ribbons connecting neighboring streamlines
- Corresponds to a triangulation in parameter space
- Extremely inaccurate and/or inefficient



Stream Surface

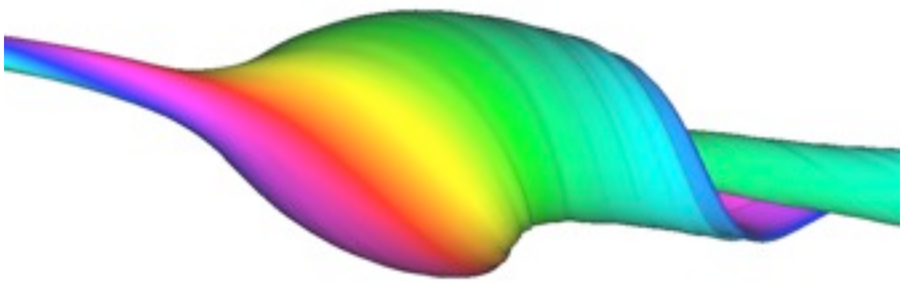


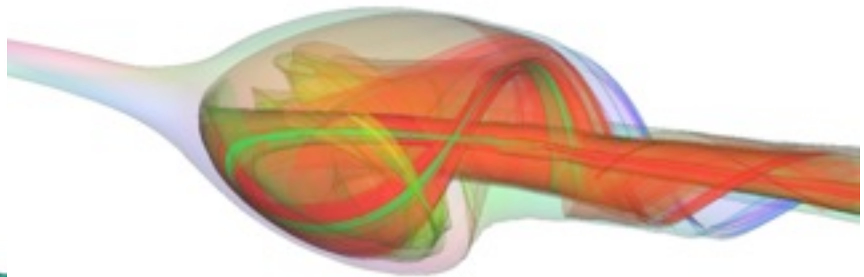
Advancing Front



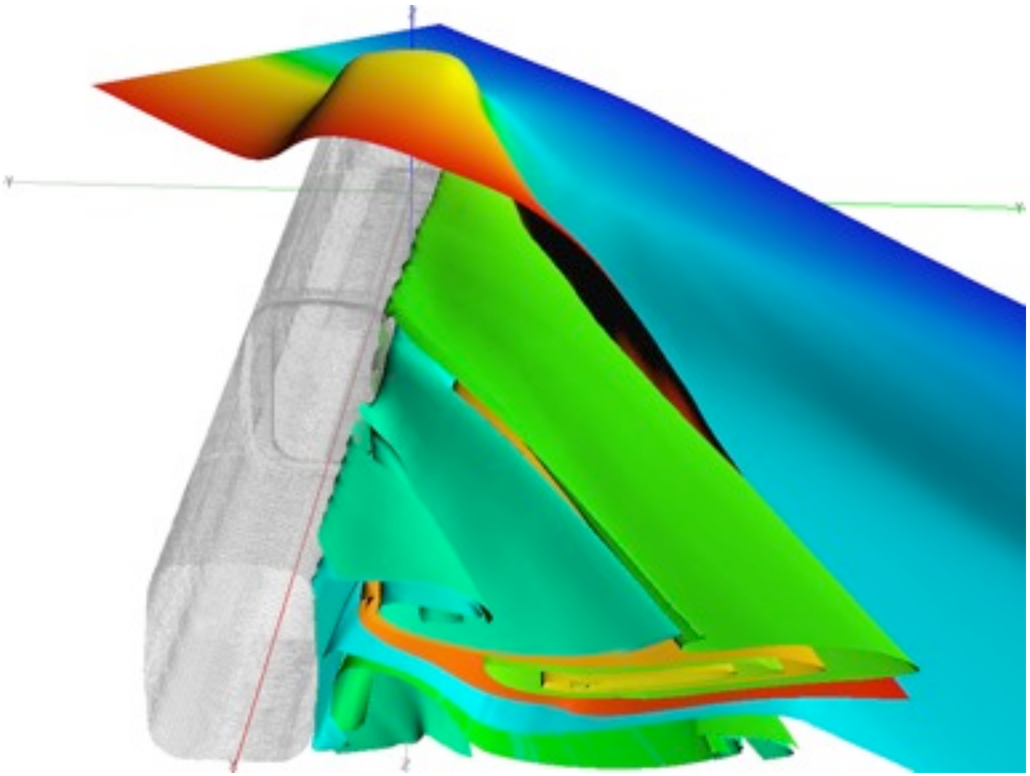
Garth et al., VisSym 2004

Advancing Front

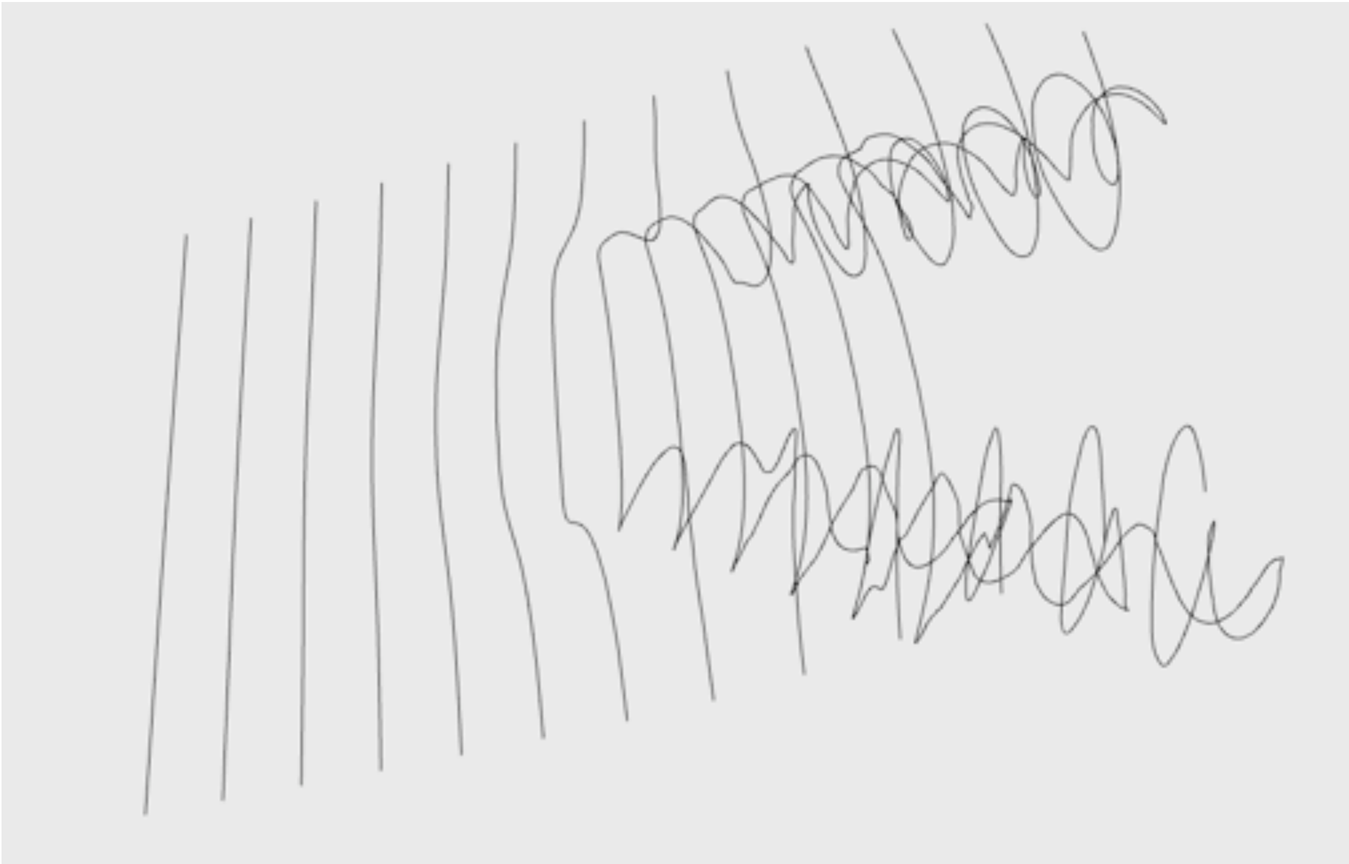




Advancing Front

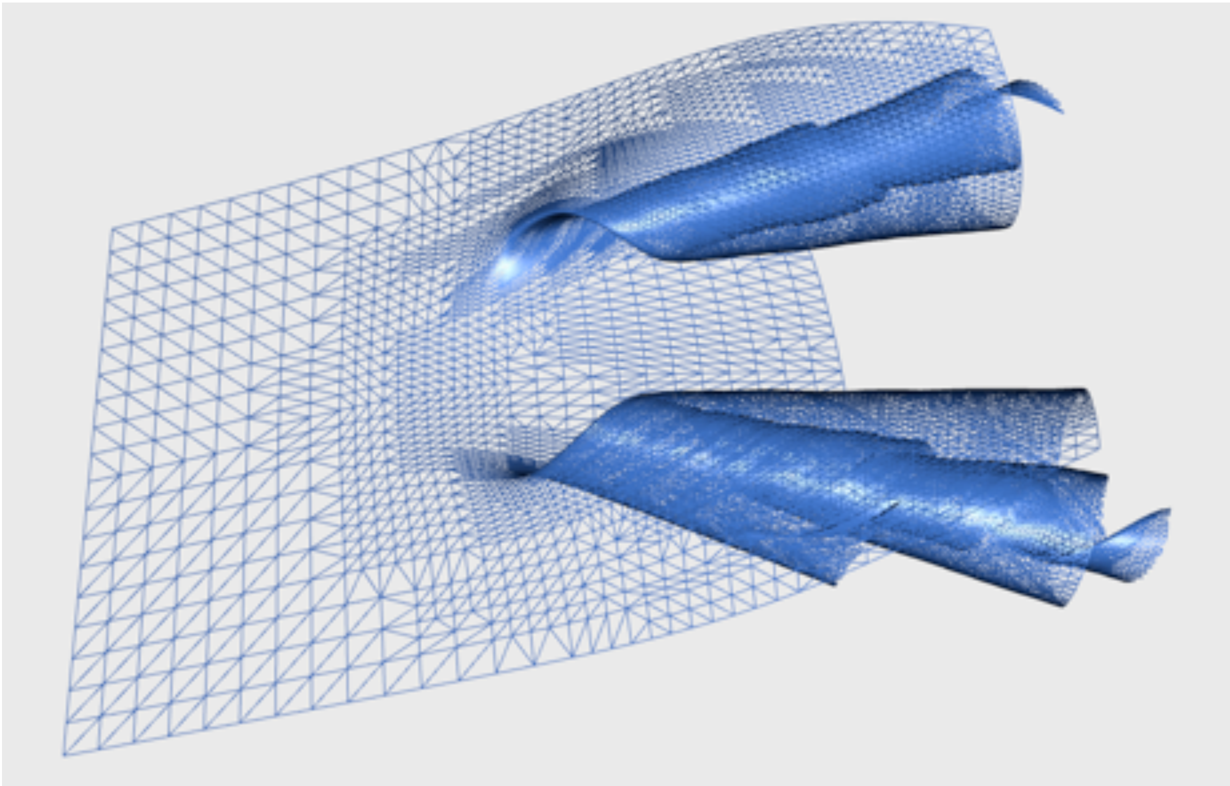


Path Surface

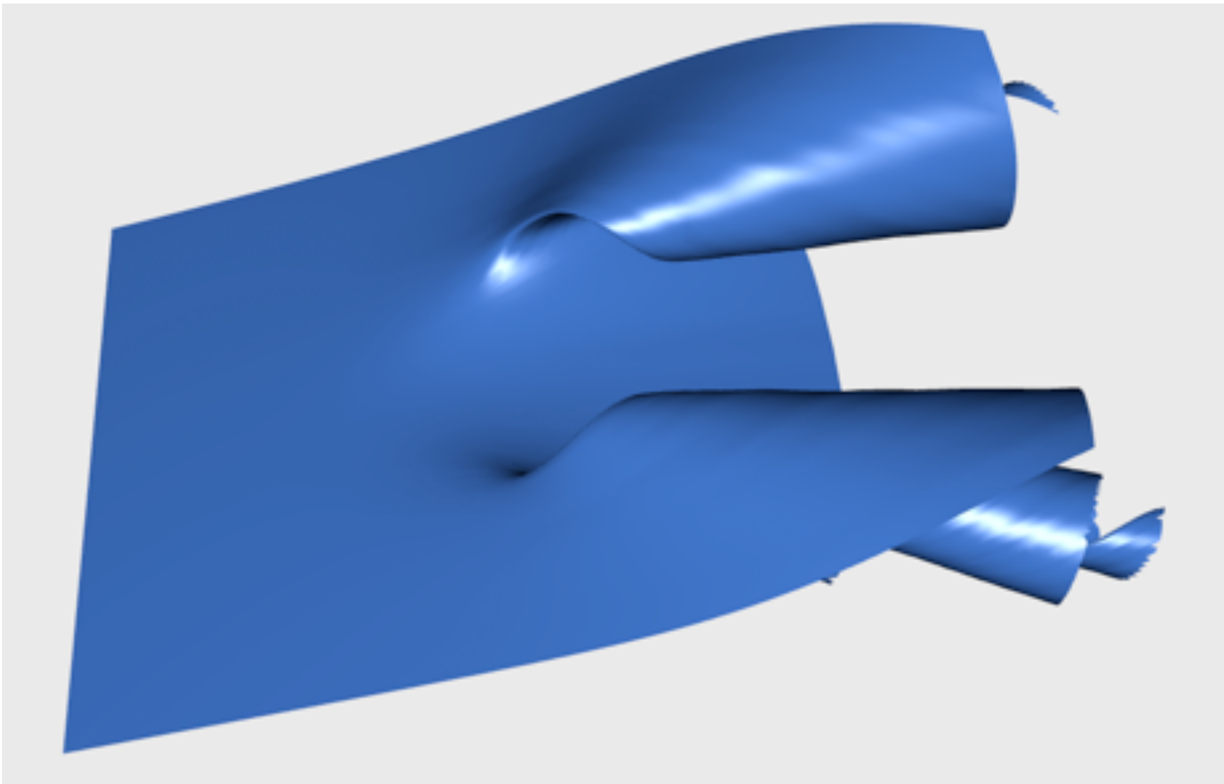


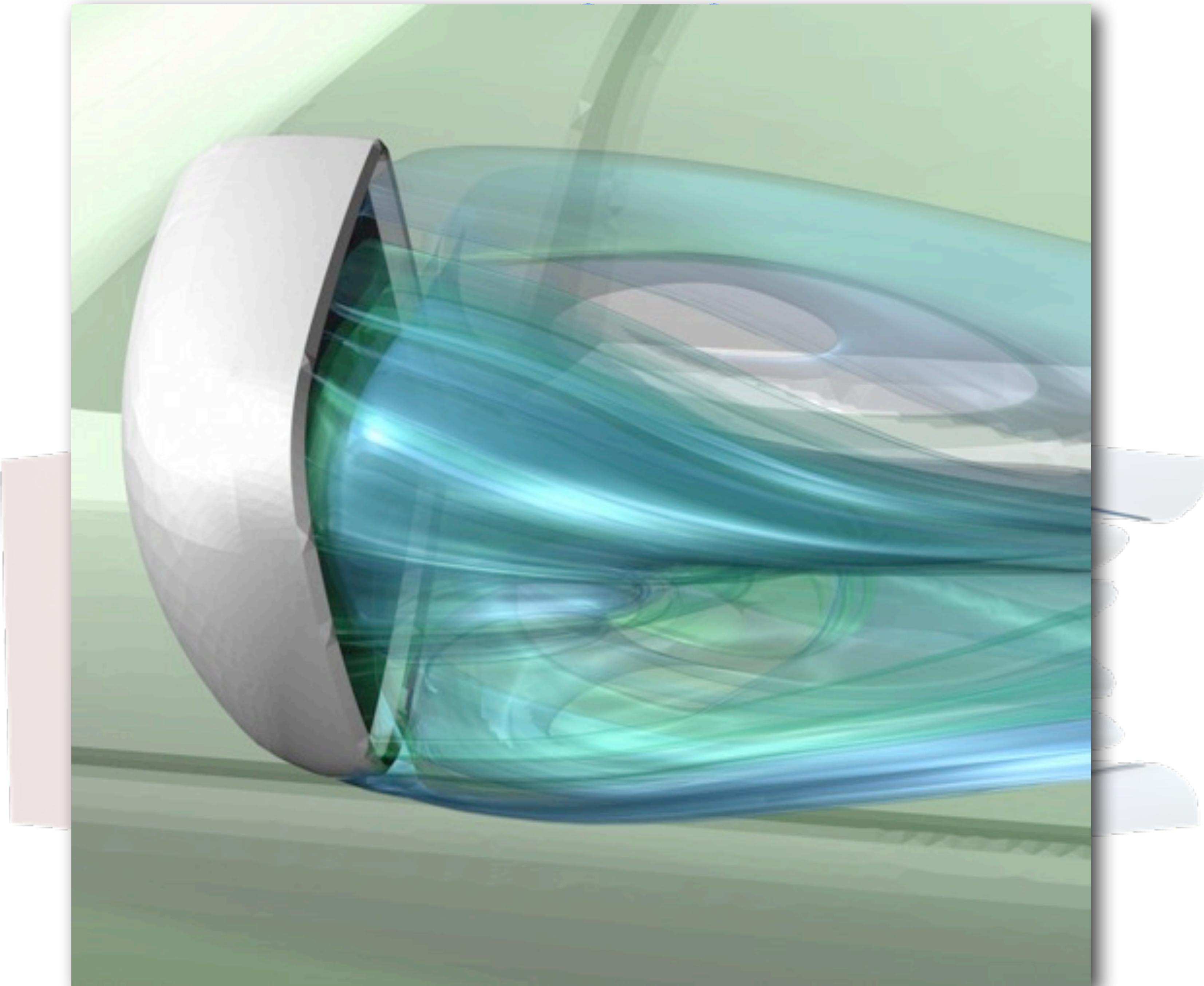
C. Garth et al., Generation of Accurate Integral Surfaces in Time-Dependent Vector Fields. IEEE Visualization 2008

Path Surface



Path Surface





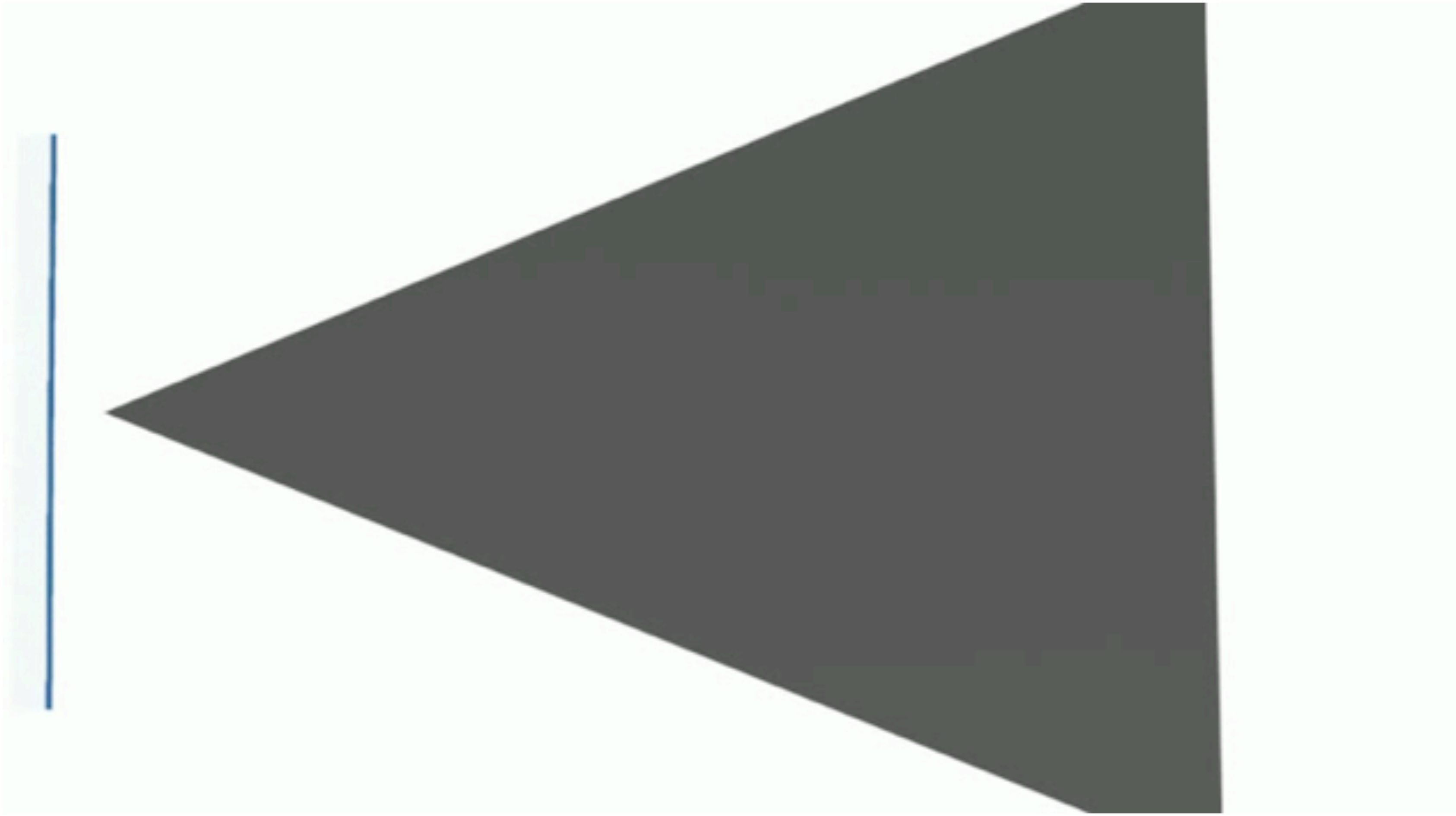
Texture Mapping on Path Surfaces

Comparative visualization of vortex formation

steady simulation

unsteady simulation

Texture Mapping



C. Garth et al., IEEE Visualization 2008

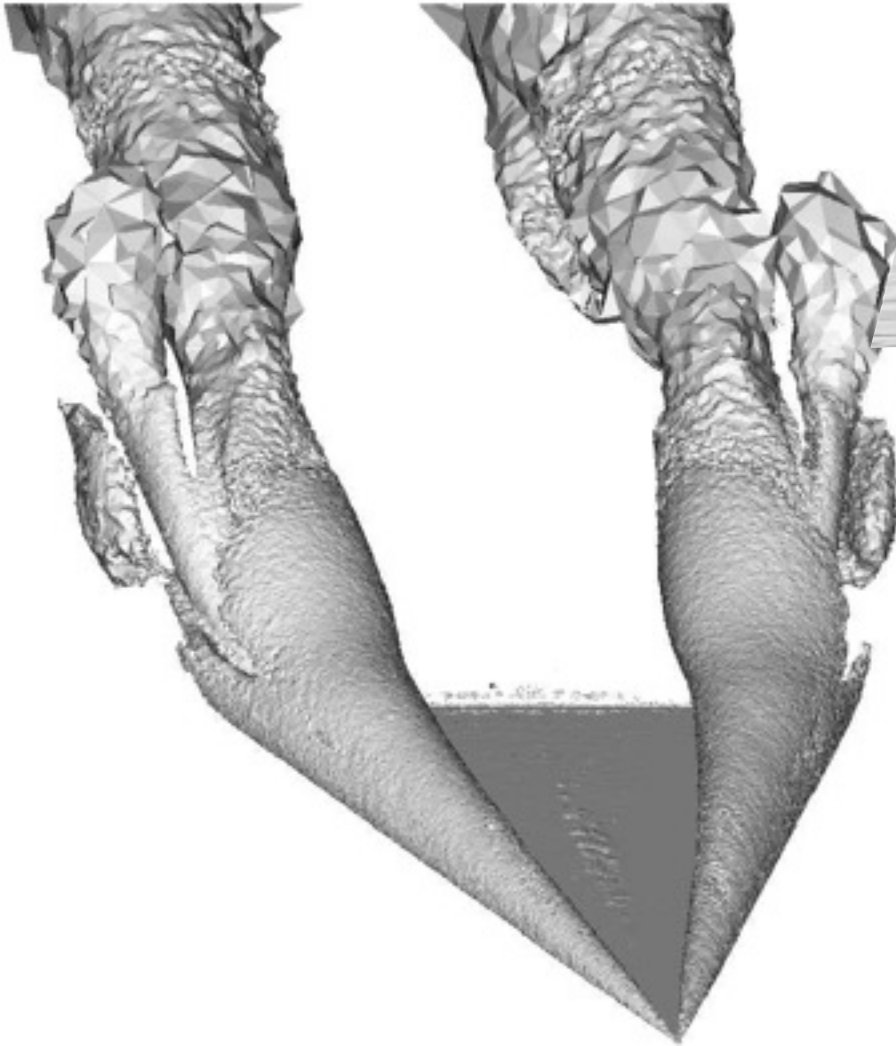
Streak and Time Surfaces

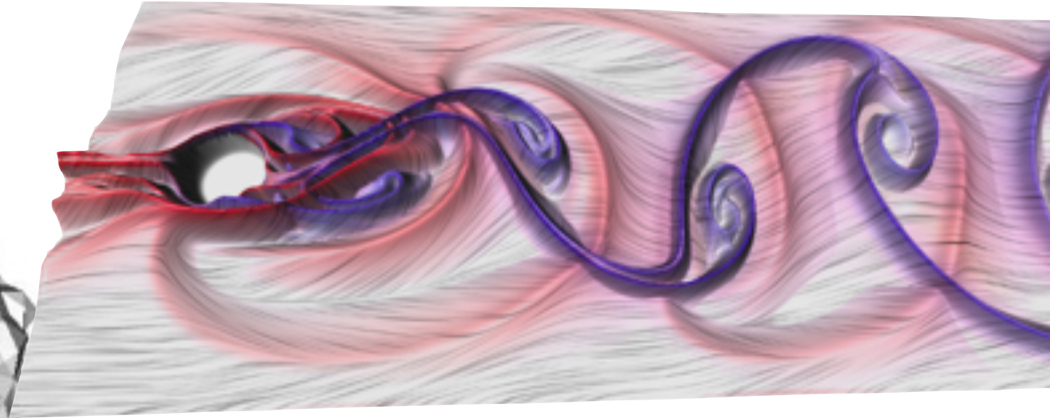
- Similar adaptive front refinement principle

H. Krishnan et al., IEEE Visualization 2009

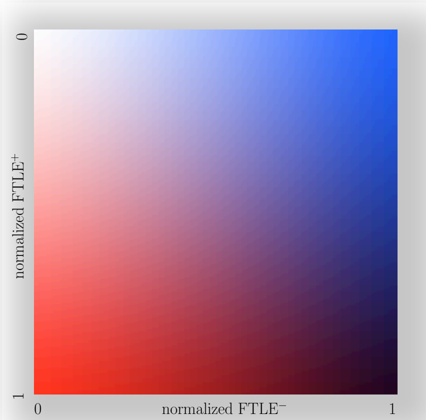
Streak and Time Surfaces

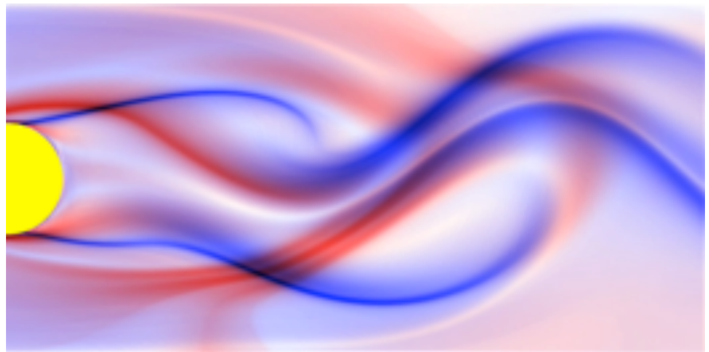
Coherent Structures in Flows



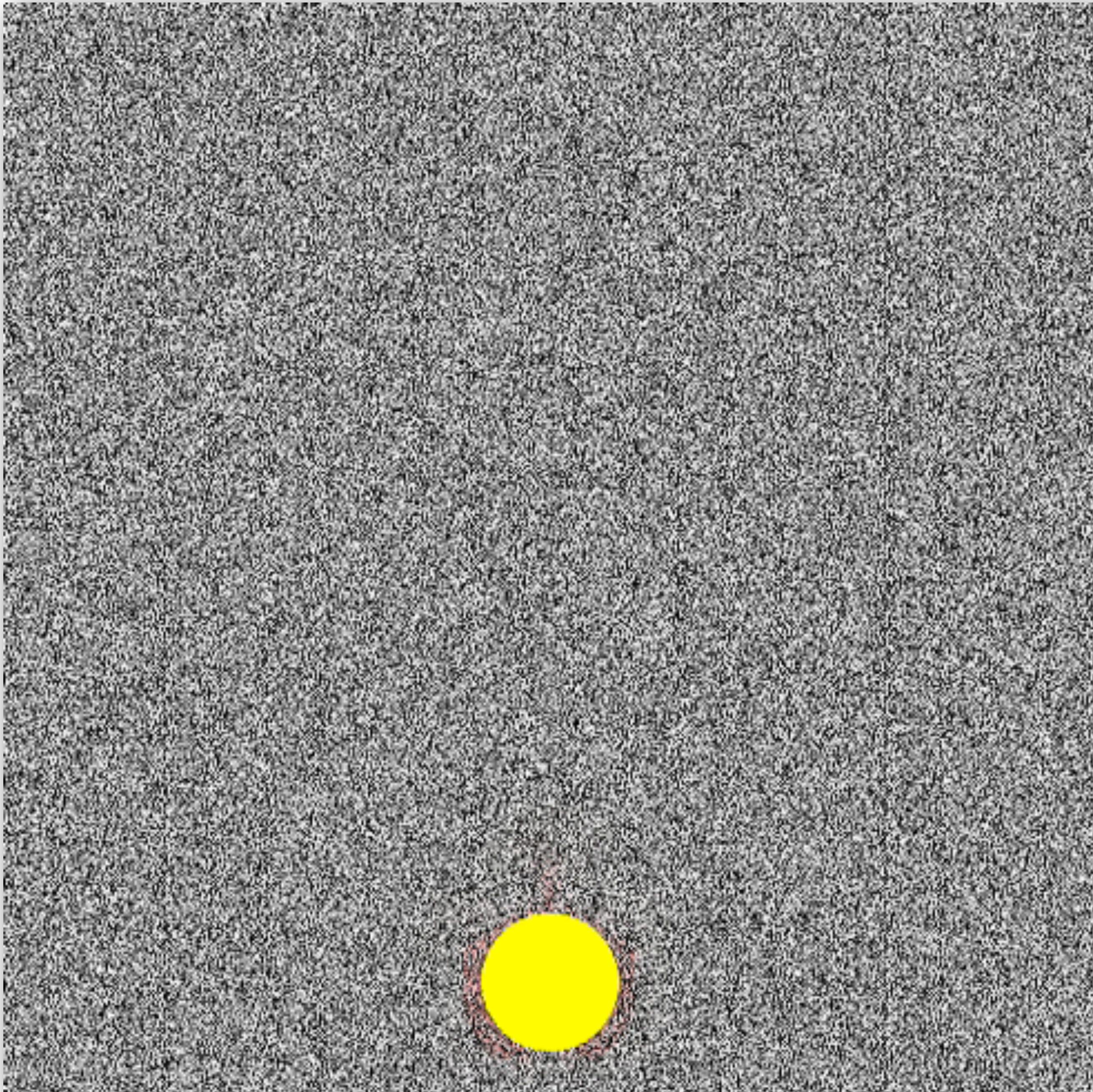


Lagrangian Coherence





von Kármán vortex street



Interactive Computation and Rendering of Lagrangian Coherent Structures

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