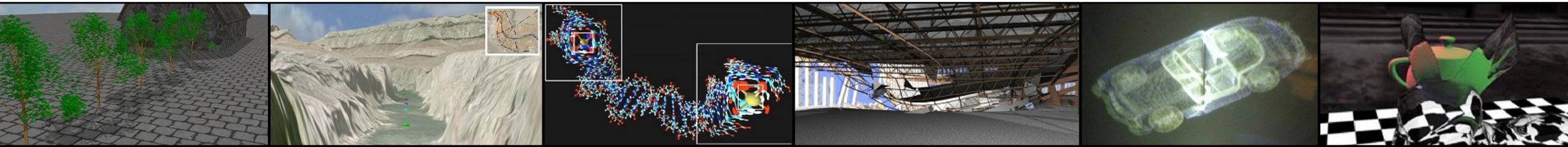
CIS 4930/6930-902
SCIENTIFIC VISUALIZATION

VECTOR FIELD VISUALIZATION

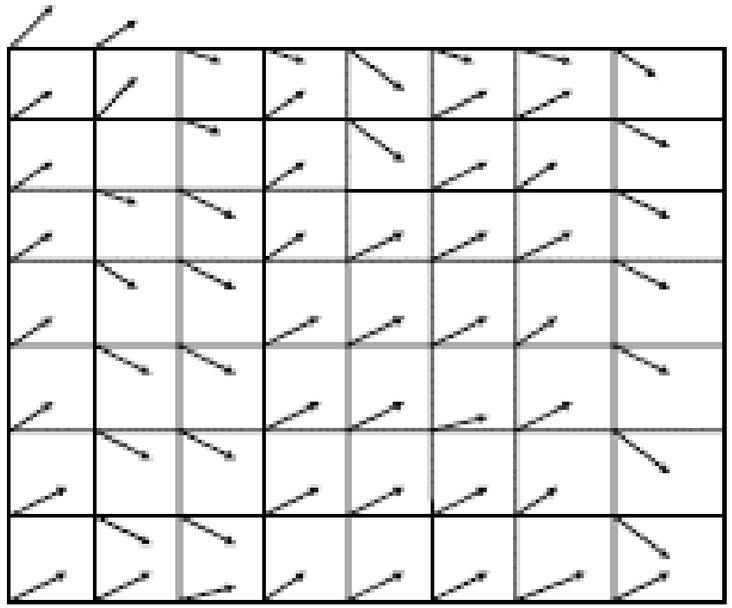
Paul Rosen
Assistant Professor
University of South Florida



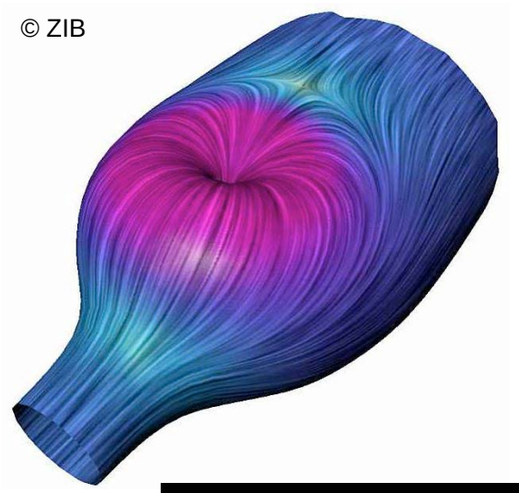
VECTOR FIELD VISUALIZATION

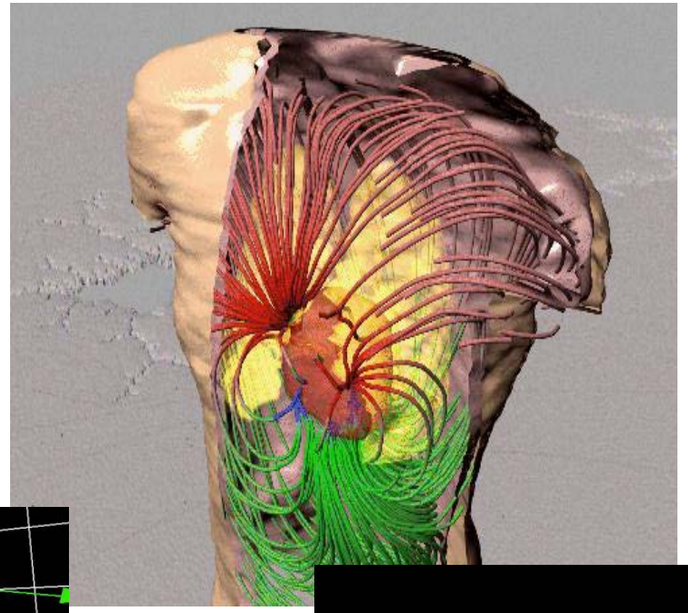
Data set is given by a vector component and its magnitude

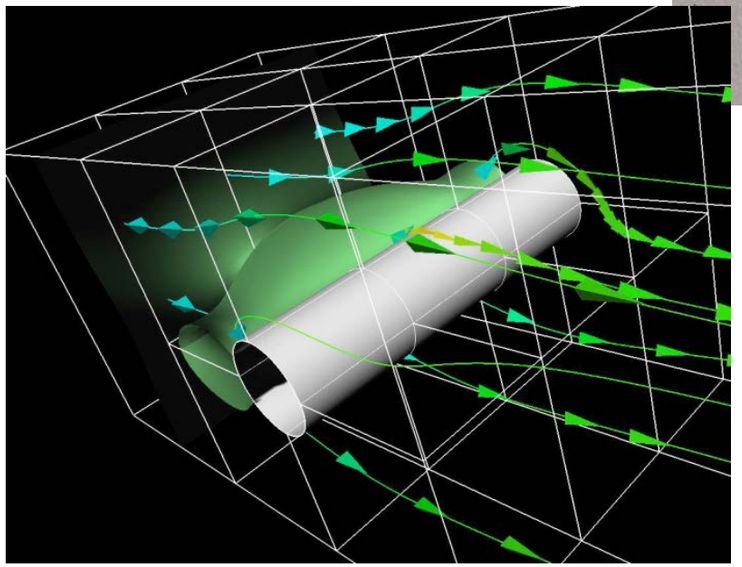
Often results from study of fluid flow or by looking at derivatives (rate of change) of some quantity

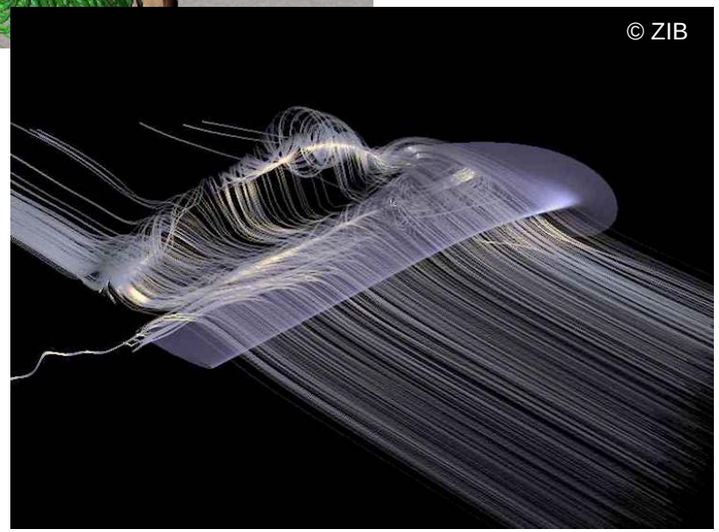


Vector Fields









Vector Field Visualization: Problem Definition

Given (typically):

Physical position vector

Force vector

Electric or magnetic field vector

Velocity vector

Steady flow - vector field stays constant

Unsteady - vector field changes with time

Now, make some visualizations!

Global techniques

Display the flow direction everywhere in the field

Hedgehogs, line integral convolution (LIC), texture splats, etc.

Local techniques (advection-based methods)

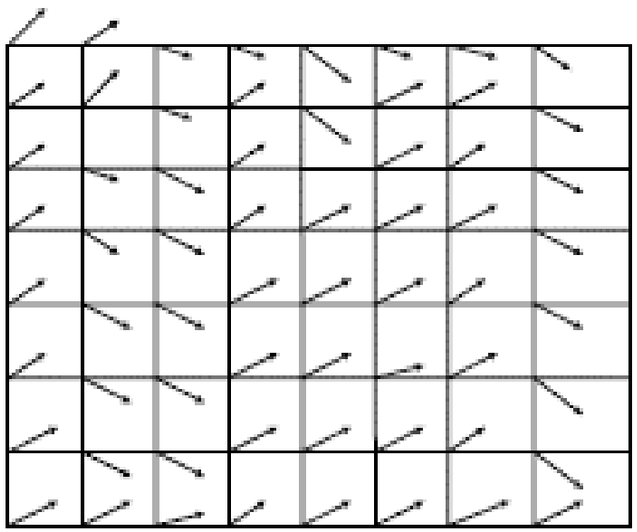
Display the trajectory starting from a particular location

Streamlines, stream ribbons, contours

Global Techniques: Display the entire flow field in a single picture

Minimum user intervention

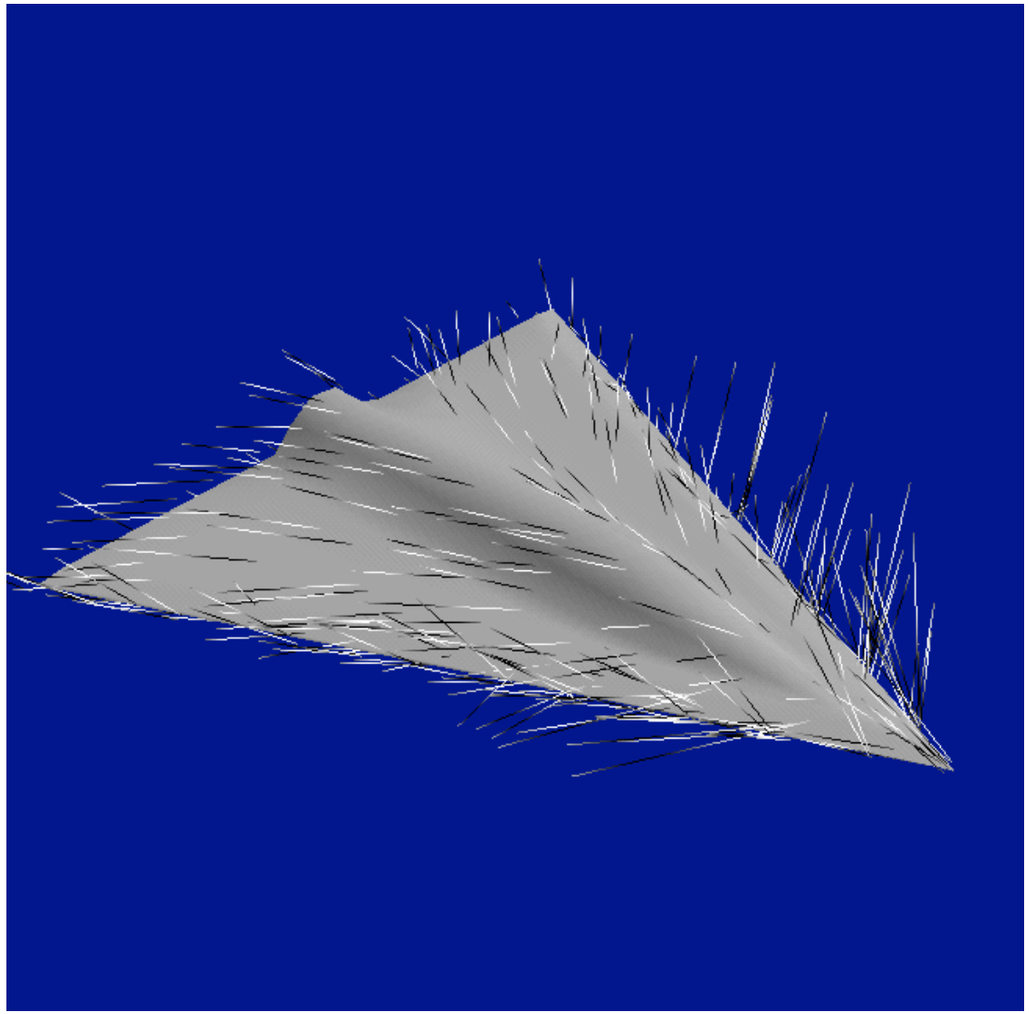
Example: *hedgehogs* (global arrow plots)



PUT "ICONS" AT CERTAIN PLACES IN THE FLOW

e.g., arrows representing direction & magnitude

Other primitives are possible



PROBLEMS WITH *GLYPHS*?

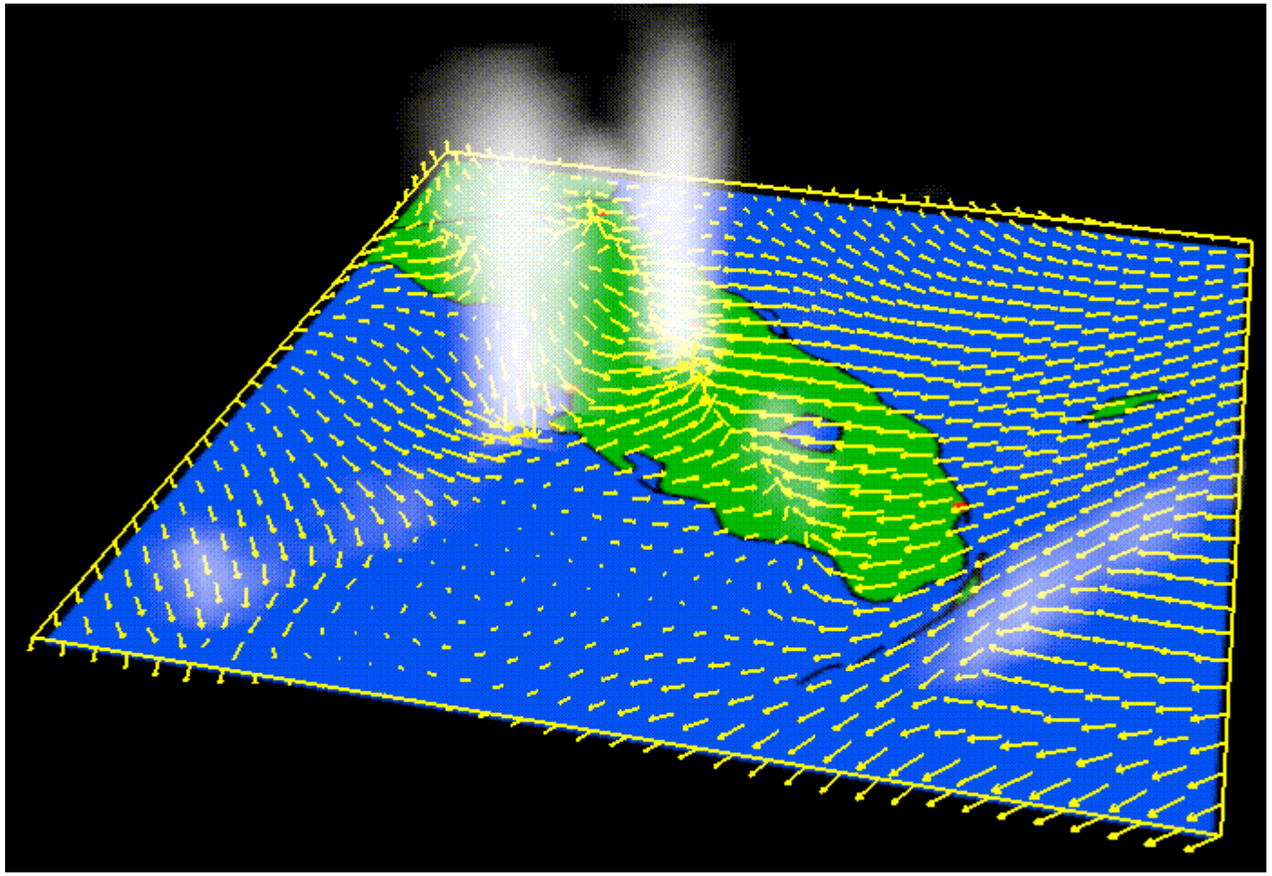
Clutter the image (maybe ok for 2D)

Sometimes not very informative (complex glyphs)

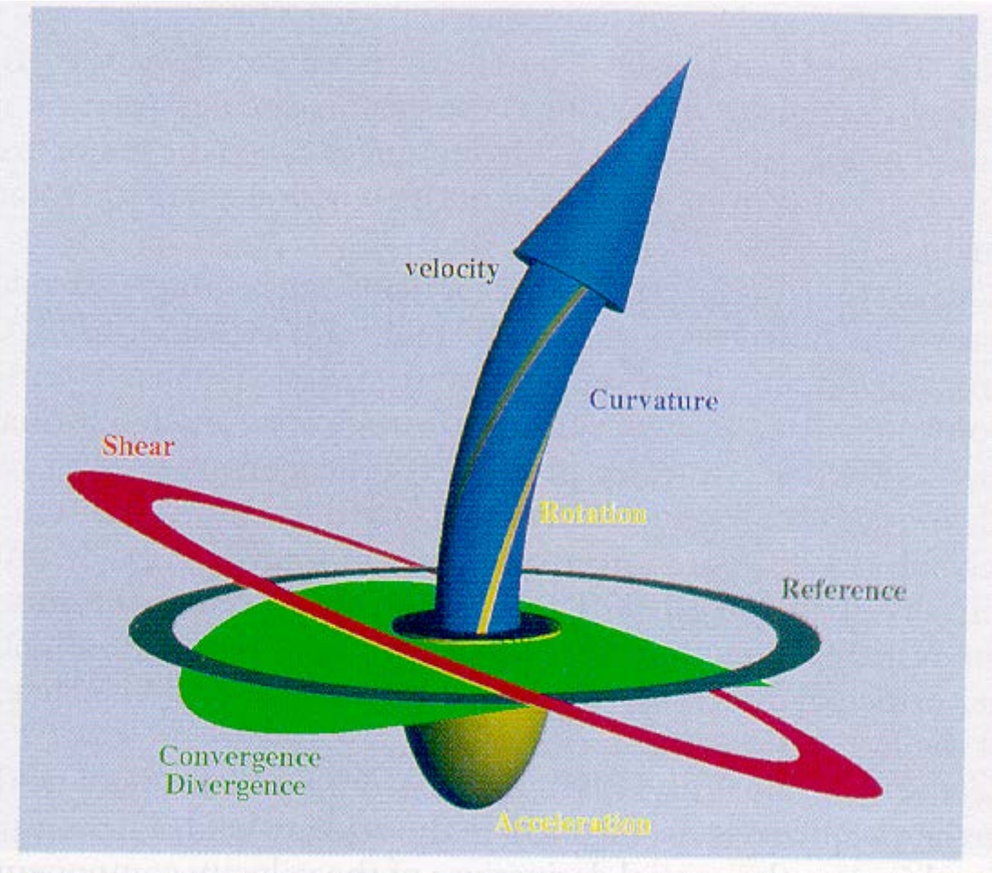
Perspective problems in 3D

Icon Placement to Decluttering the Image

Hedgehogs or arrow plots: uniform grid

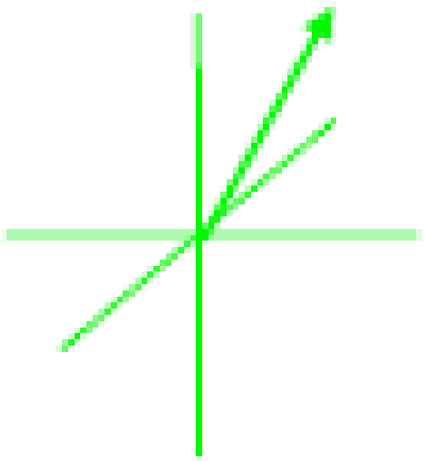


Complex Glyph



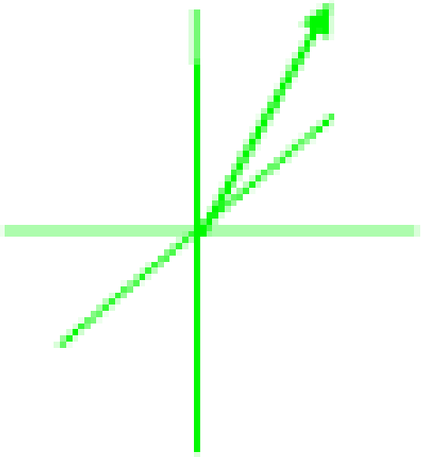
Perspective Problems

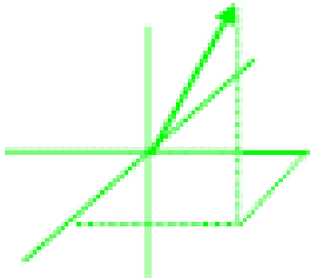
In 3D, arrows suffer from perception problems:



Perspective Problems

In 3D, arrows suffer from perception problems:

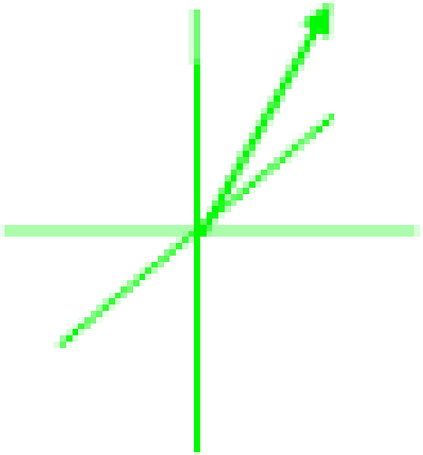


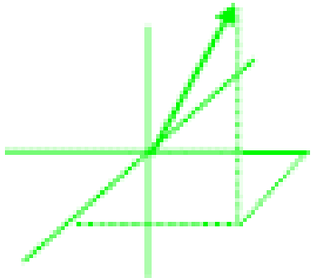


Is it this?

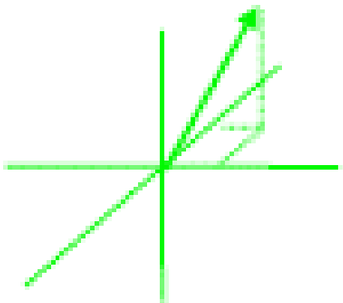
Perspective Problems

In 3D, arrows suffer from perception problems:





Is it this?



Or this?

Local Techniques

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

These methods use advection

Advection is just an application of the forward Euler method

Mathematical background on advection:

http://en.wikipedia.org/wiki/Advection

Local Techniques: Streamlines

Streamlines are a family of curves that are instantaneously tangent to the velocity vector of the flow

Algorithm: Release a particle into the flow and trace its position over time

Pick point

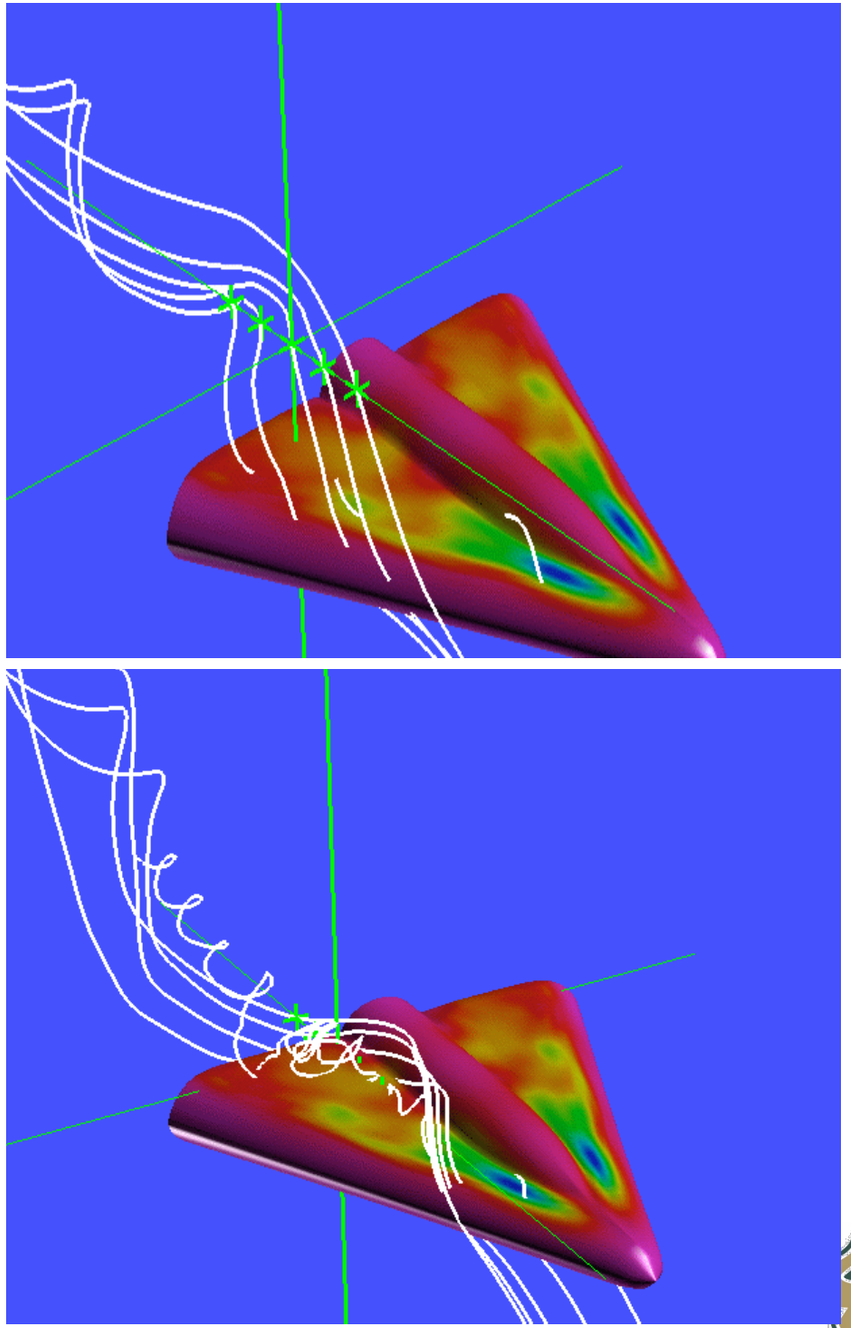
Move small distance along tangent direction

Find new point

Repeat and connect to draw out streamline

Local Techniques: Streamlines

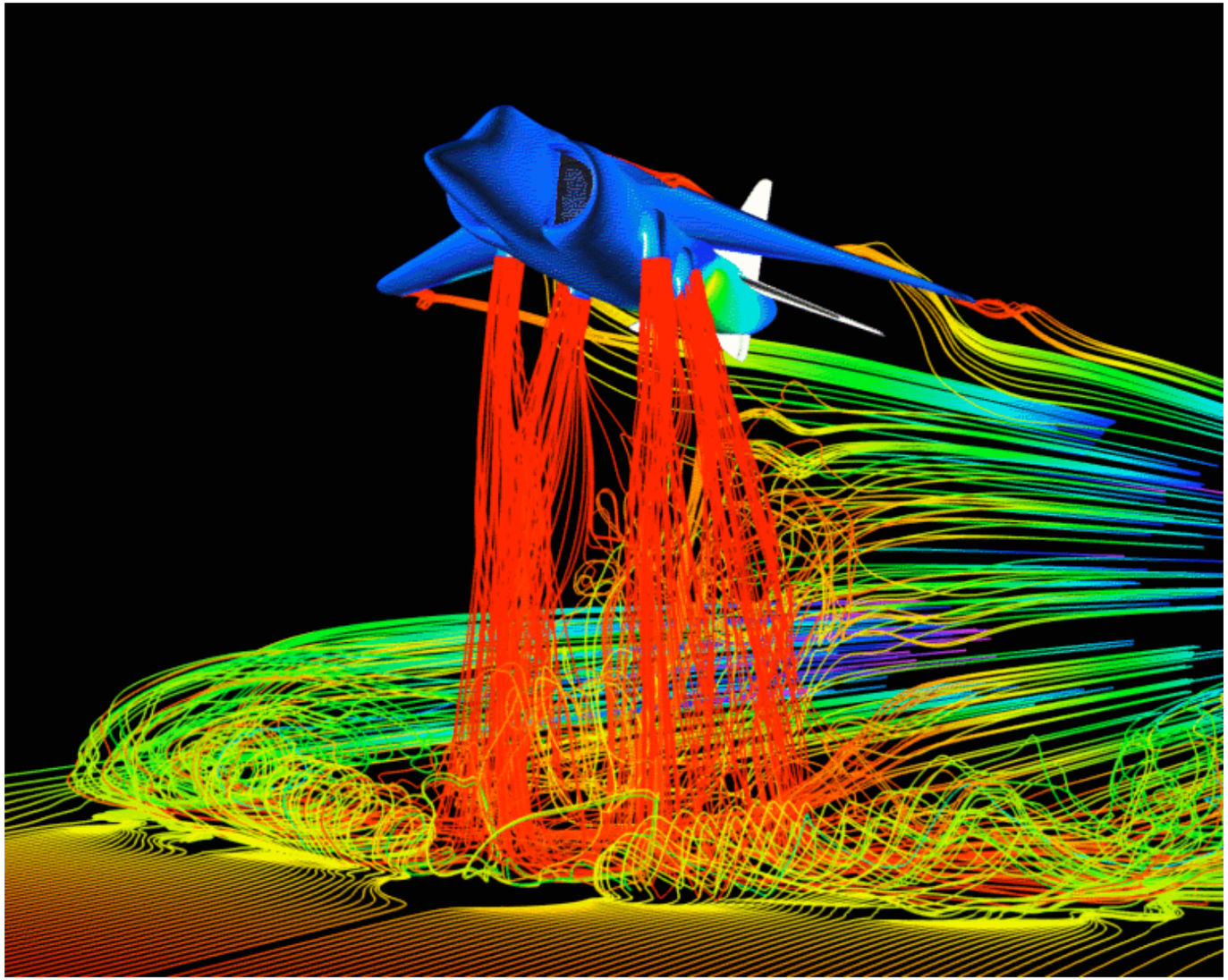
Displaying streamlines is a local technique because you can only visualize the flow directions initiated from one or a few particles



Streamline Limitations?

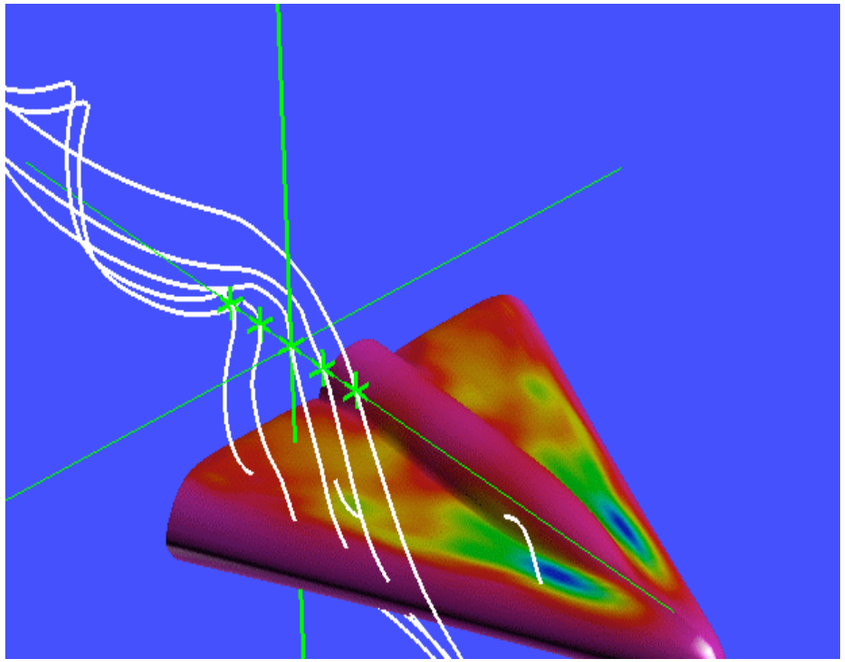
Streamline Limitations

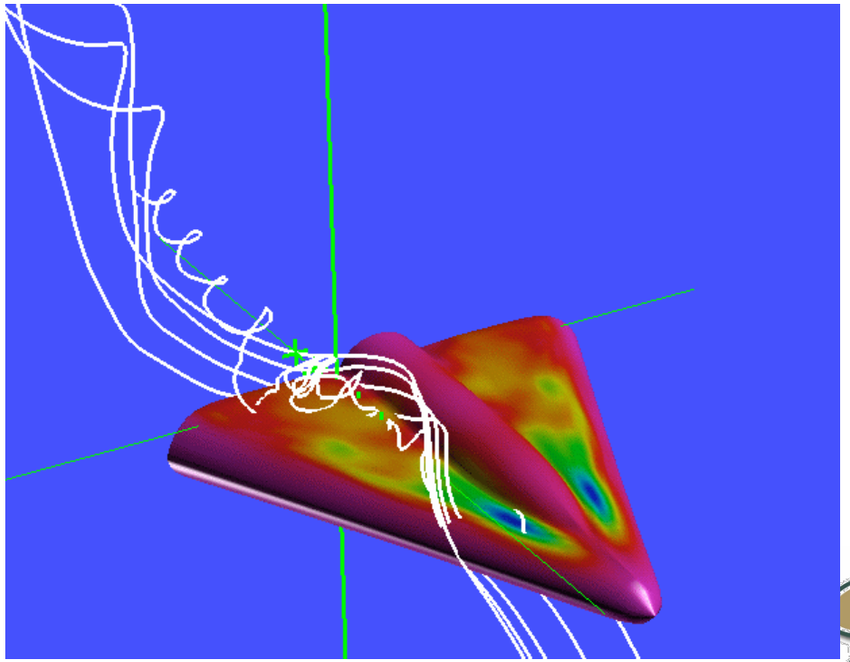
As the number of streamlines increases, the scene becomes cluttered



Streamline Limitations

Need to know where to drop the particle seeds





Streamline Limitations

computation is expensive!

Unsteady Flow

As presented, streamlines work for steady flow

We want techniques for unsteady flow

Many techniques, we'll discuss these:

Pathlines

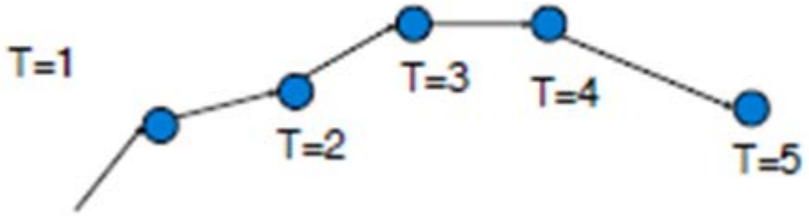
Timelines

Streaklines

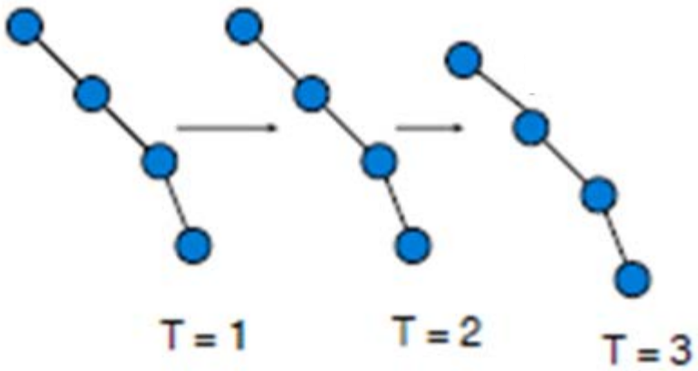
Unsteady Flow: Pathlines & Timelines

Extensions of streamlines for time-varying data (unsteady flow)

Pathline:



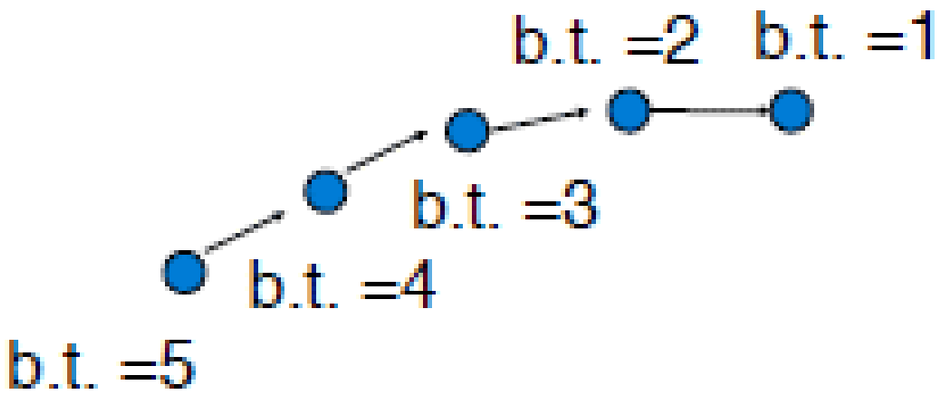
Timelines:



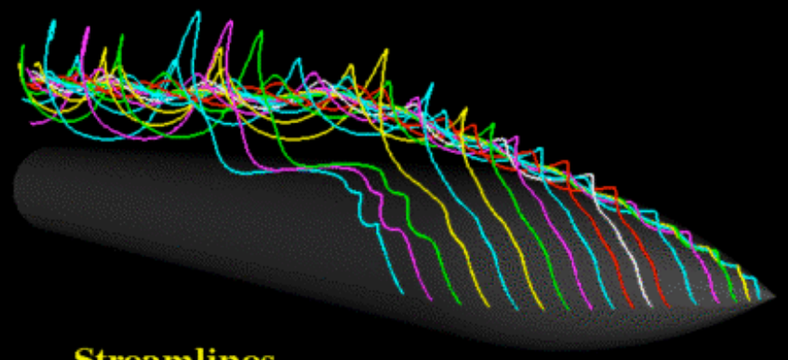
Unsteady Flow: Streaklines

Continuously inject a new particle at the same location for each time step

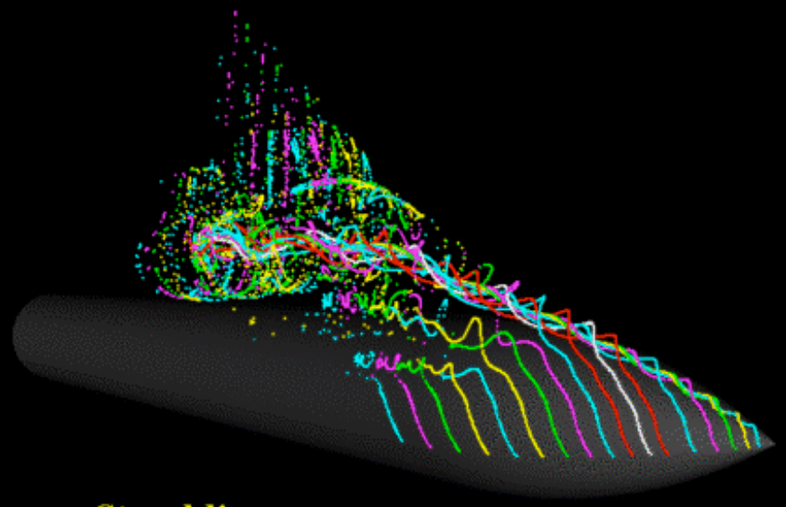
Advect all existing particles and connect them together into a *streakline*



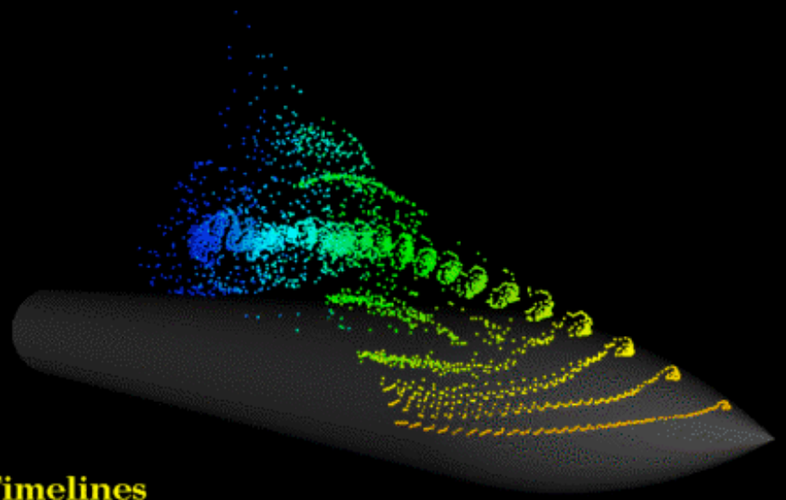
Flow Advection Method Comparison



Streamlines



Streaklines



Timelines

More Complex Primitives

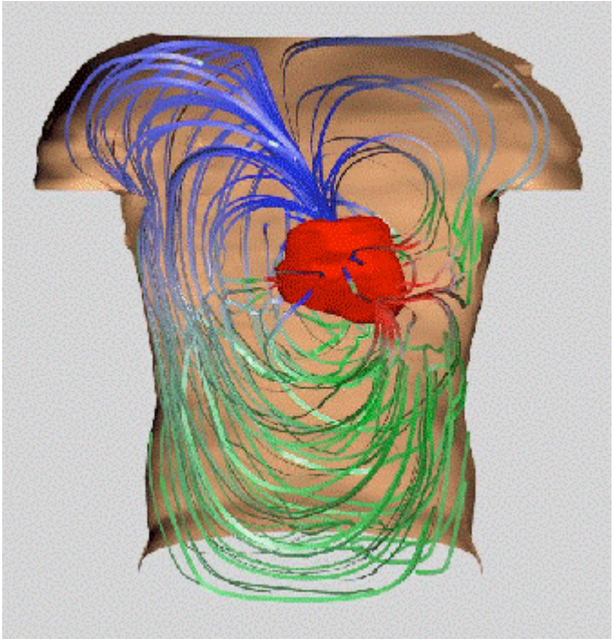
We really would like to see vorticities (i.e., places were the flow twists)

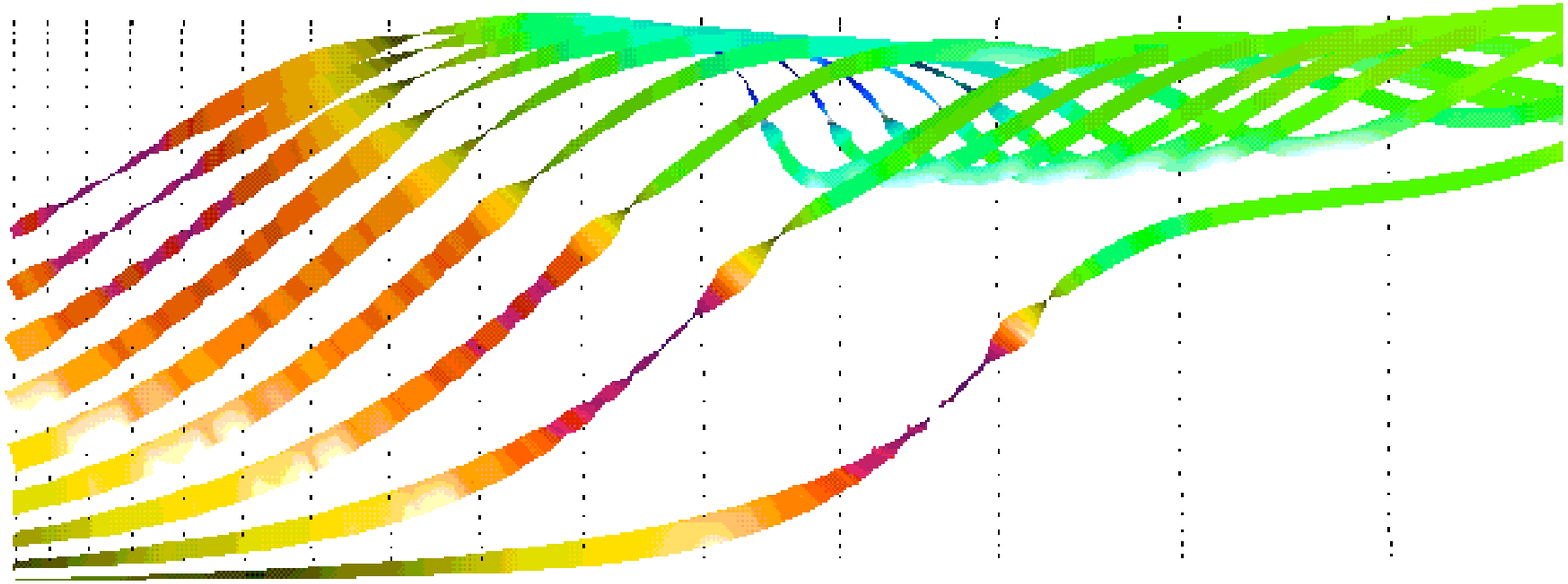
A point primitive or icon can hardly convey this

Stream Ribbon

Idea: Trace neighboring particles and connect them with polygons

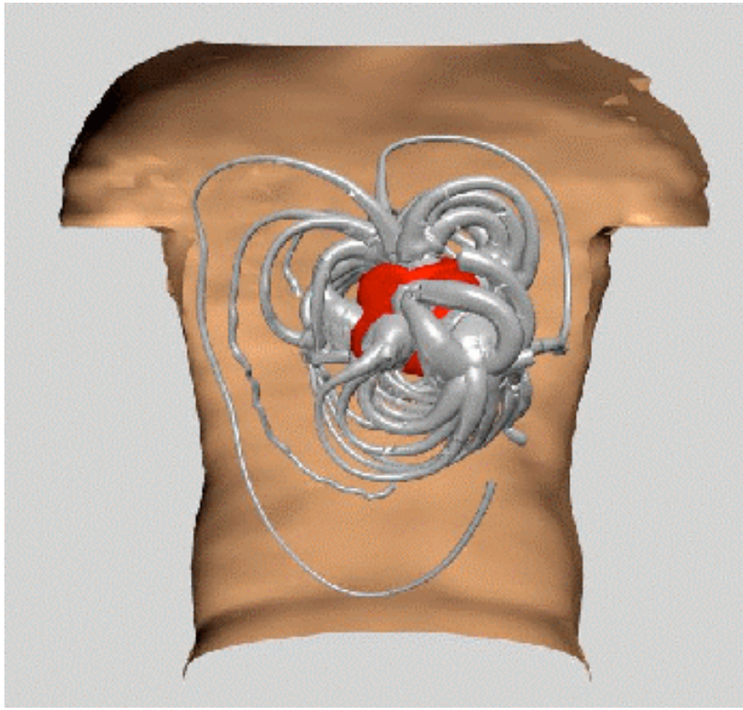
Shade those polygons appropriately; can then detect twists

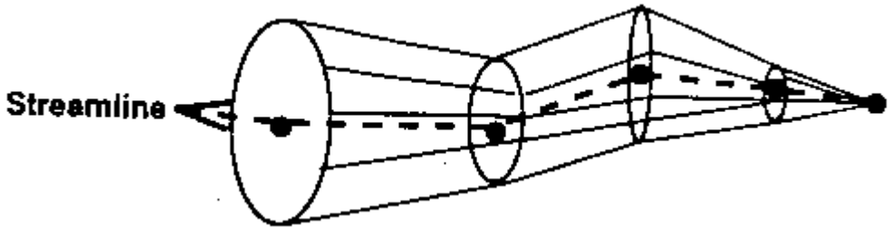


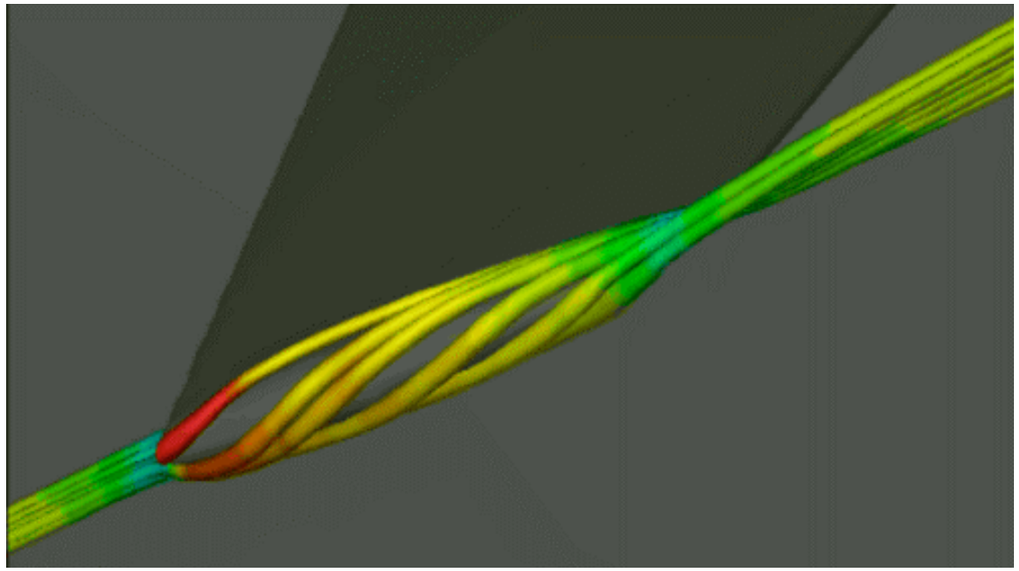


STREAM TUBE

Generate a streamline and connect circular crossflow sections along the streamline

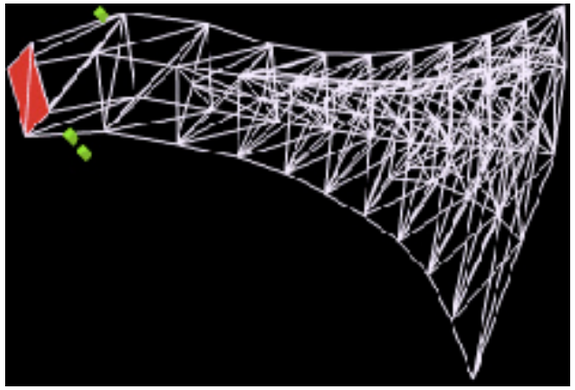


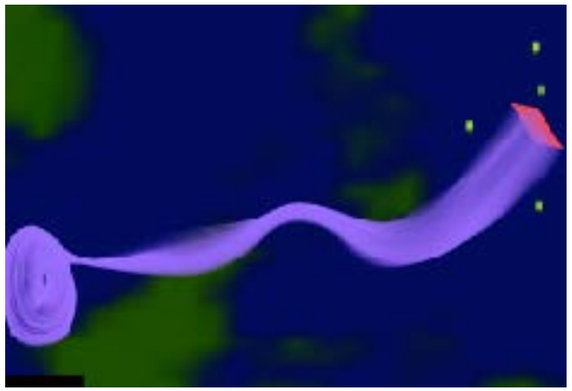


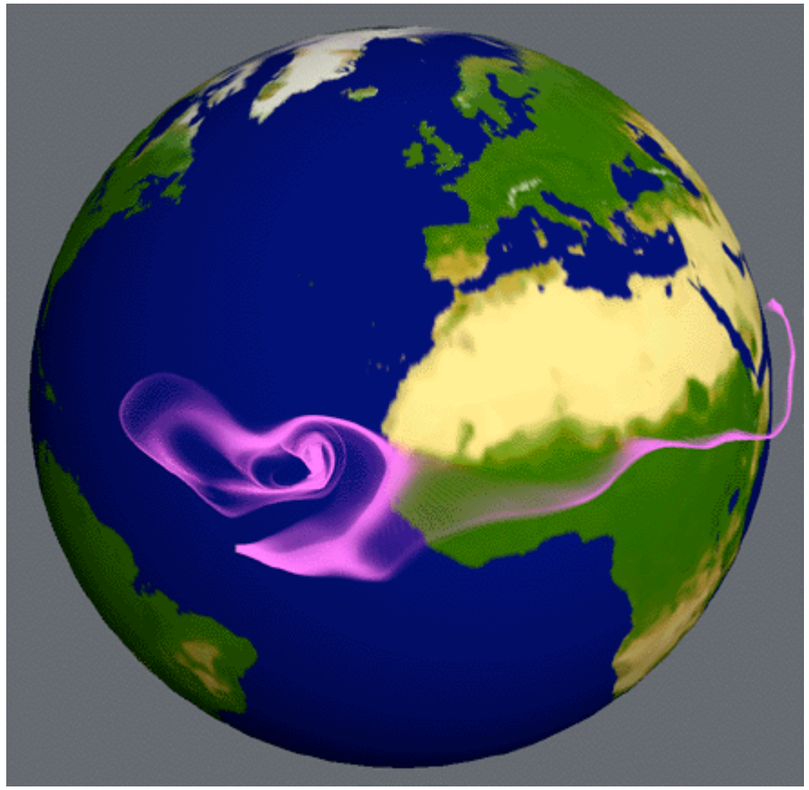


FLOW VOLUMES

Instead of tracing a line, trace a small polyhedron







PROBLEMS?

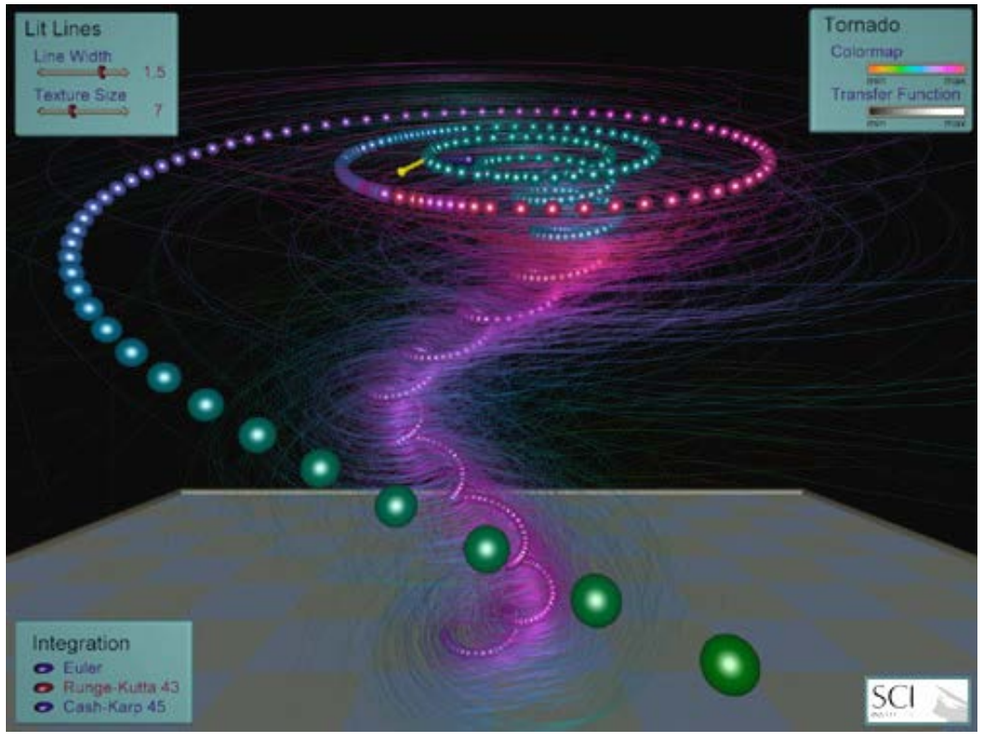
Divergent flows

Stream Balls

A way to get around diverging streamlines

Simply put implicit surface primitives at particle traces

At places where they are close, they will merge elegantly



Stream Balls

Based on metaballs

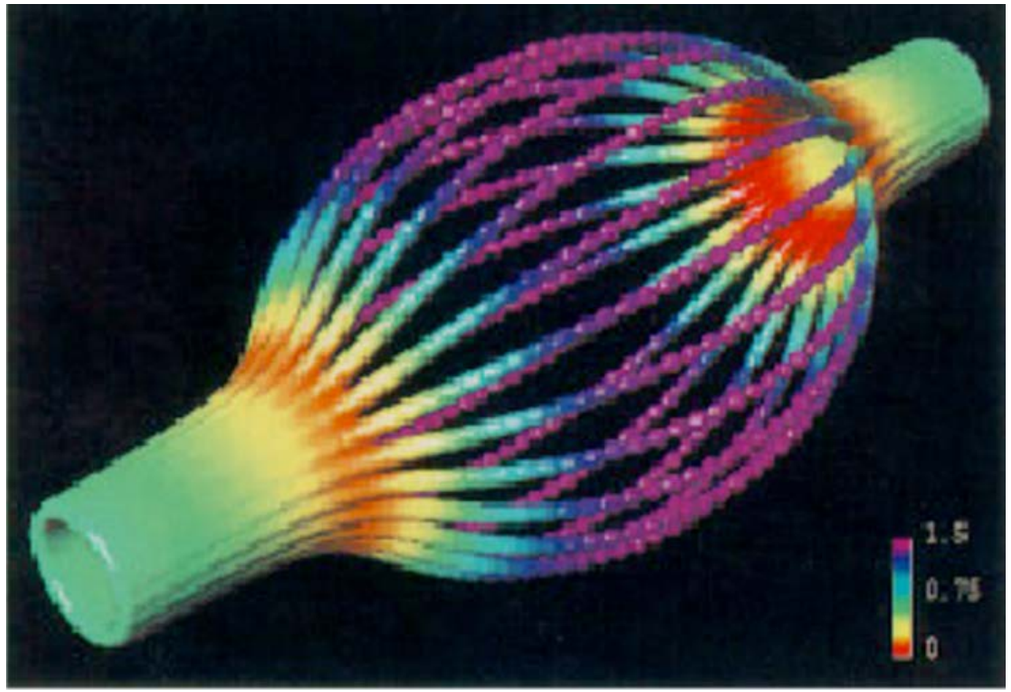
http://en.wikipedia.org/wiki/Metaballs

+ Implicitly generated surfaces

+ Easily split and merge

- Computationally expensive

- Need fine meshing to do accurate isocontouring/isosurfacing



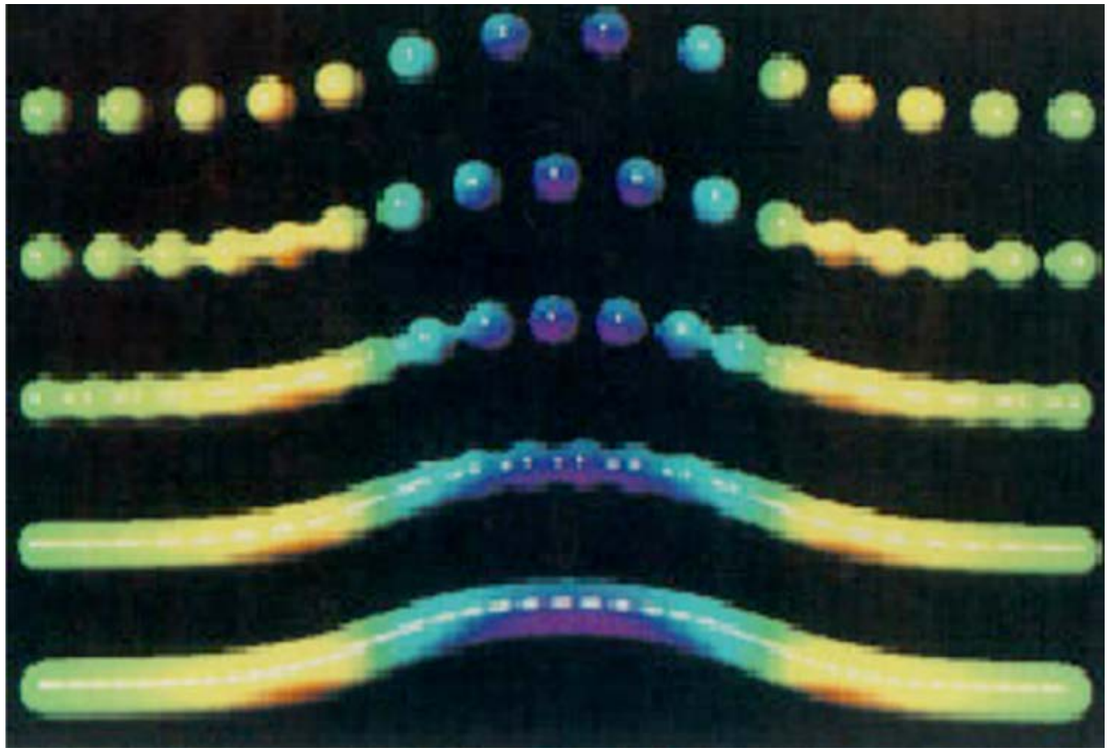
Stream Balls

Basic idea: Create a continous function $f(x, y, z)$ and take isosurfaces of this function

Use metaballs to generate this function

Metaballs developed separately by Nishimura, Blinn, and Wyvill, and further refined by Bloomenthal and Shoemake

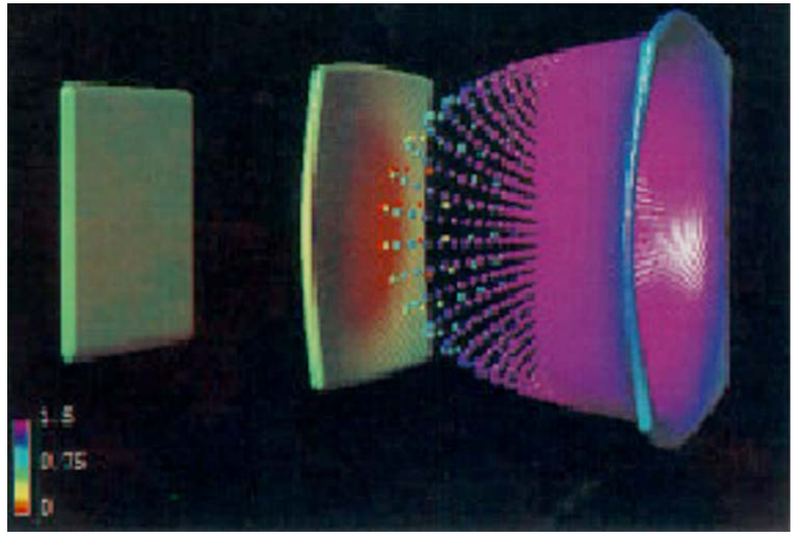
Treat particles as metaballs or use a timeline curve

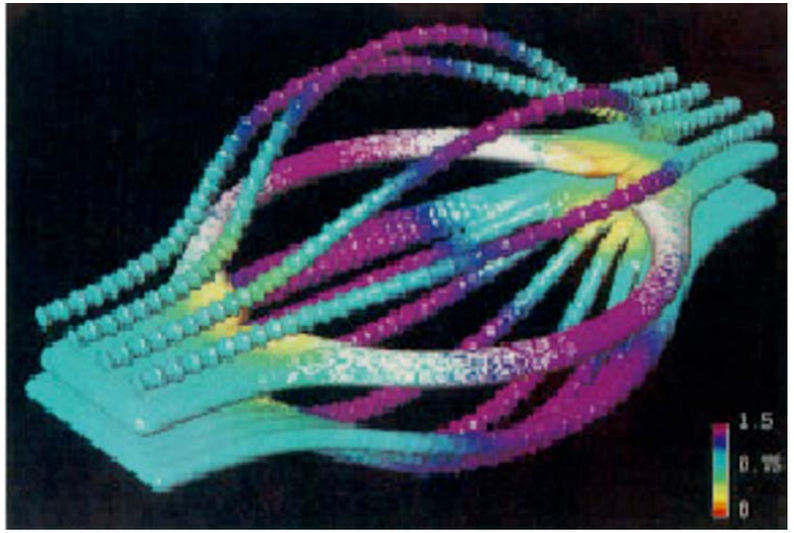


Stream Balls

Can easily map other variables to the surface's color and texture

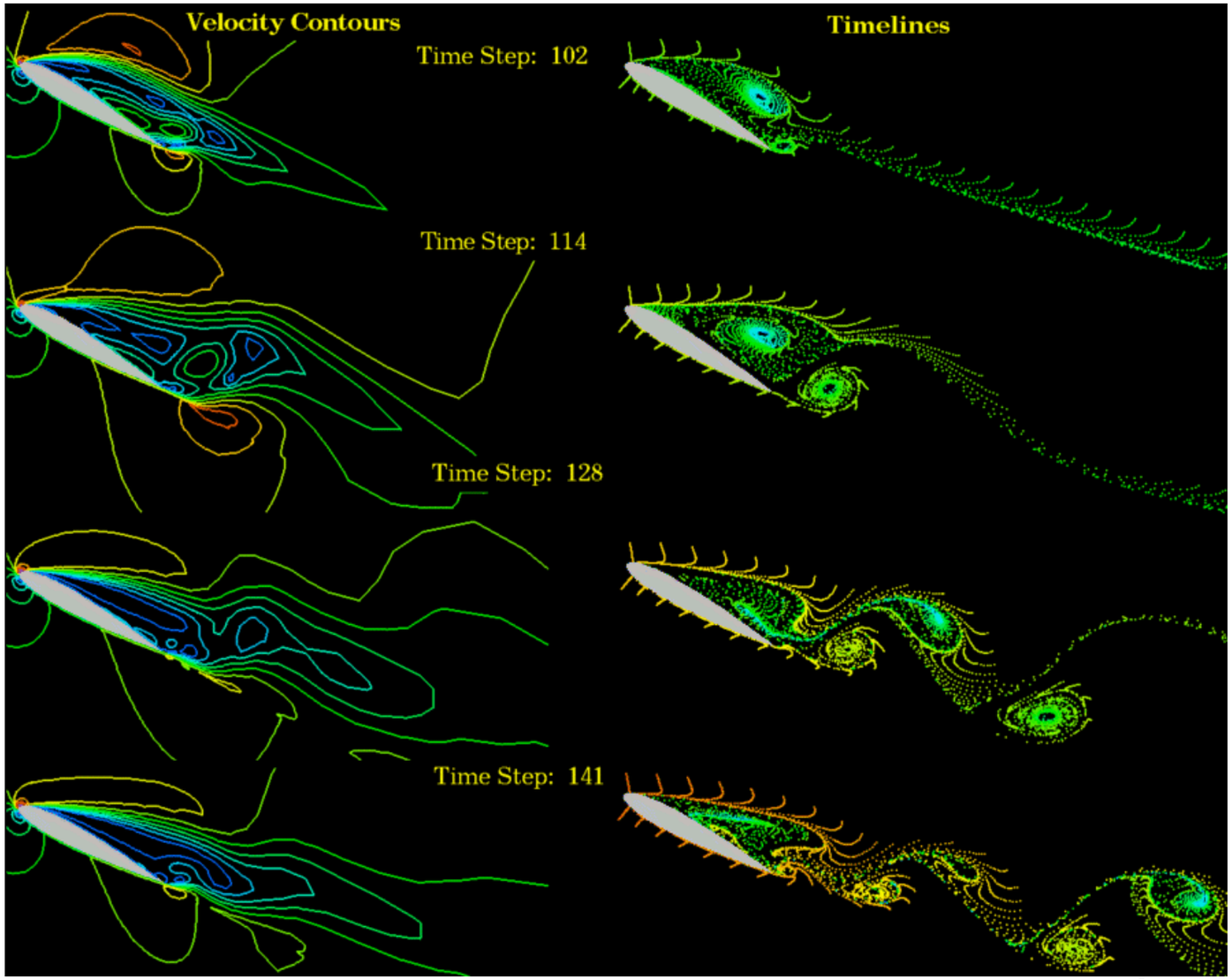
Can use other variables to control the shape of the resulting contour surface



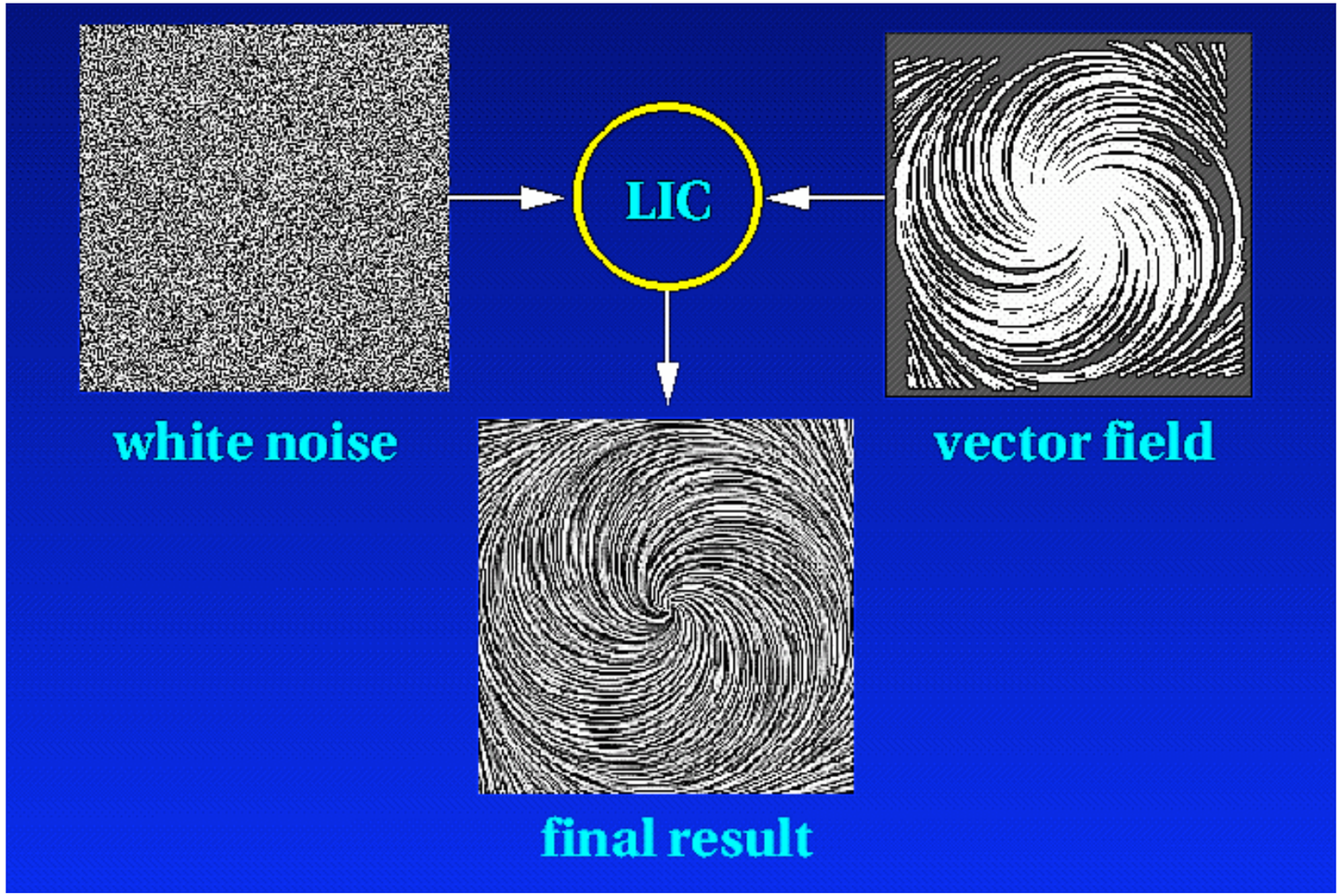


CONTOURS

Contour lines can display certain quantities by connecting identical values along a line



Line Integral Convolution (LIC)



Cabral & Leedom '93

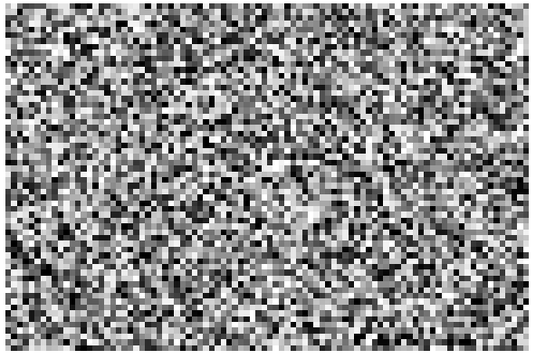
Line Integral Convolution (LIC)

Essence of method:

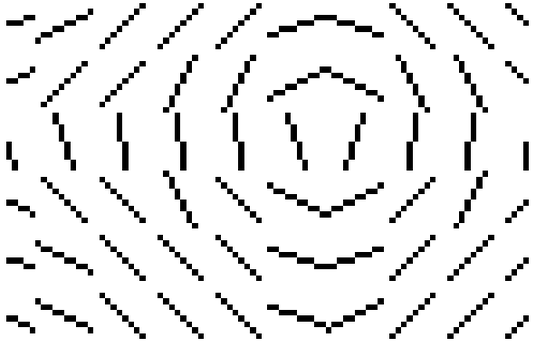
Consider a white noise texture, *T(x,y)*

Set each pixel's intensity as a function (e.g., average) of values of *T* along a short line segment through the pixel

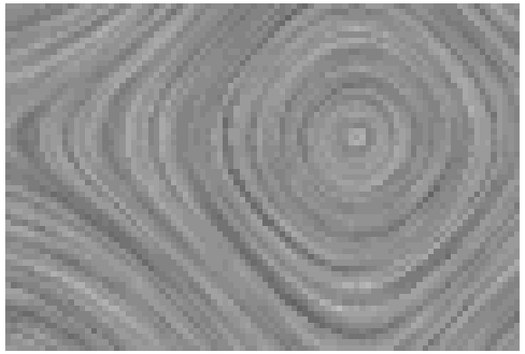
This has the effect of correlating the resulting pixel values along streamlines, giving a sense of the flow direction



White noise



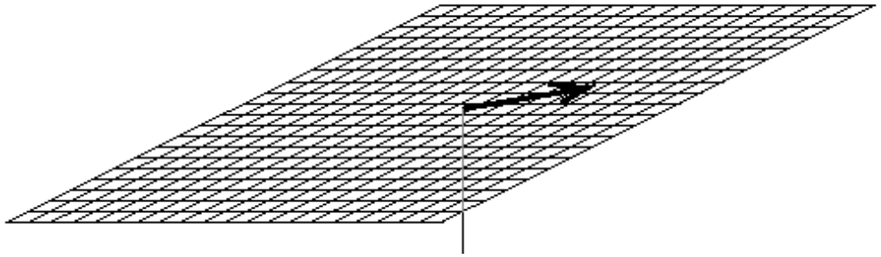
Flow lines



LIC

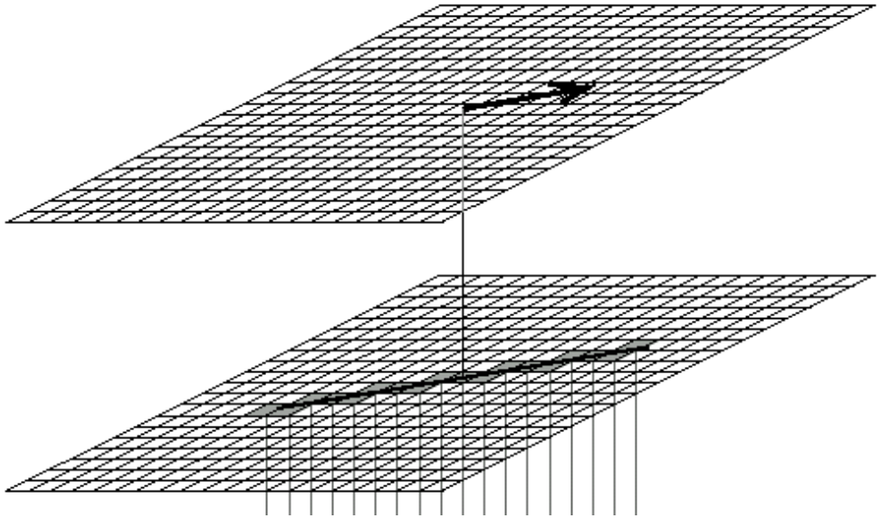
Line Integral Convolution (LIC)

Rather than deposit energy on each pixel, integrate the icon weights with a white noise function



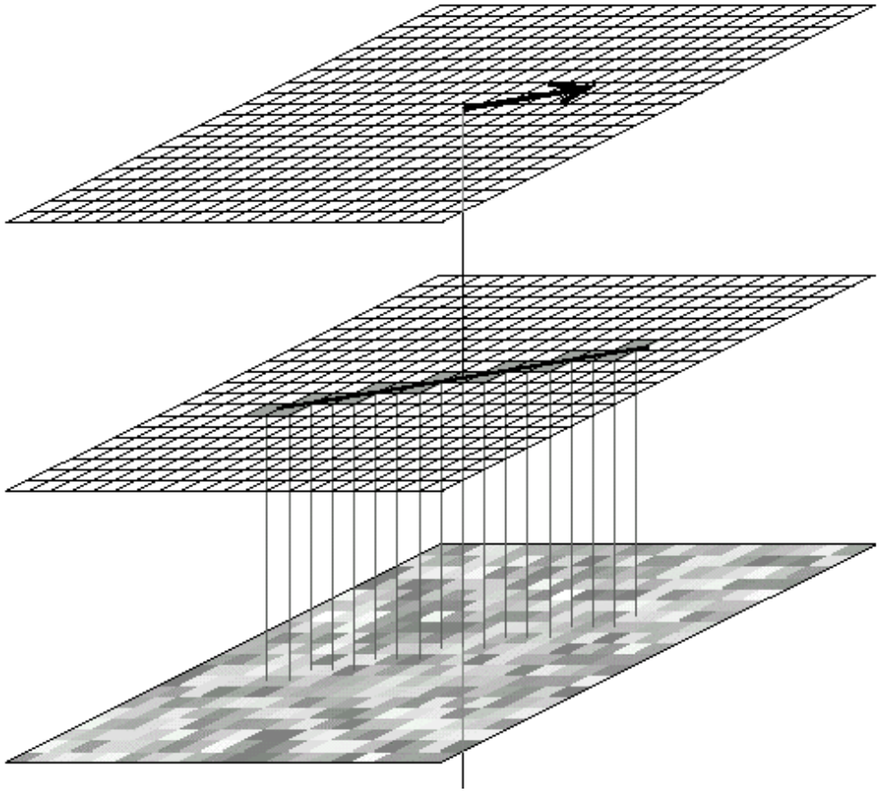
Line Integral Convolution (LIC)

Rather than deposit energy on each pixel, integrate the icon weights with a white noise function



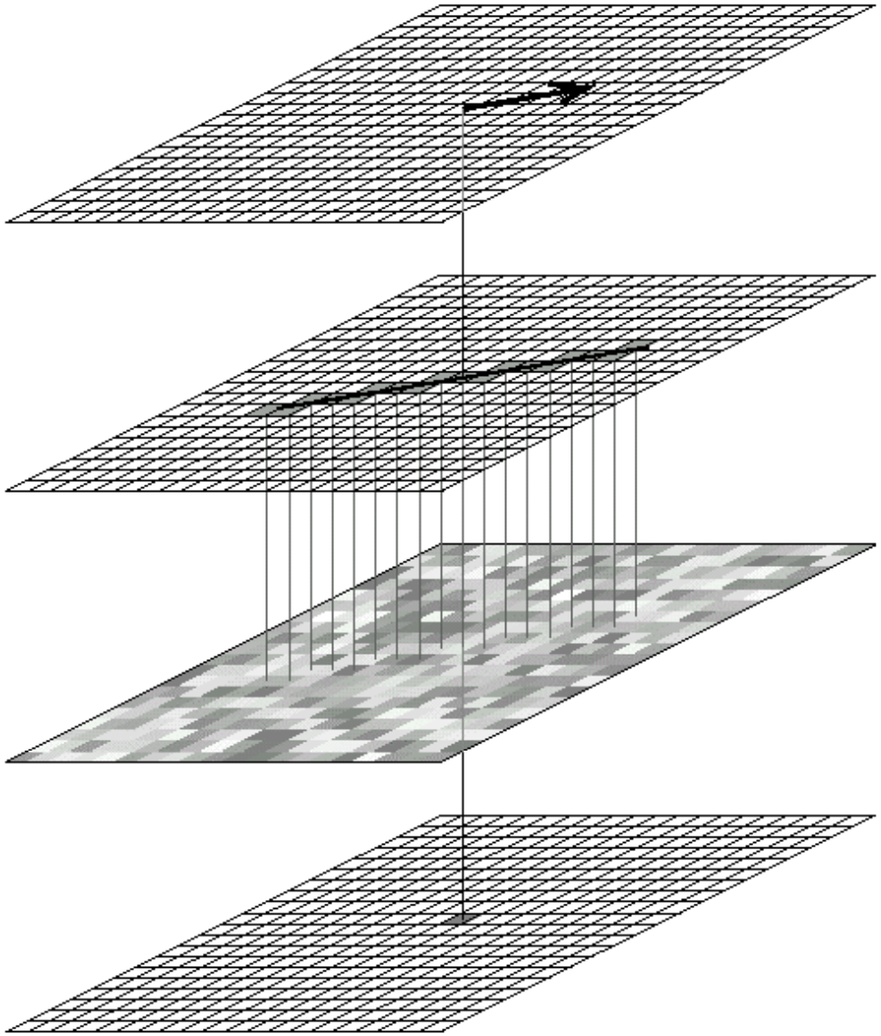
Line Integral Convolution (LIC)

Rather than deposit energy on each pixel, integrate the icon weights with a white noise function



Line Integral Convolution (LIC)

Rather than deposit energy on each pixel, integrate the icon weights with a white noise function

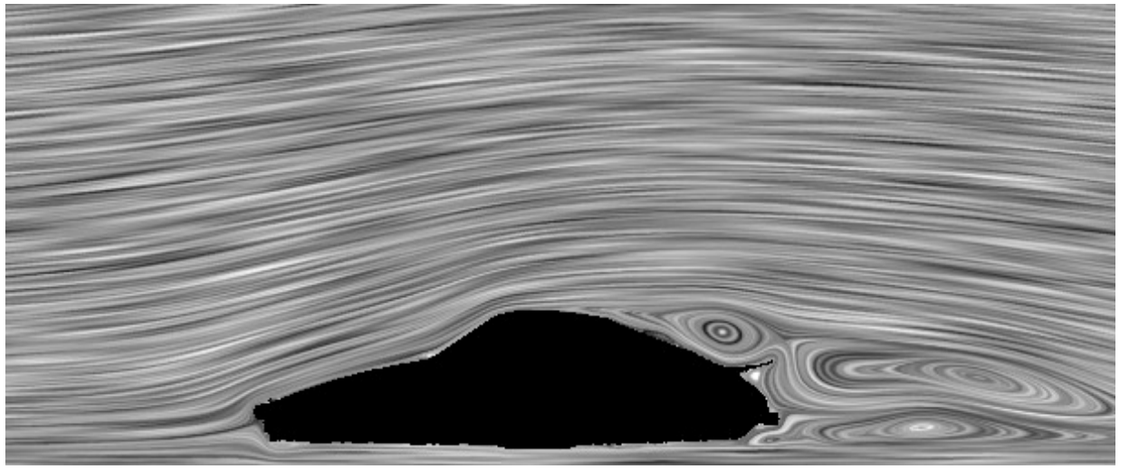


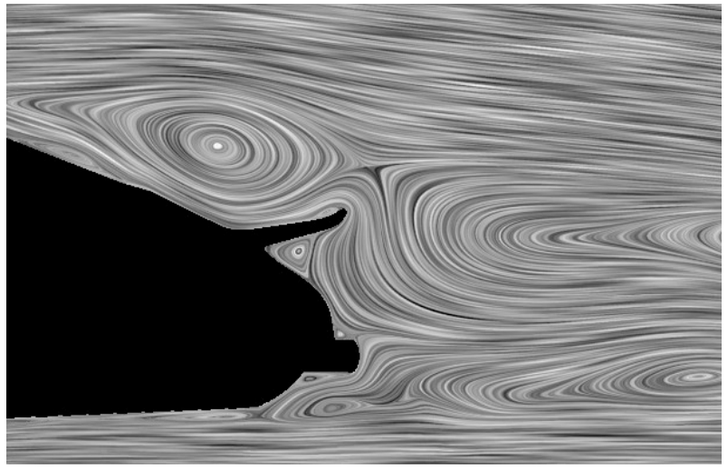
2D LIC: What do LIC images look like?

Smooth change of color along a flow, but rough alternation perpendicular to it

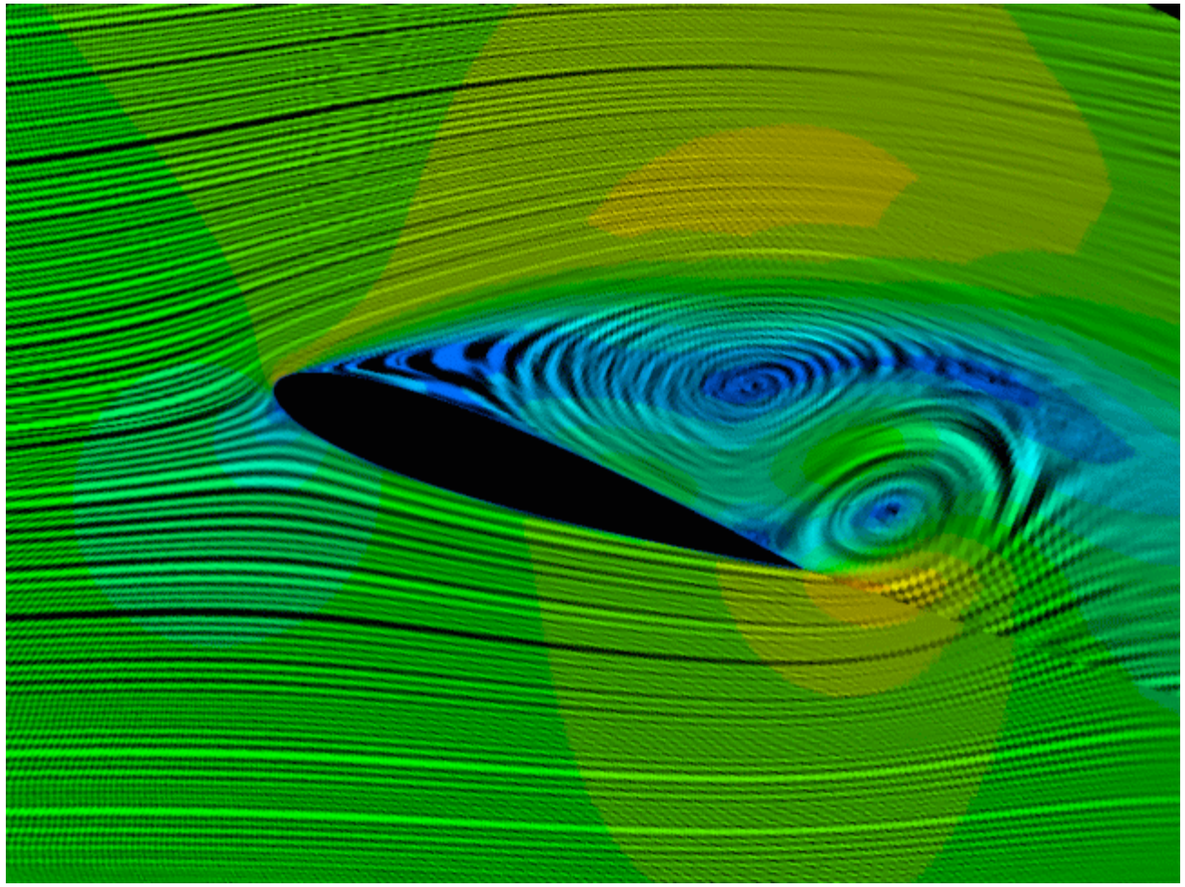
Visual impression like a painting

Depiction of the directional structure of the vector field, but not the magnitude of the flow

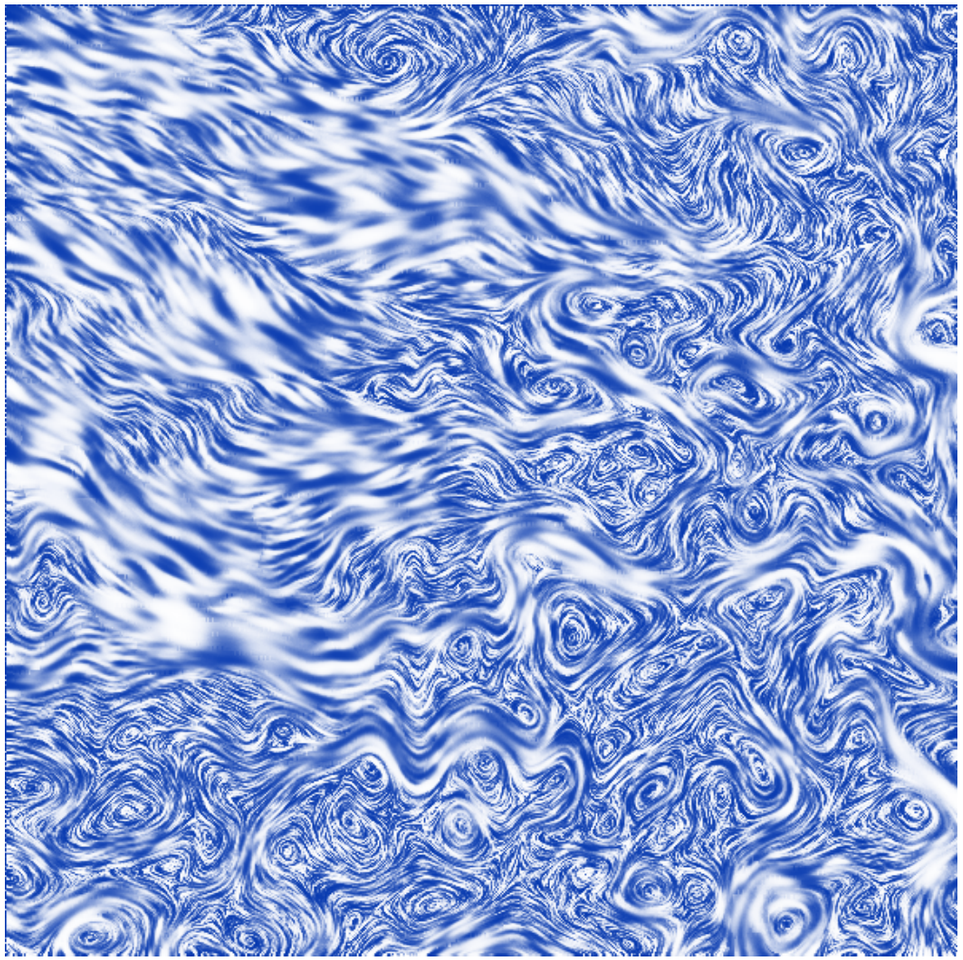


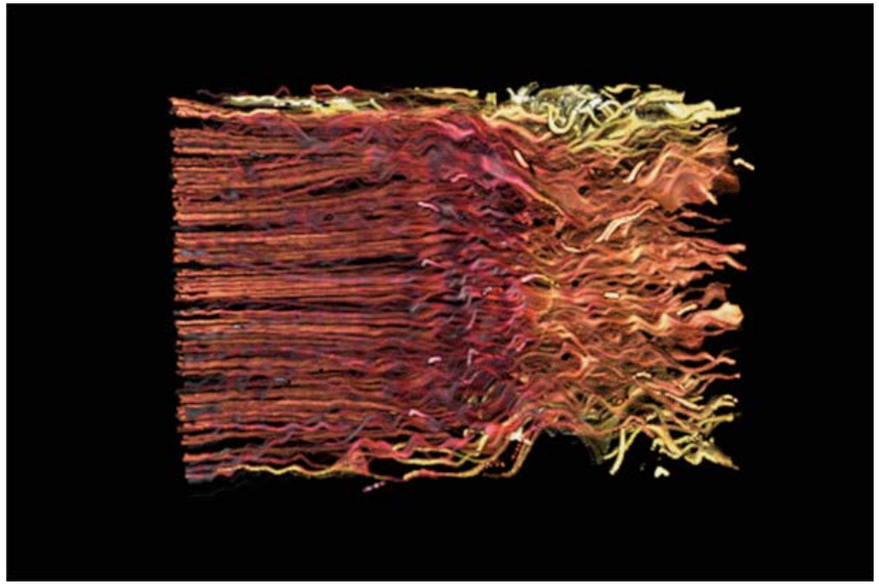


LIC Example: 2D Airfoil (color by magnitude)

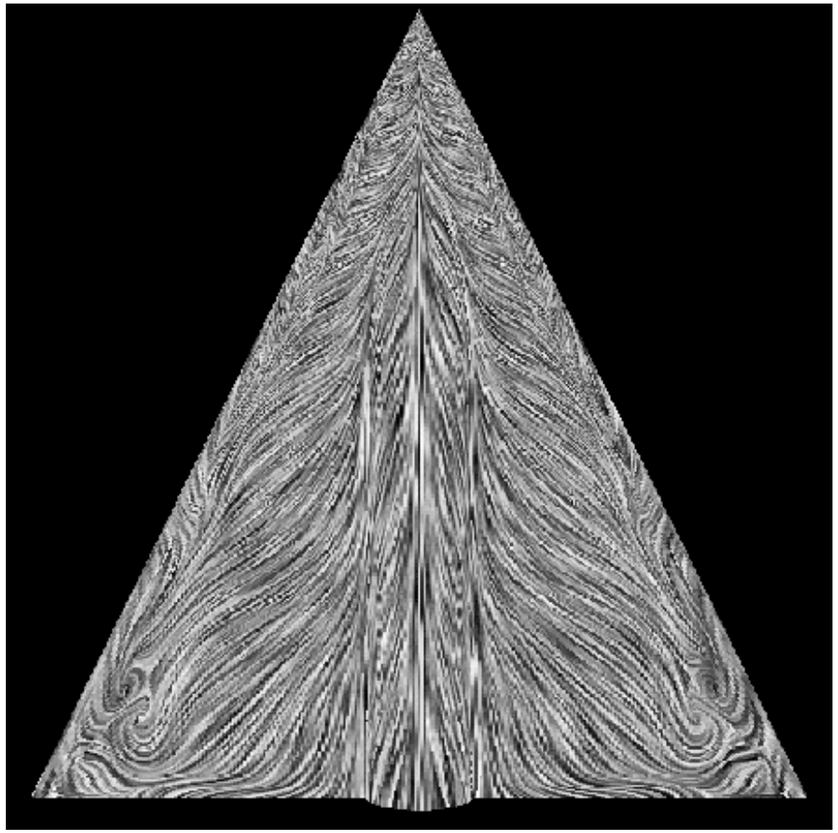


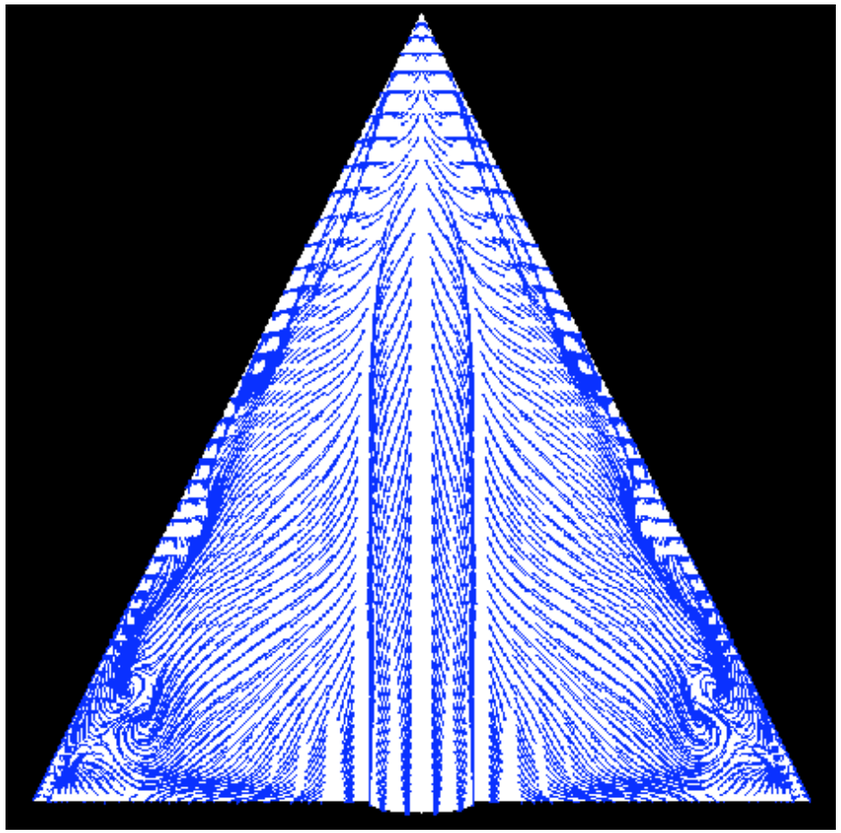
LIC Flow



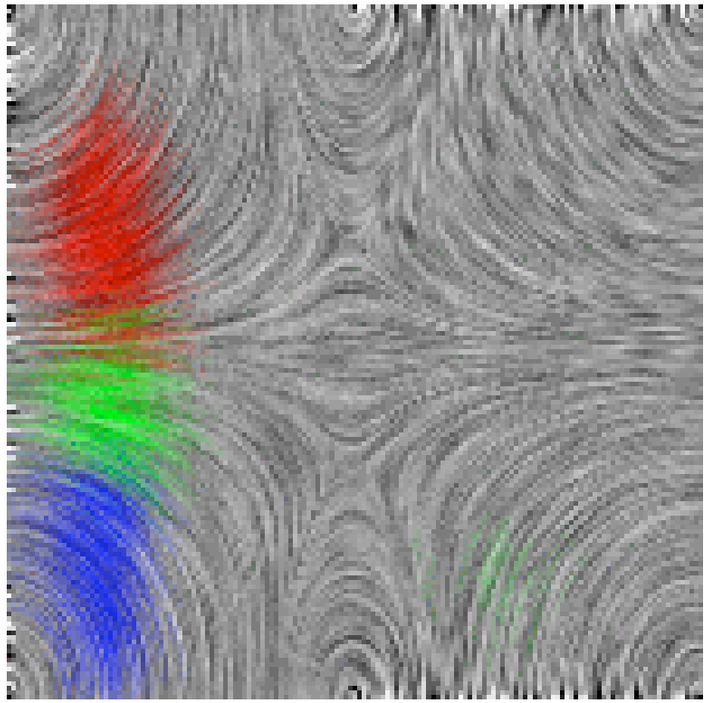


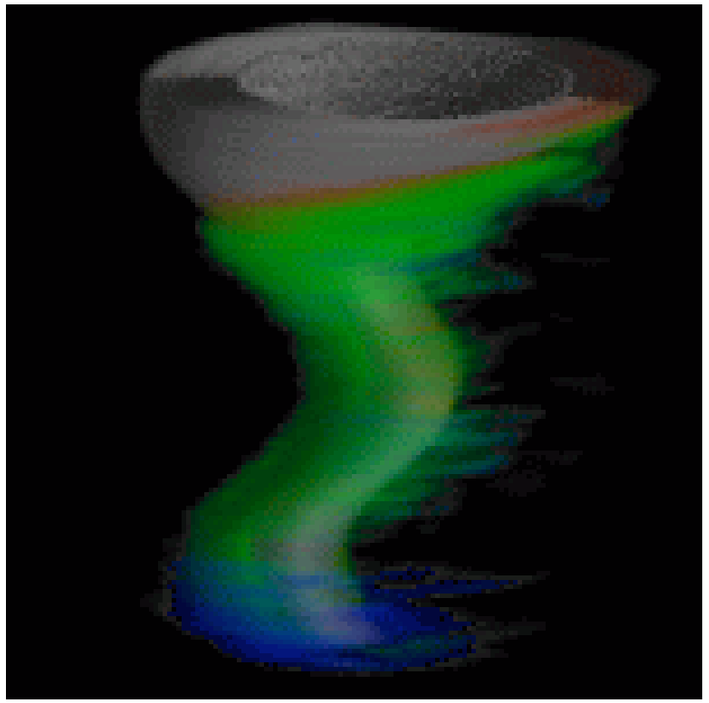
LIC/Streamline Comparison



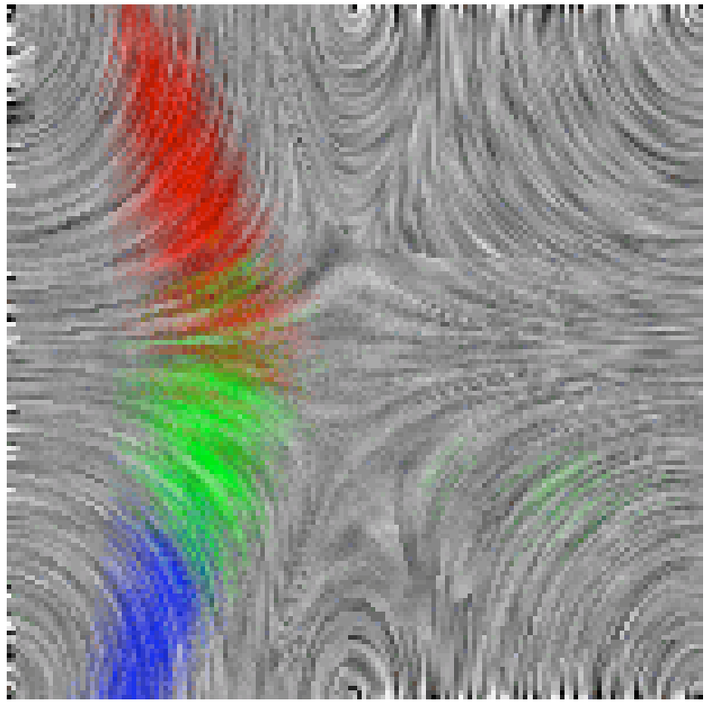


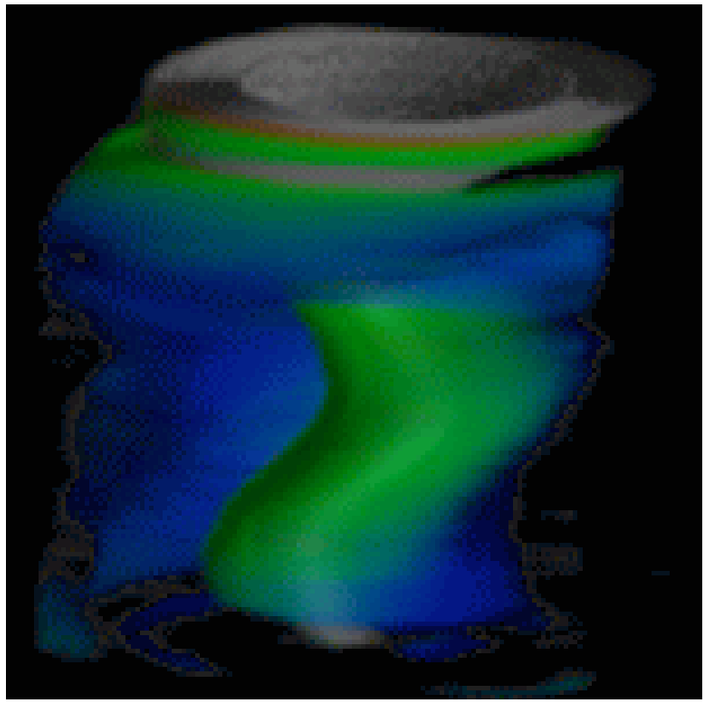
LIC and Dye Advection



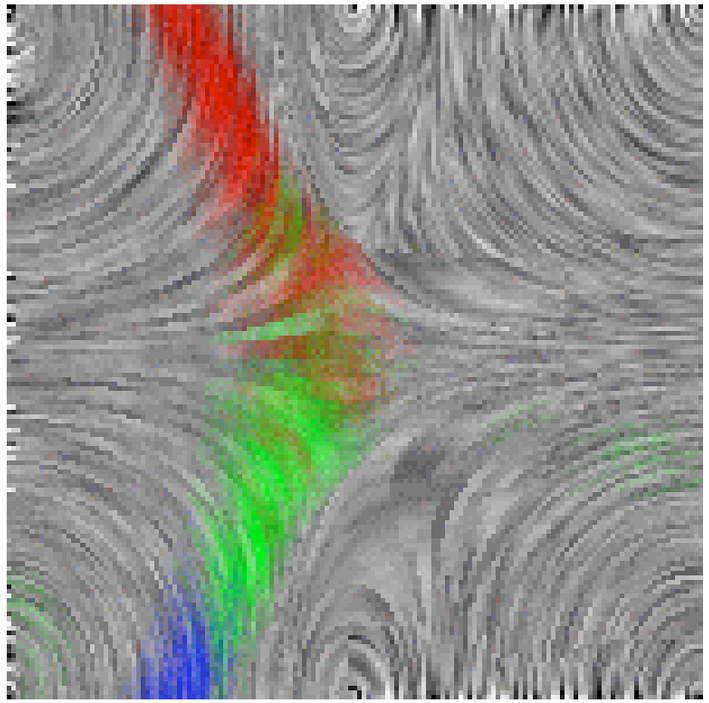


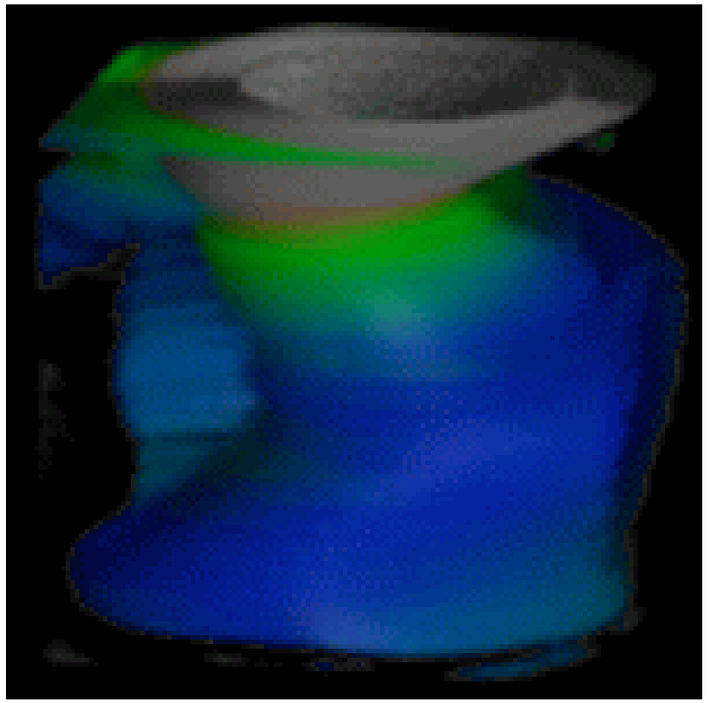
LIC and Dye Advection



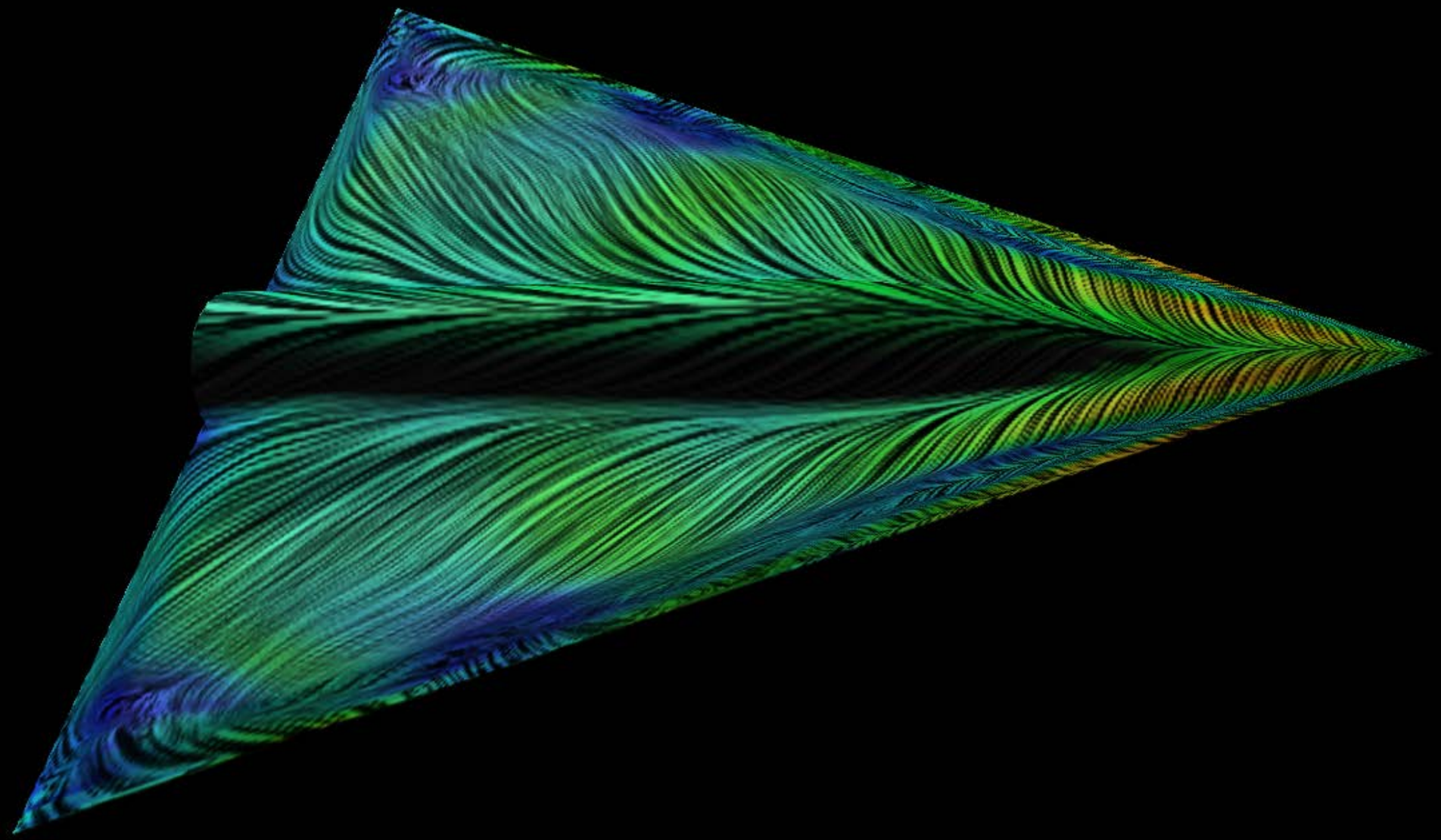


LIC and Dye Advection

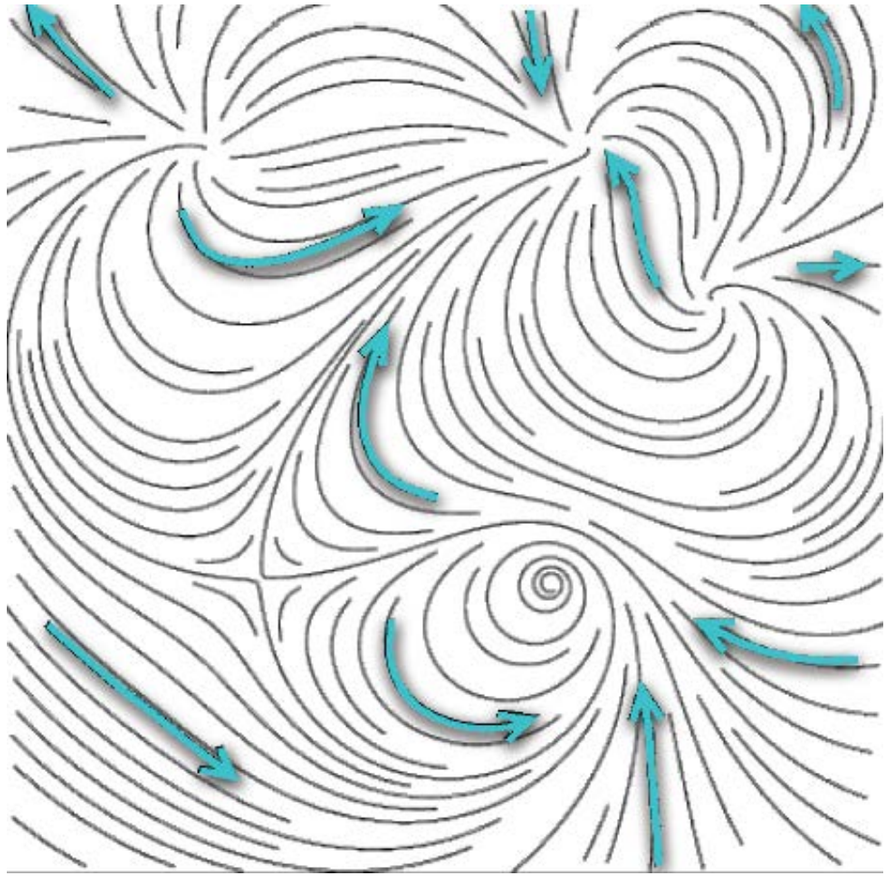




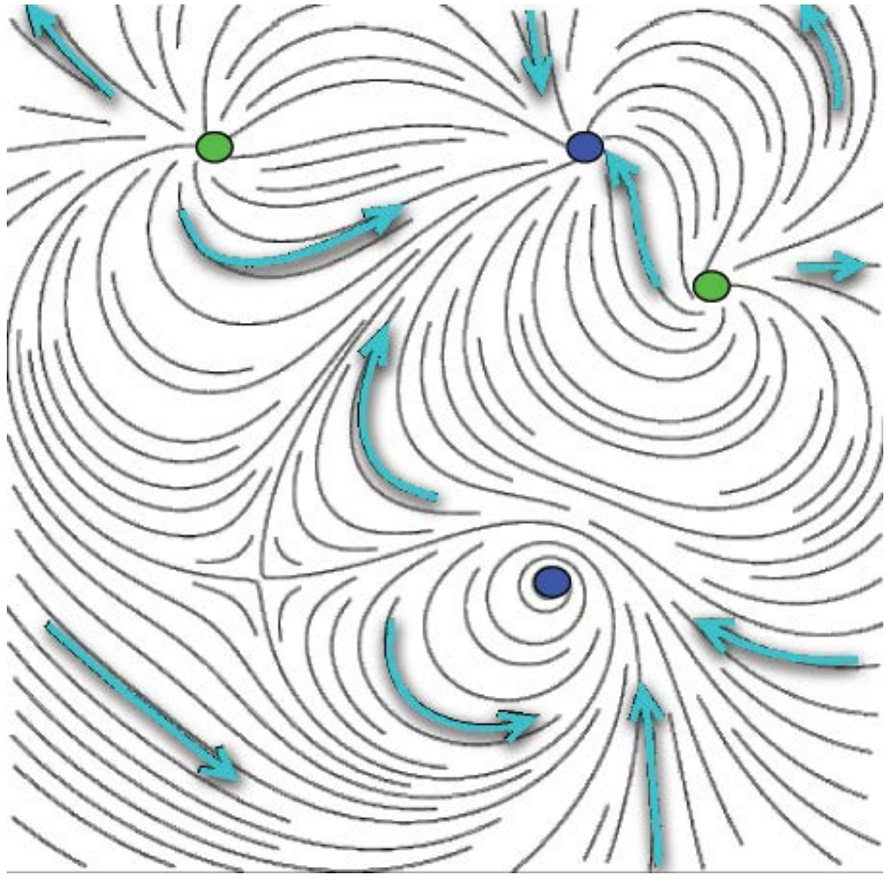
LIC (2D ON 3D SURFACE; COLOR BY MAGNITUDE)



Flow Topology



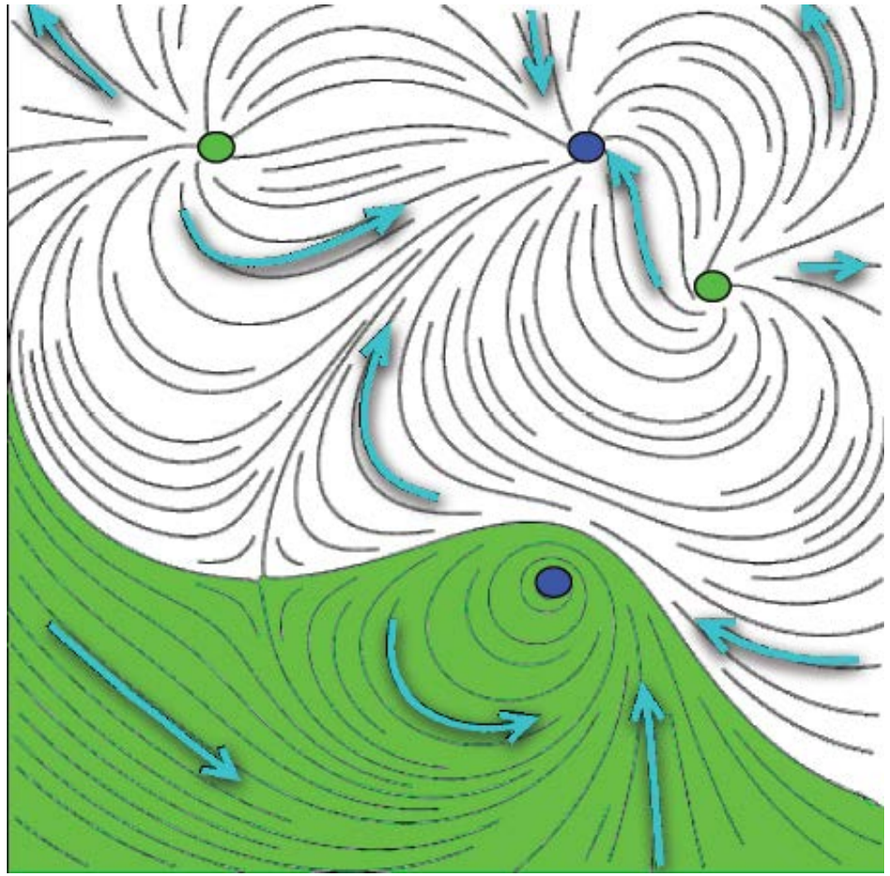
Flow Topology



Source

Sink

Flow Topology

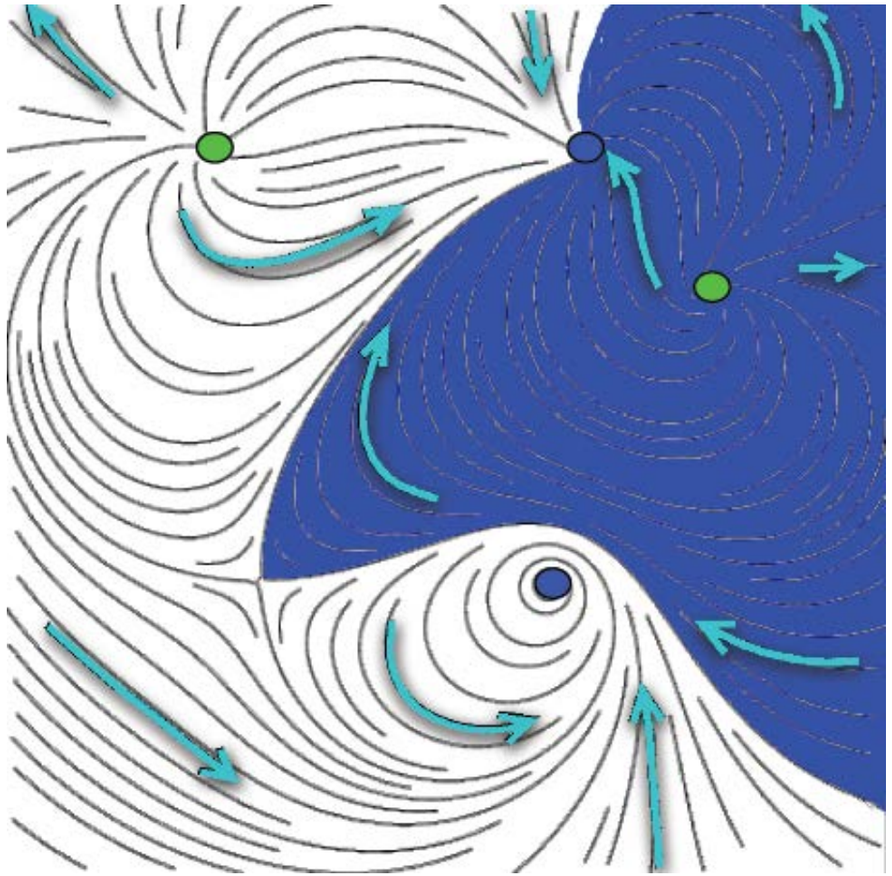


Source

Sink

Sink basin

Flow Topology

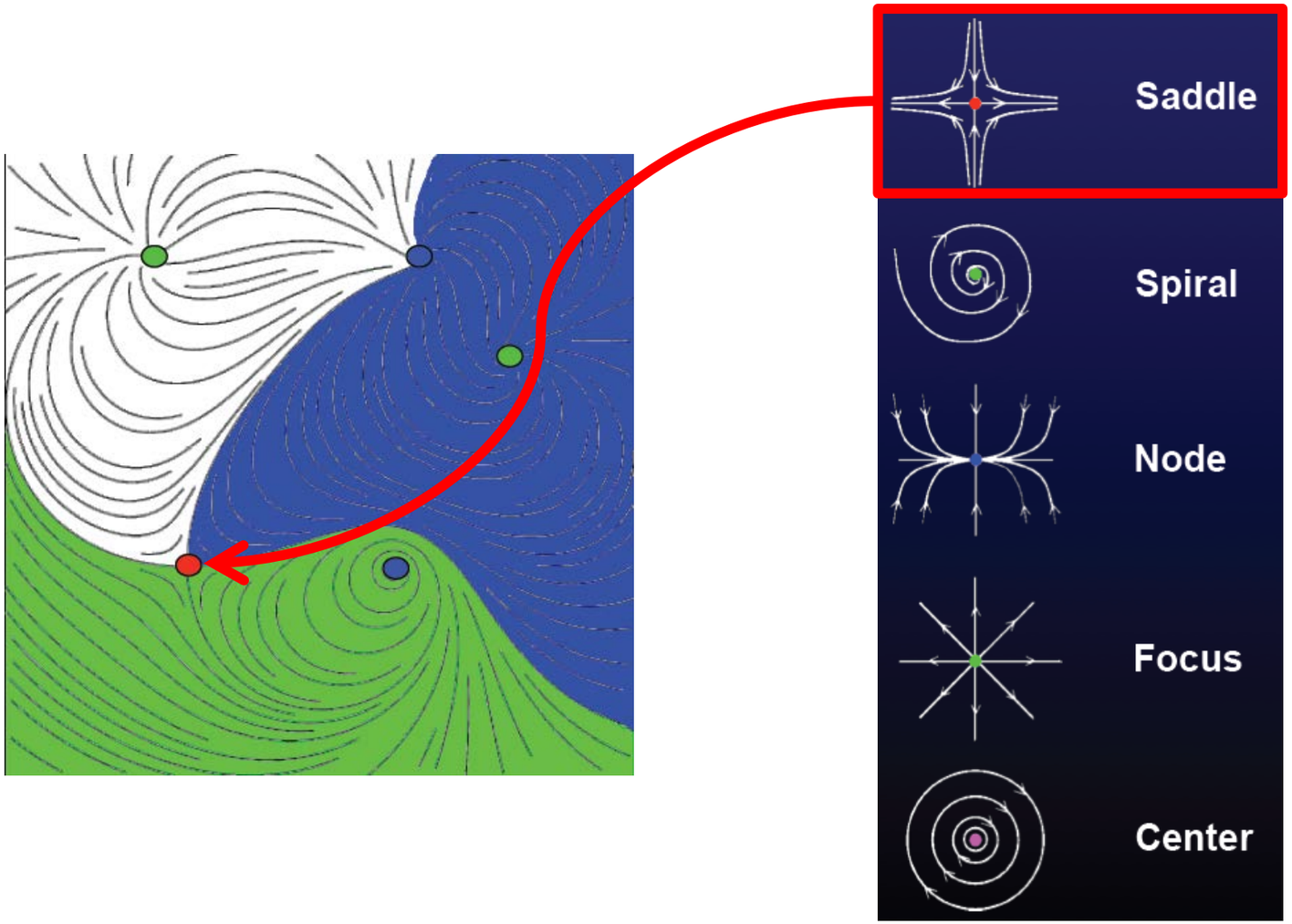


Source

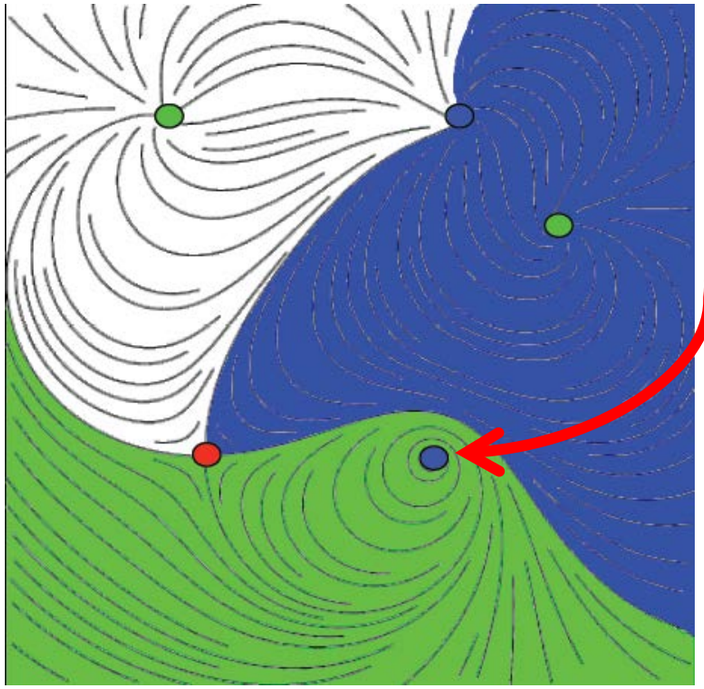
Sink

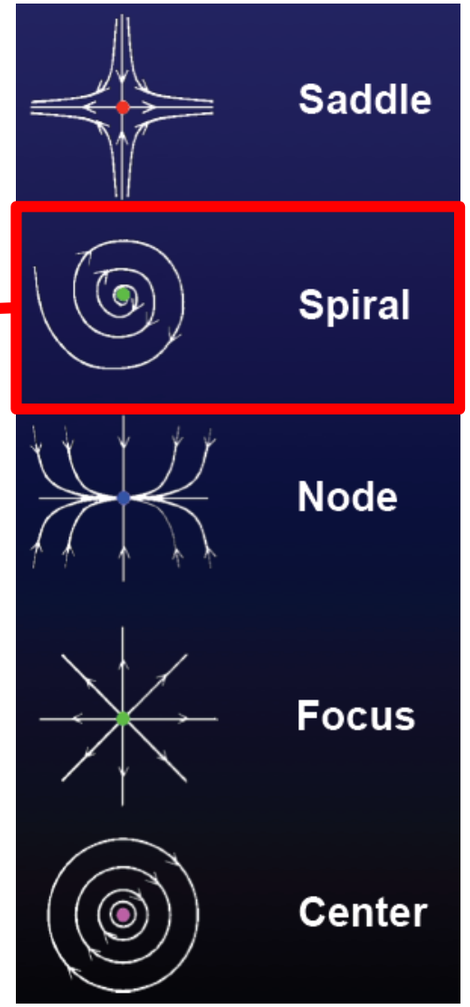
Source basin

Flow Topology – Critical Points

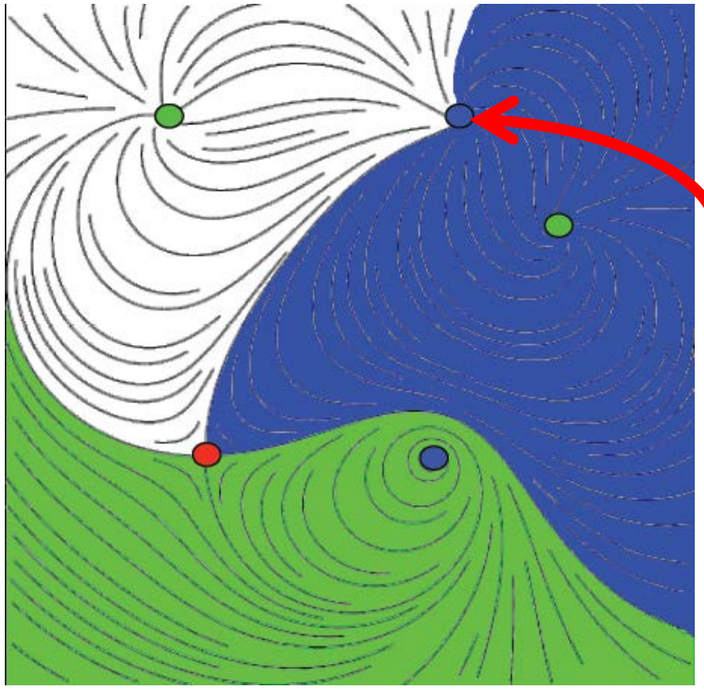


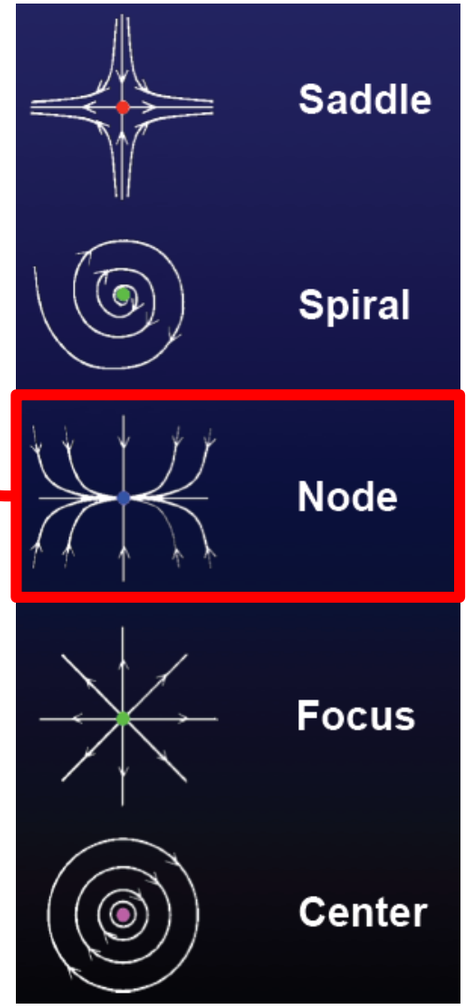
Flow Topology – Critical Points



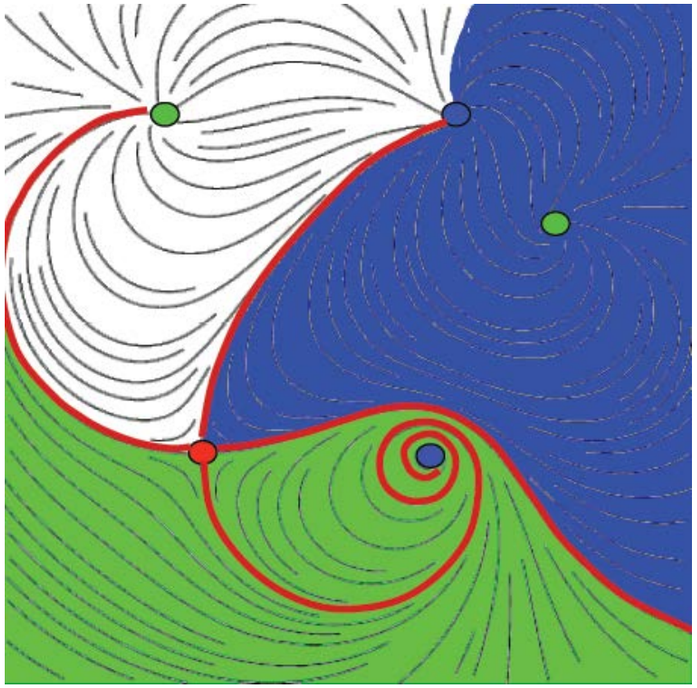


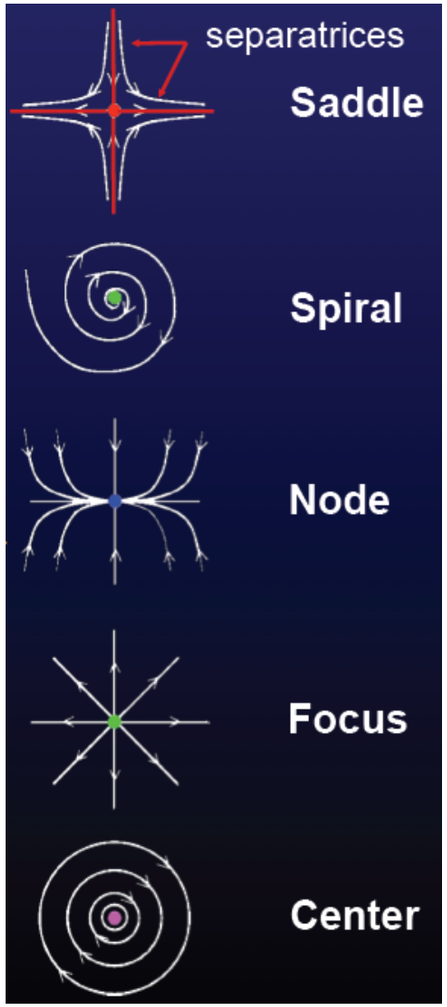
Flow Topology – Critical Points



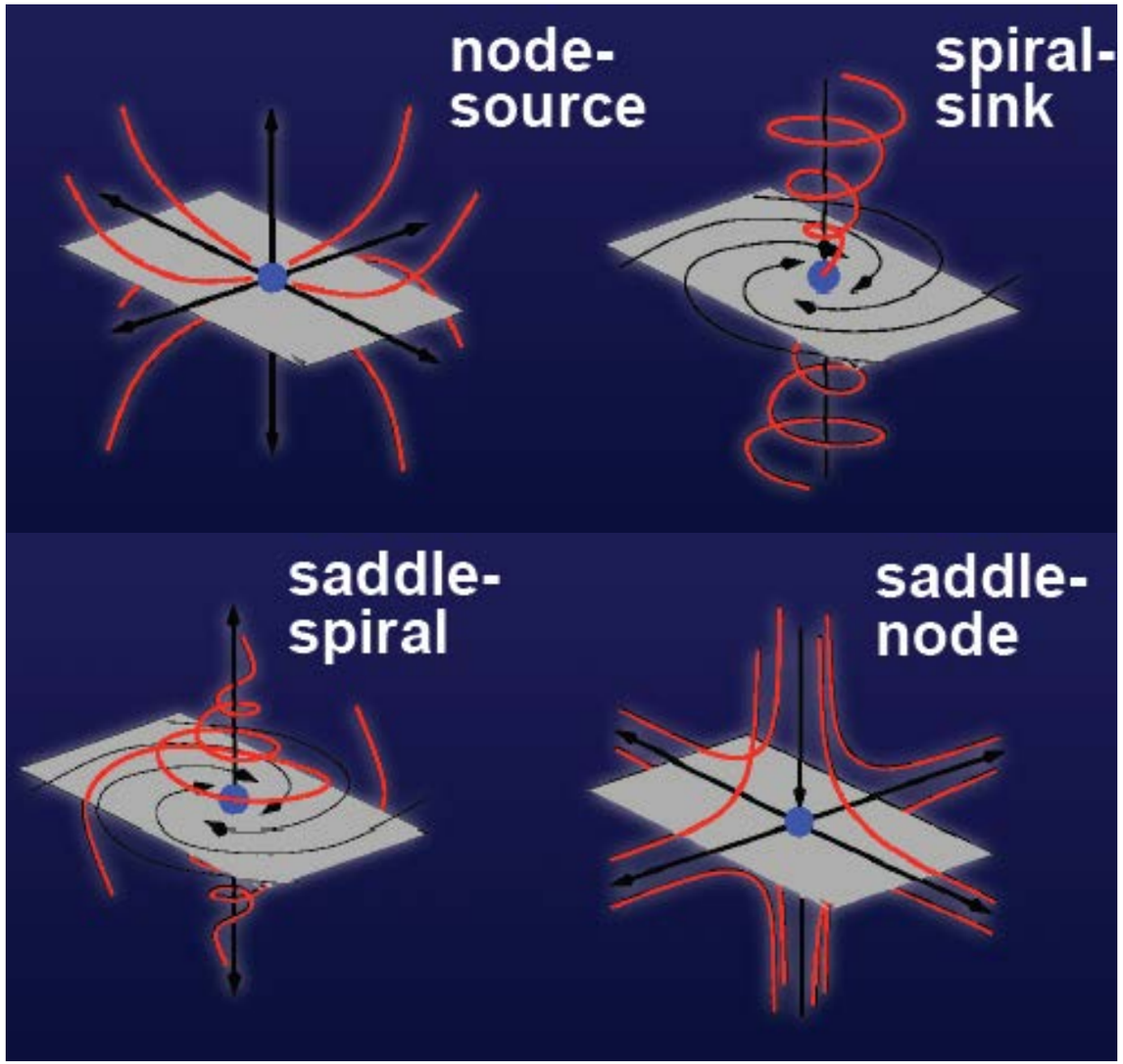


Flow Topology – Topological Skeleton





Flow Topology – 3D Critical Point



Feature Stability and Cancellation

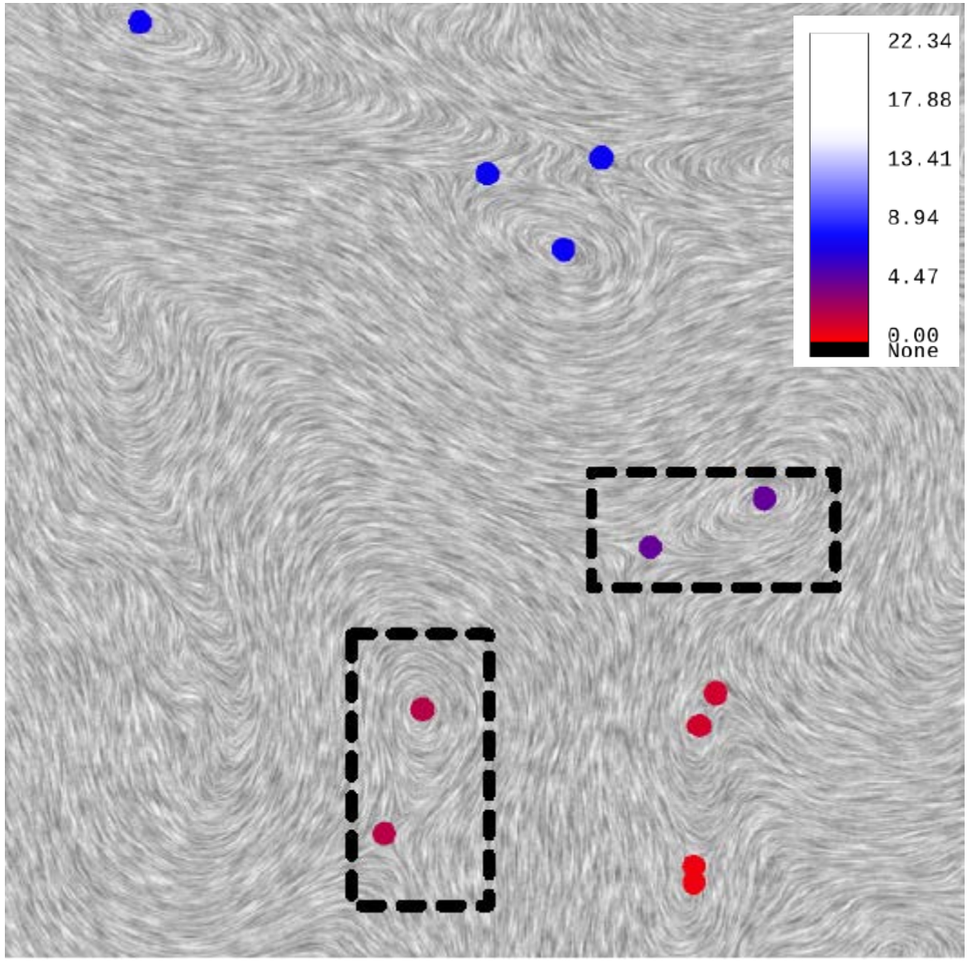
Robustness is measure that determines how much a vectorfield must be perturbed to cancel critical points

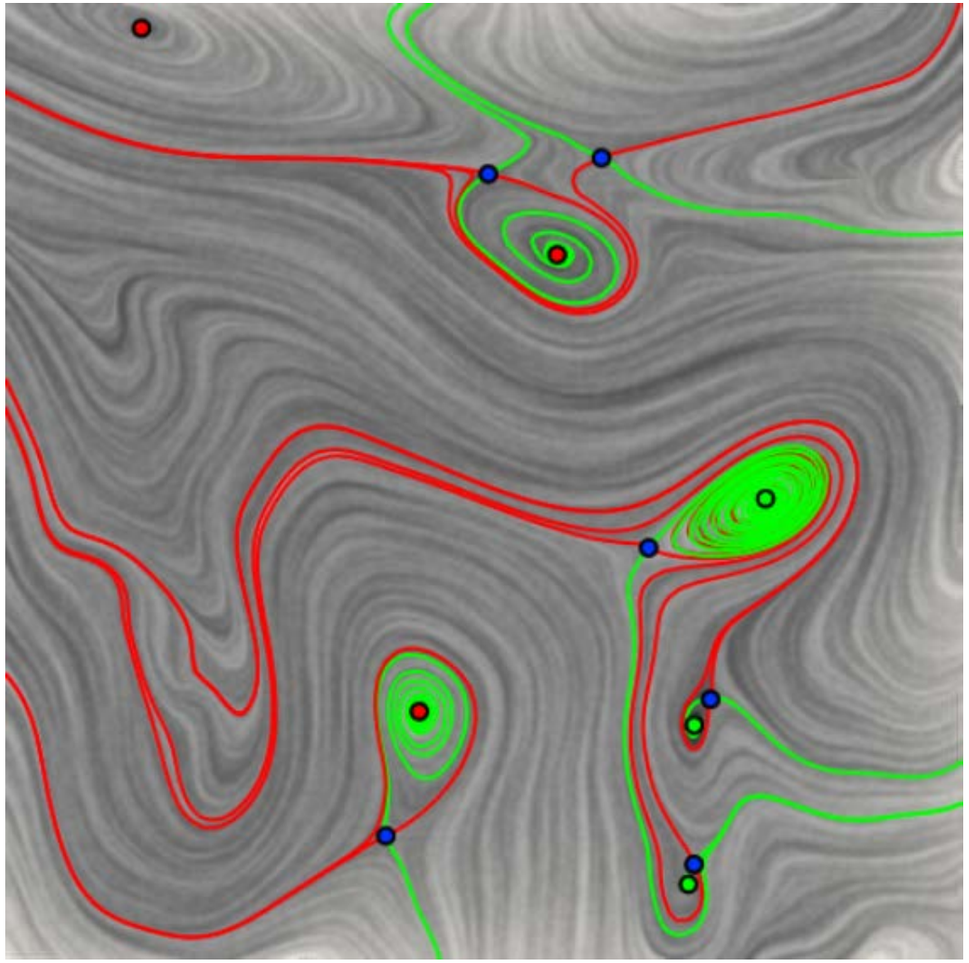
Critical points with *low robustness* may represent *noise* in the data

Cancelling point with low robustness may improve interpretation

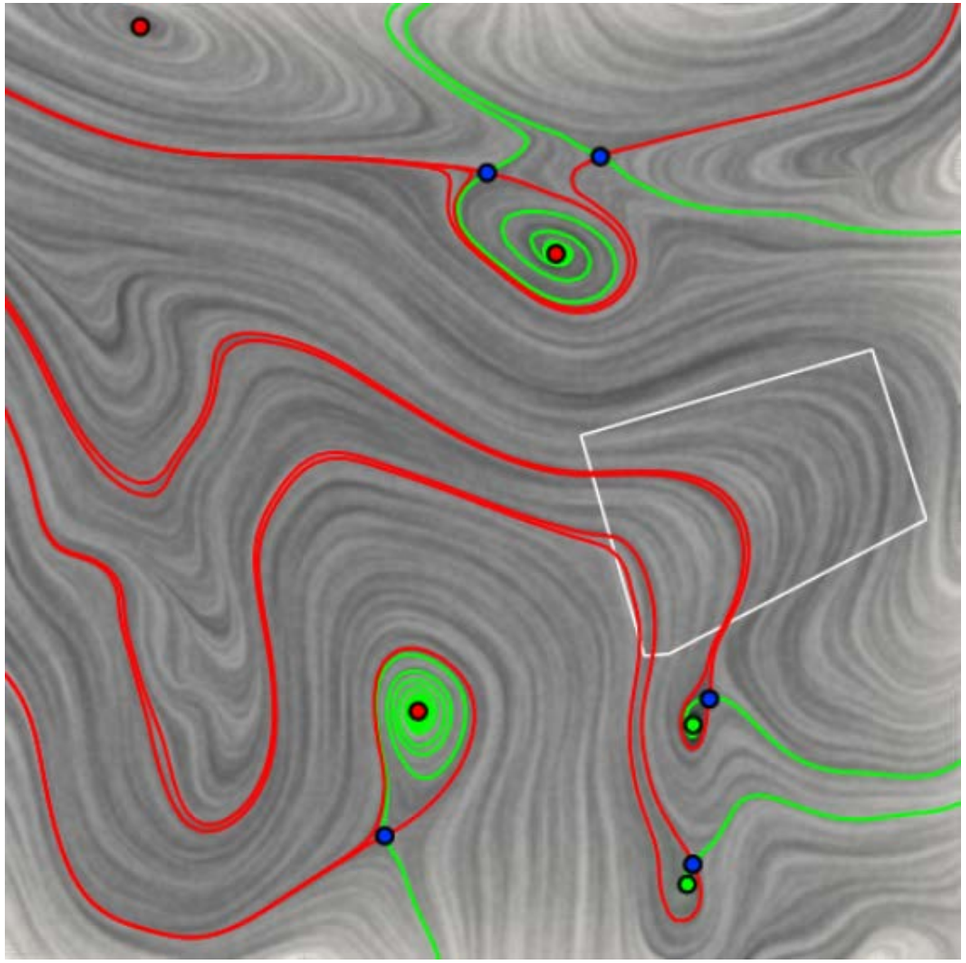
Skraba, Wang, Chen, Rosen 2014

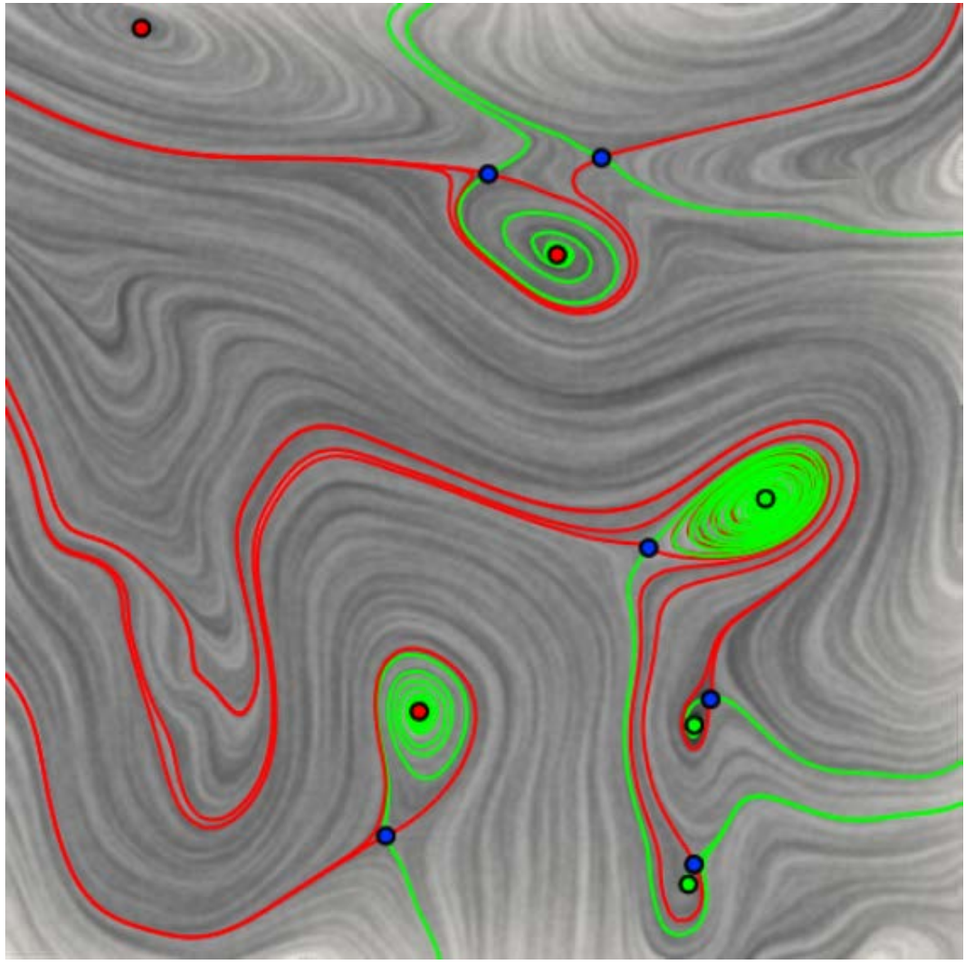
Feature Stability and Cancellation



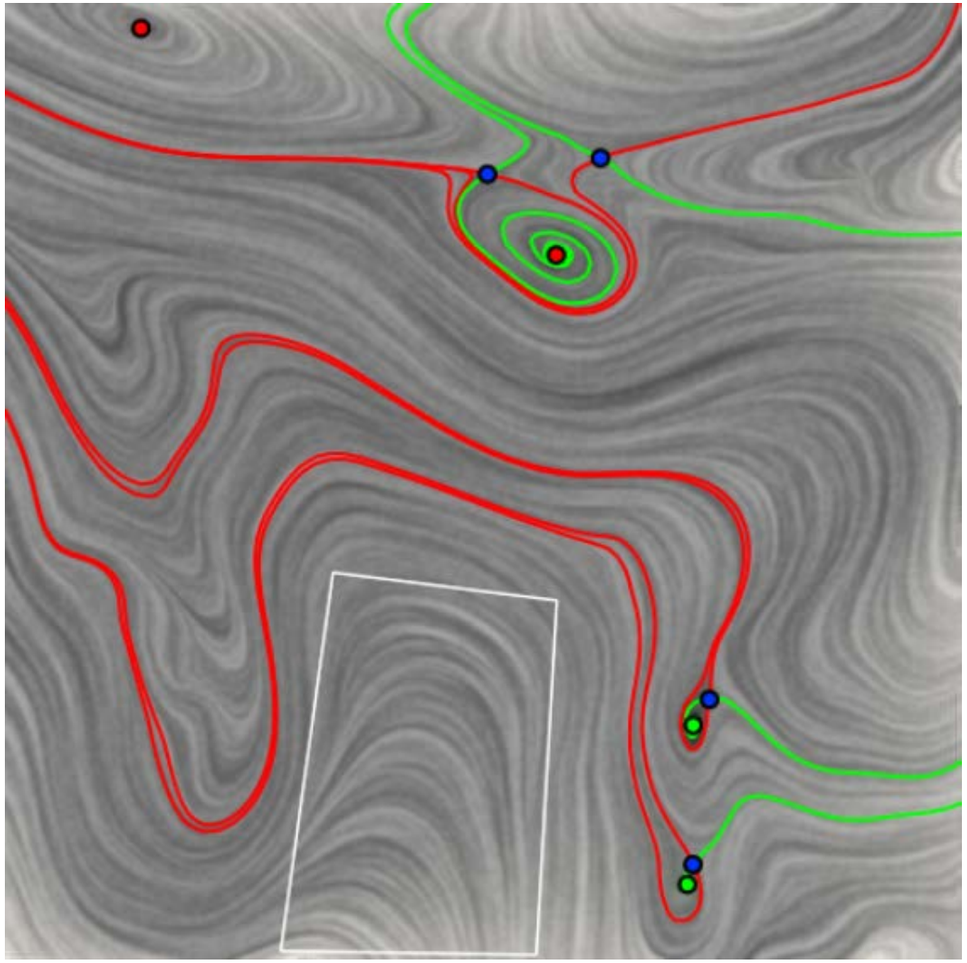


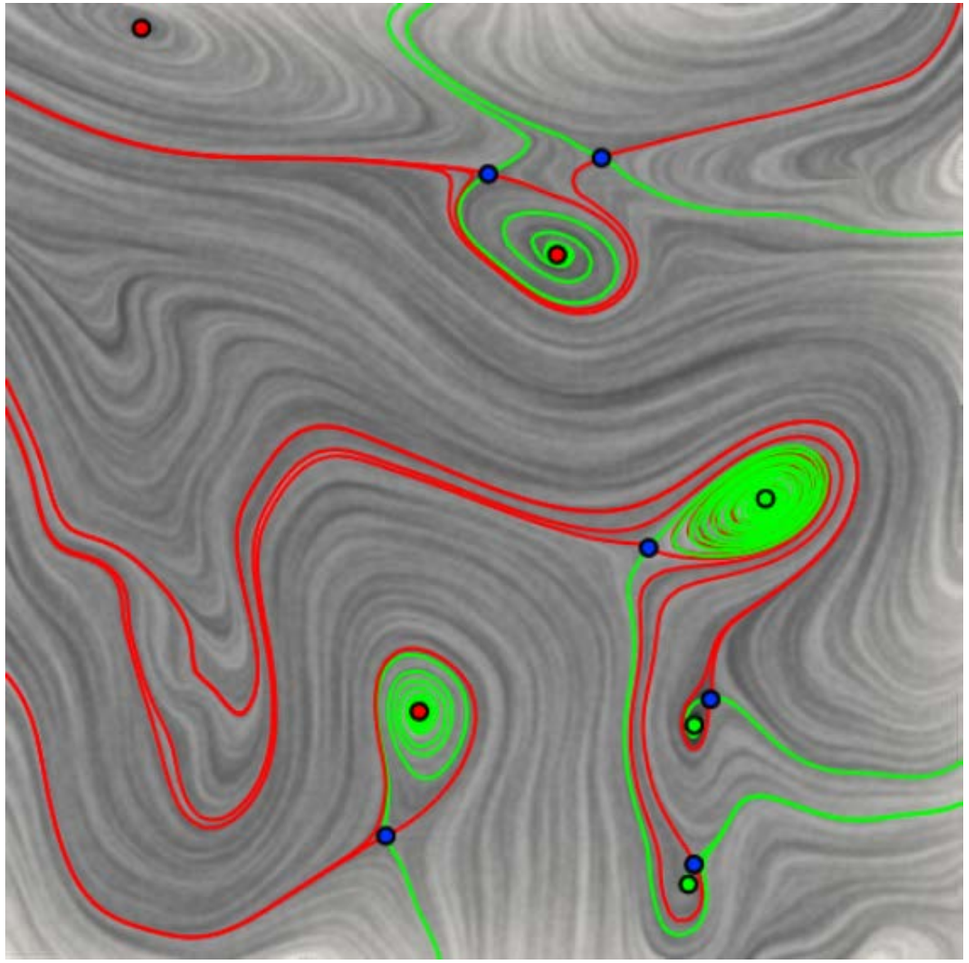
Feature Stability and Cancellation





Feature Stability and Cancellation





Discussion: SciVis 2015 Best Paper

Visualization-by-Sketching

An Artist's Interface for Creating Multivariate Time-Varying Data Visualizations

David Schroeder and Daniel F. Keefe
Interactive Visualization Lab
Department of Computer Science and Engineering
University of Minnesota

{daschroe, keefe}@cs.umn.edu