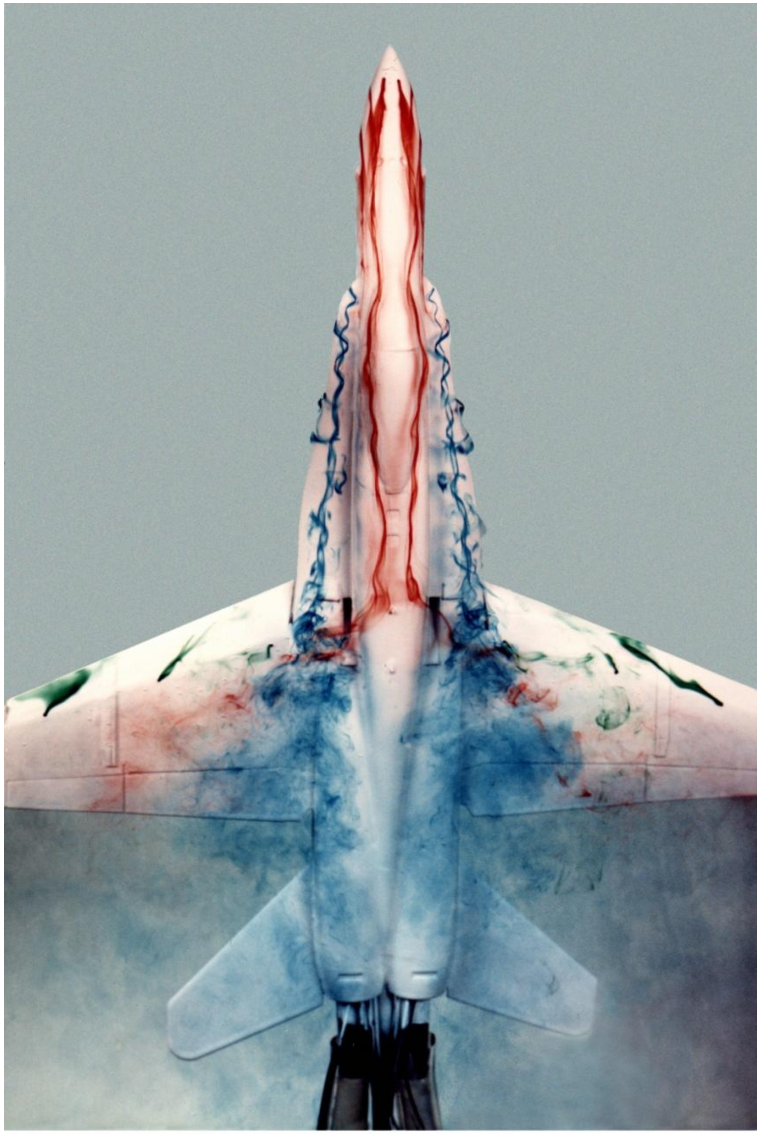
2D Vector Field Visualization

Experimental Flow Vis

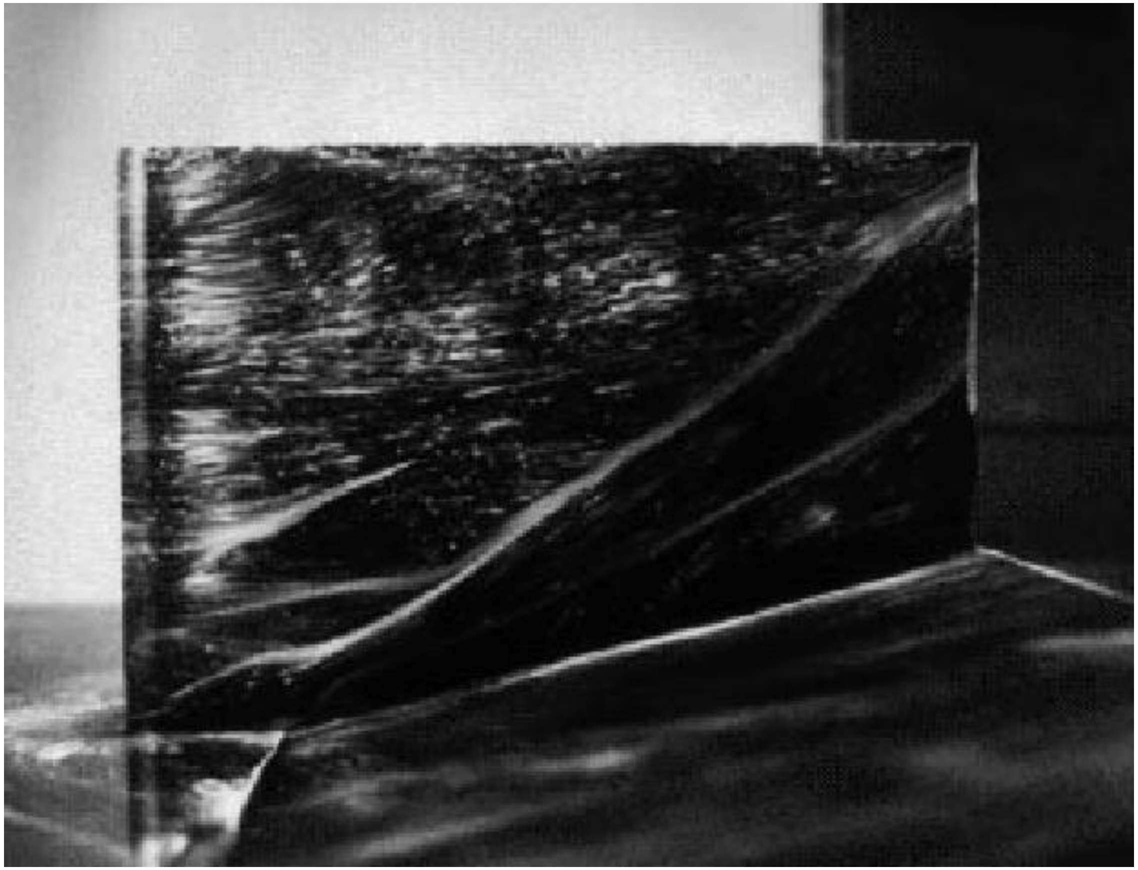


NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/gallery/photo/index.html
NASA Photo: ECN-33298-03 Date: 1985

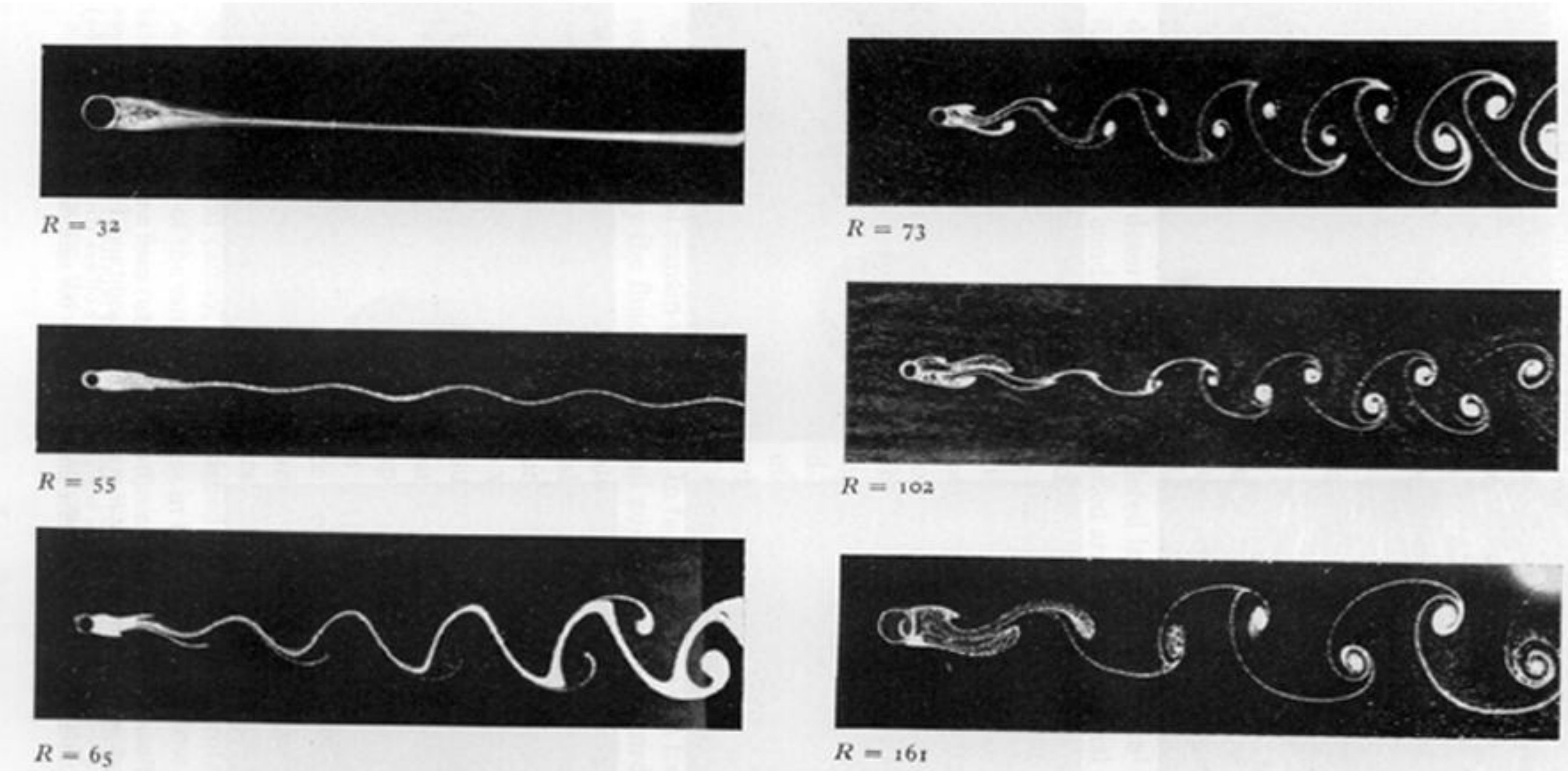
1/48-scale model of an F-18 aircraft in Flow Visualization Facility (FVF)

Dryden Flight Research Center ECN 33298-47 Photographed 1985
F-18 water tunnel test in Flow Visualization Facility NASA/Dryden

Experimental Flow Vis



Experimental Flow Vis



Experimental Flow Vis

Why would we not stick with these?

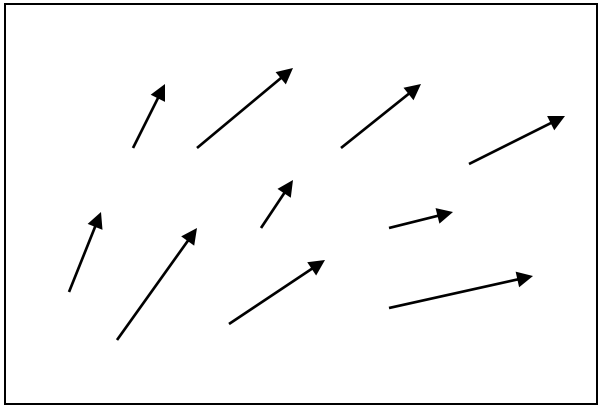
Vectors

- Directional information
- Wind, mechanical forces (earthquakes)
- **Flows**
- Harder: more than one pixel per vector
    - Clutter

Vector Field Visualization

-A vector field: F(U) = V

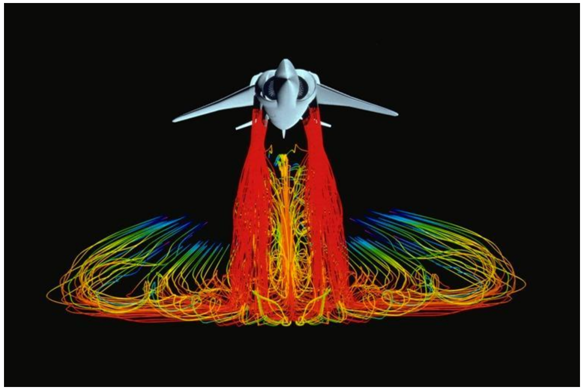
U: field domain (x,y) in 2D
V: vector (u,v)

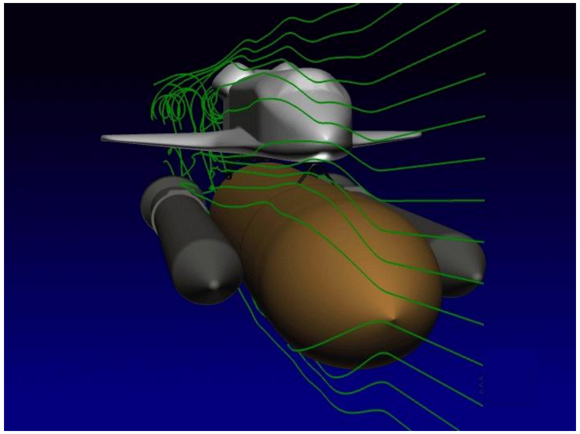


-Like scalar fields, vectors are defined at discrete points:
-interpolation issues

Visualization techniques

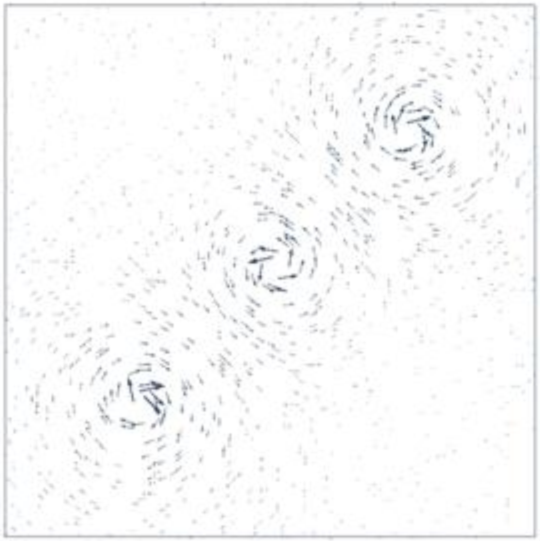
- Geometry-based methods: rendering primitives built from particle trajectories
  - Glyphs
  - streamlines
  - pathlines
  - streaklines
  - topology
  - LIC
  - …….

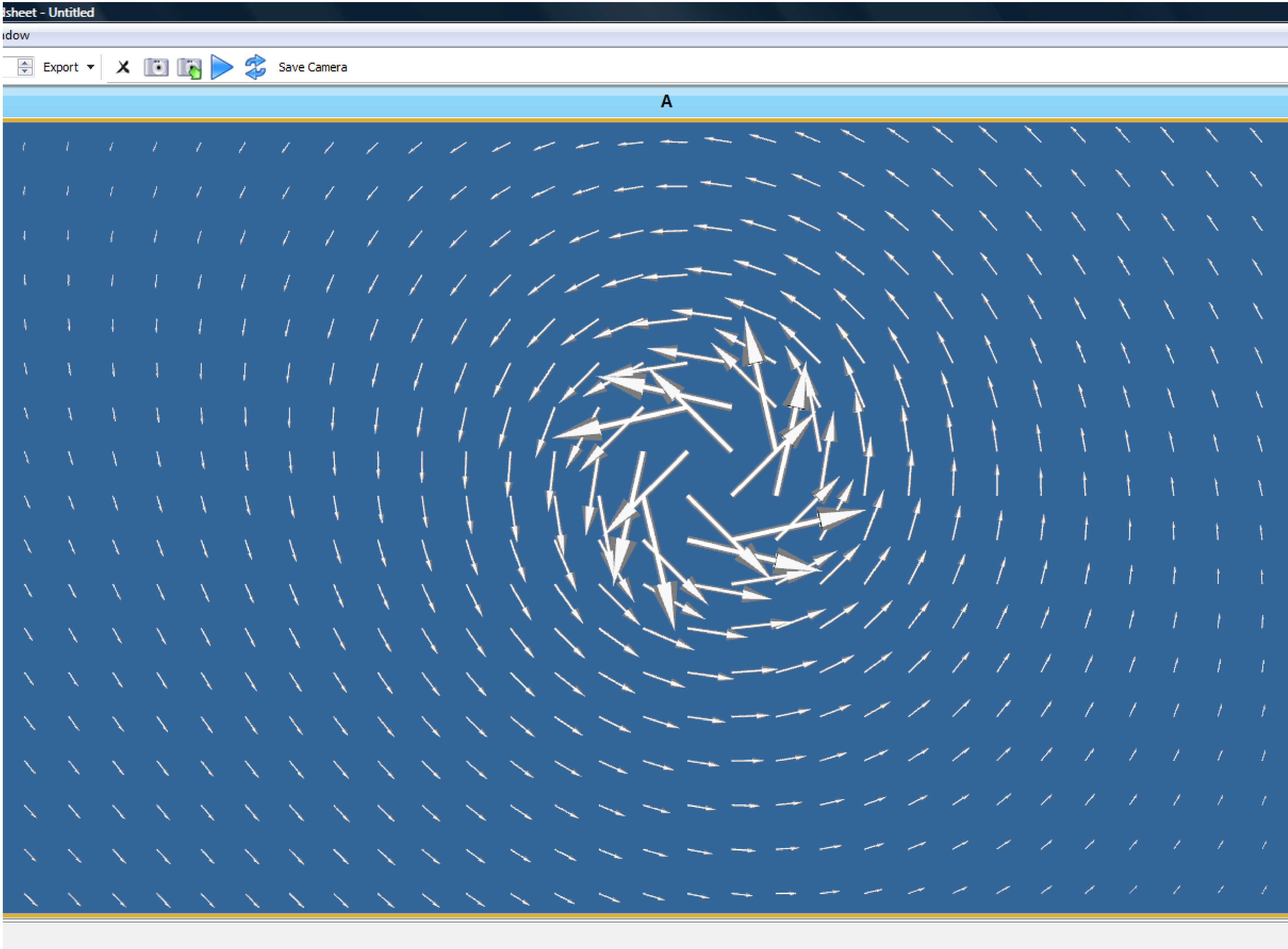




Glyphs

- Place symbols over vector field
  - Regularly spaced
  - Randomly spaced
  - Scale
- Watch out for clutter

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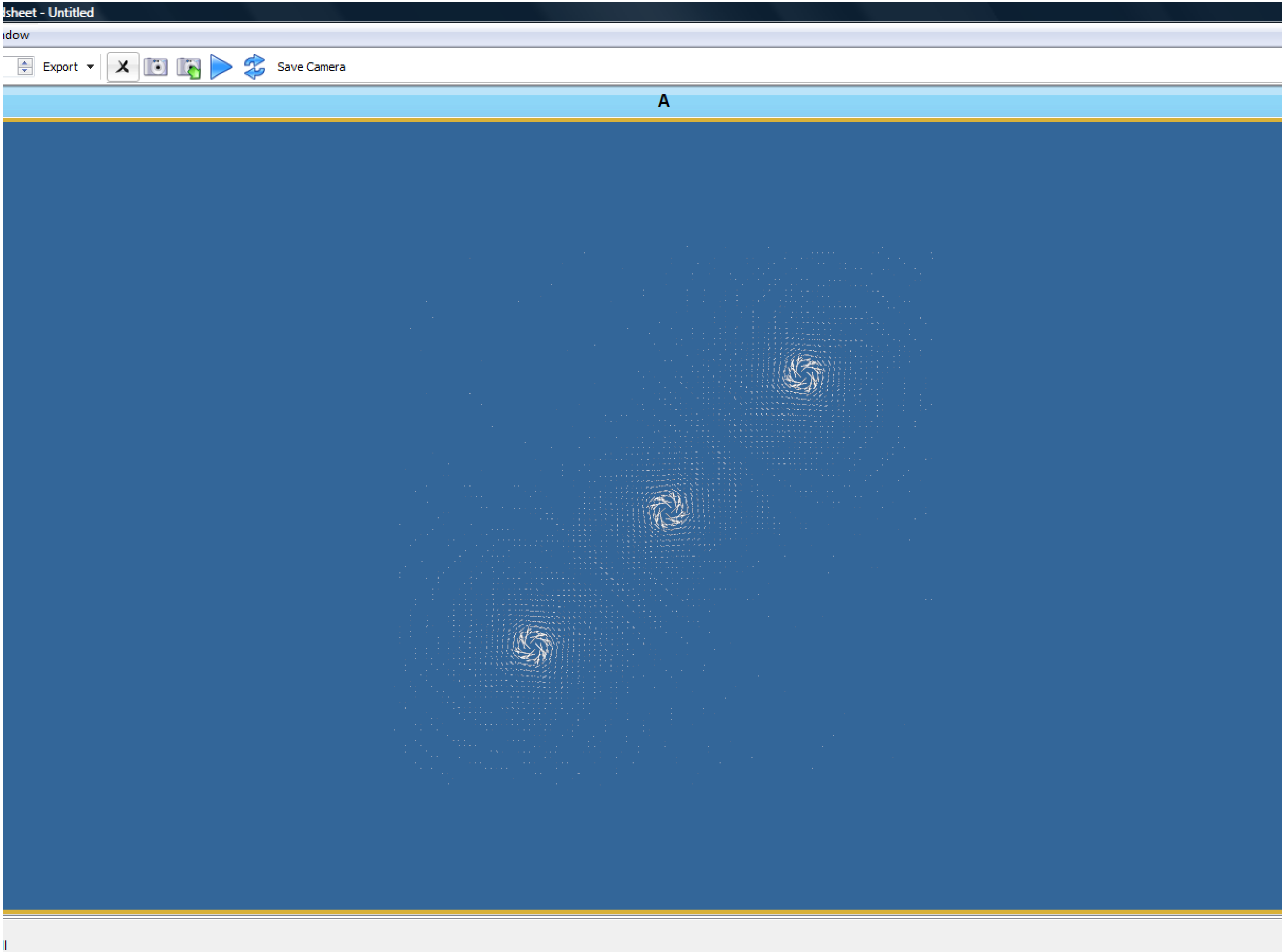

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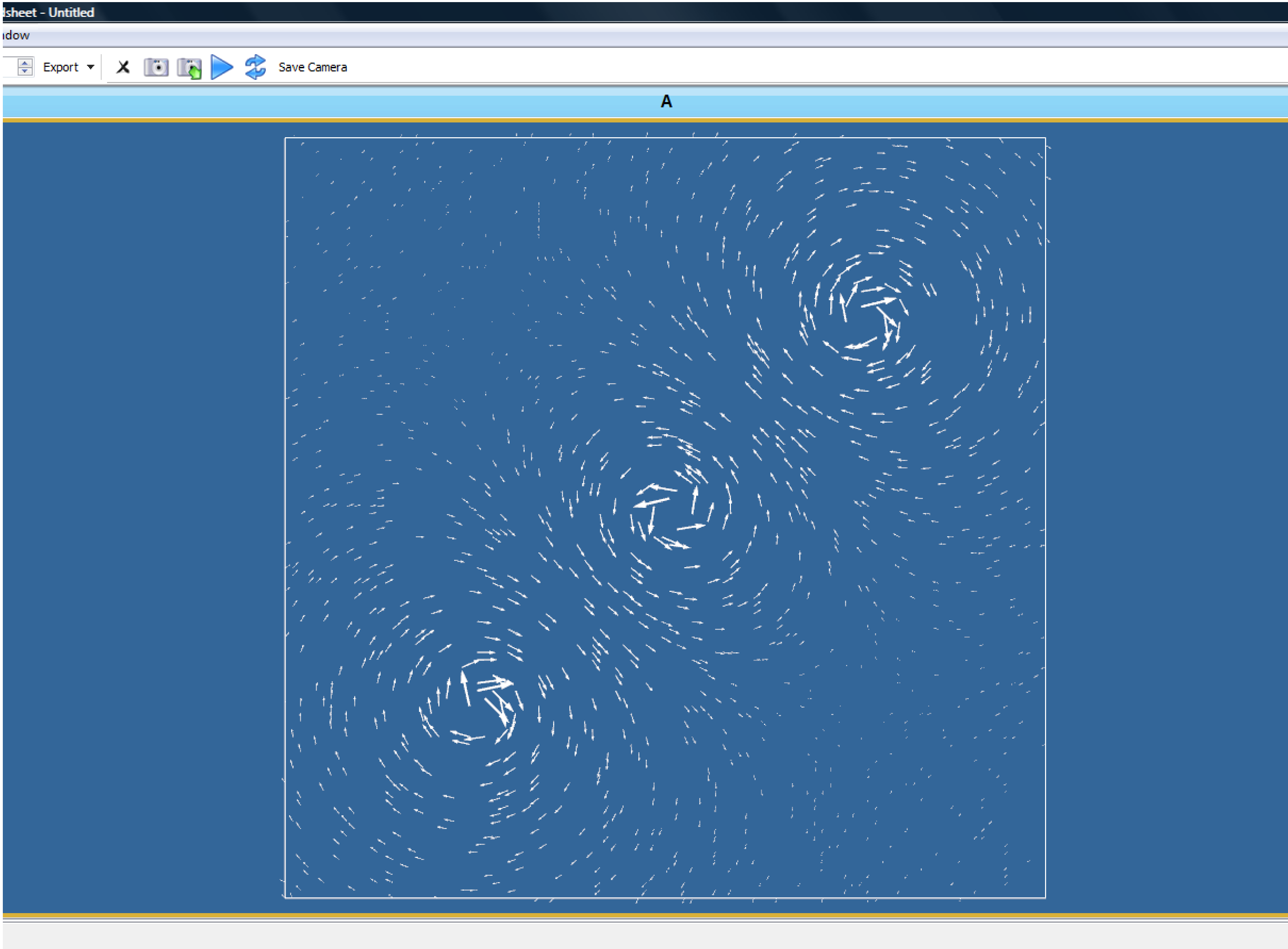
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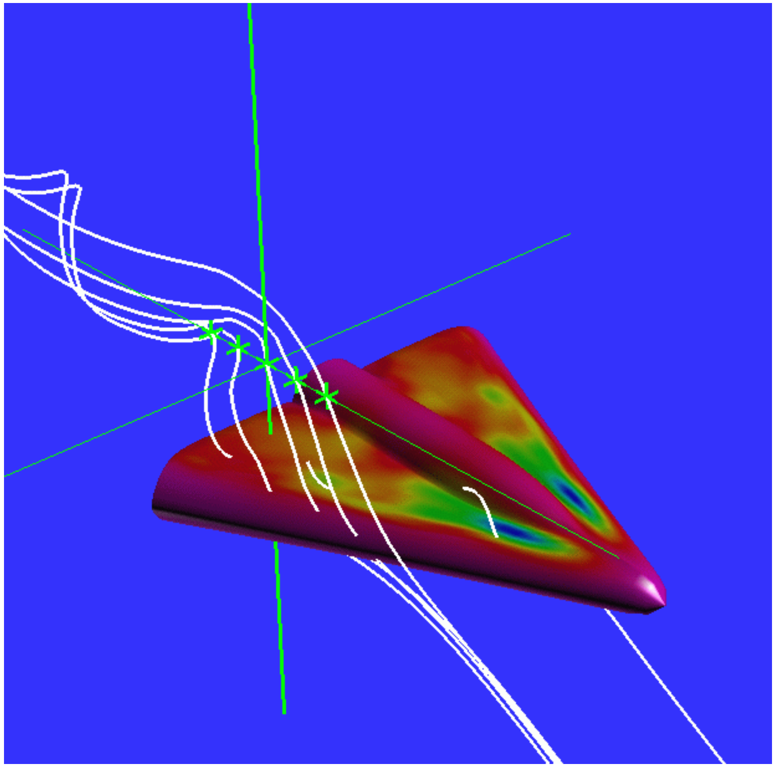
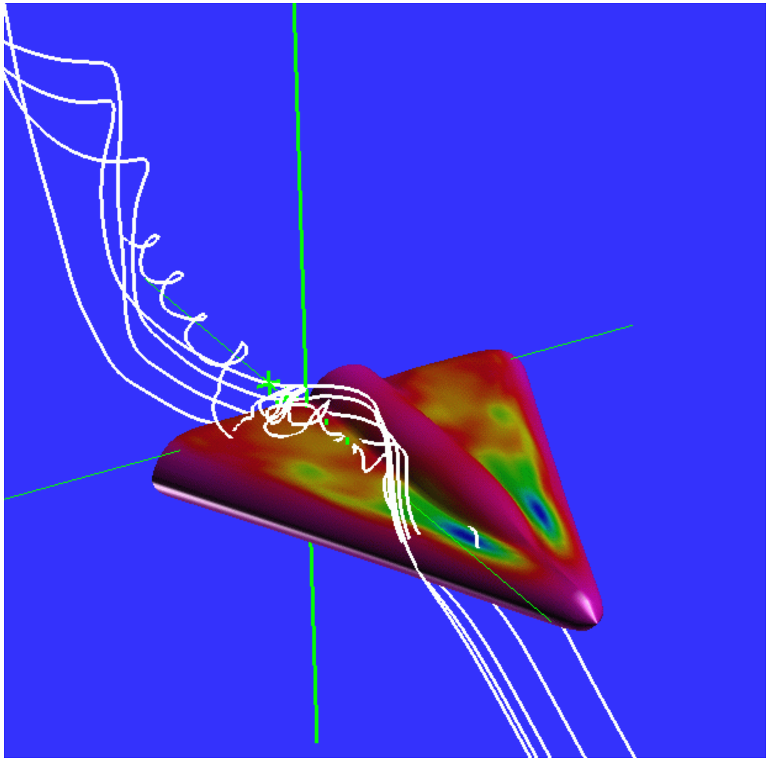
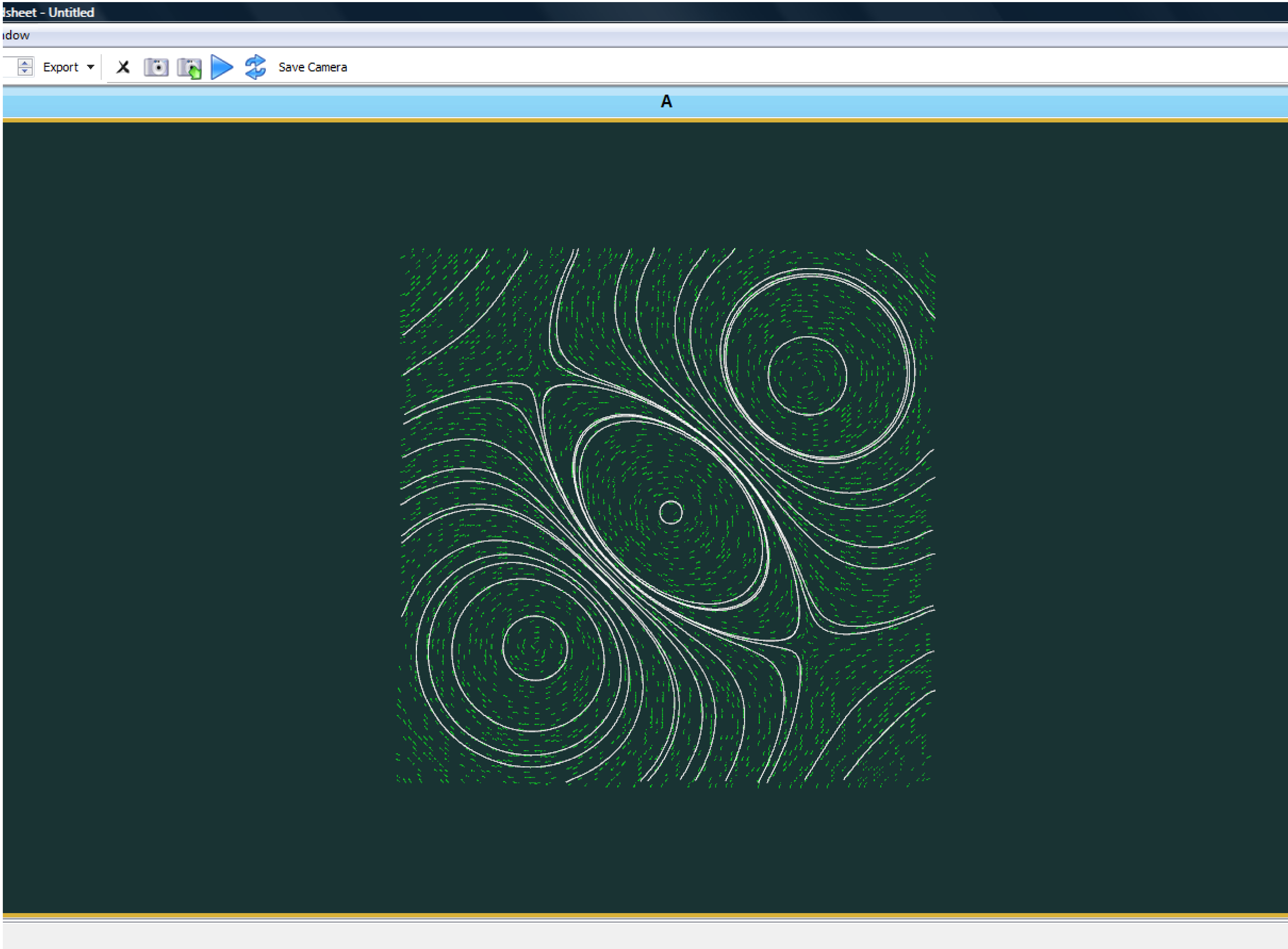
Streamlines

A curves that connect all the particle positions



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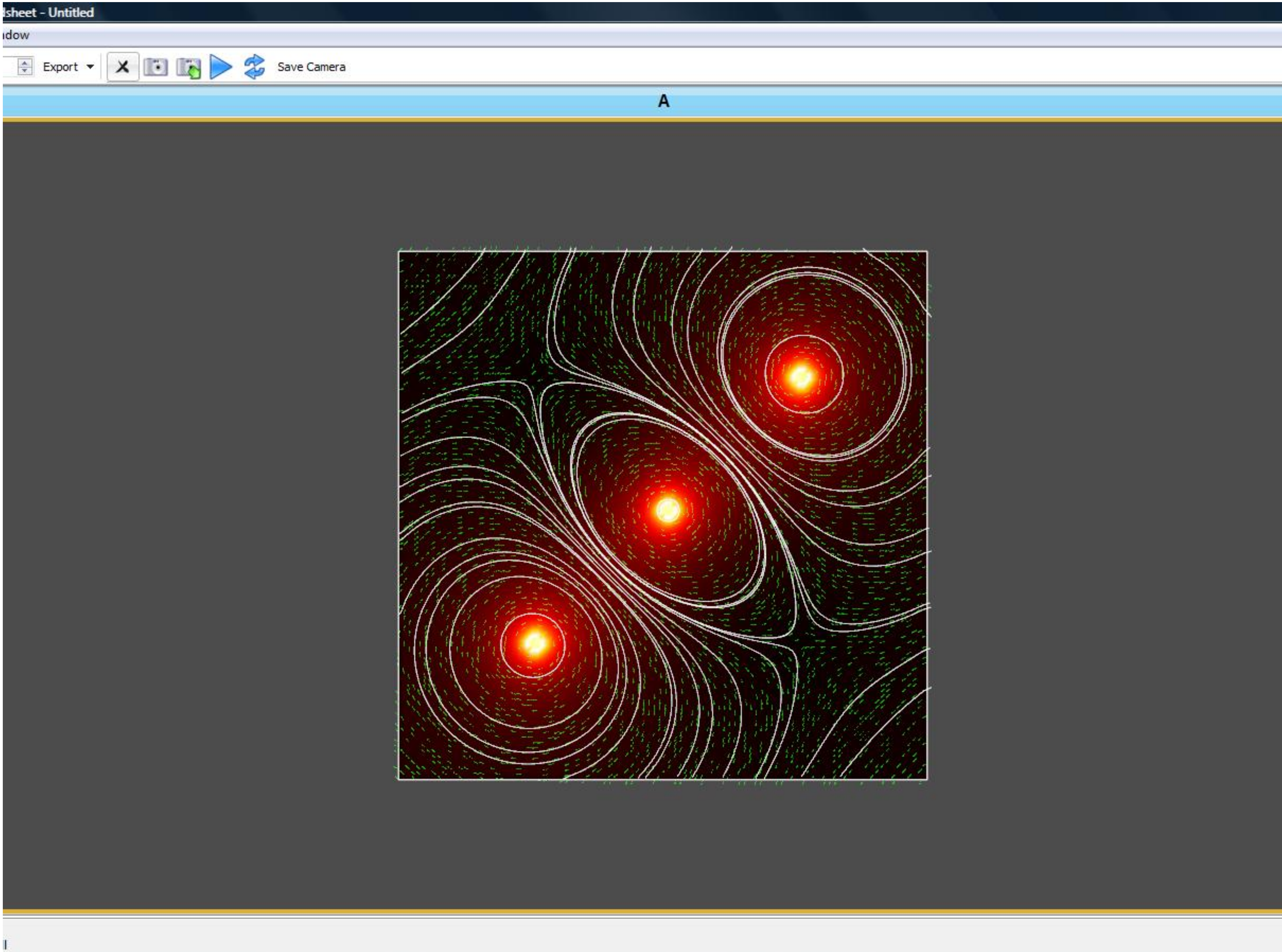
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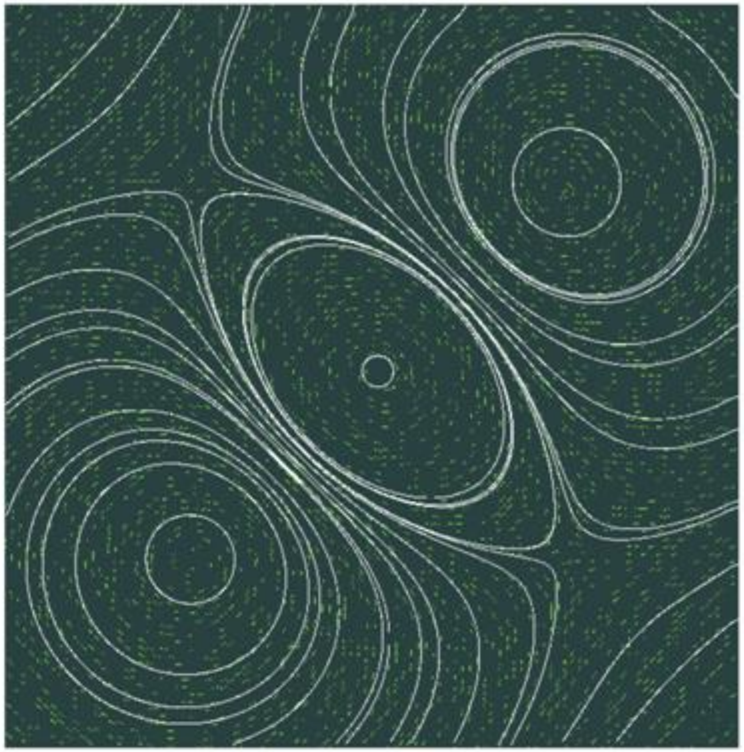
Streamlines

- Lines that are everywhere tangent to the vector field
  - $f(0) = x_0,\ \dot{f}(x) = u(x)$
- That's a diff. eq.
- Solving for $f(x)$ is an **initial value problem**



Local technique - Particle Tracing

Visualizing the flow directions by releasing particles and calculating a series of particle positions based on the vector field

The motion of particle: $dx/dt = v(x)$

x: particle position (in 2D (x_1, x_2) position vector)
v(x): the vector (velocity) field

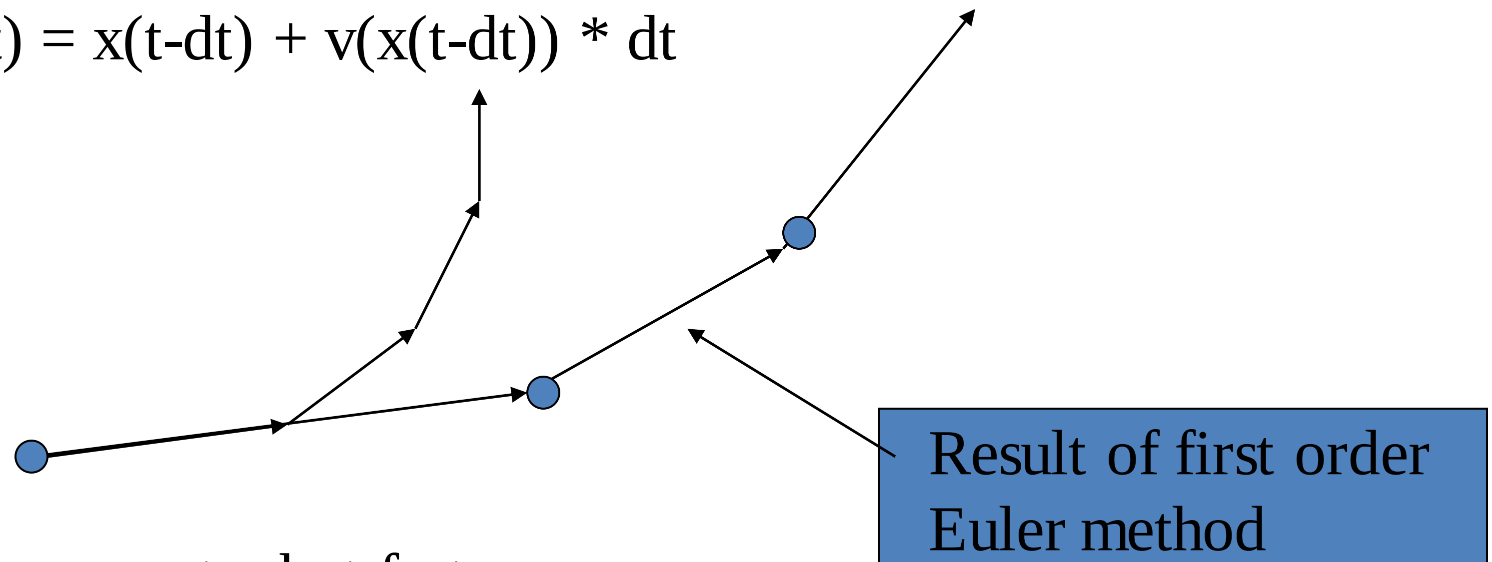
Use numerical integration to compute a new particle position

$$x(t) = x(t-dt) + \text{Integration}(v(x(t-dt))\, dt)$$

Numerical Integration

First Order Euler method:

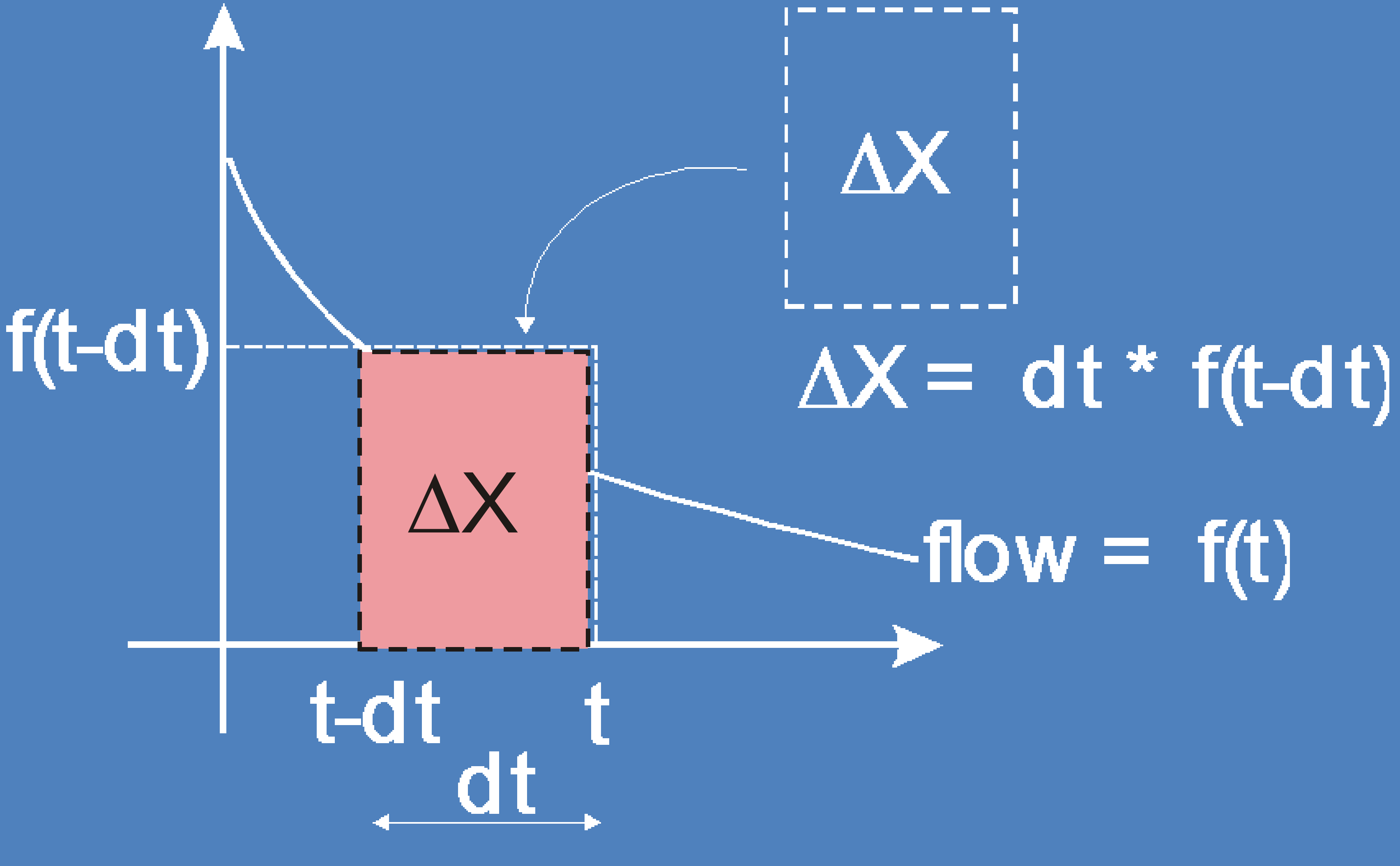
$$x(t) = x(t-dt) + v(x(t-dt)) * dt$$



- Not very accurate, but fast
- Other higher order methods are avilable: Runge-Kutta second and fourth order integration methods (more popular due to their accuracy)

Euler's Method

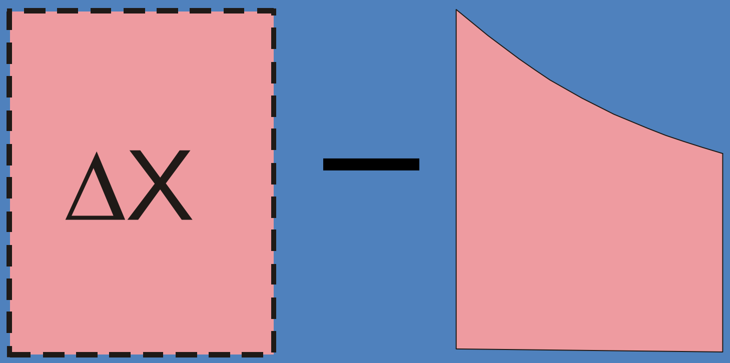
Assume flow = f(t)



Euler Integration Error

- Error = ΔX - area under flow curve

Error =



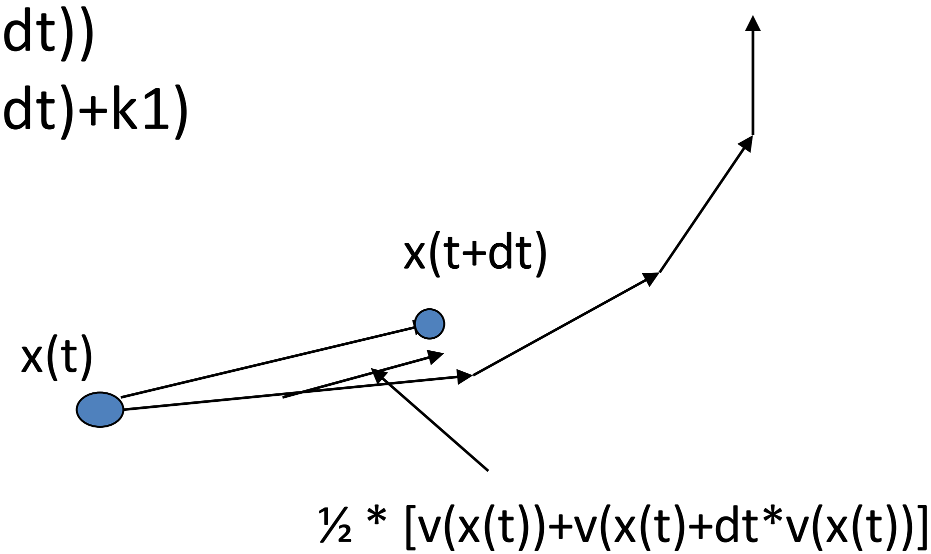
Numerical Integration (2)

Second Runge-Kutta Method

$$x(t) = x(t-dt) + ½ * (K1 + K2)$$

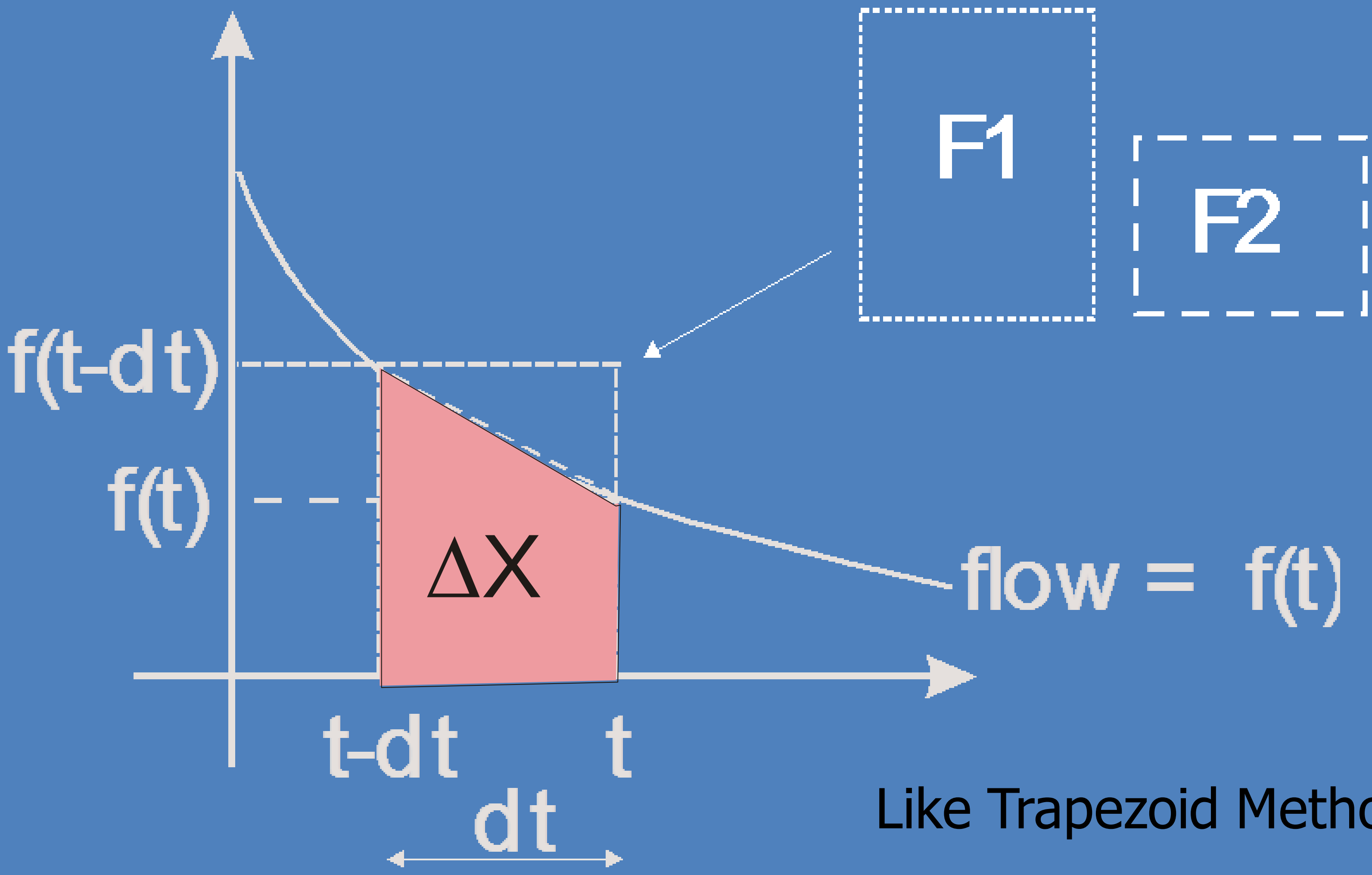
$$k1 = dt * v(x(t-dt))$$

$$k2 = dt * v(x(t-dt)+k1)$$



Runge-Kutta 2

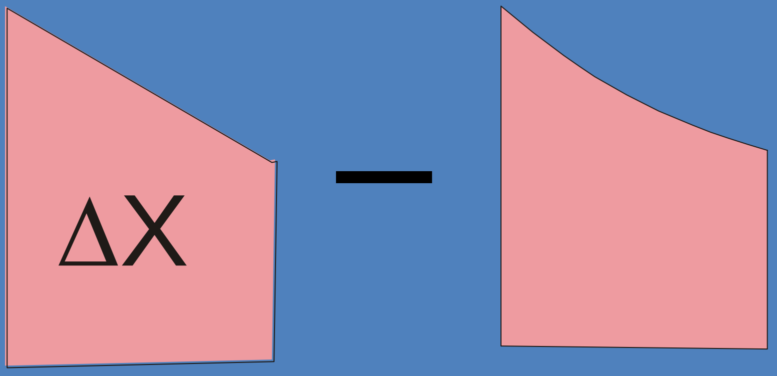
Assume flow = f(t)



Like Trapezoid Method.

RK2 Integration Error

- Error = ΔX - area under flow curve

Error = 

Numerical Integration (3)

Standard Method: Runge-Kutta fourth order

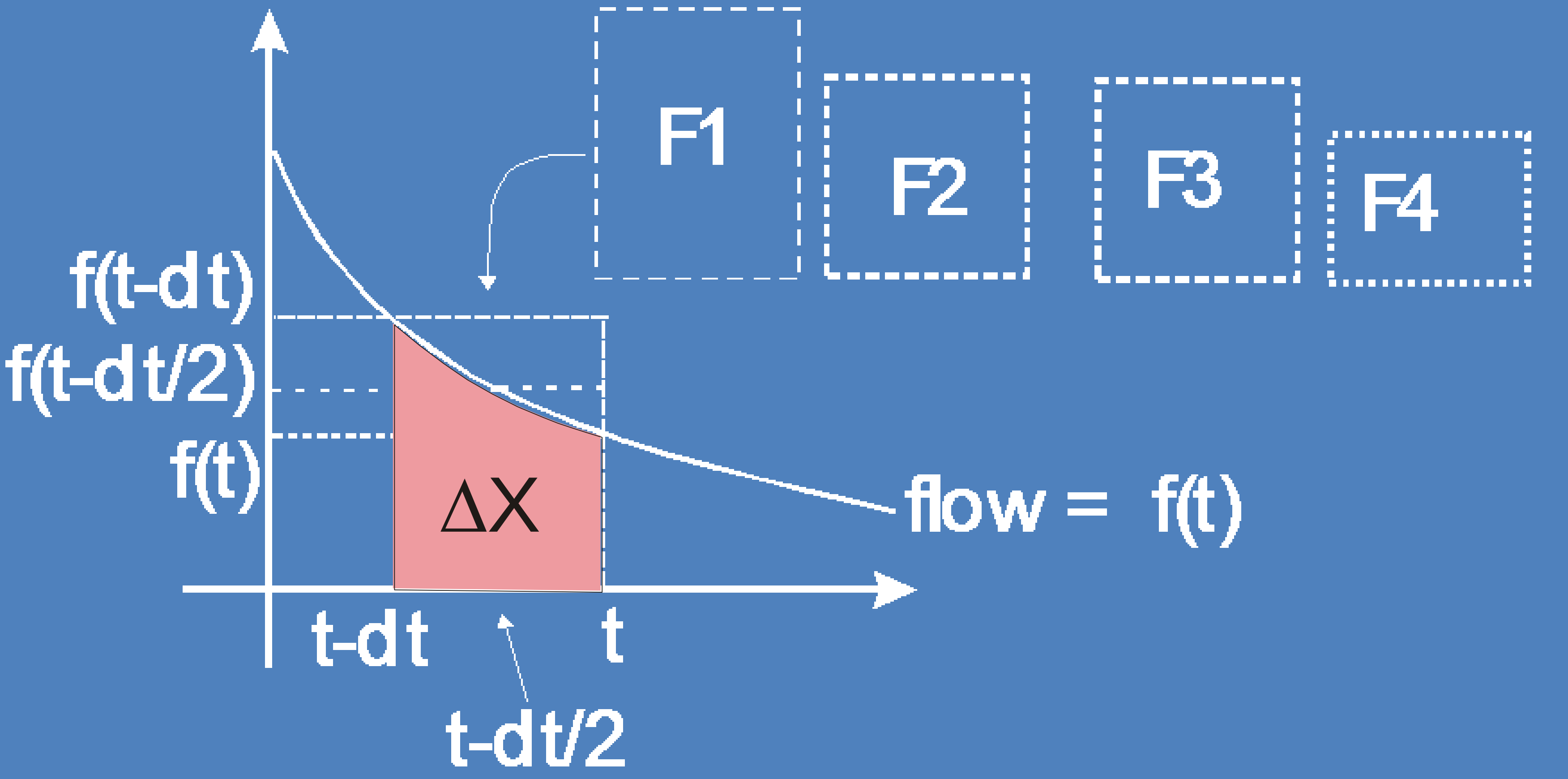
$$x(t) = x(t\text{-}dt) + 1/6\ (k_1 + 2k_2 + 2k_3 + k_4)$$

$k_1 = dt * v(t\text{-}dt)$; $k_2 = dt * v(x(t\text{-}dt) + k1/2)$

$k_3 = dt * v(x(t\text{-}dt) + k2/2)$; $k_4 = dt * v(x(t\text{-}dt) + k3)$

Runge-Kutta 4

Assume flow = f(t)

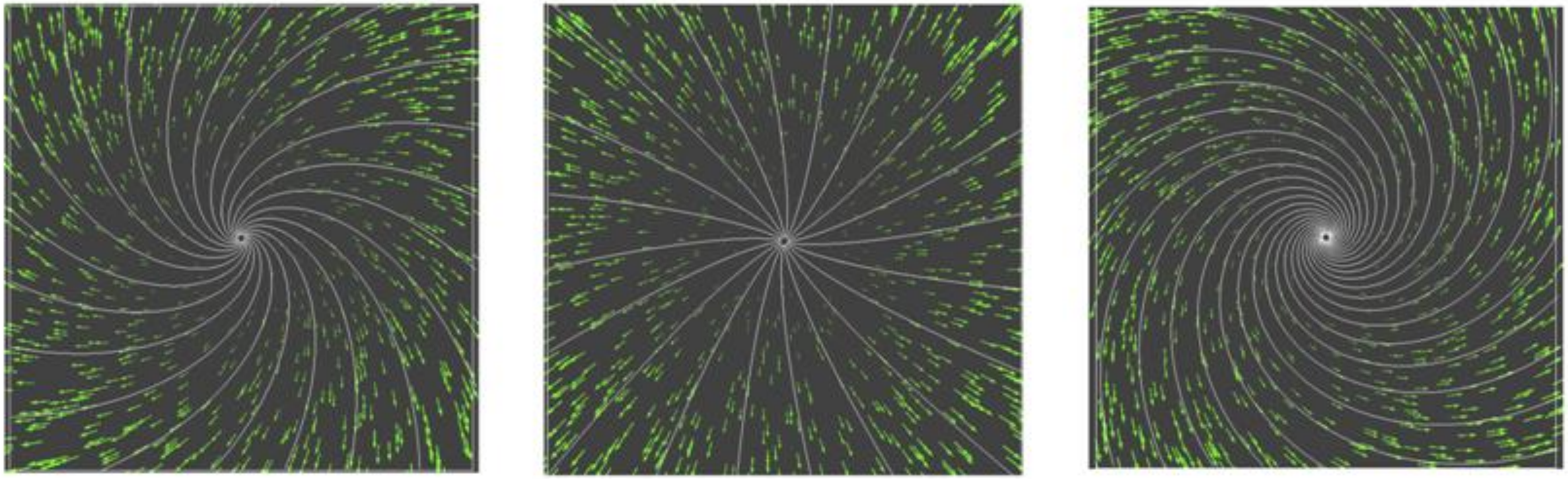


What Method to Use?

- RK2 and RK4 are more accurate for same dt than Euler
- RK2 and RK4 work well for continuous systems
- Euler works poorly for oscillatory systems
- RK2 and RK4 work poorly with discrete systems

Steady vs. unsteady

- Flows change with time
- For every timestep, a different vector

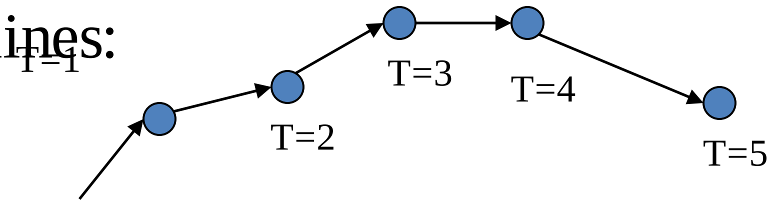


- But, what about streamlines, then?

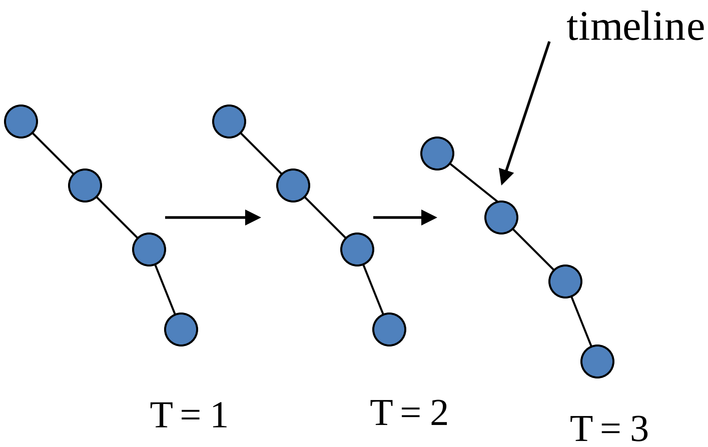
Pathlines, Timelines, and Streaklines

-Extension of streamlines for time-varying data

Pathlines:

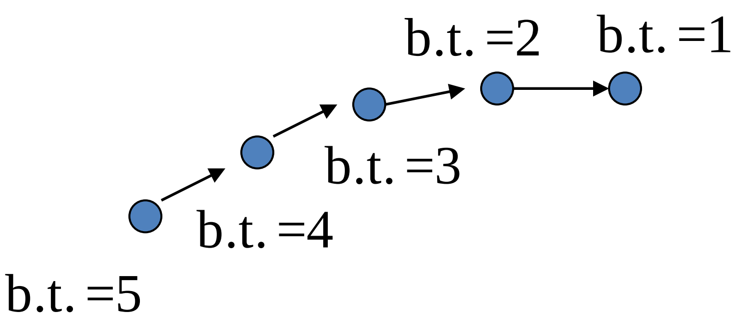


Timelines:

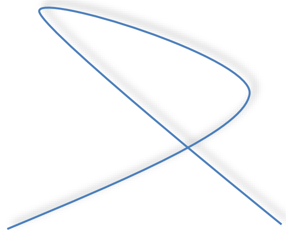


Streaklines

- Continuously injecting a new particle at each time step, advecting all the existing particles and connect them together into a *streakline*



When should we expect self-intersections?



- Streamlines
- Pathlines
- Streaklines

Pathlines and Streaklines

- Streamlines do not cross
- Streaklines still never cross
- Pathlines do cross

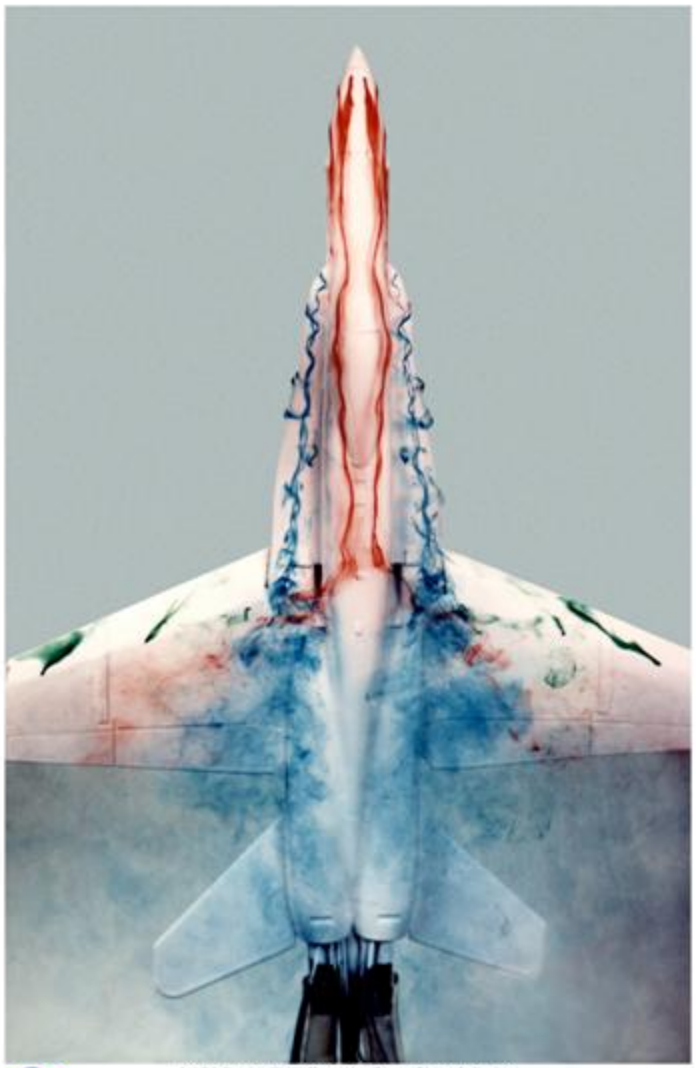
Pathlines and Streaklines

- Streamlines should not cross
- Streaklines still seldom cross
- Pathlines do cross

Seed Placement

- The placement of seeds directly determines the visualization quality
  - Too many: scene cluttering
  - Too little: no pattern formed
- It has to be the right number at the right places!!!

Streaklines in real life



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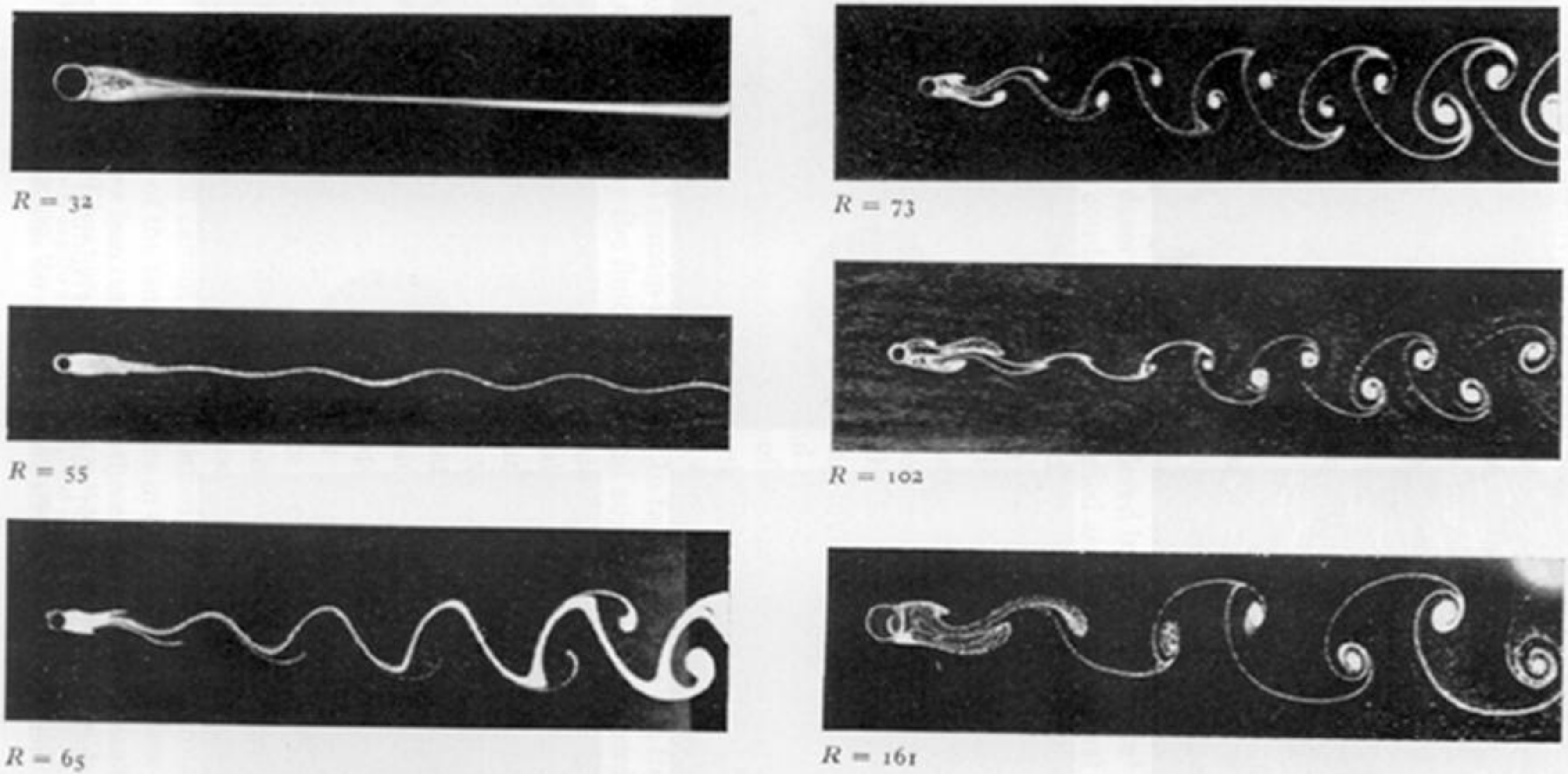
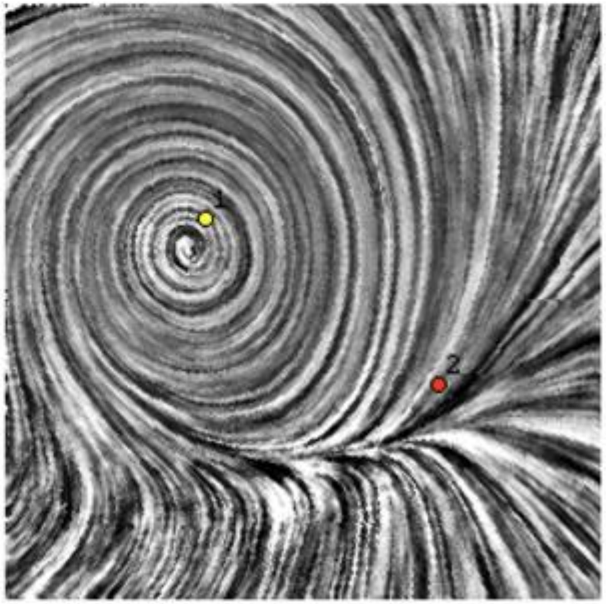


Line Integral Convolution

- Basic idea: Integrate noise along streamlines
- demo: http://www.javaview.de/demo/PaLIC.html

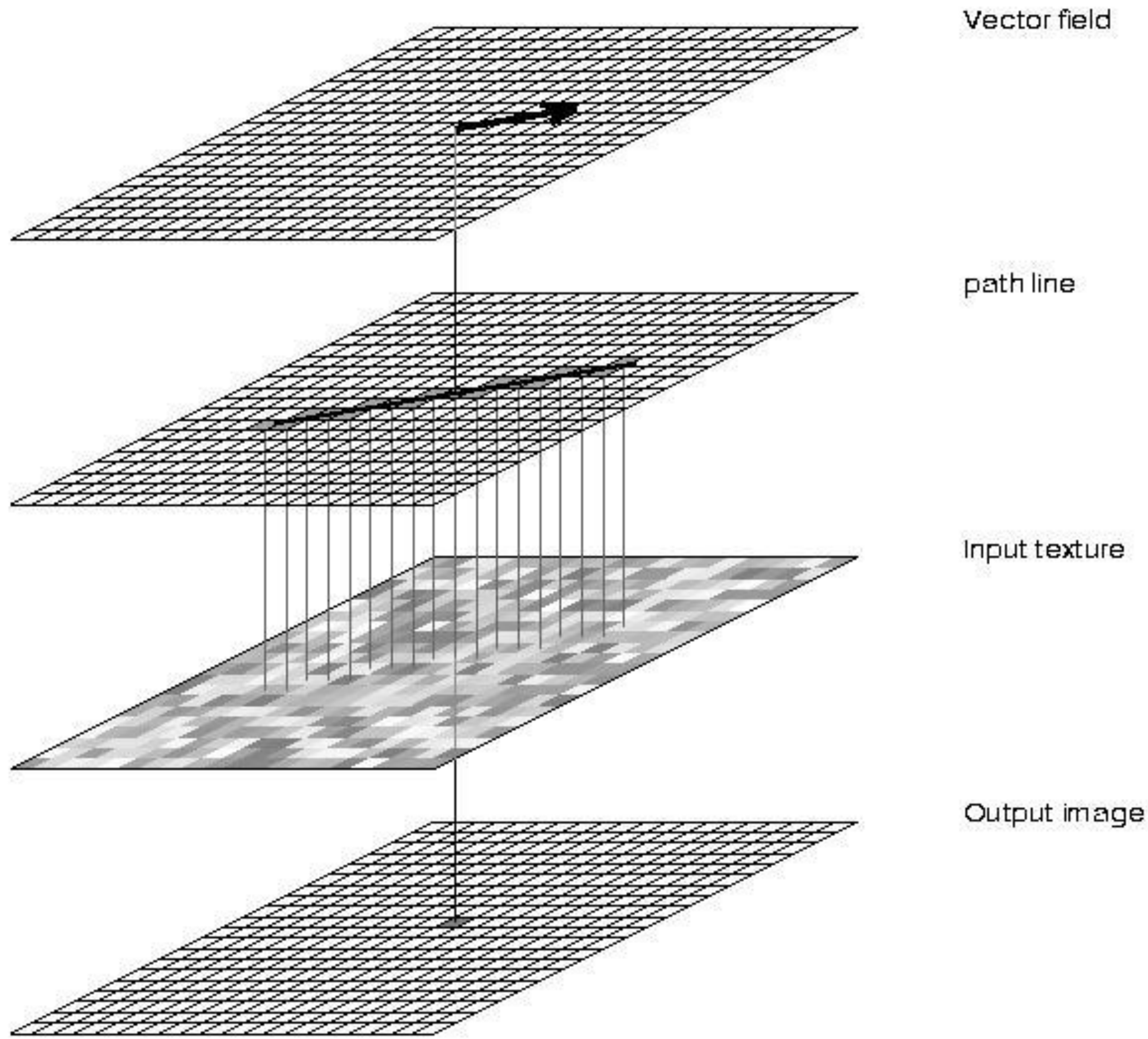


Rendering - LIC

- embed a noise texture under the vector field
- integrates along a streamline

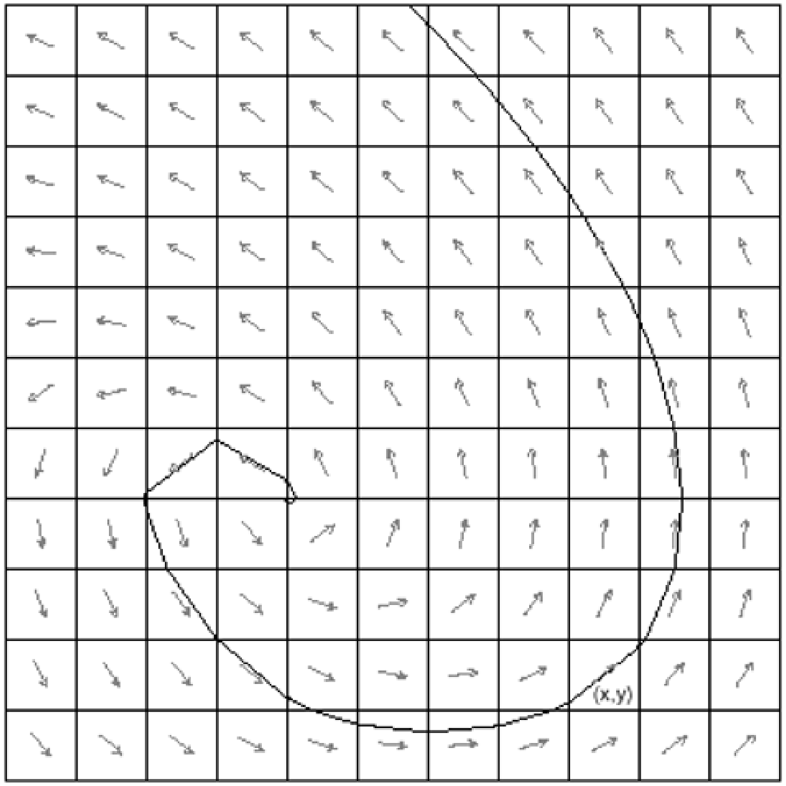
Line Integral Convolution (LIC)

- LIC:
- convolve a
- random texture
- along the
- streamlines



Line Integral Convolution (LIC)

- Assume input texture, vector and output images are all the same resolution.
- For each output pixel/voxel, generate a streamline both forwards and backwards of a fixed length.
- Integrate the intensity that the streamline passes through



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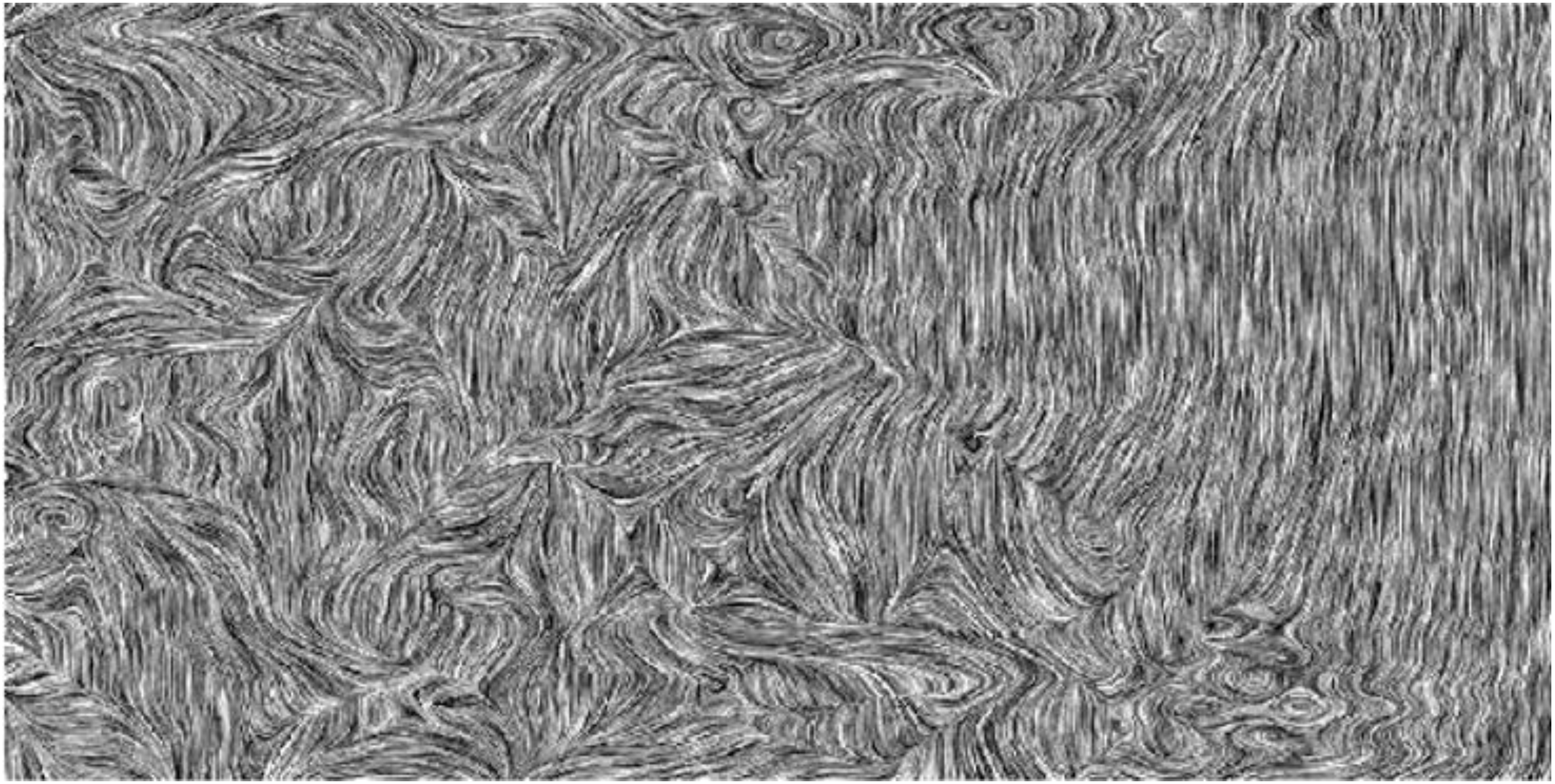

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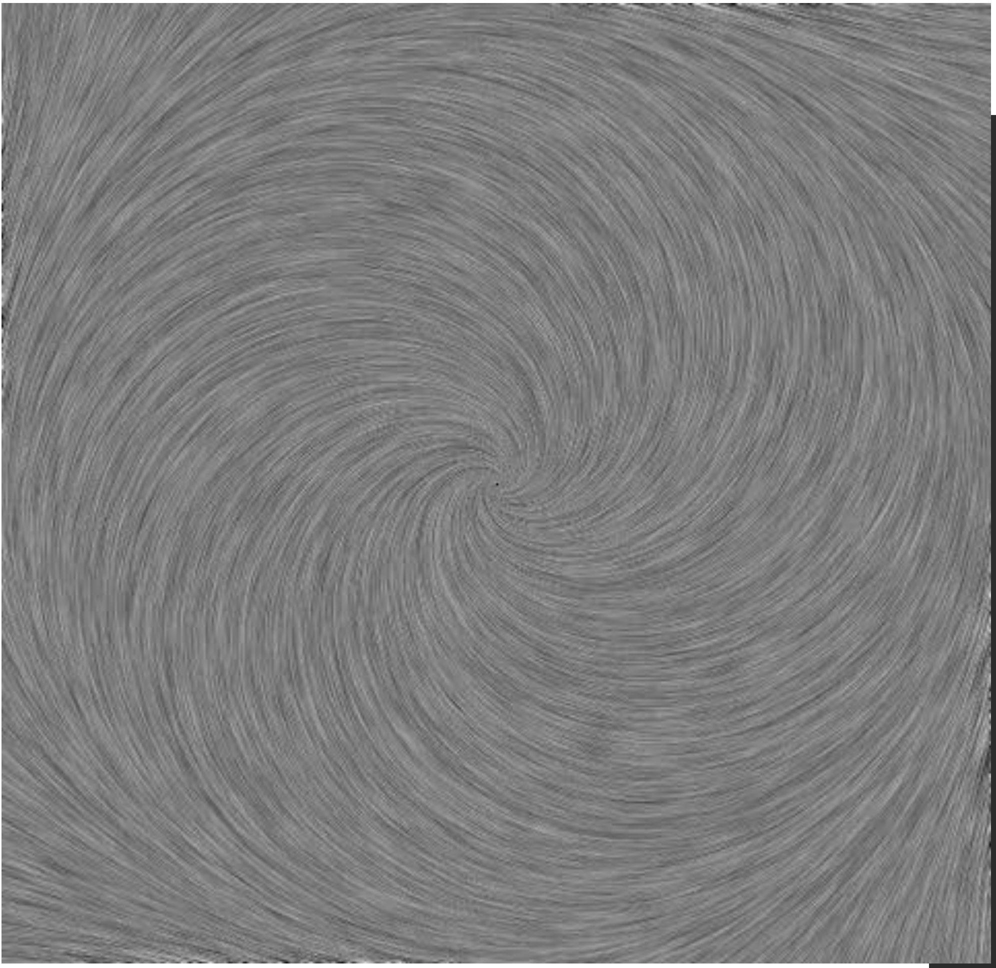

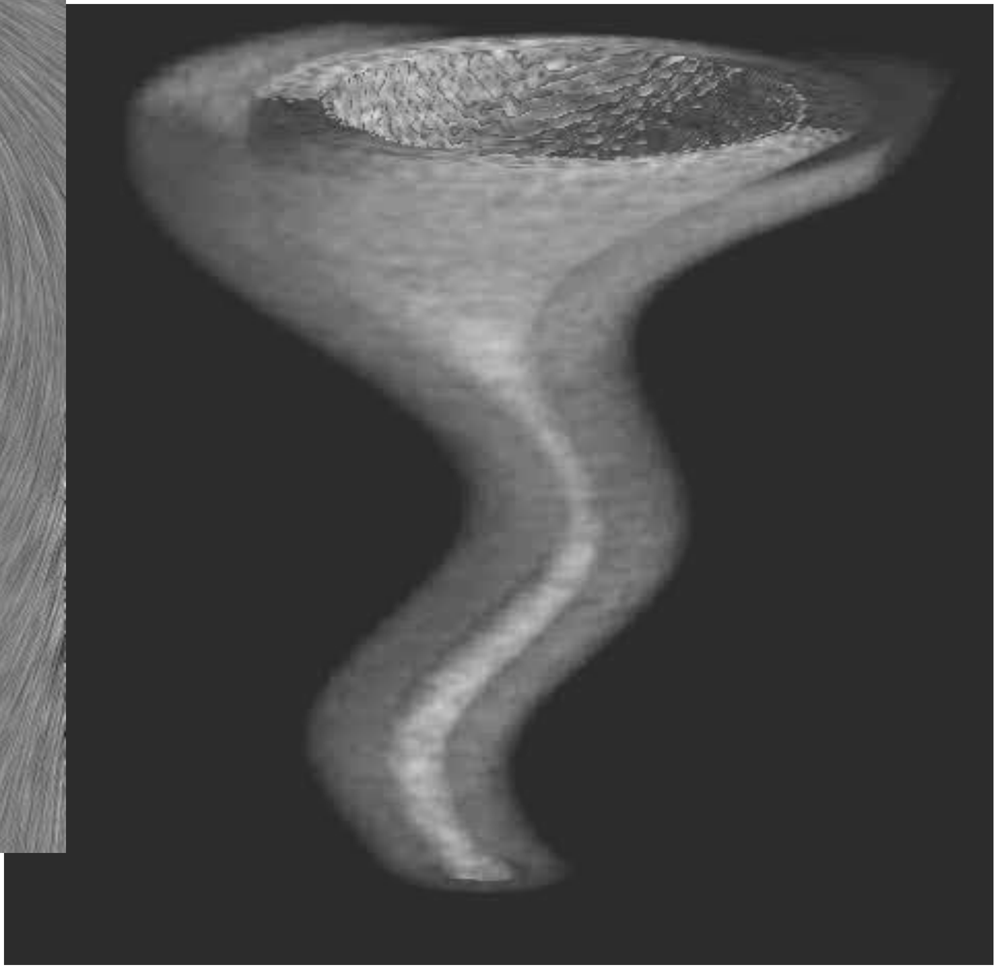

Comparison (LIC and Streamlines)