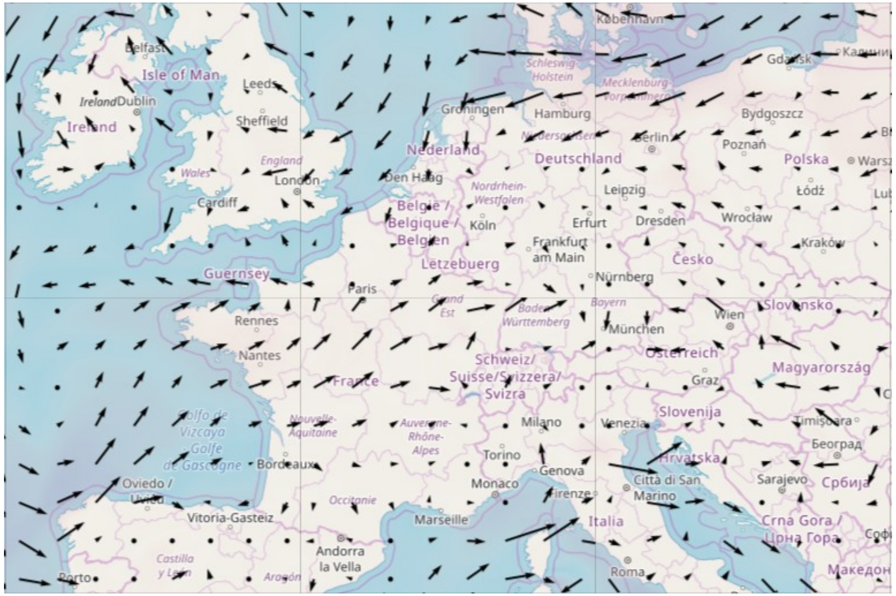
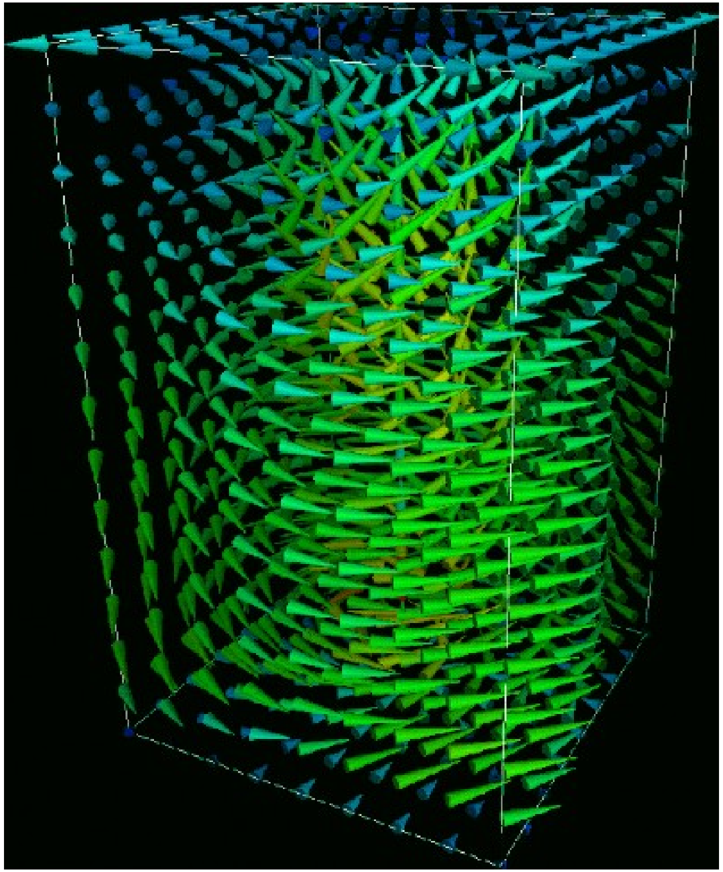
Geometric flow visualization

Thomas Torsney-Weir

Direct flow visualization

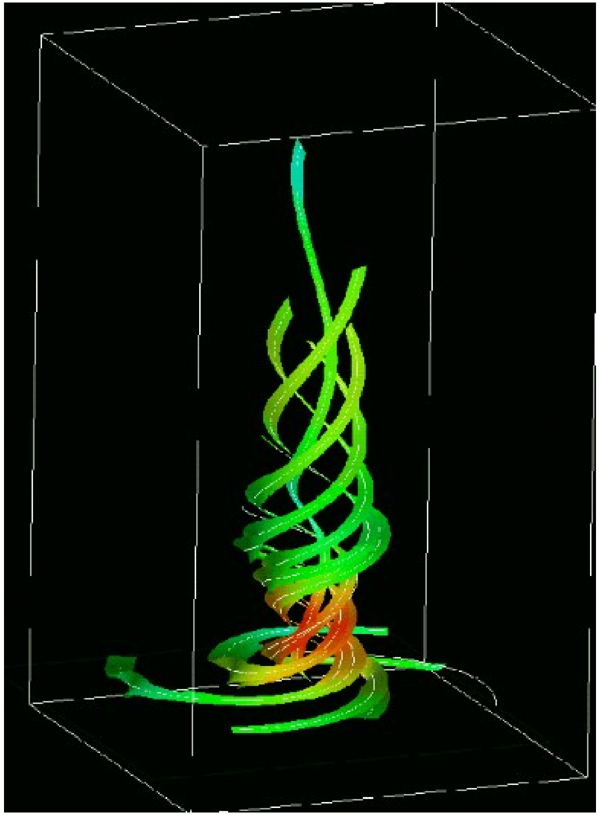
User needs to mentally integrate the flow

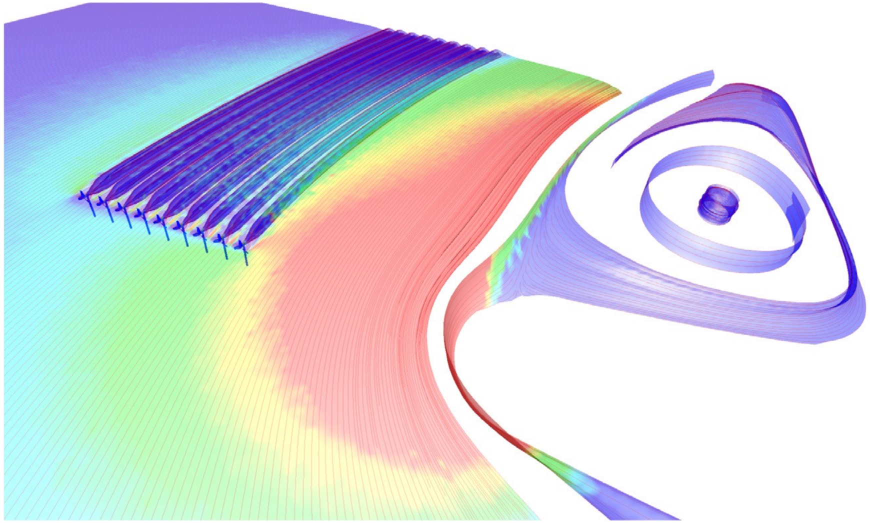




Geometric flow visualization

Visualization of the integrated flow





Edmunds et al., “Aspects of Tidal Stream Turbine Modelling in the Natural Environment Using a Coupled BEM–CFD Model.”

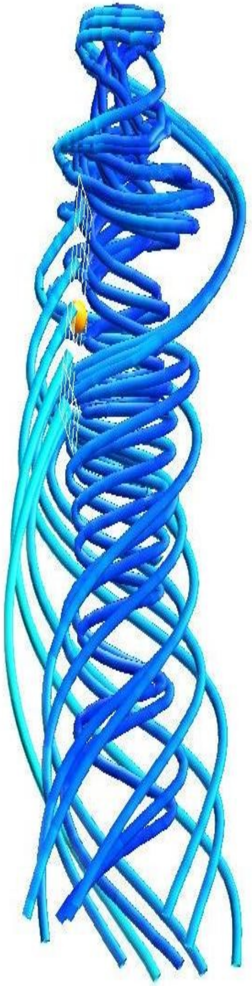
Pros and cons

Advantages:

- *Implementation* : various easy-to-implement streamline tracing algorithms (integration)
- *Intuitive* : interpretation is not difficult
- *Applicability* : generally applicable to all vector fields, also in three-dimensions

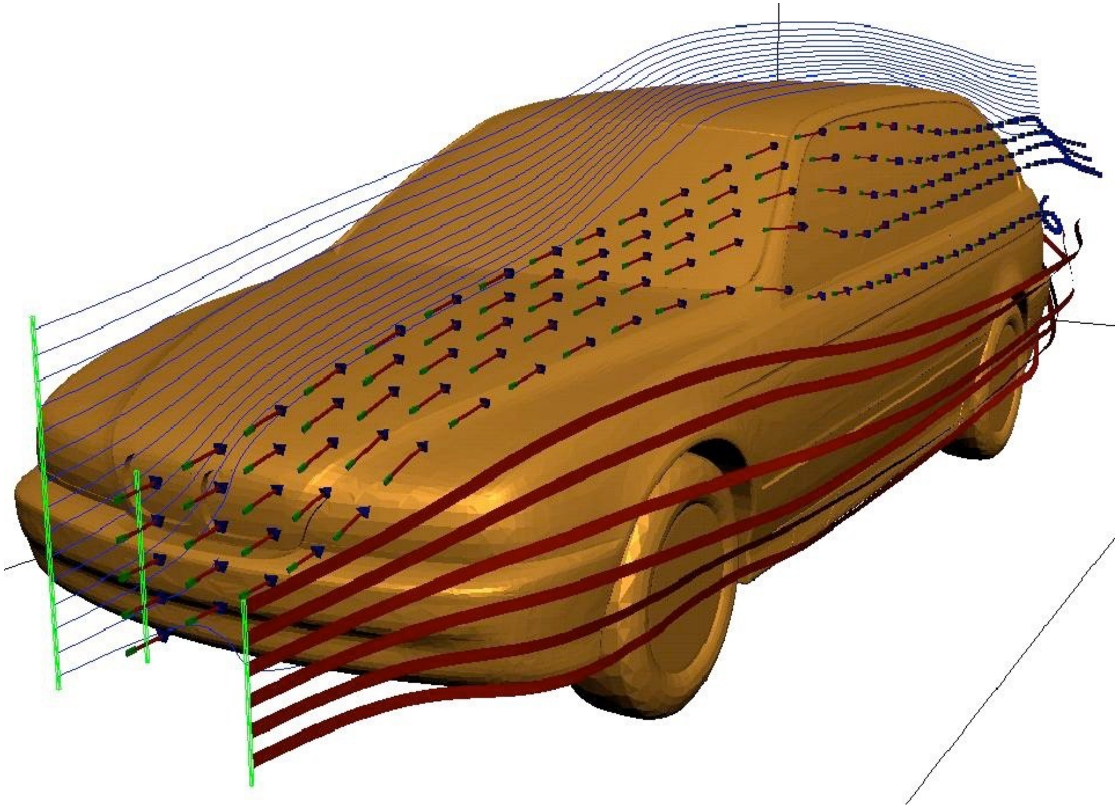
Disadvantages:

- *Perception* : too many lines can lead to clutter and visual complexity
- *Perception* : depth is difficult to perceive, no well-defined normal vector
- *Seeding* : optimal placement is very challenging (unsolved problem)



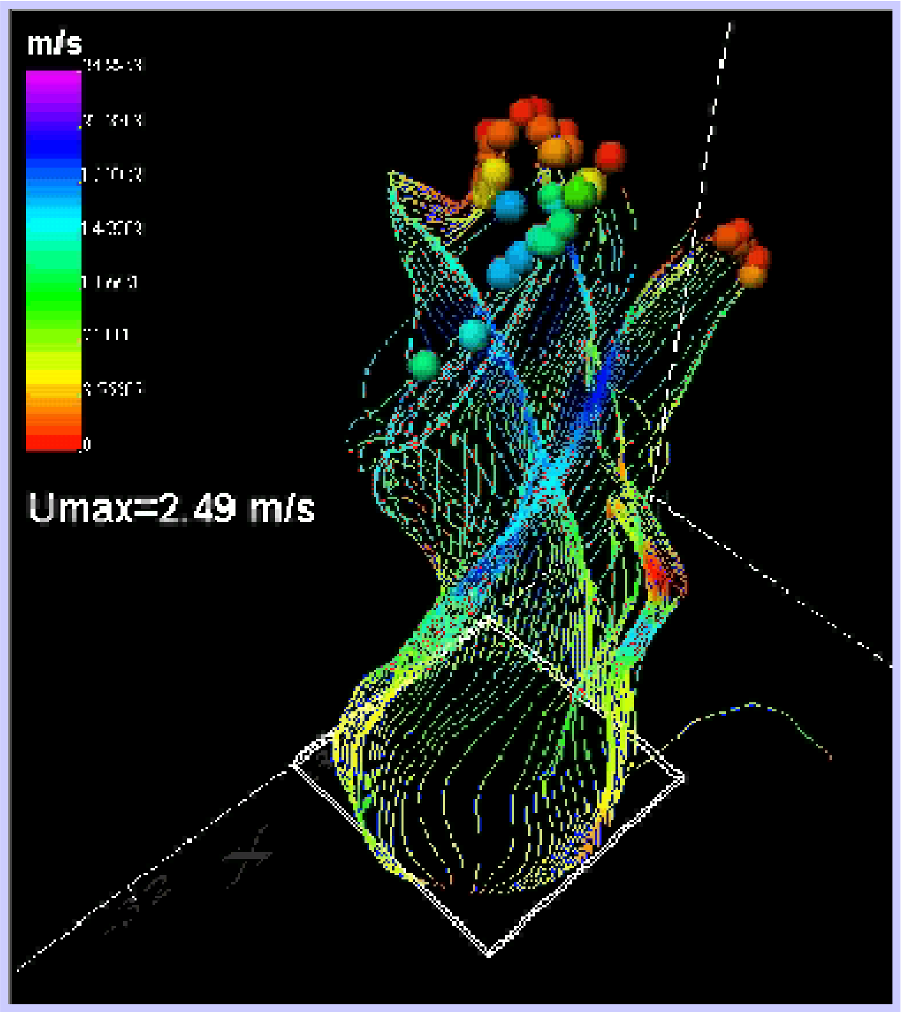
Creating geometry

- Each mark is created by following the path of the flow
- *Steady-state flow* : follow the path
- *Unsteady flow* : depends on observation method

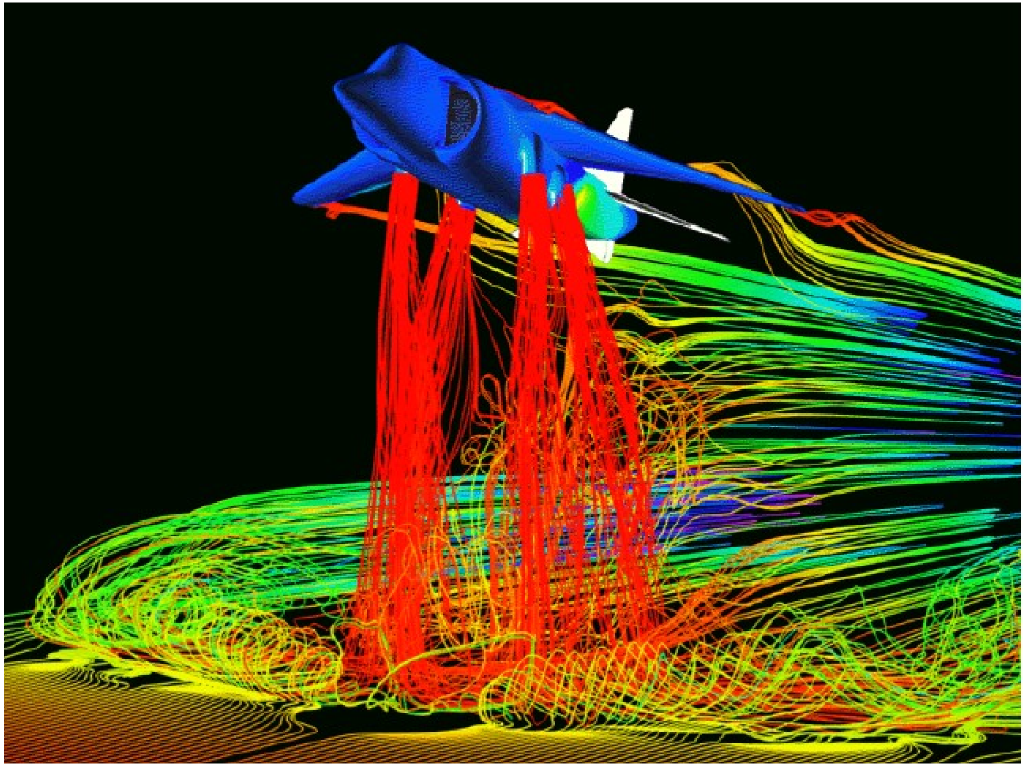


Steady-state flow

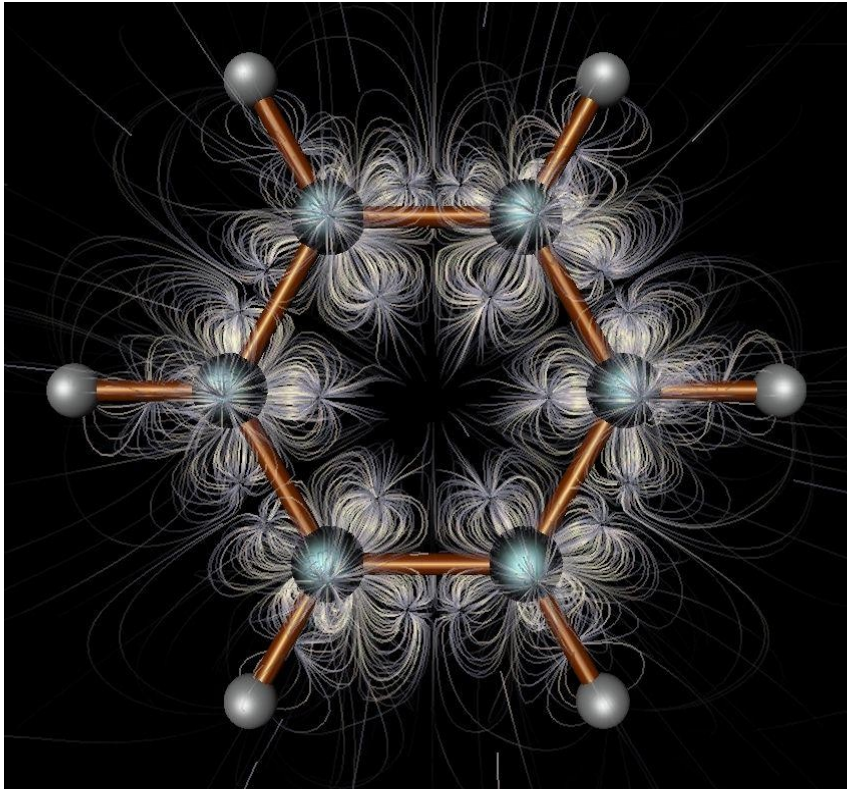
- Based on particle motion
- (Continuous) path becomes a mark to show on screen
- **Field lines** : lines tangent to direction of flow



Steady-state flow



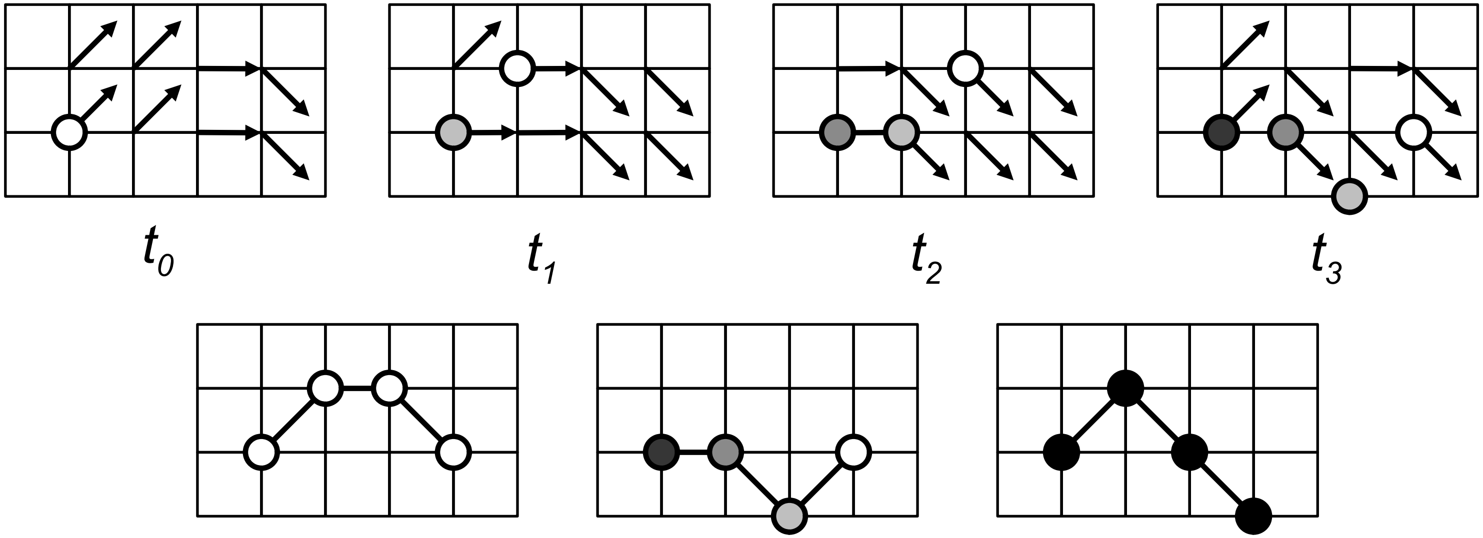
Color = velocity



Illumination helps 3D perception

Unsteady flow

- Now we want to see 2 things:
  - Direction of flow
  - How flow changes over time
- Where/when particles are introduced changes visualization

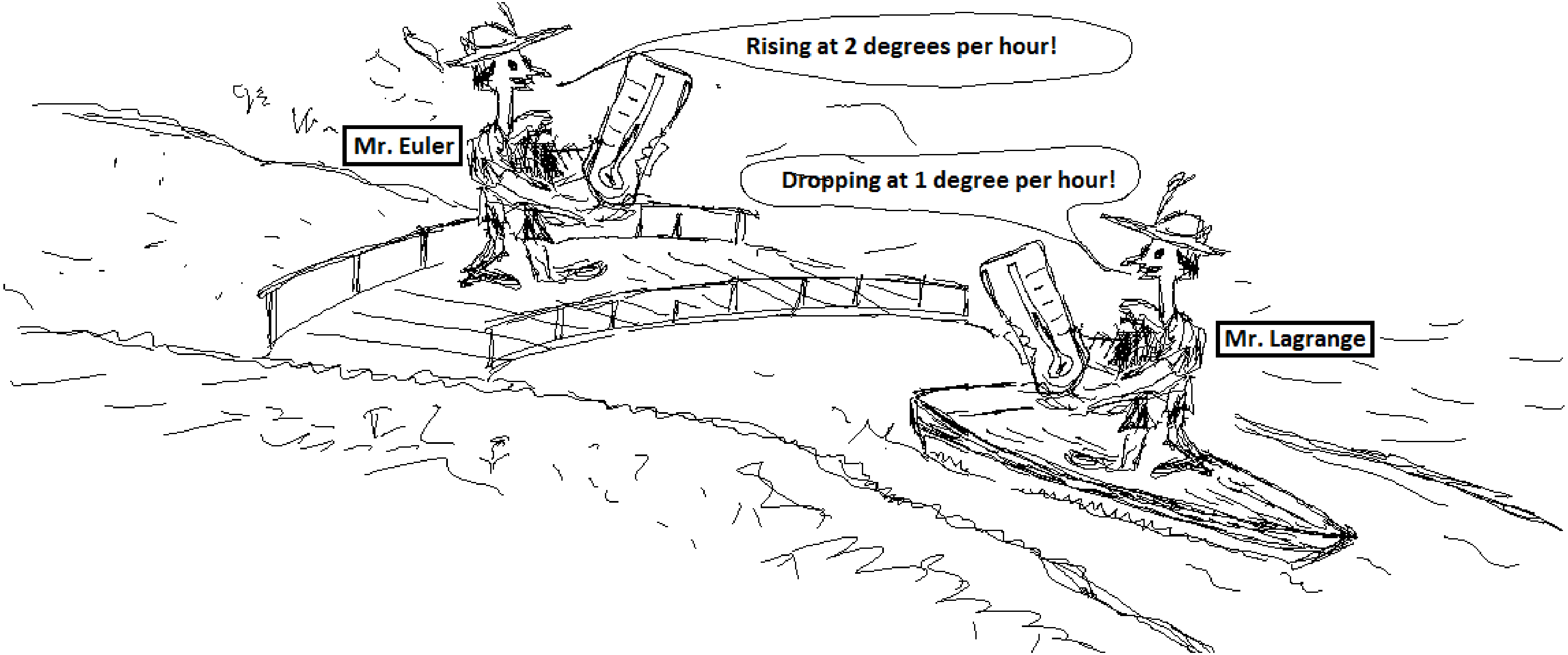


t_0 t_1 t_2 t_3

pathline streakline streamline for t_3

Flow obervation

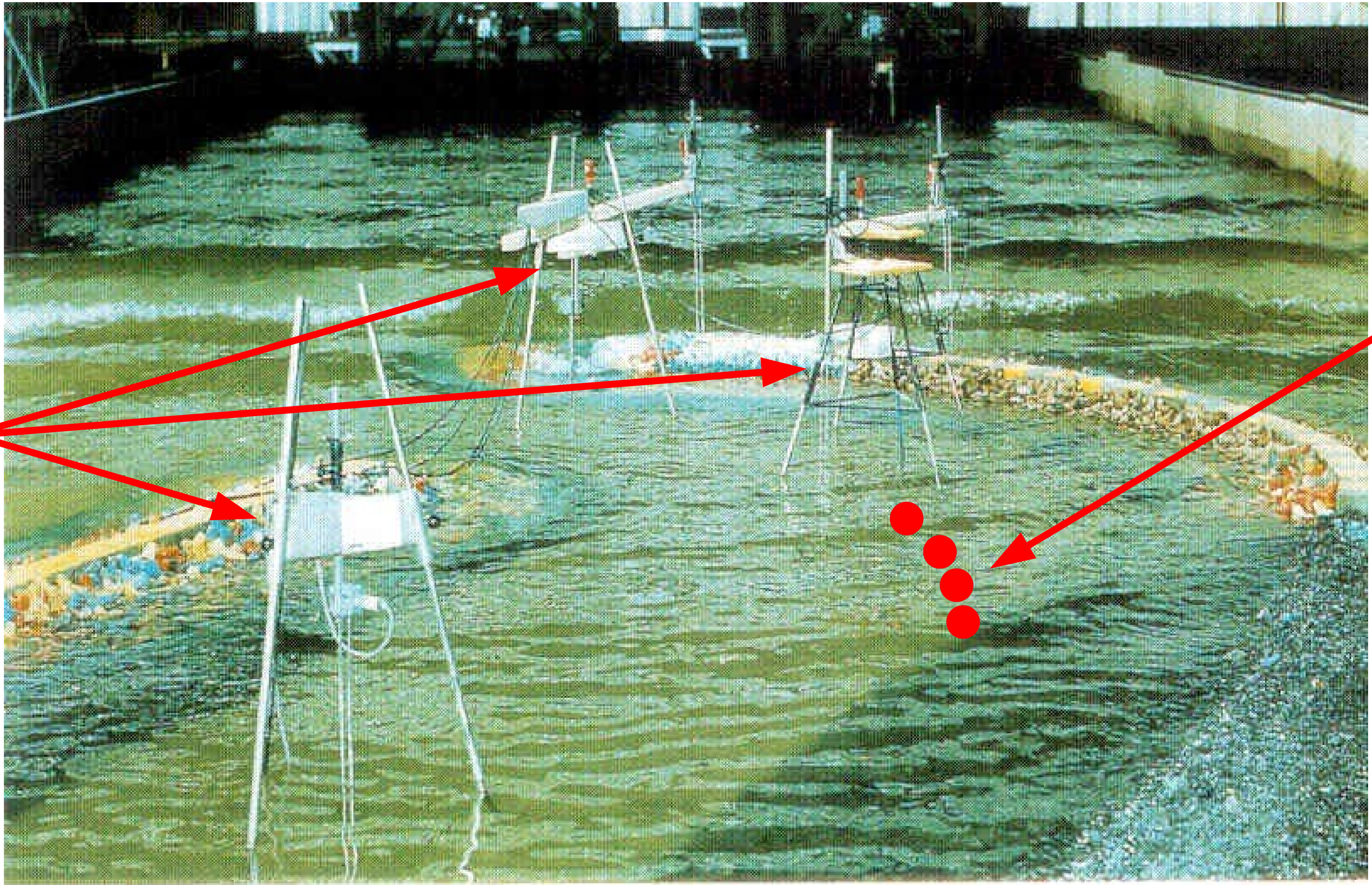
Euler vs Langrange



http://www.flowillustrator.com/fluid-dynamics/basics/lagrangian-eulerian-viewpoints.php

Flow observation

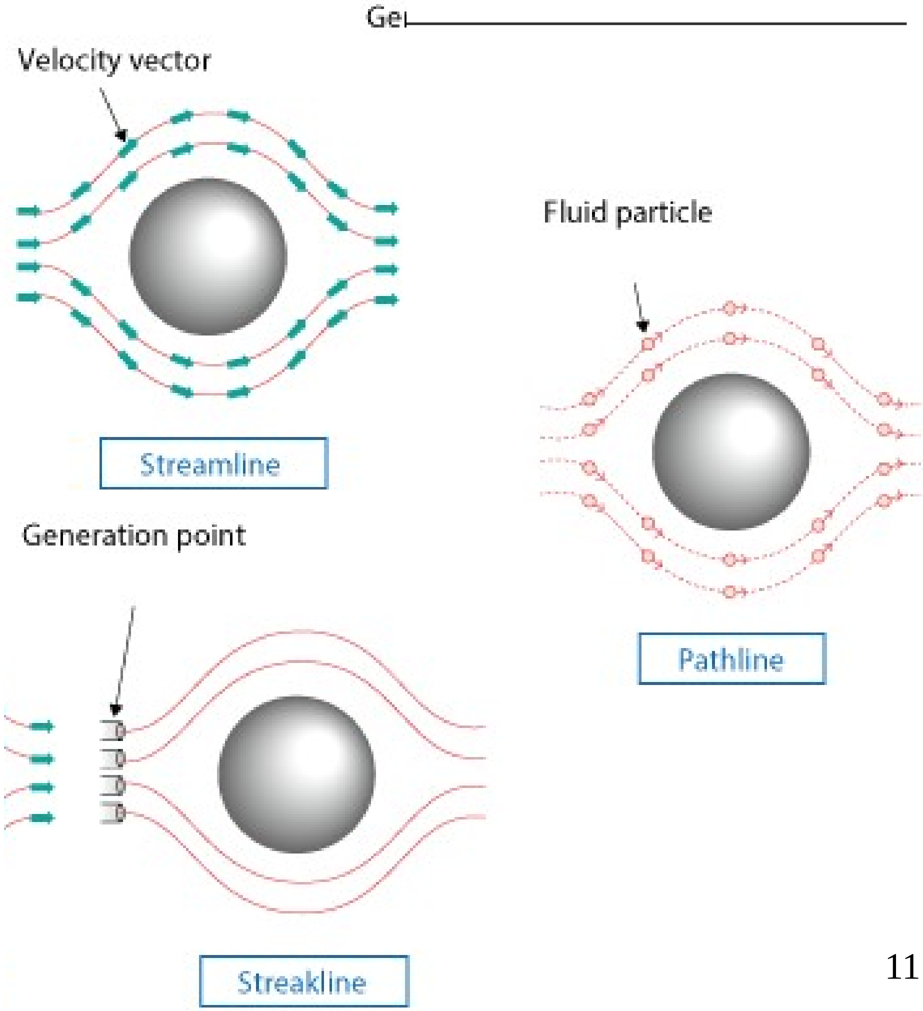
Euler



Lagrange

Flow visualization

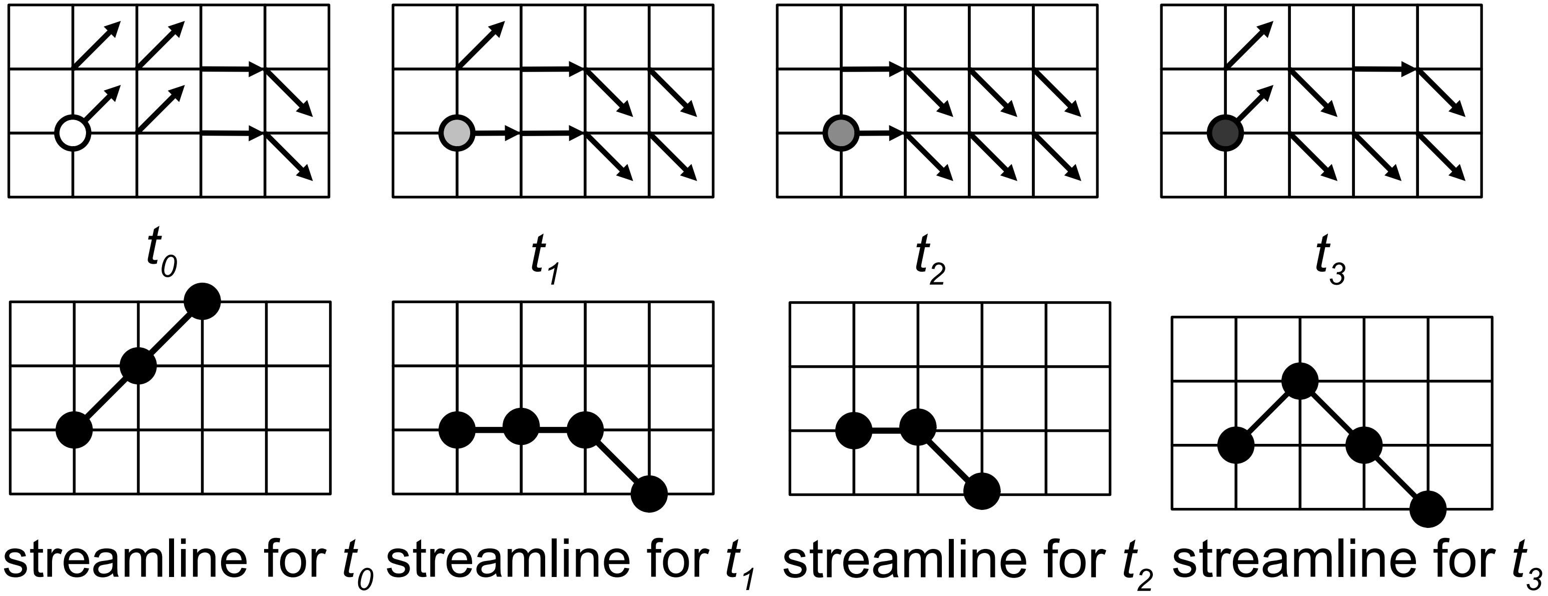
- **Streamline**: a curve that is everywhere tangent to the flow (release 1 massless particle)
- **Pathline**: a curve that is everywhere tangent to an unsteady flow field (release 1 massless particle)
- **Streakline**: a curve traced by the continues release of particles in unsteady flow from the same position in space (release infinitely many massless particles)



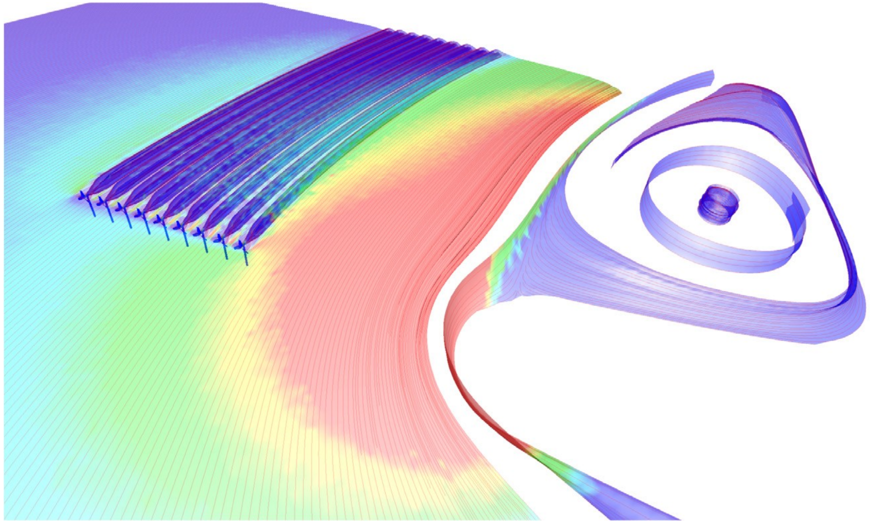
https://www.cradle-cfd.com/media/column/a147

Streamlines

- Tangential to the vector field at fixed time t
- Cannot intersect



Streamlines



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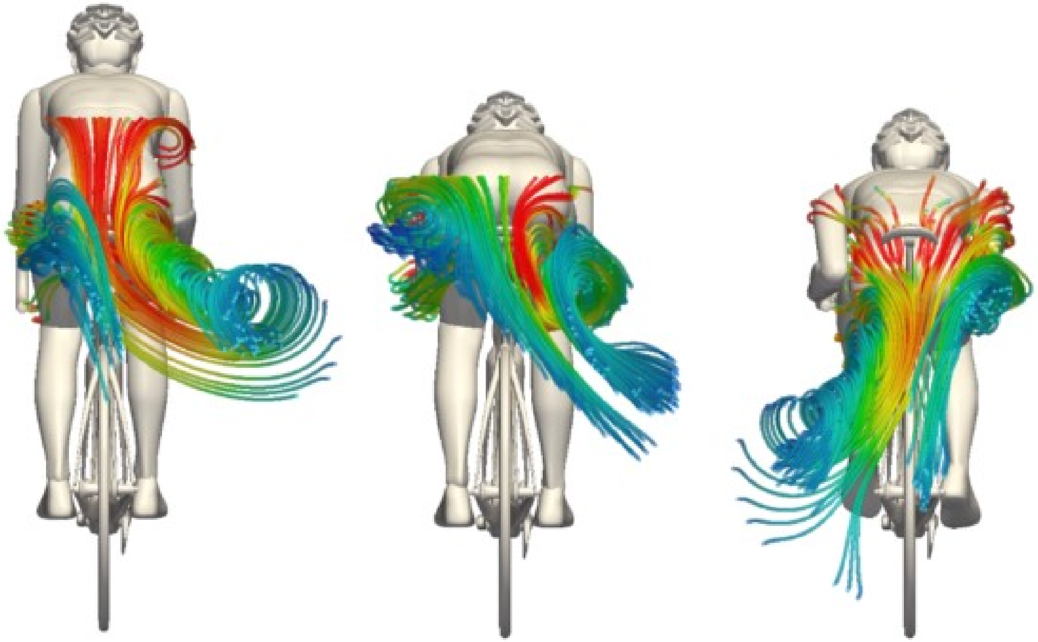
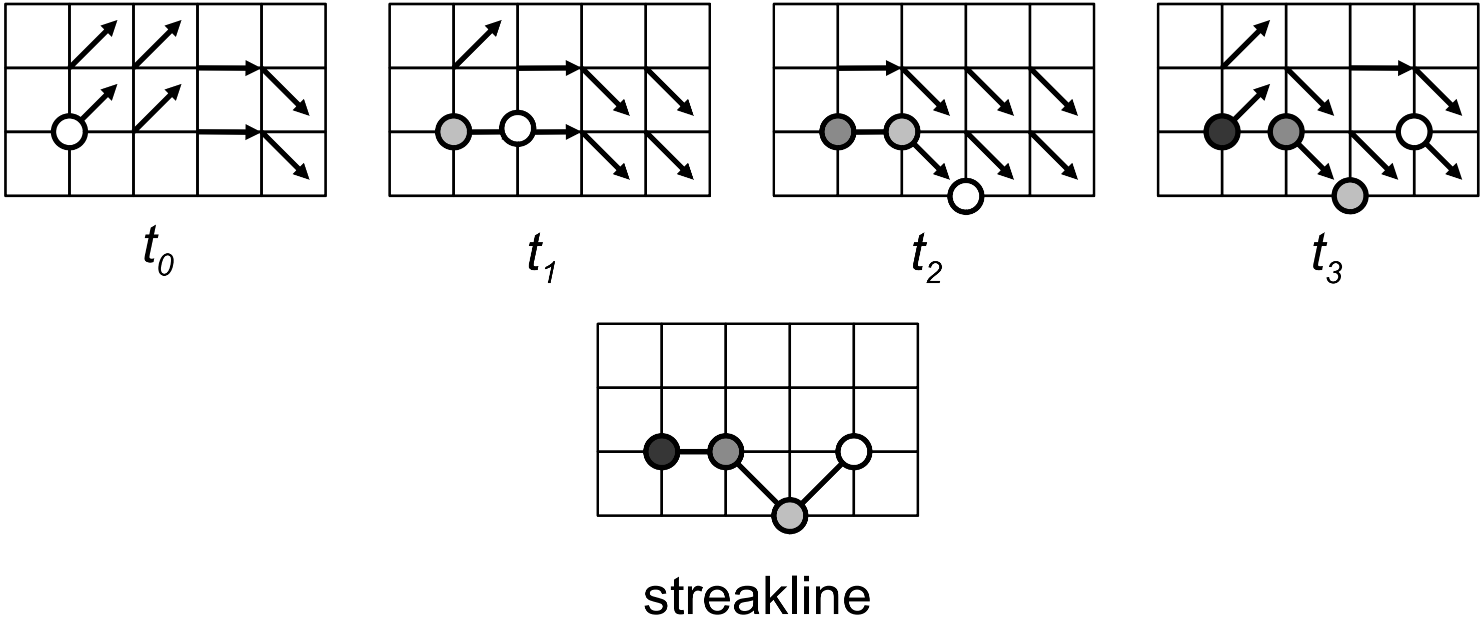


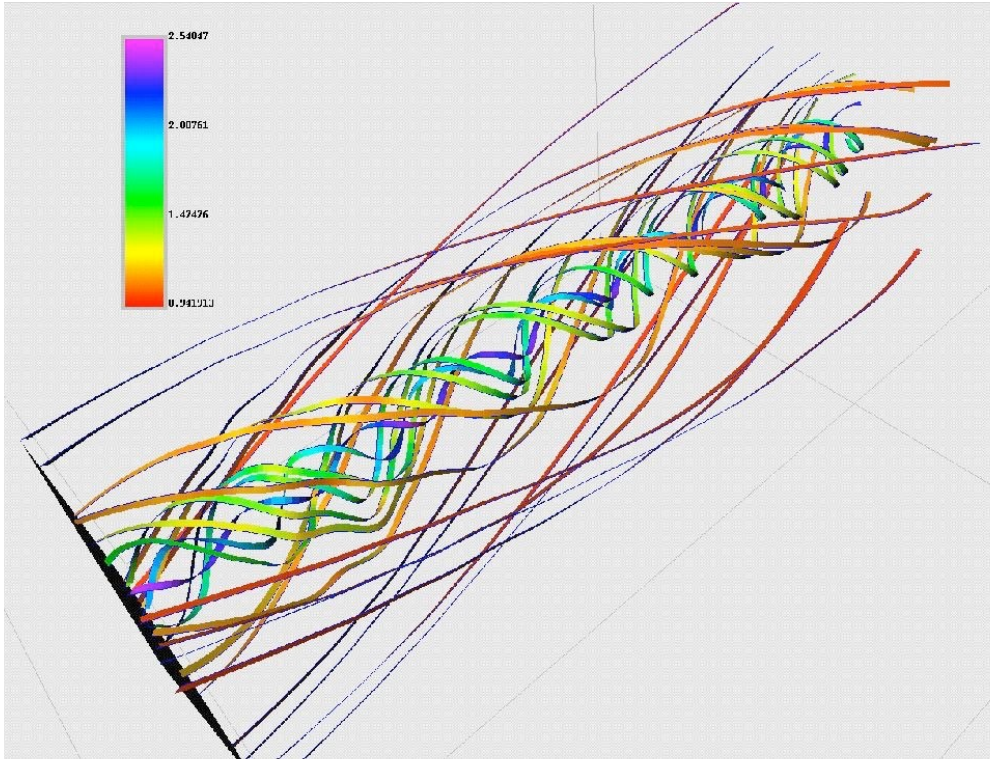
https://www.simscale.com/blog/2017/07/cycling-aerodynamics/

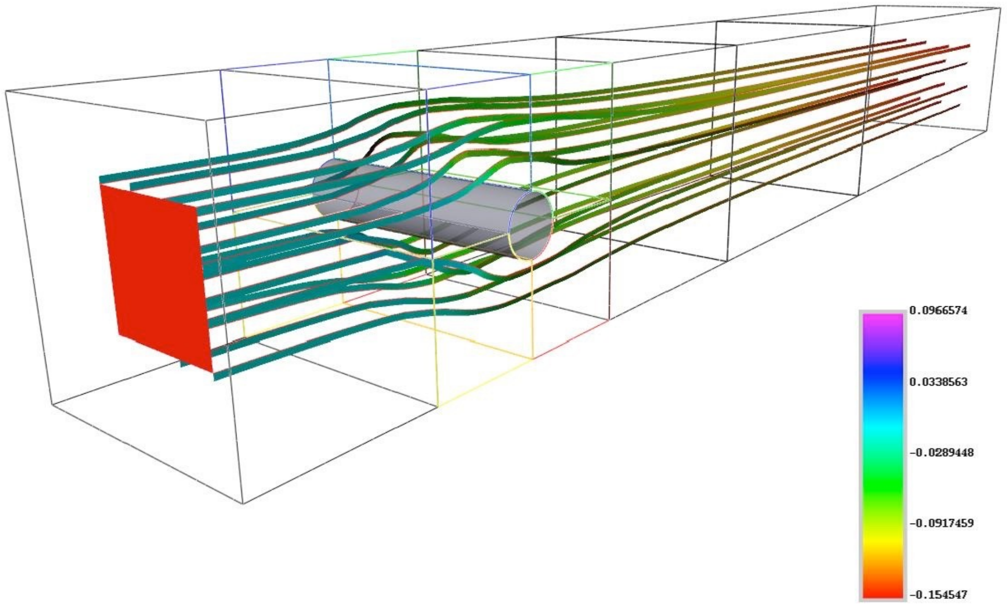
Streaklines

- Trace of dye released into the flow at a fixed position
- Cannot intersect
- Looking "backwards in time"



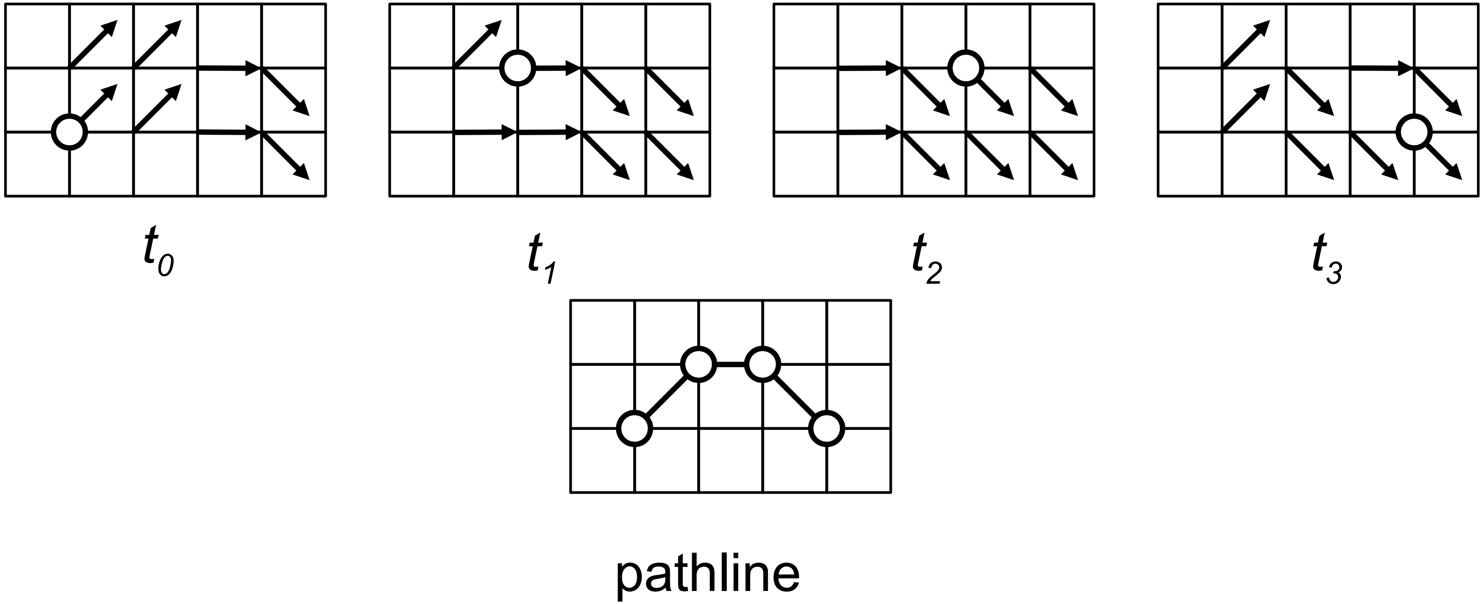
Streaklines



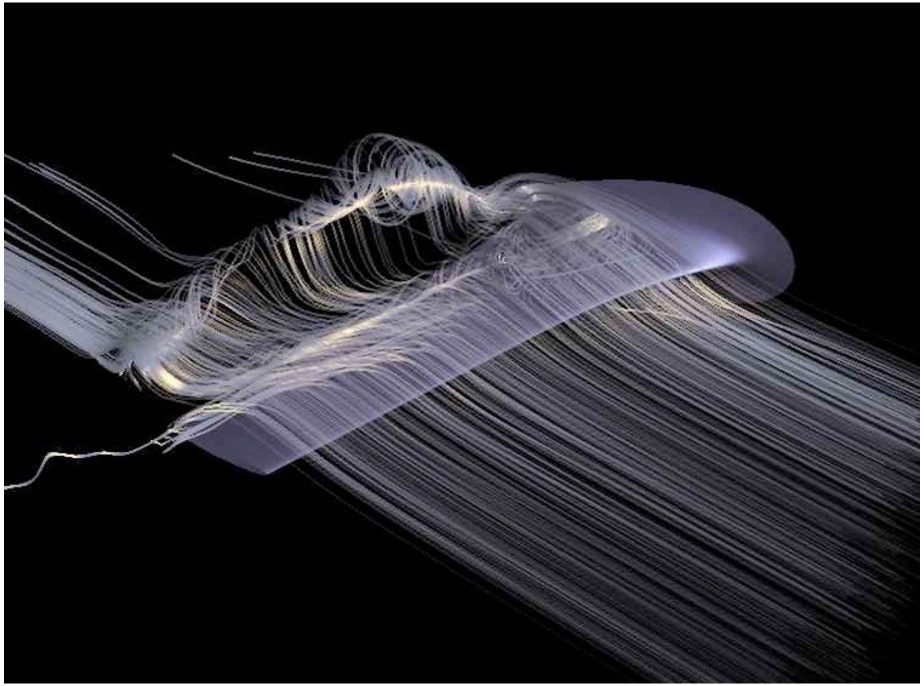


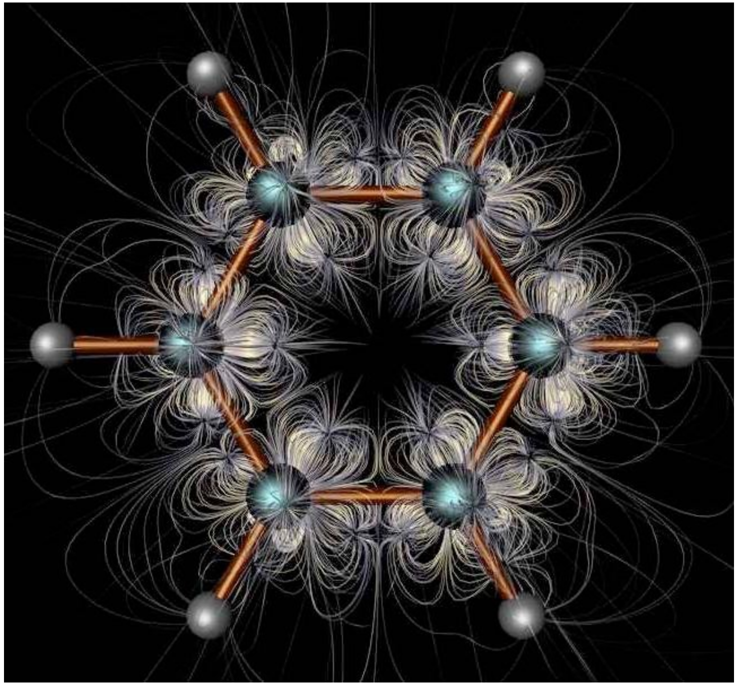
Pathlines

- Trajectories of massless particles in the flow
- Start particle at t_0, see where it goes



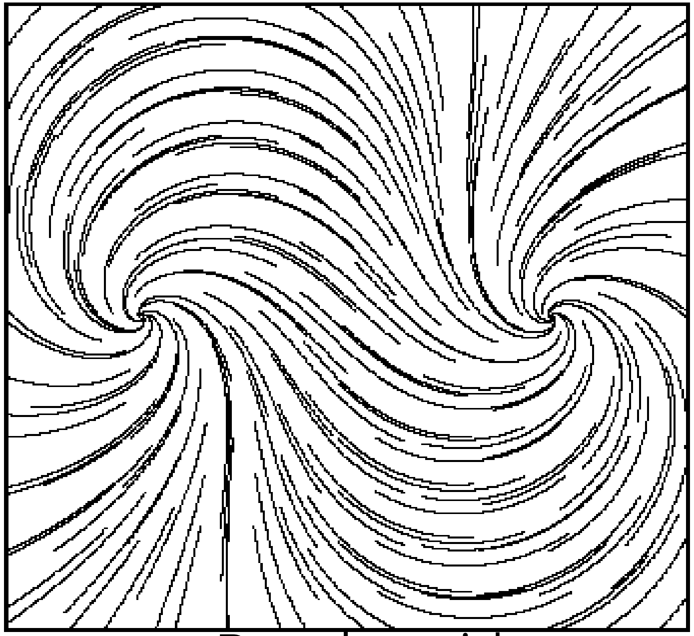
Pathlines



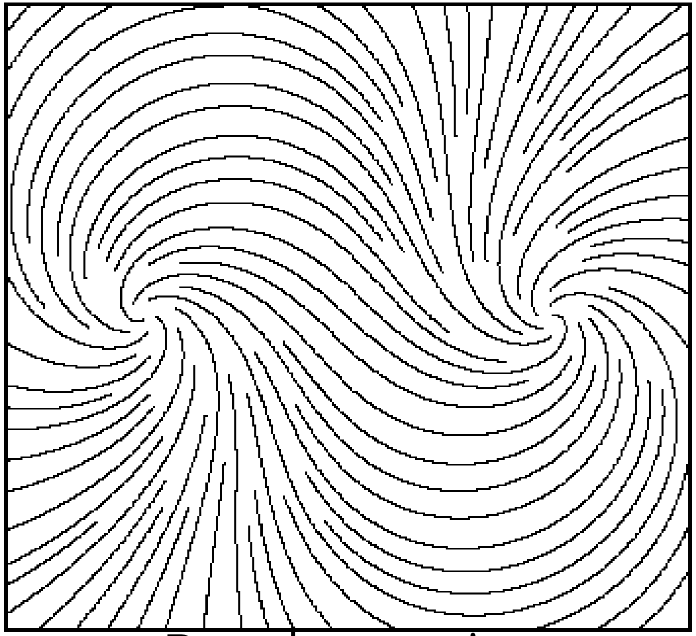


Considerations

- Distribution of lines
- Number of lines
- Seeding

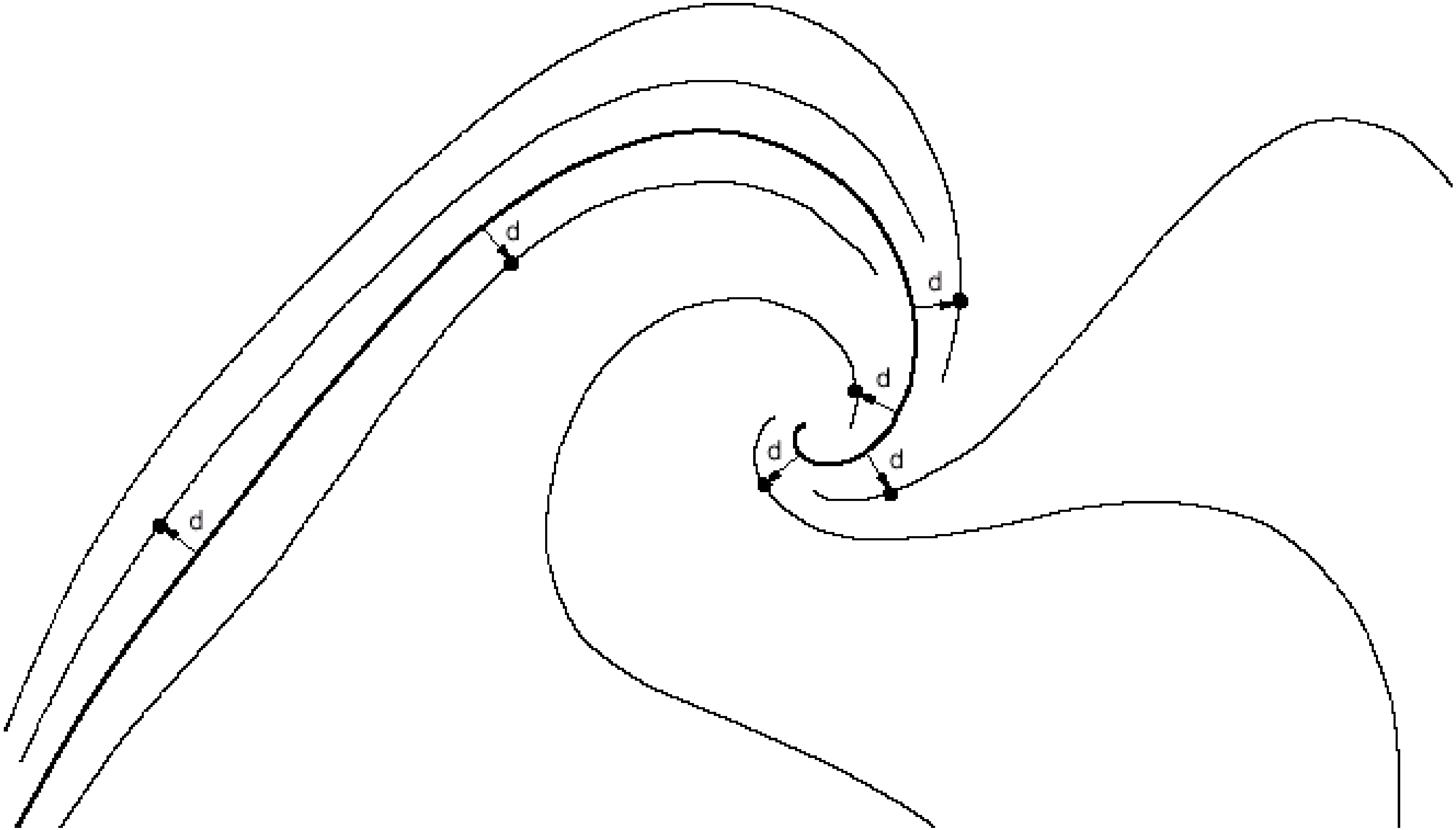


Regular grid



Regular spacing

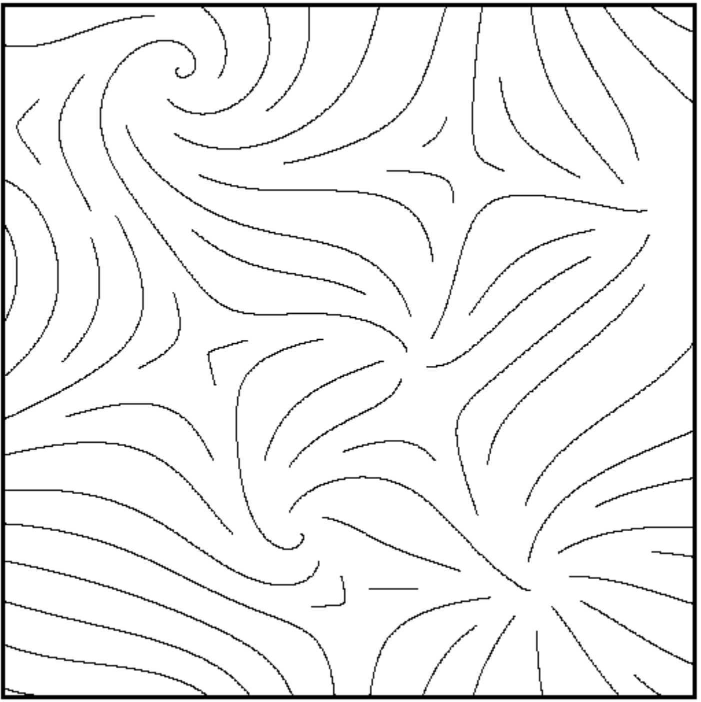
Regular spacing



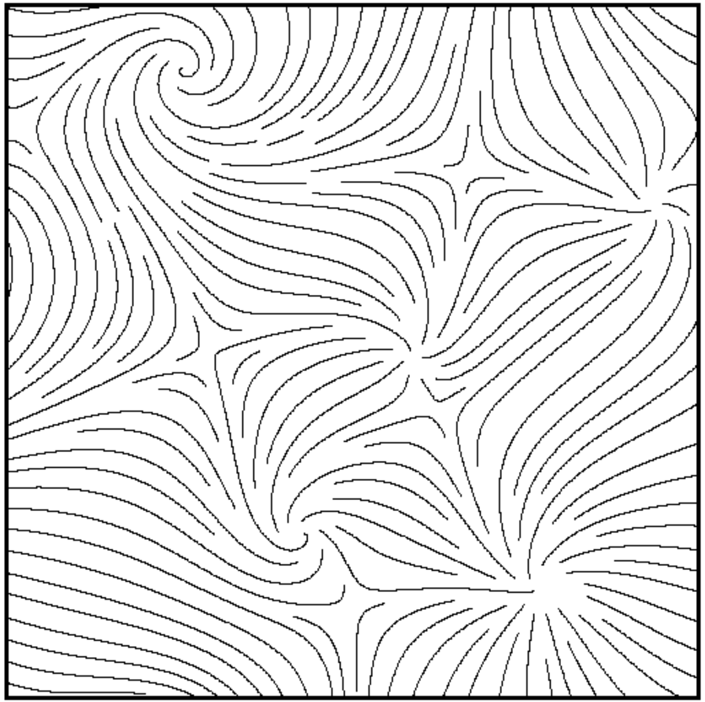
Number of lines

Variations of d_{sep} relative to image width:

6%



3%



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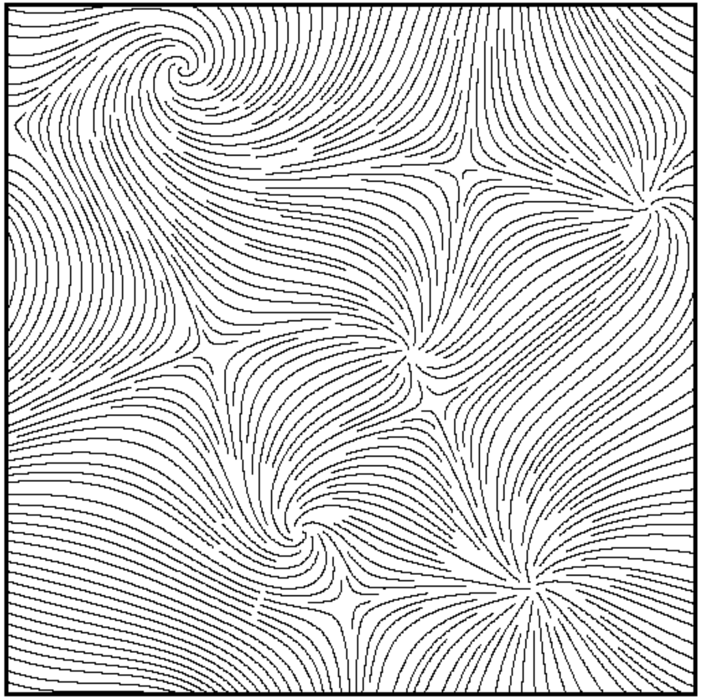
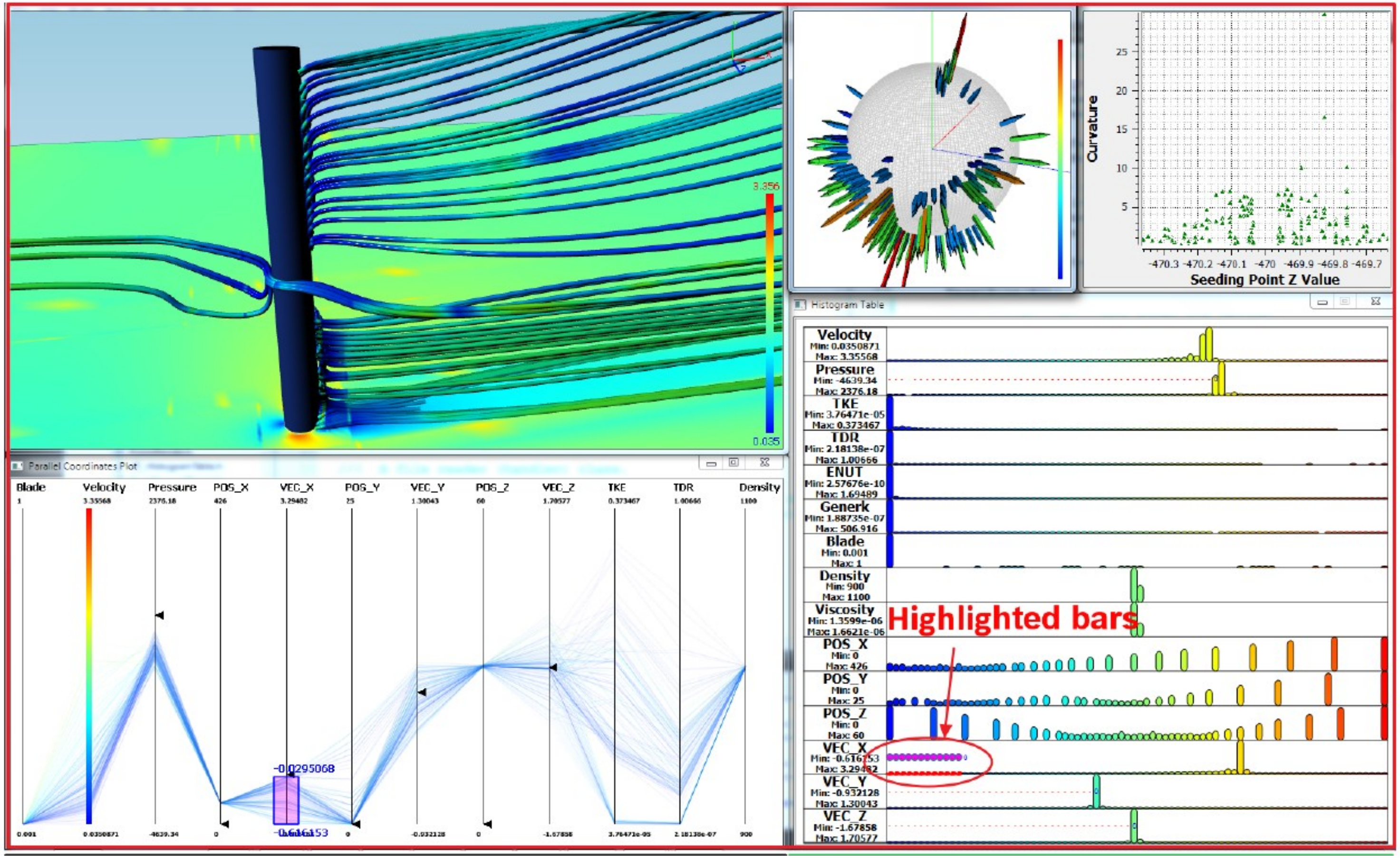


Seeding



Peng, Zhenmin, Zhao Geng, Michael Nicholas, Robert S. Laramee, Nick Croft, Rami Malki, Ian Masters, and Chuck Hansen. "Visualization of Flow Past a Marine Turbine: The Information-Assisted Search for Sustainable Energy." Computing and Visualization in Science 16, no. 3 (June 1, 2013): 89–103. https://doi.org/10.1007/s00791-014-0229-4.

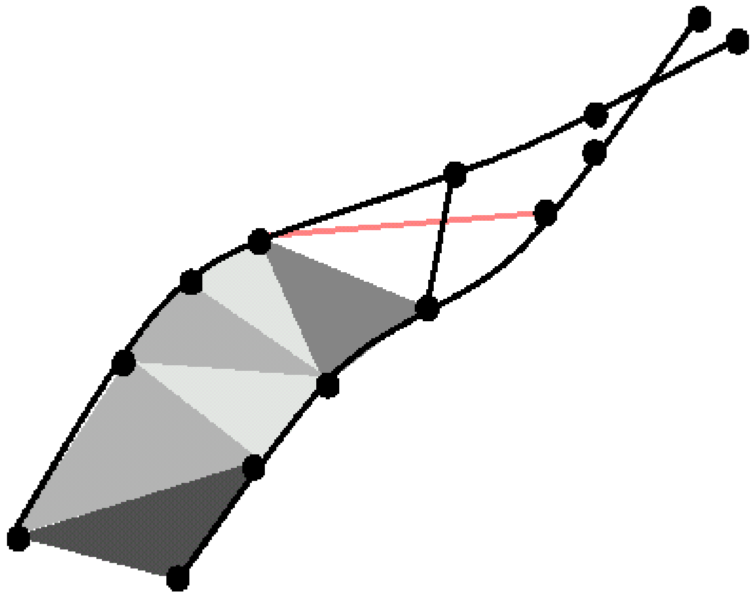
Other techniques

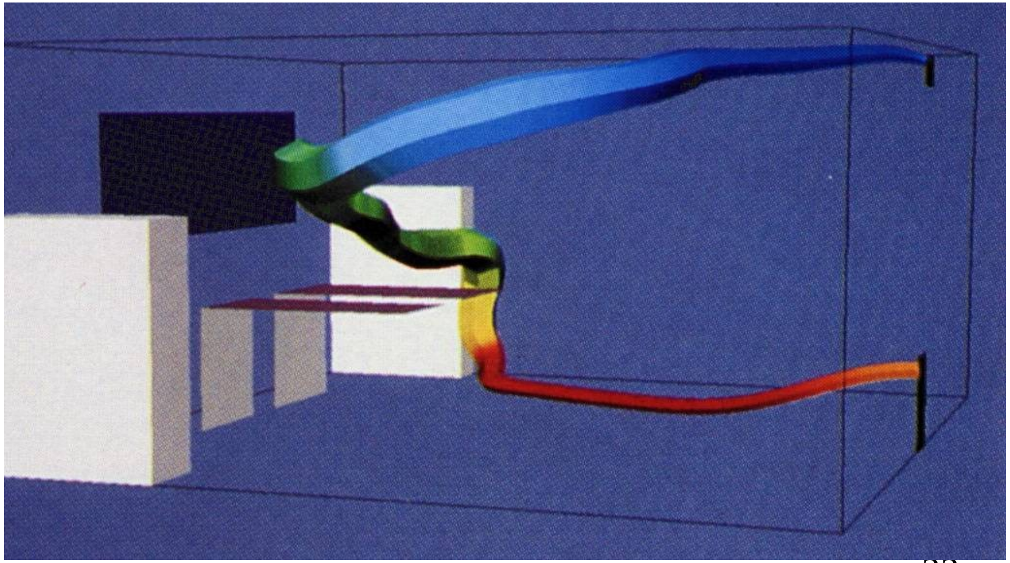
Ribbons and tubes

Can show rotation of vector field

Streamribbon : a ribbon (surface of fixed width) always tangent to the vector field -shows rotational properties of flow

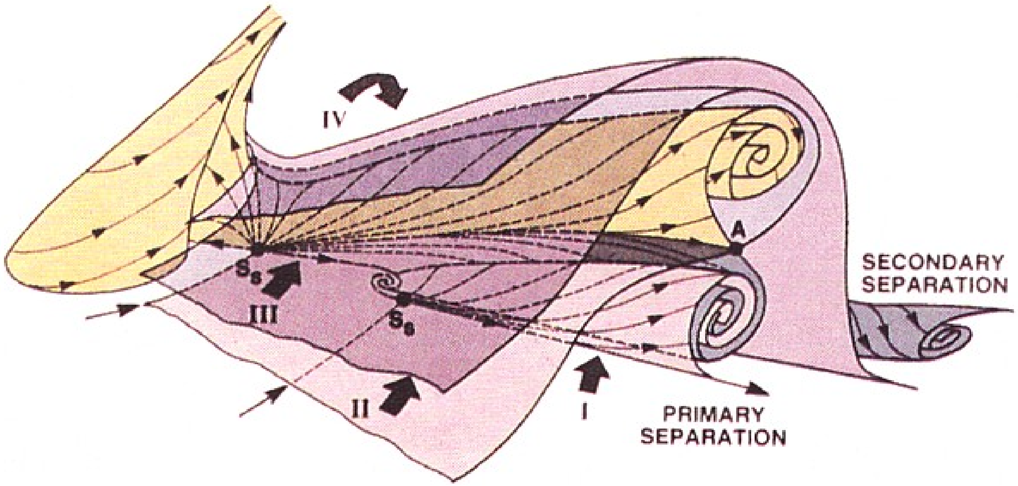
Streamtube : shows convergence and divergence of flow





Stream surfaces

- **Stream surface** : a surface that is everywhere tangent to flow
- **Stream surface** : the union of stream lines seeded at all points of a curve (the seed curve)
- Next higher dimensional equivalent to a streamline
- Unsteady flow can be visualized with a **path surface** or **streak surface**



YING, SUSAN, LEWIS SCHIFF, and JOSEPH STEGER. “A Numerical Study of Three-Dimensional Separated Flow Past a Hemisphere Cylinder.” In 19th AIAA, Fluid Dynamics, Plasma Dynamics, and Lasers Conference. American Institute of Aeronautics and Astronautics. Accessed March 24, 2020. https://doi.org/10.2514/6.1987-1207.

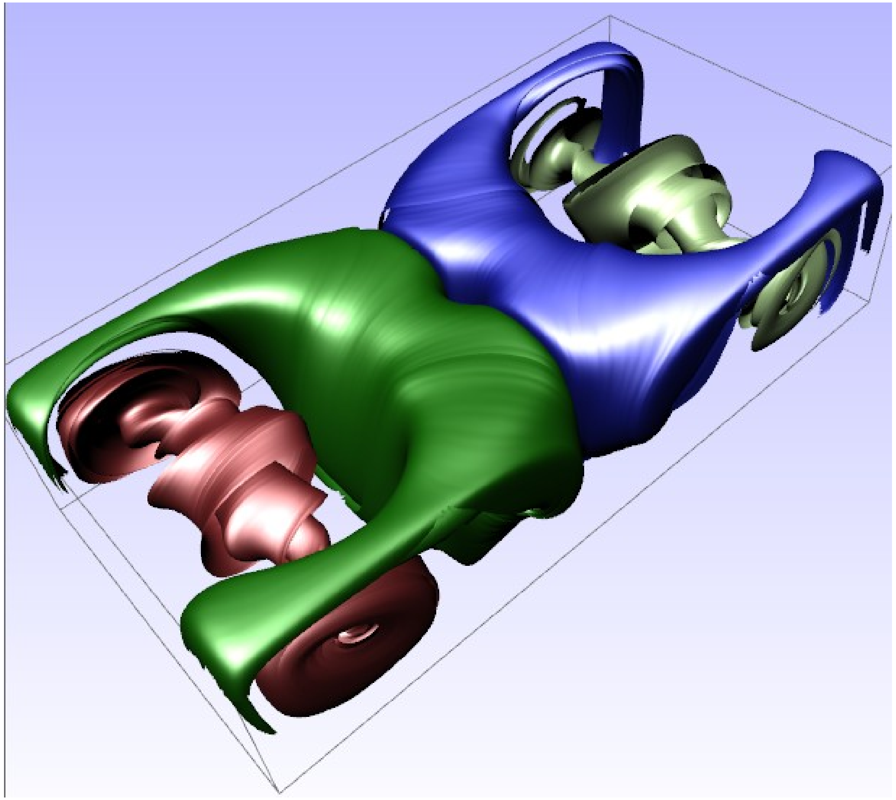
Stream surfaces

Motivation:

- Separates (steady) flow: flow cannot cross surface (stream surfaces only)
- Perception: Less visual clutter and complexity than many lines/curves
- Perception: well-defined normal vectors make shading easy, improving depth perception
- Rendering: surfaces provide more rendering options than lines: e.g., shading and texture-mapping etc.

Disadvantages:

- Construction/Implementation: more complicated algorithms are required to construct integral surfaces
- Occlusion: multiple surfaces hide one another
- Placement: placement of surfaces is still an unsolved problem



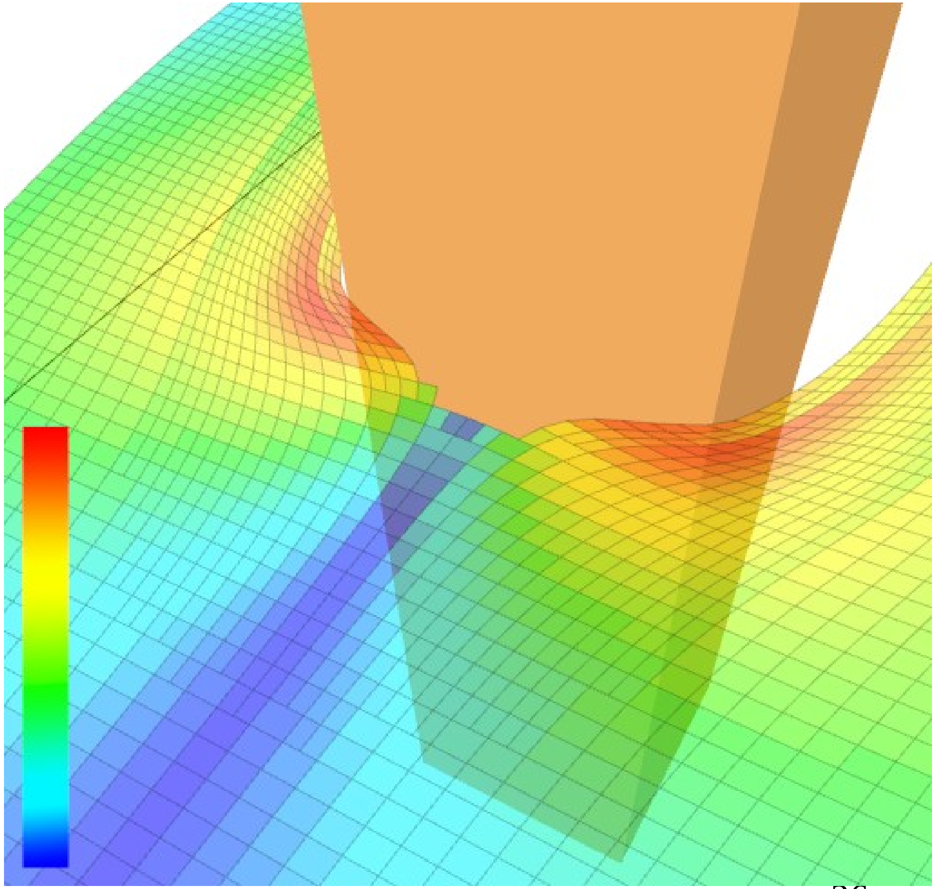
Splitting/merging

Surface may split when object boundary encountered

Separate portions computed independently

Terminating Conditions:

- Critical Point (Zero Velocity)
- Object Intersection
- Leave Domain
- Desired geodesic length reached



Conclusion

Summary

- Geometric flow visualization visualizes the integrated flow field
- Different viewpoints of flow:
  - Eulerian
  - Lagrangian
- Standard techniques:
  - streamlines
  - pathlines
  - Streaklines
- Need to be careful w.r.t. placement and number of lines

Acknowledgements

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- Daniel Weiskopf
- Raghu Machiraju

References

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- Data Visualization: Principles and Practice, Chapter 6: Vector Visualization by A. Telea, AK Peters 2008
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