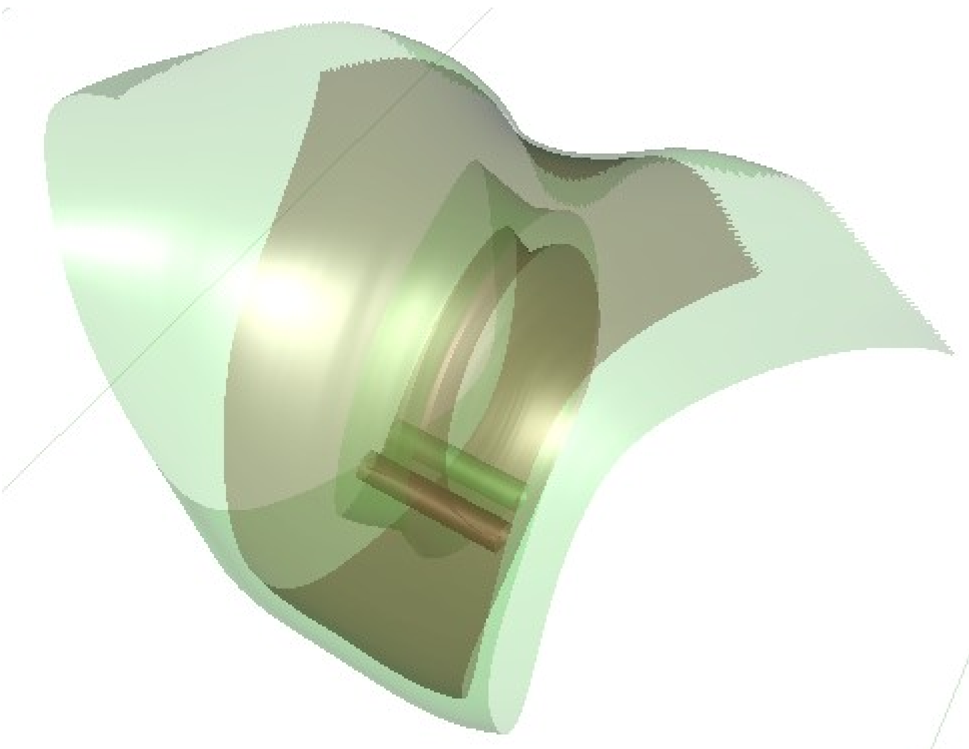
Using Integral Surfaces to Visualize CFD Data



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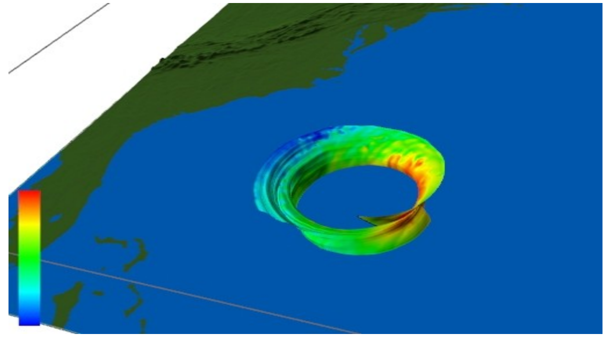
Overview

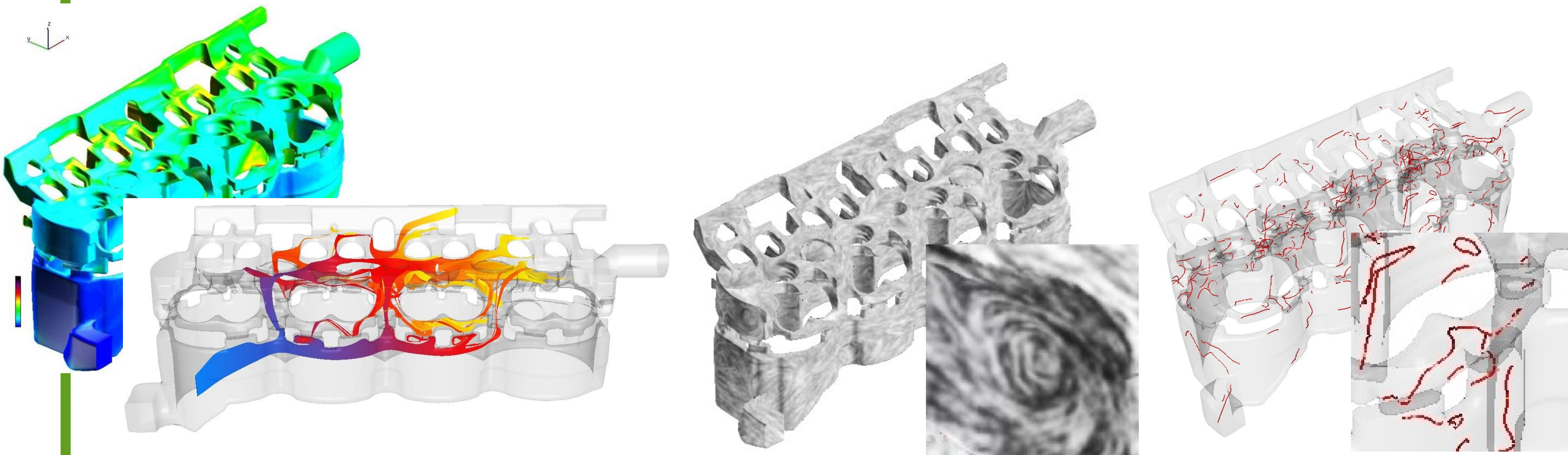
Flow Visualization with Integral Surfaces:



- Introduction to flow visualization
- Stream, path, and streaklines
- Integral surface-based flow visualization
- Advantages of surfaces over curves
- Stream and path surfaces
- Stream and path surface demo
- Streak surface demo
- Conclusions and Acknowledgments

Flow Visualization: Background

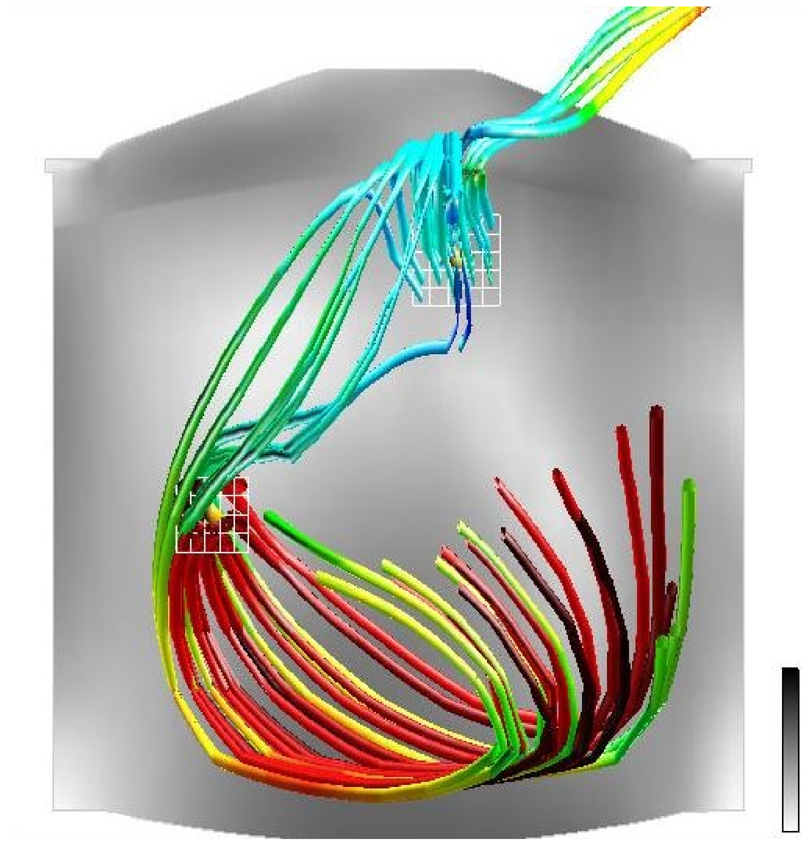
1. **direct:** overview of vector field, minimal computation, e.g. glyphs, color mapping
2. **texture-based:** covers domain with a convolved texture, e.g., Spot Noise, LIC, ISA, IBFV(S)
3. **geometric:** a discrete object(s) whose geometry reflects flow characteristics, e.g. streamlines
4. **feature-based:** both automatic and interactive feature-based techniques, e.g. flow topology



Stream, Path, and Streaklines

Terminology:

- **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)



Each is equivalent in steady-state flow

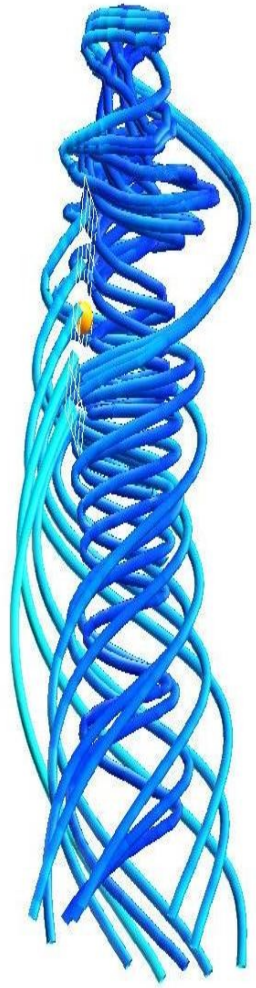
Characteristics of Integral Lines

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:

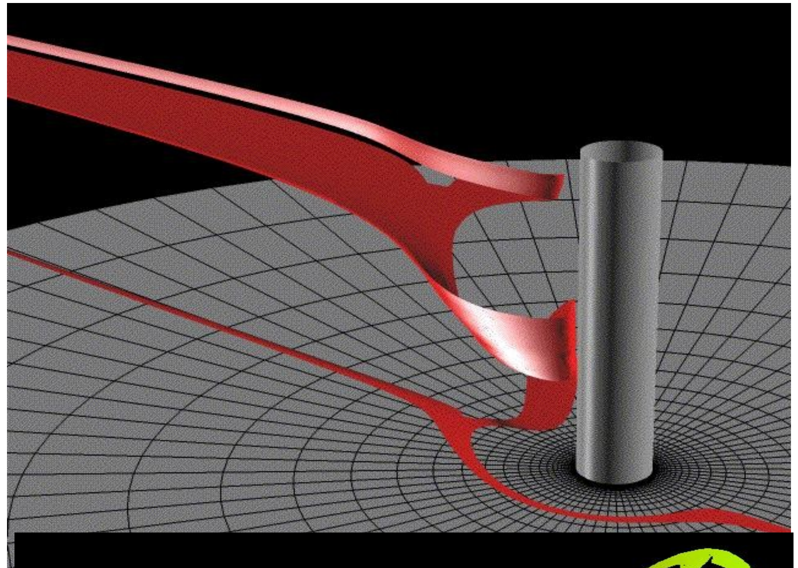
- **Perception:** too many lines can lead to clutter and visual complexity
- **Perception:** depth is difficult to perceive, no well-defined normal vector
- **Seeding:** optimal placement is very challenging (unsolved problem)

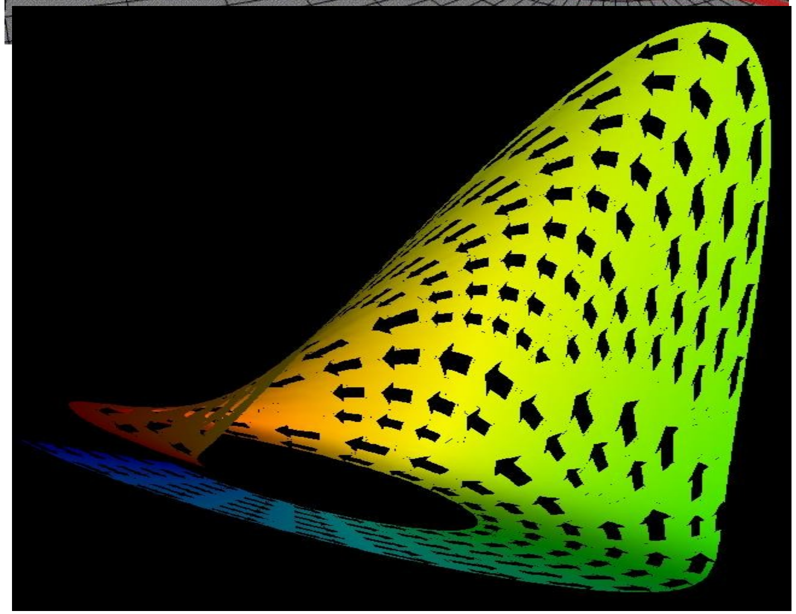


Stream Surfaces

Terminology:

- **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**





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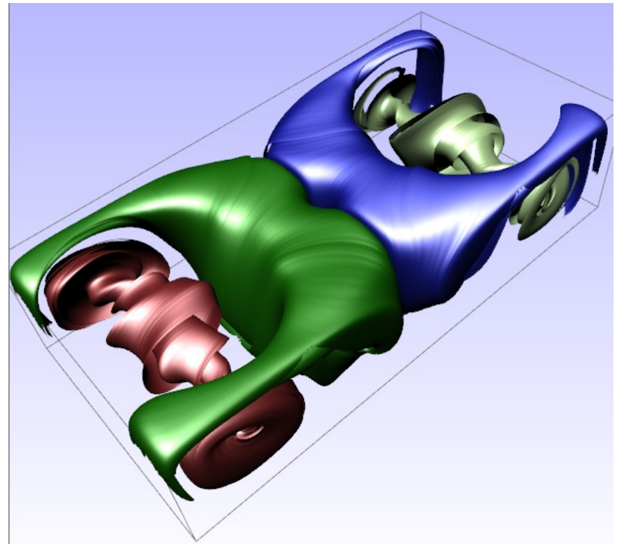
Stream Surfaces: Advantages

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.

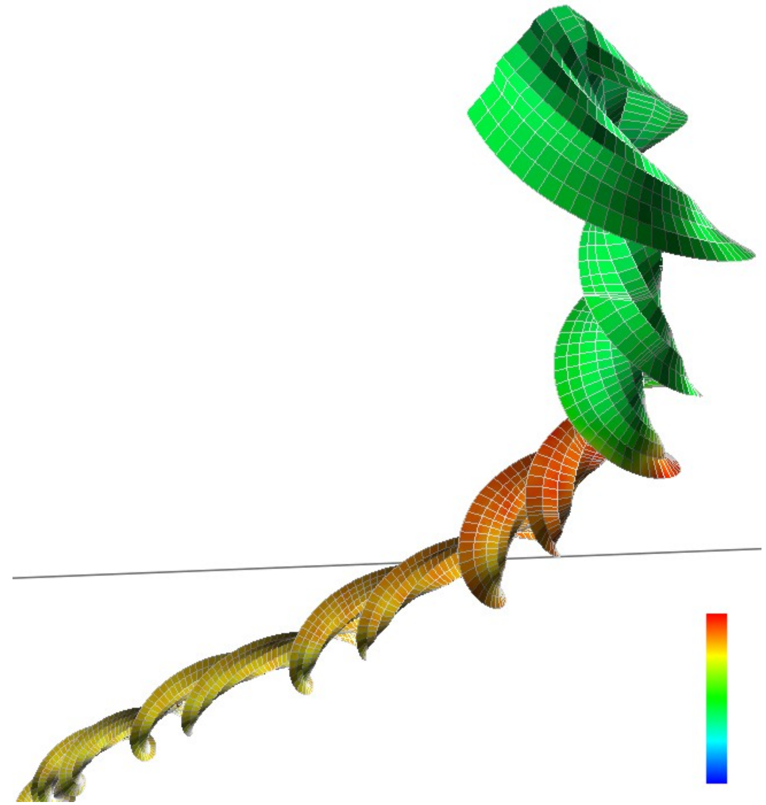


Disadvantages:

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

Easy Integral Surfaces

- Relies on use of quad primitives
- Use of local operations (per quad).
- Simple data structure
- Implicit parameterization
- Formulated as a reconstructive sampling of the vector field
  - `d_sample`
  - `d_advance`
  - `d_sep`



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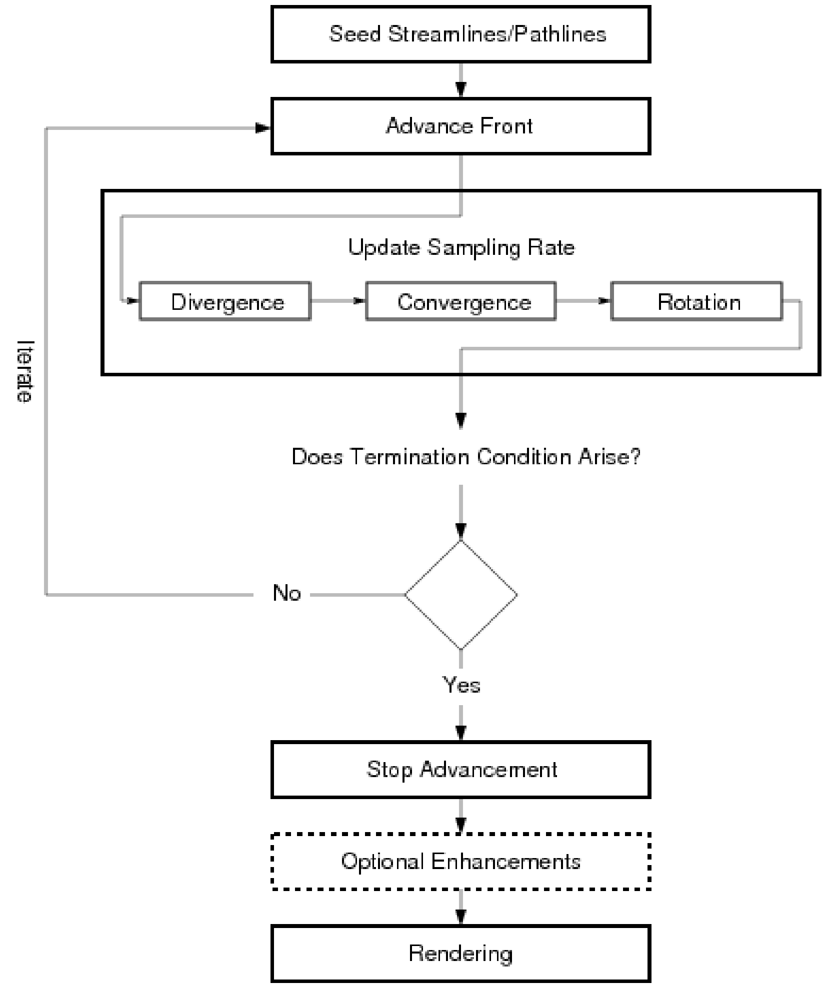
Algorithm Overview

```
Seed;
While(not terminated)
    Advance front;
    Update Sampling Rate;
End While
Render;
```



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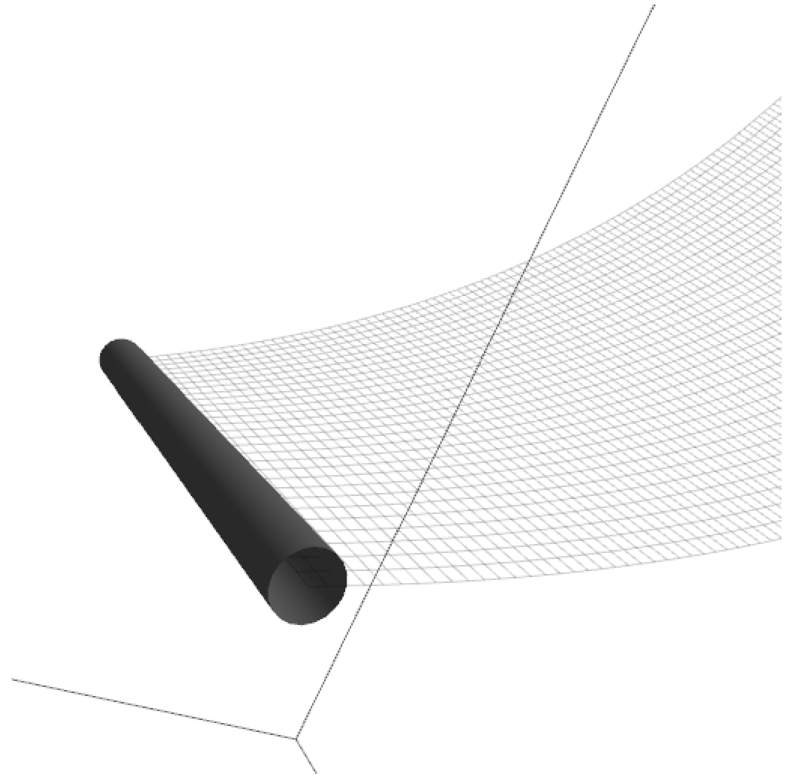
Seeding and Advancement

- Interactive seeding curve:
  - Position and orientation
  - Length
  - Prongs/number of seeds
- Integral surface front advance distance guided by
  - Nyquist rate
  - 0.5 d_sample



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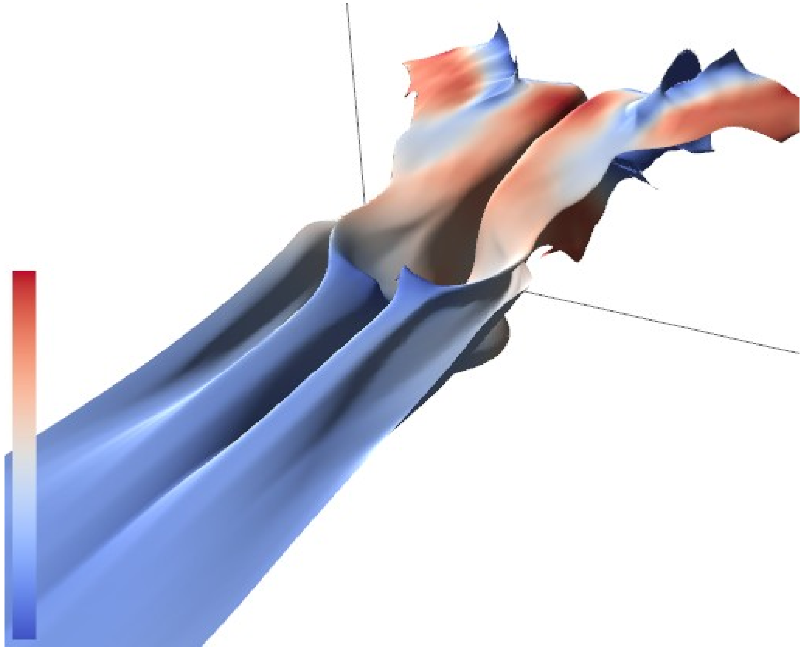
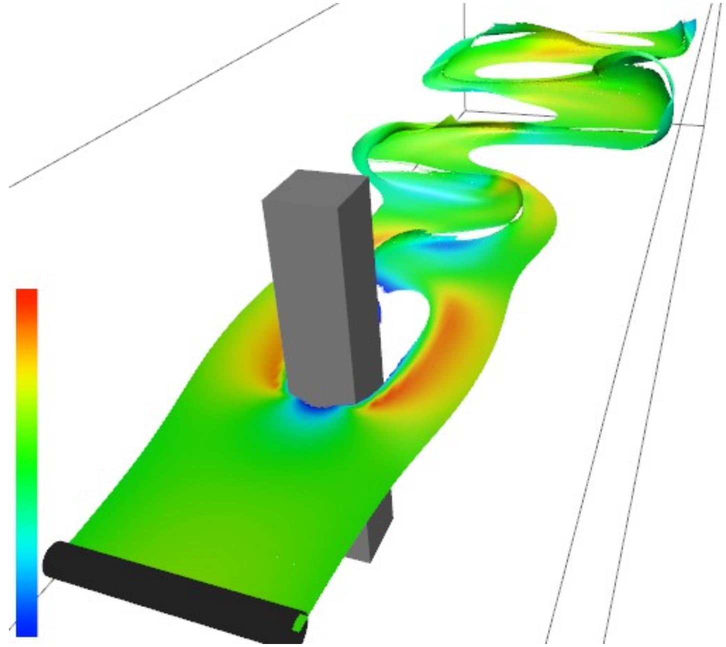
Stream and Path Surface Results: Video(s)

Constructing Streak Surfaces in 3D Unsteady Vector Fields





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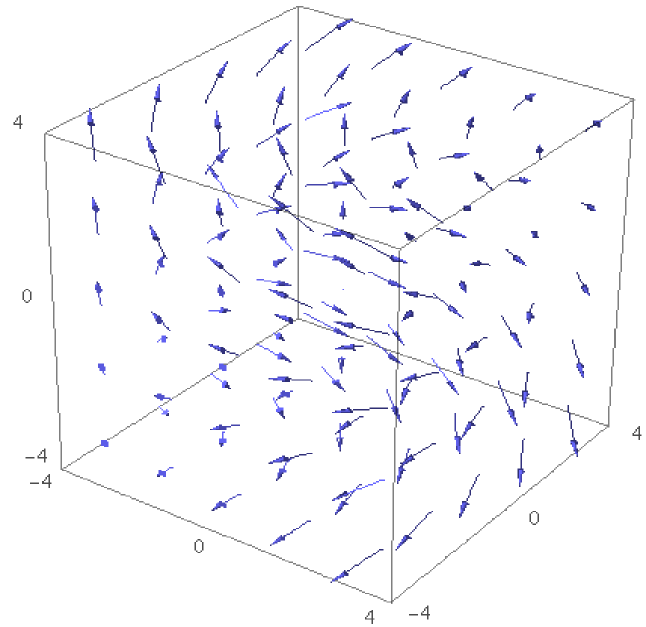
3D, Unsteady Flow

Discrete locations in 3D space

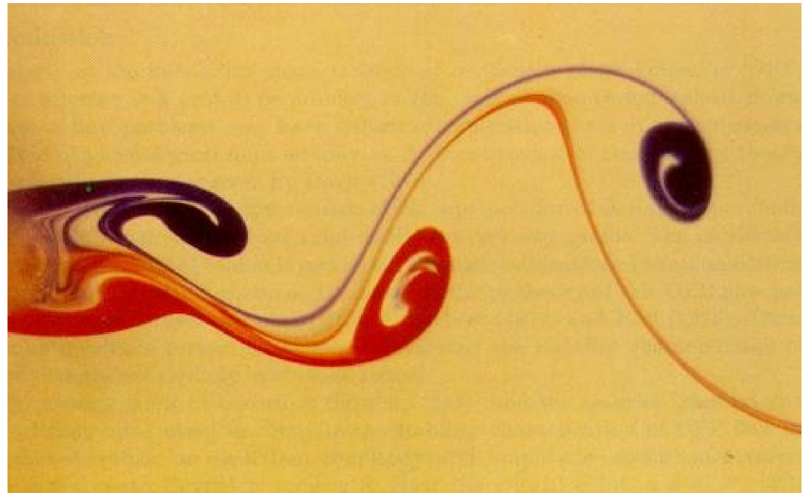
- 4-tuple (4D vector) for each sample
- x-, y-, z-, t- components
- Direction
- Magnitude
- Velocity field when describing the motion of a fluid
- Obtained from CFD simulations or constructed from empirical data
- Unsteady vector fields vary over time

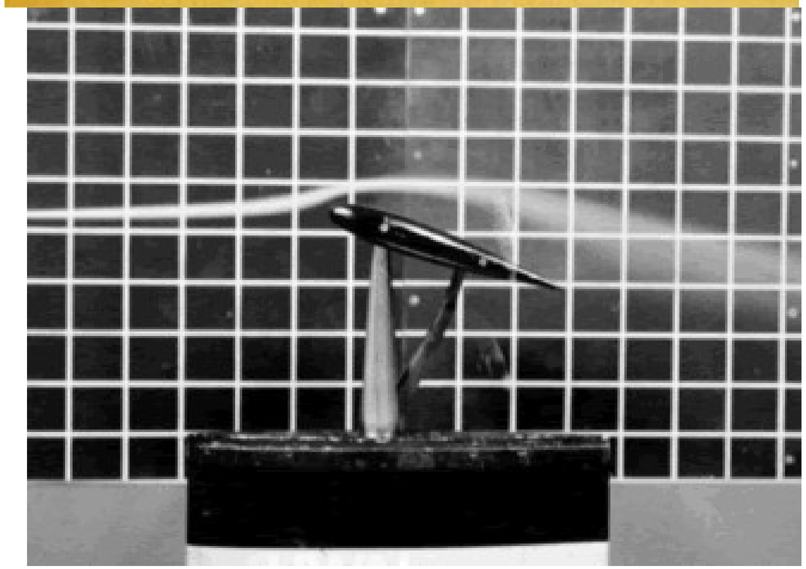


Streak Surface: Terminology

Terminology

- **Streaklines**: curved formed by joining all particles passing through same point in space (at different times)
- Strong relation to smoke/dye injection from experimental flow visualization.
- **Streak surfaces** are an extension of streak lines (next higher dimension)





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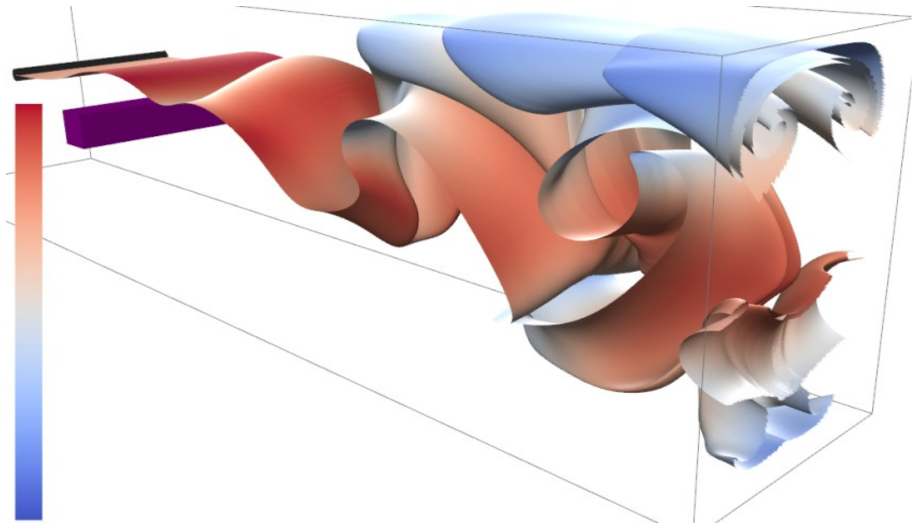
Streak Surface Construction Challenges

Challenges:

- Computational cost: surface advection is **very** expensive
- Surface completely dynamic: entire surface (all vertices) advect at each time-step
- Mesh quality and maintaining an adequate sampling of the field.
  - Divergence
  - Convergence
  - Shear
- Objects in domain and critical points
- Large size of time-dependent (unsteady) vector field data, out-of-core techniques



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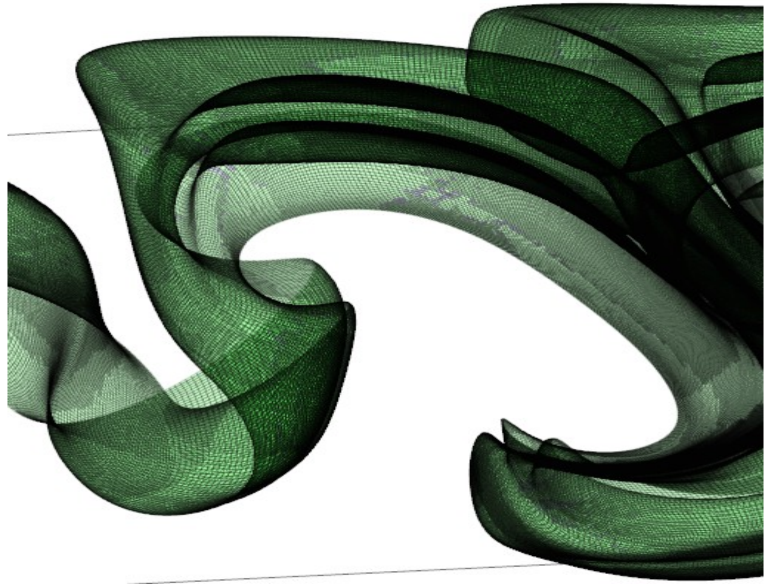
Streaksurface Properties

Properties:

- Surface constructed using quad primitives (as opposed to triangles)
- Local operations for surface refinement performed on a quad-by-quad basis
- No global optimization required
- Allows the construction of large surfaces
- CPU-based for easier implementation
- Fills the gap between methods of Burger et al. [2009] and Krishnan et al. [2009]
    - Not as fast as GPU but interactive
    - Fewer constraints than GPU implementation – does not need to fit into GPU memory

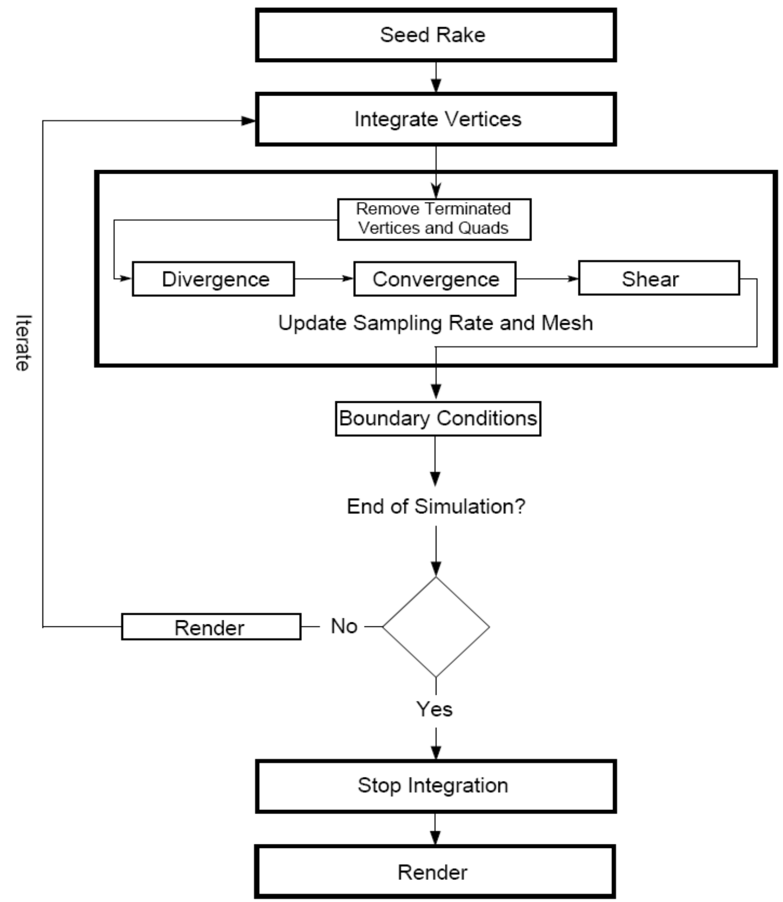


Streak Surface Algorithm

Do:

Position seed with interactive rake

- Iteratively construct surface:
  - Advect surface
  - Refine Surface
  - Test for boundary conditions
  - Update
  - Test for termination criteria
- Final rendering



Streak Surface Results: Video

Summary and Conclusions

- We claim surfaces offer advantages over traditional curves when visualizing 3D and 4D flow
- We present interactive algorithms for construction of stream, path and streak surfaces
- Algorithms are based on local operations performed on quads for mesh refinement
- Technique handles divergence, convergence and shear flow
- Splitting of surface to adapt to flow around object boundaries
- Demonstrated on a variety of data sets

Acknowledgements

Thank you for your attention! Any questions?

We thank the following for material used here:

- **Tony McLoughlin**

This work was partially funded by EPSRC Grant EP/F002335/1