Vector and Flow Field Visualization

- We have looked primarily at scalar field visualization
- Iso-surface extraction, volume rendering algorithms
- These algorithms do not extend to vector-valued quantities, which may have 2, 3 or more values per voxel
- What would it mean to volume-render a field of velocity vectors?
- How would we perform classification, shading, compositing, and the other stages of the pipeline?

Scalar Generation

- Vectors and other n-D quantities can be turned into scalars
- Example: taking magnitude of vectors
- Example: Hawaii terrain visualization created by projecting vector onto vertical
- Normalize vectors to give maximum magnitude of 1.0
- Steepest slope mapped to brightest color

Scalar Generation

$$s_i = \frac{(p_i - p_l) \cdot (p_h - p_l)}{\left|p_h - p_l\right|^2}$$

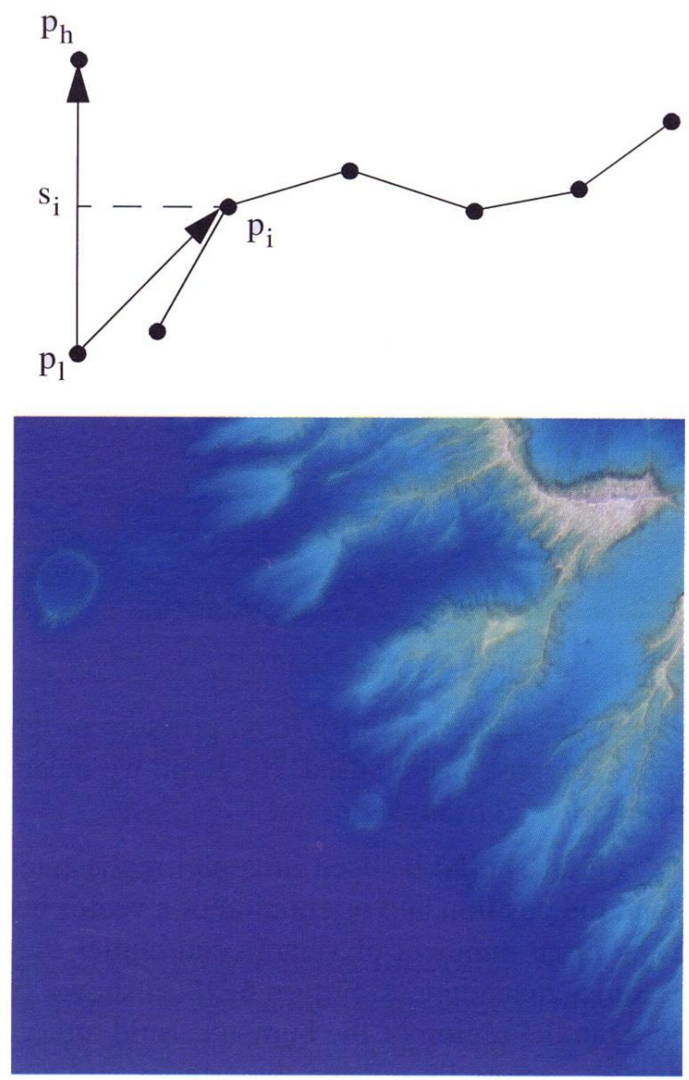


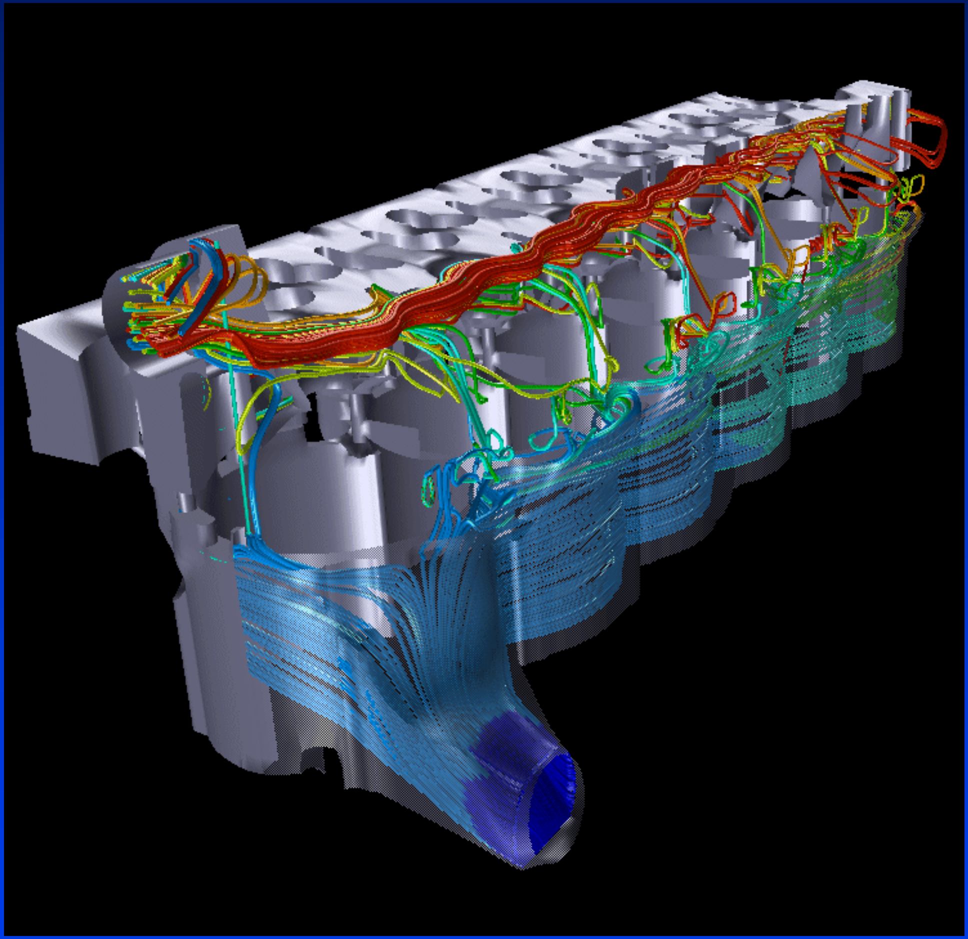
Figure 6–12 Computing scalars using normalized dot product. Bottom half of figure illustrates technique applied to terrain data from Honolulu, Hawaii (`hawaii.tcl`).

Vector and Flow Field Visualization

Vector and Flow Field Visualization

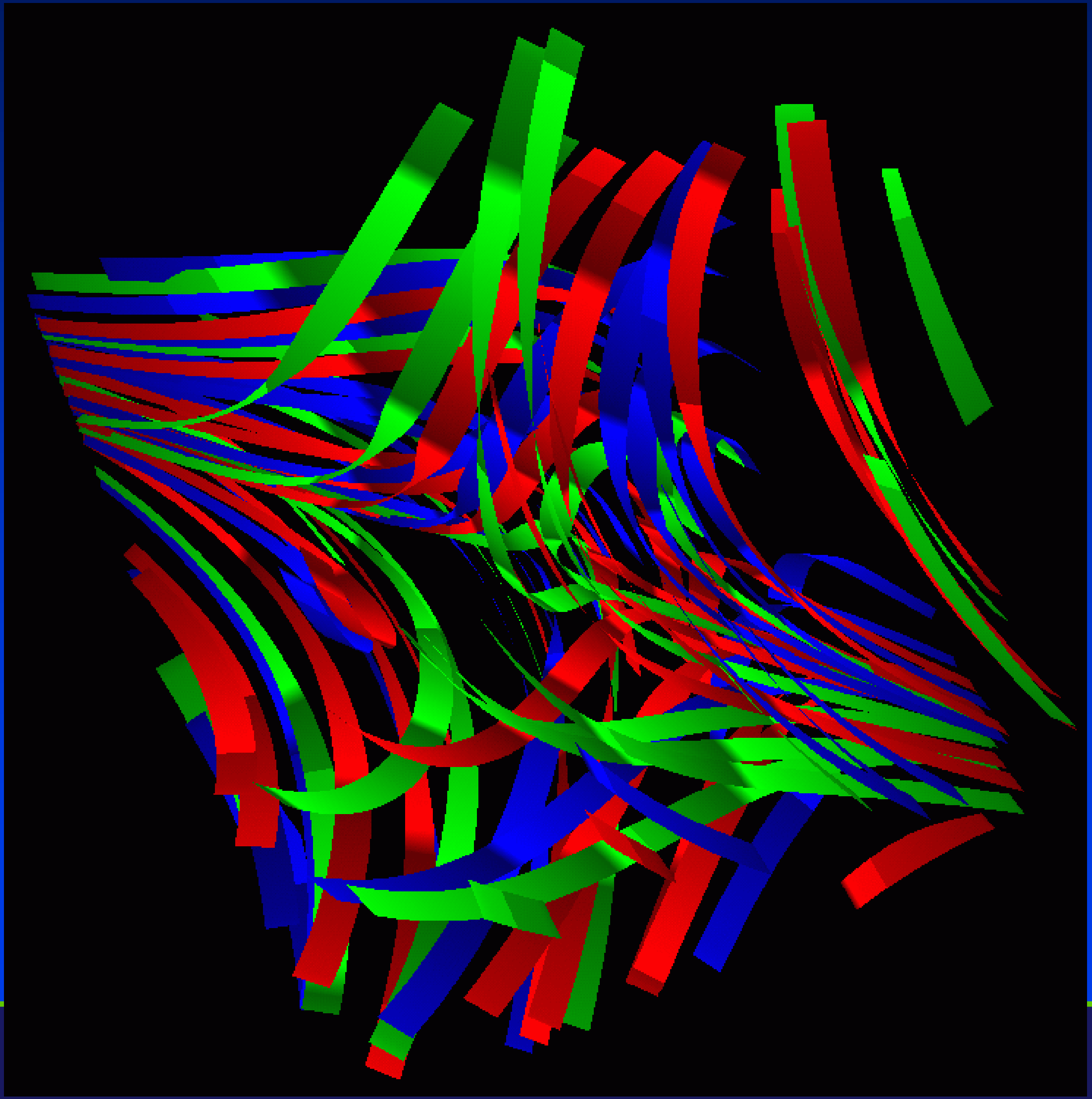
- Streamlines
  - Integration through vector field
- Stream ribbons
  - Connect two streamlines
- Streamtubes
  - Connect three or more streamlines
- Stream surfaces
  - Sweep line segment through vector field

Streamlines Example

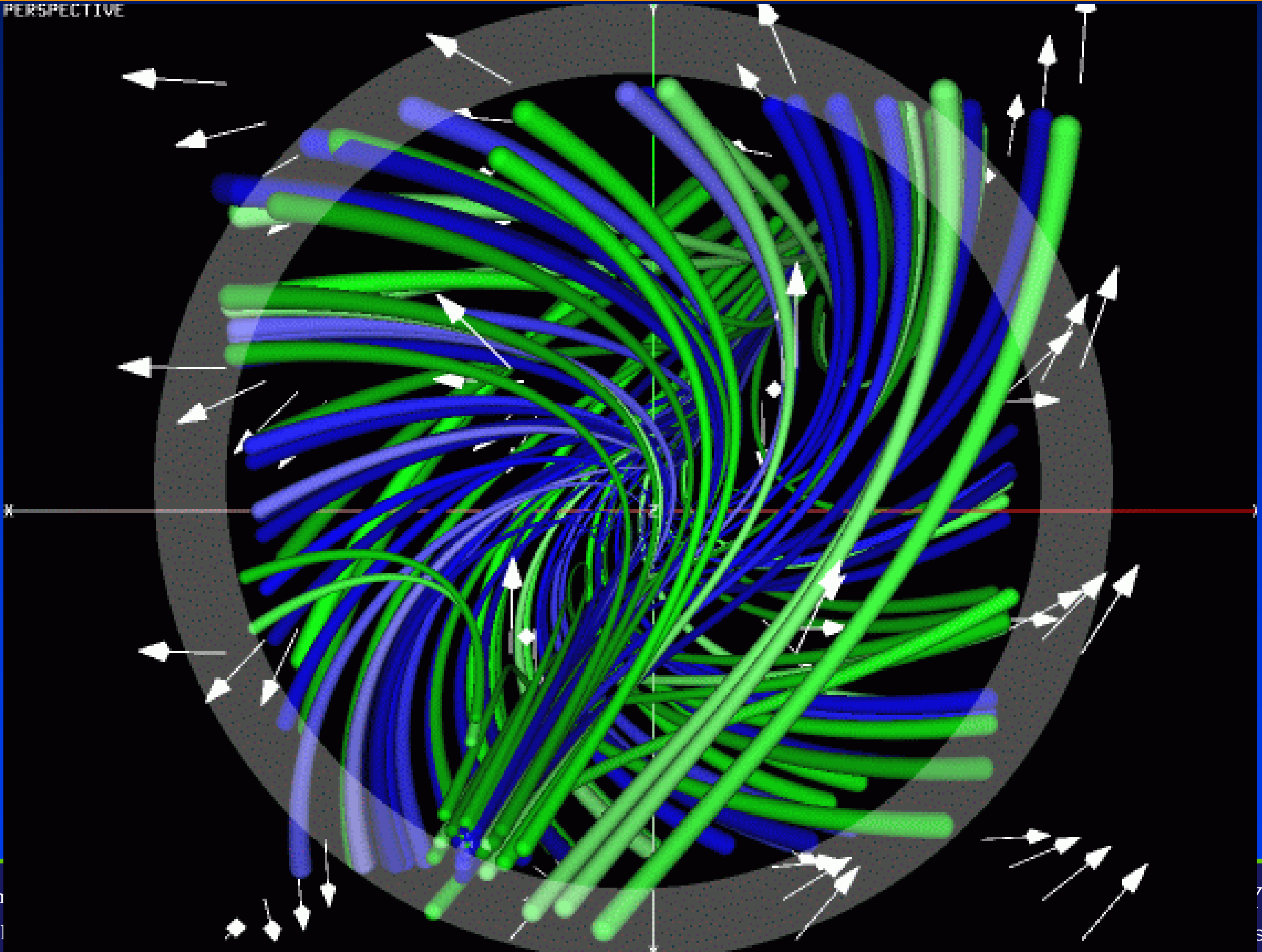


Color indicates temperature of air flowing through engine

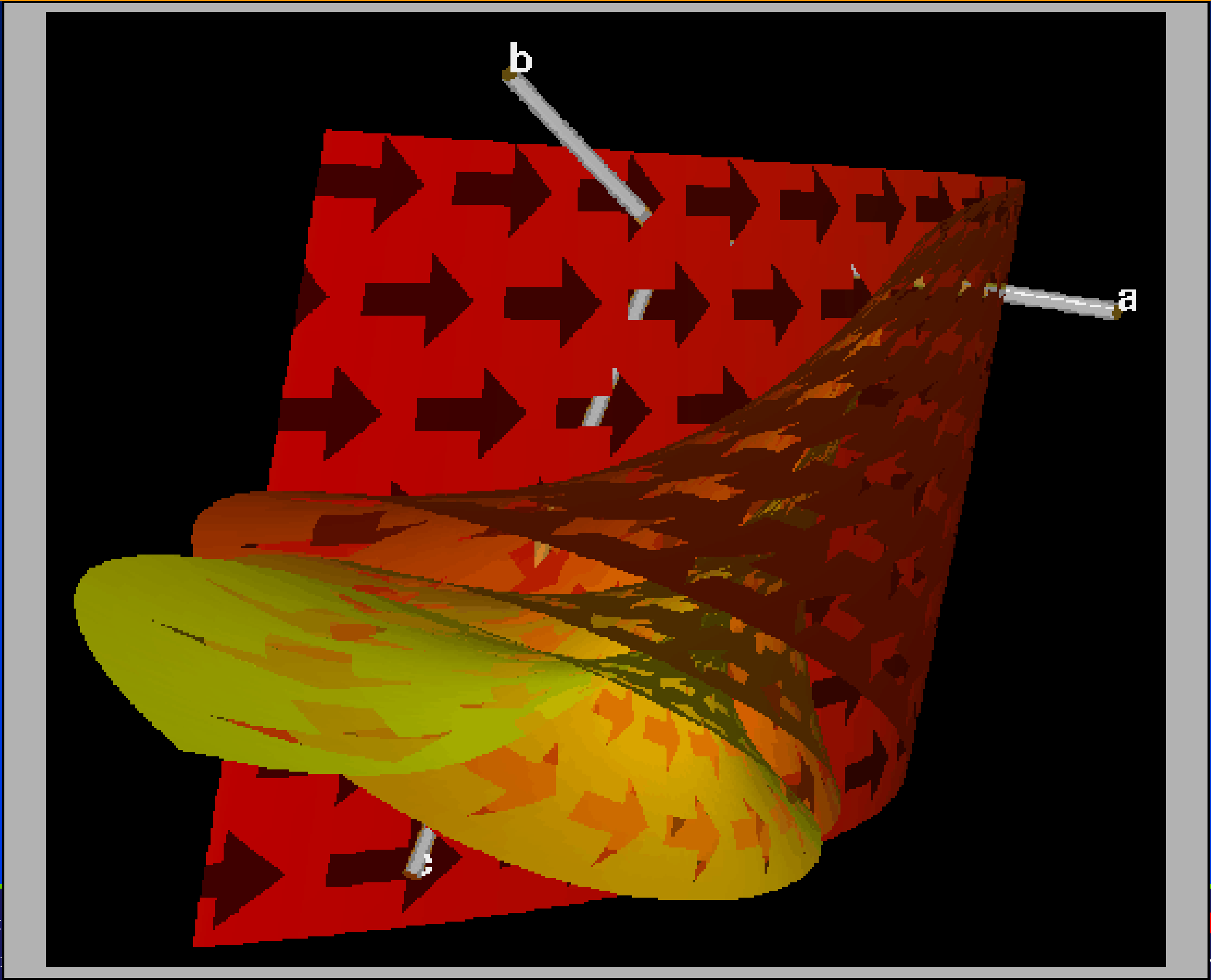
Streamribbons Example



Streamtubes Example



Streamesurfaces Example



Vector and Flow Field Visualization

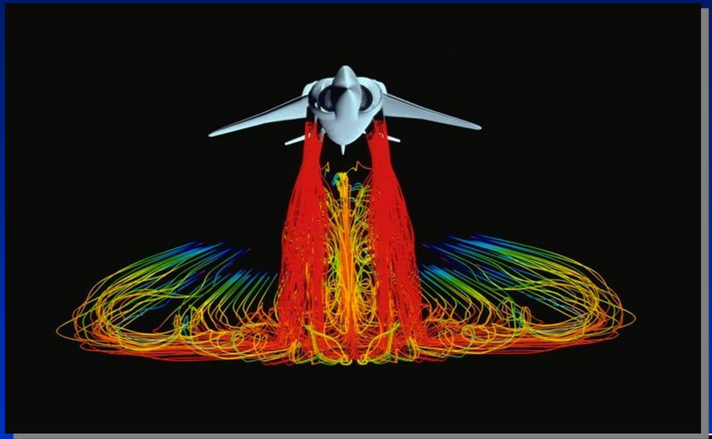
- Computational fluid dynamics (CFD) has been the classical application driving R&D in vector visualization
- Why? Many components at a given (x,y,z) position: velocity, temperature, pressure, rotation, etc.
- Many vector field visualization techniques, some quite clever
- Remember goal of visualization: understand important aspects and features of complex data-sets

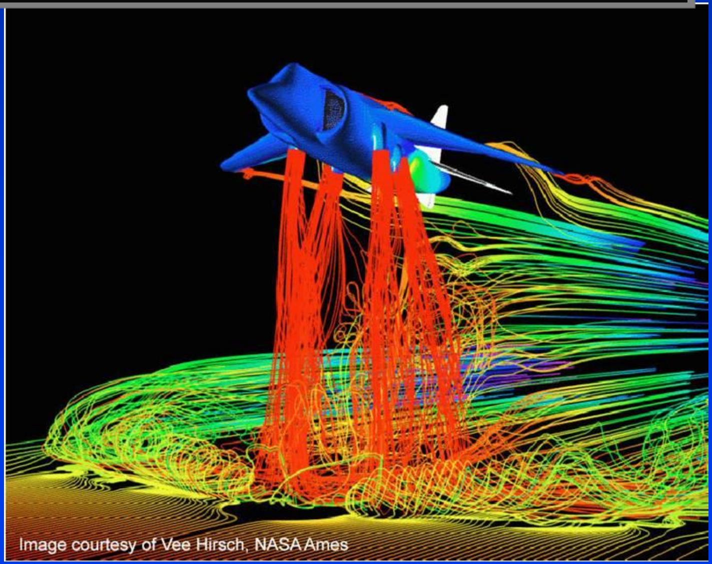
Data Contraction

- Reduce vector-valued functions to scalar ones
- Vector magnitude
- Scalar product with a given direction vector
- Advantage: very simple technique and uses existing volume visualization
- Disadvantage: very simple technique that discards too much information

Streamlines, Pathlines, Streaklines

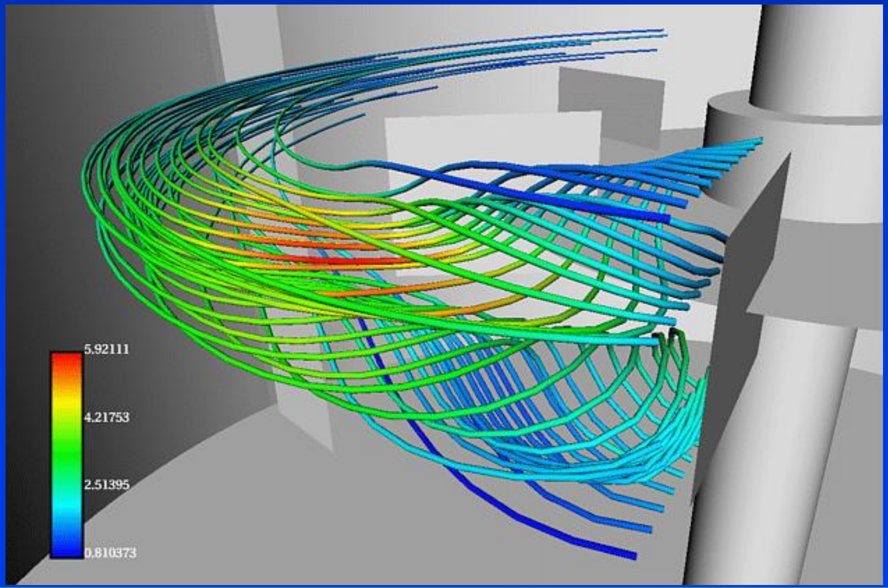
- Particle advection (line integration)
- Streamline – path always tangent to flow field
- Streamlines best used for stationary flows, flows that do not change as a function of time
- Color-coded





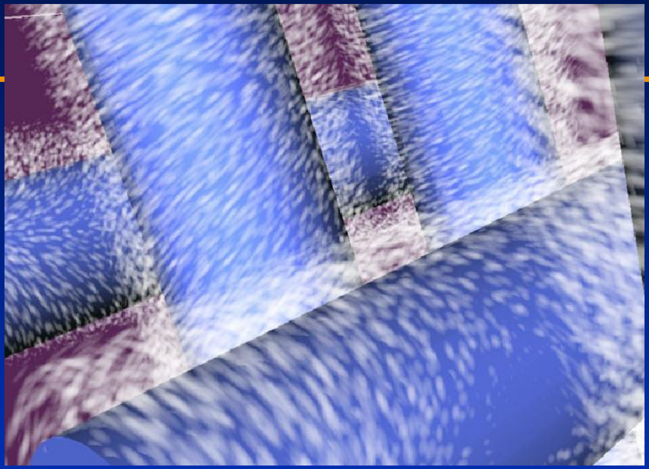
Streamlines, Pathlines

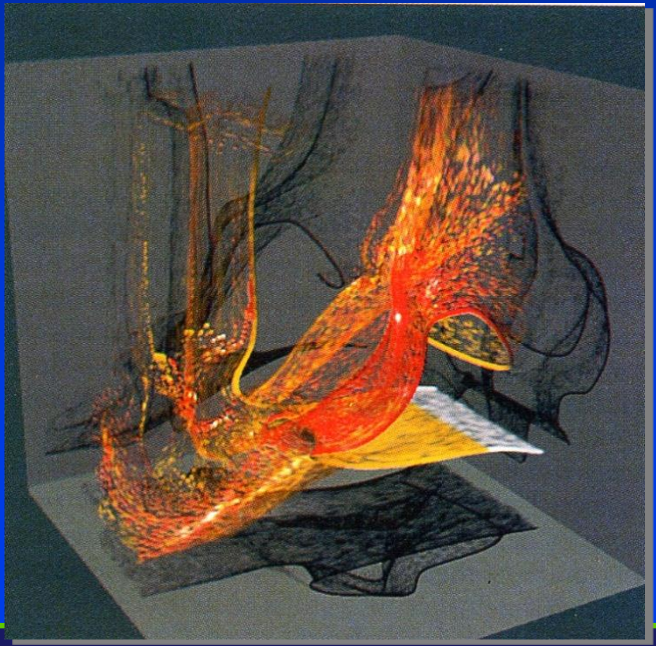
- Pathline – similar to streamline; trajectory that results if single particle is released and traced over time
- If flow is stationary (time invariant), pathline coincides exactly with the streamline at a given starting position



Particle Systems

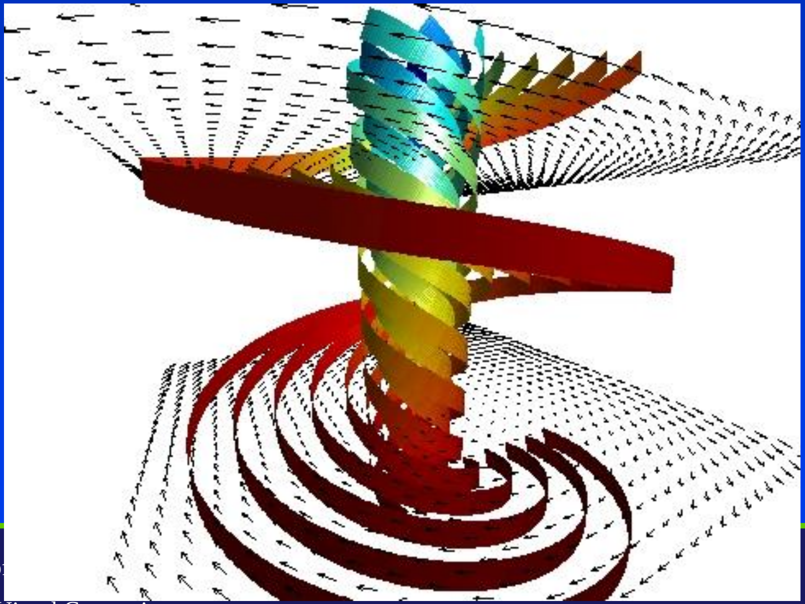
- Particles are injected into the flow field, which may be time-varying (turbulent)
- Enter, travel, leave
- Animated particles show direction and magnitude of velocity

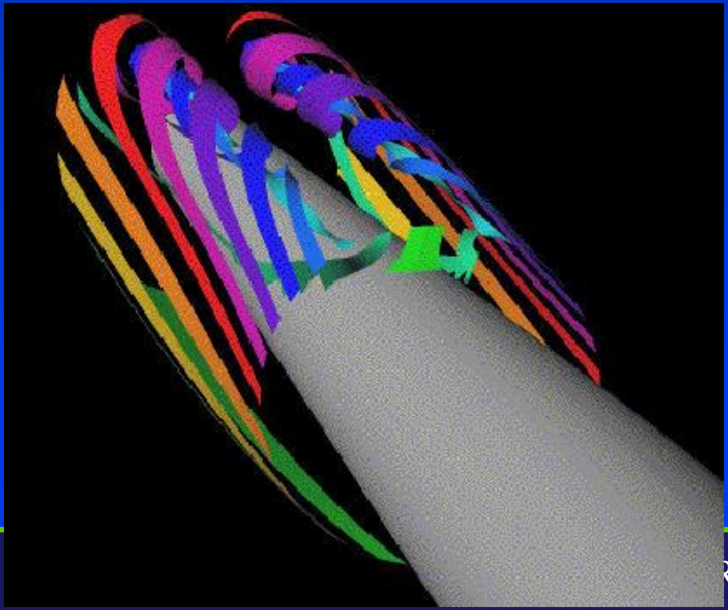




Ribbons and Tubes

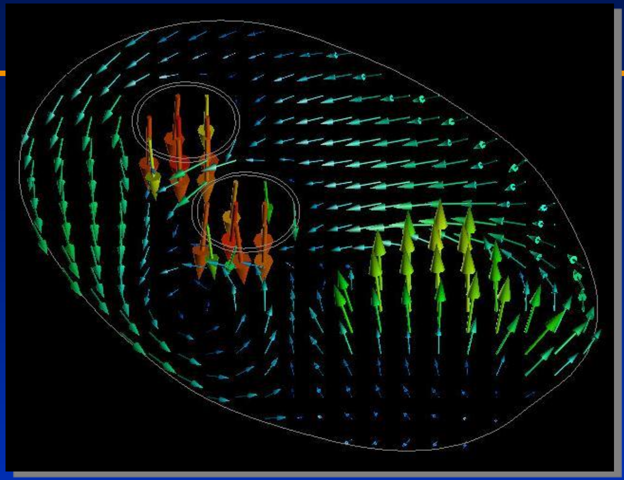
- Multiple particle advections per segment in the discretized line integration
- Connect two of them together to generate a ribbon, more to make a tube

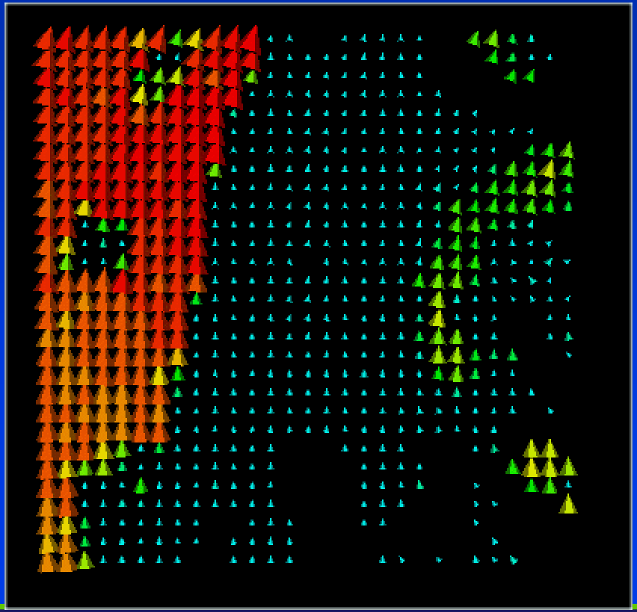




Hedgehogs

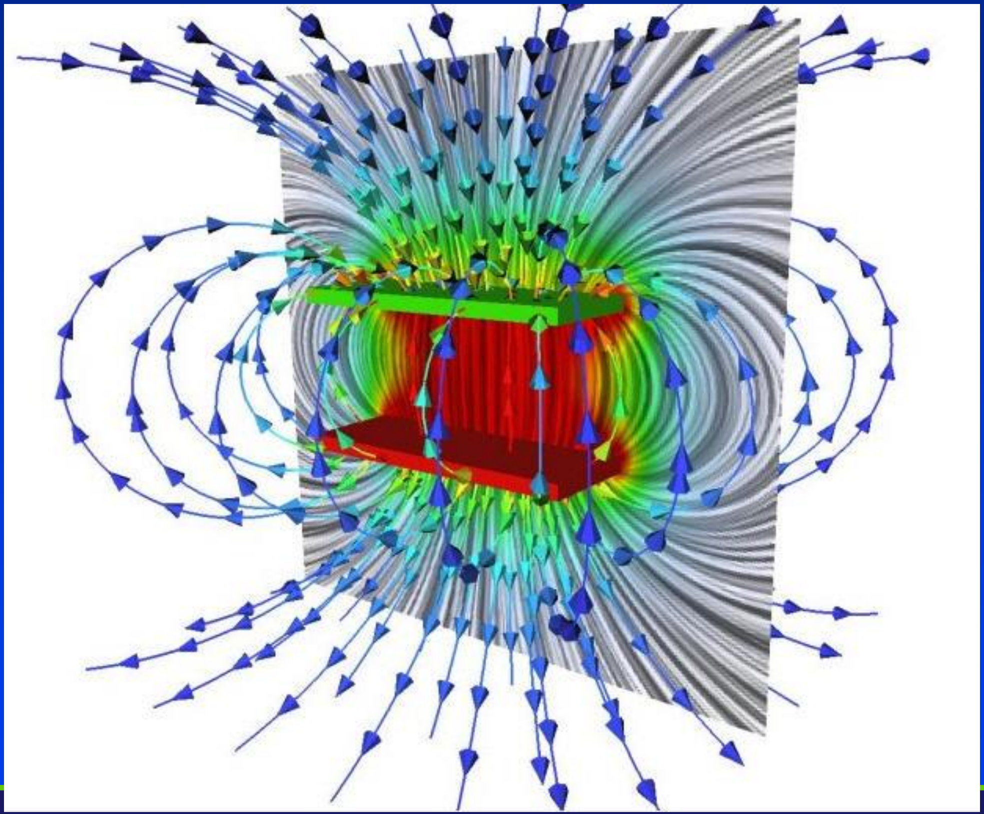
- Draw the vectors themselves
- Advantages: simple
- Disadvantages: many!
- Clutter
- Direction ambiguity
- Spatial ambiguity (start/end locations of arrow)





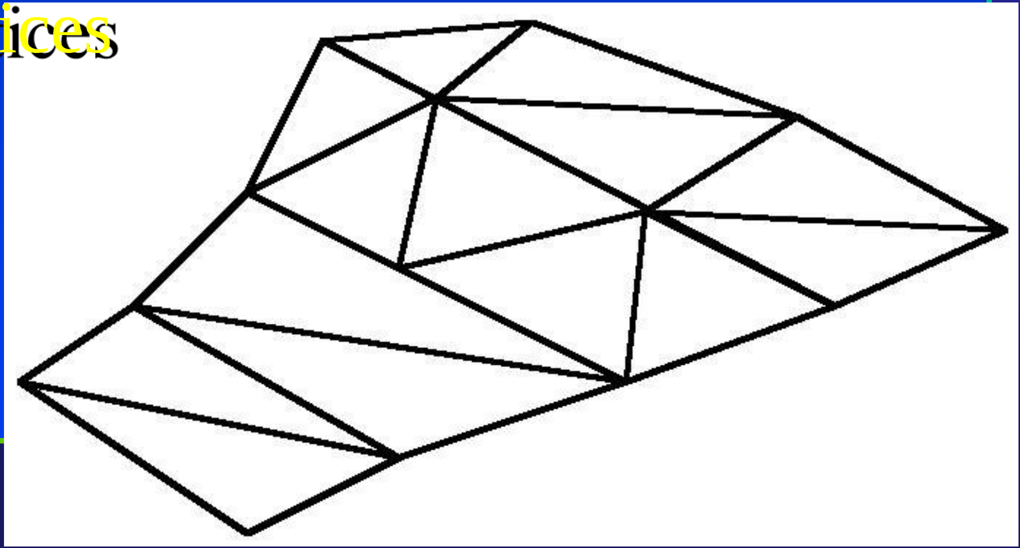
Streamlines + Hedgehogs

- Can you identify the physical phenomenon being visualized here?

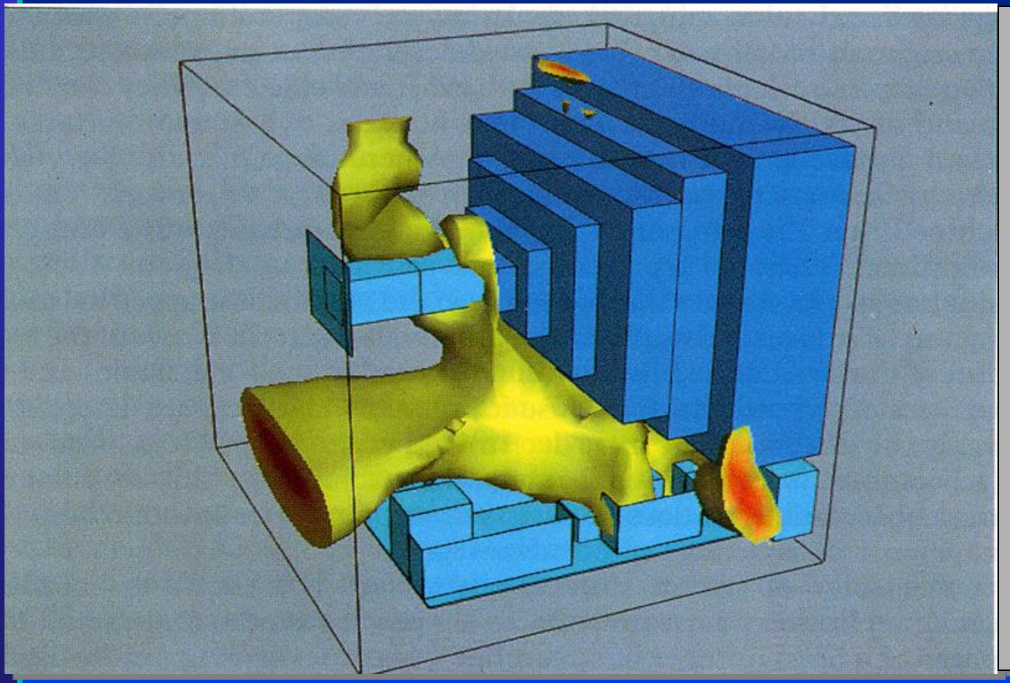


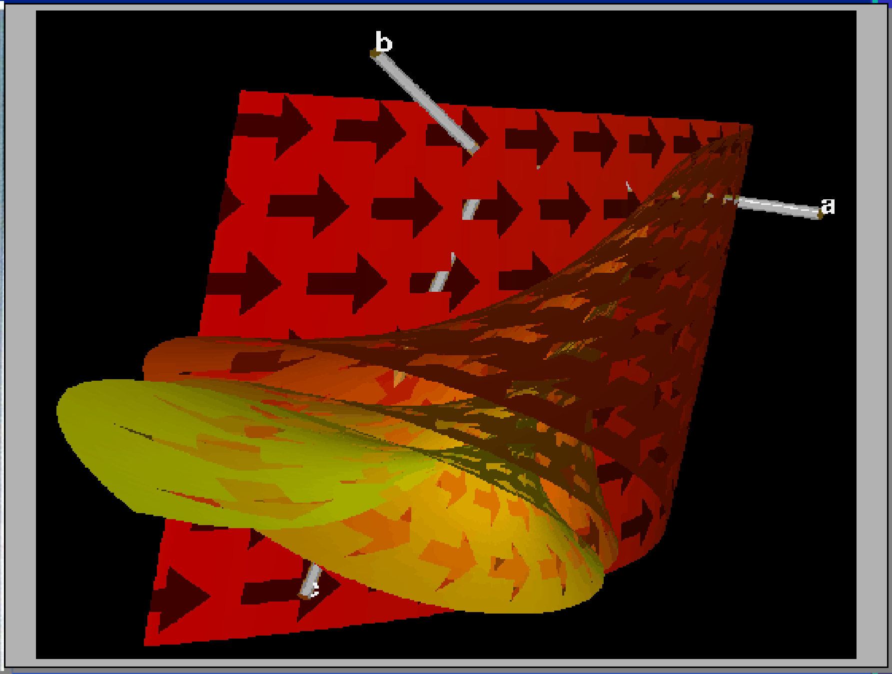
Stream Surfaces

- Calculate multiple stream lines
- Discretize
- Connect points to form triangles
- Diverging and converging flow causes problems
- Divergence: add extra vertices
- Convergence: merge vertices



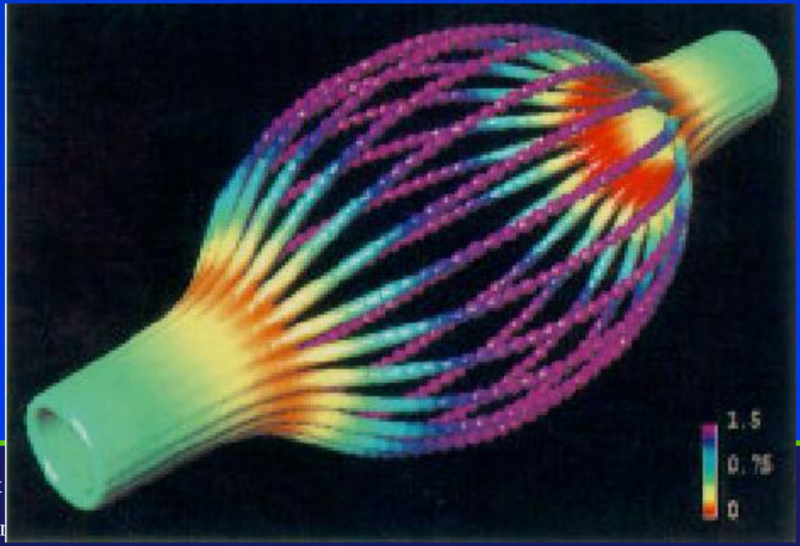
Stream Surfaces

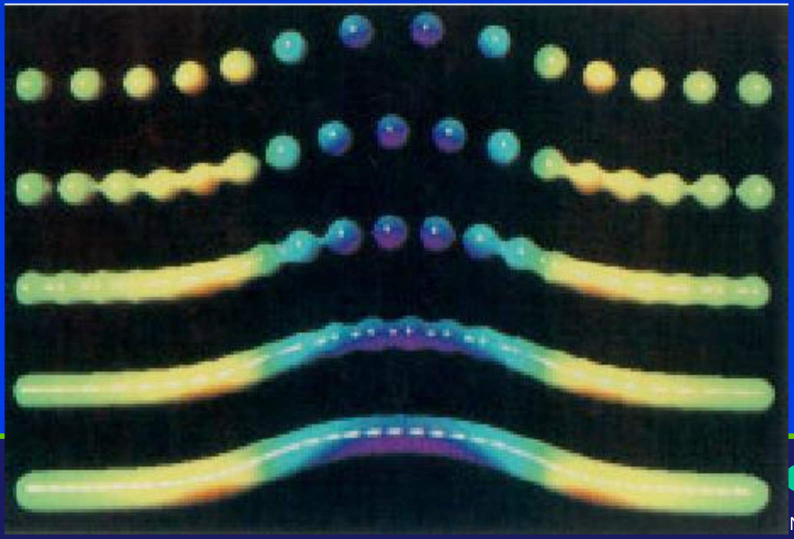




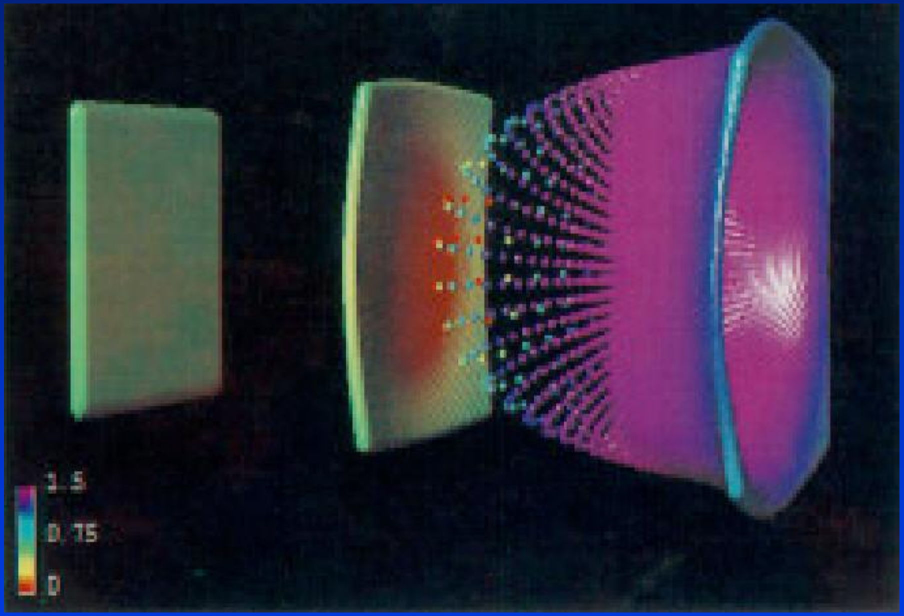
Streamballs

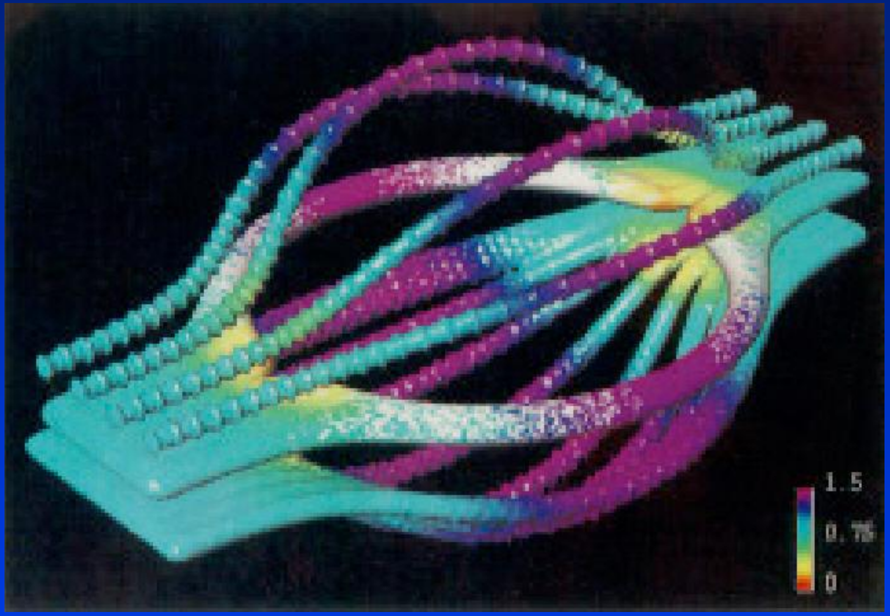
- Basic idea is to create a continuous function f(x,y,z).
- Take isocontours of this function.
- Use meta-balls (not meatballs) to generate this function





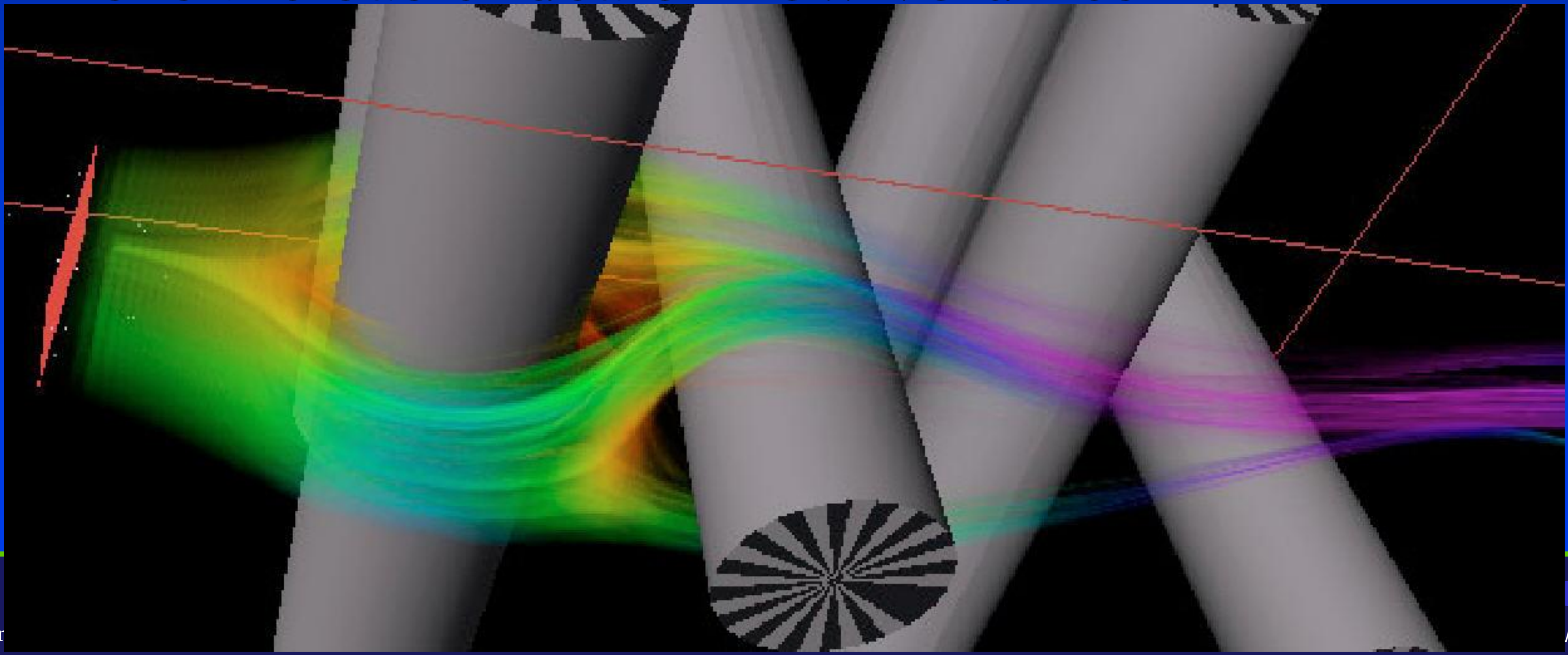
Streamballs





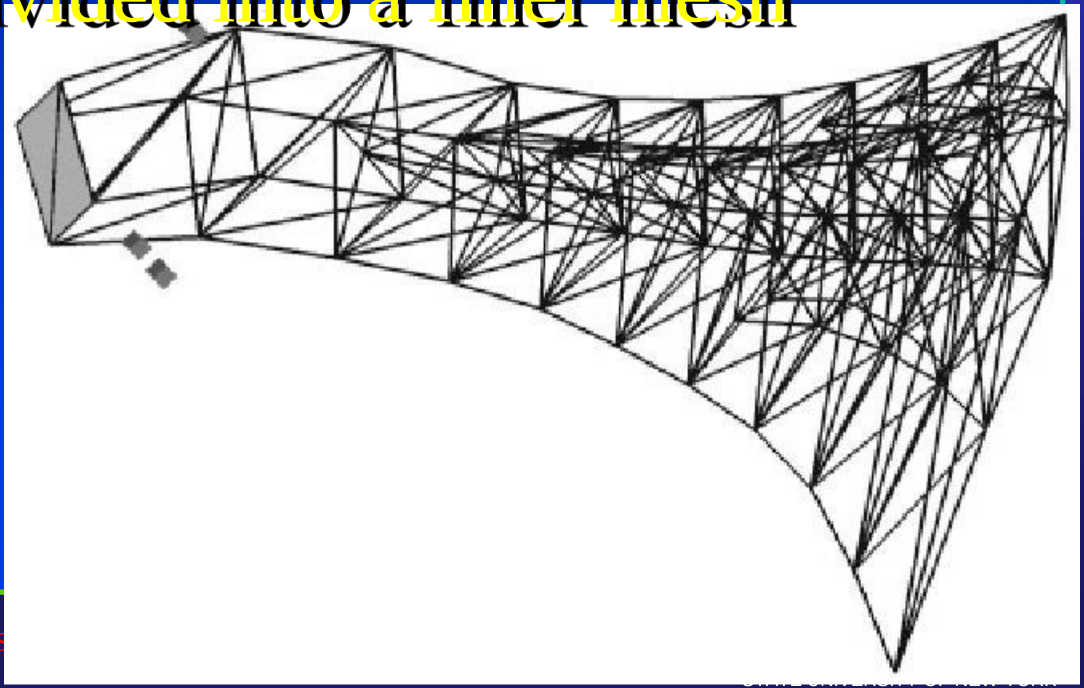
Flow Volumes

- Imagine standing outside with a smoking flare in hand
- Smoke trail guided by wind field
- This is the basic idea of flow volumes



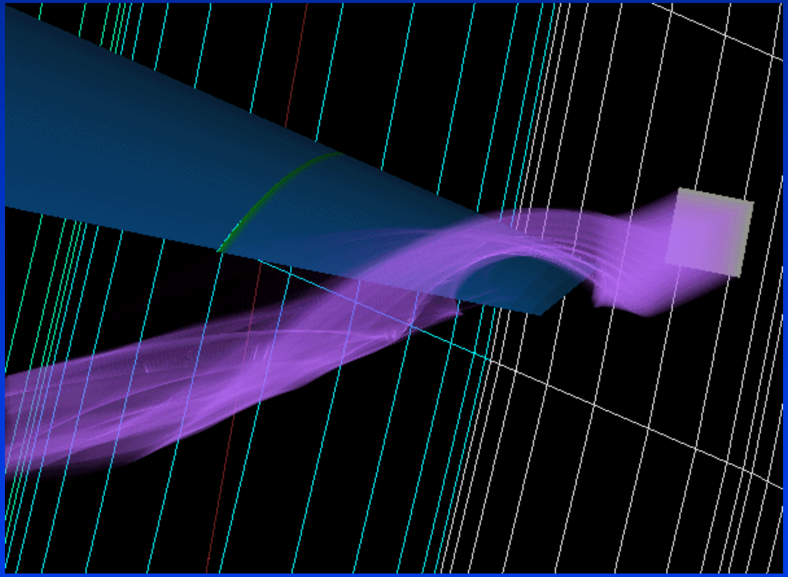
Flow Volumes

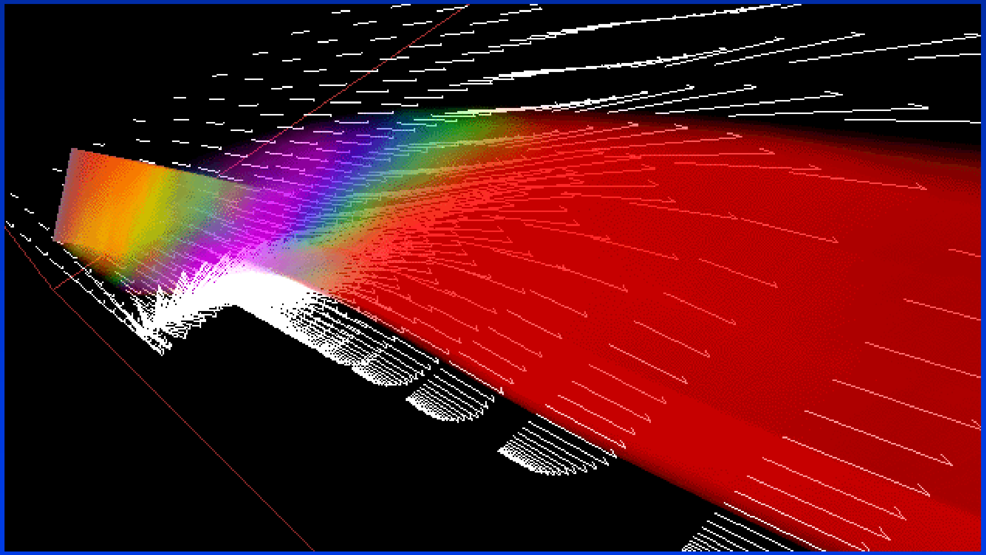
- Seed polygon (square) is used as smoke generator
- Constrained such that center is perpendicular to flow
- Square can be subdivided into a finer mesh



Flow Volumes

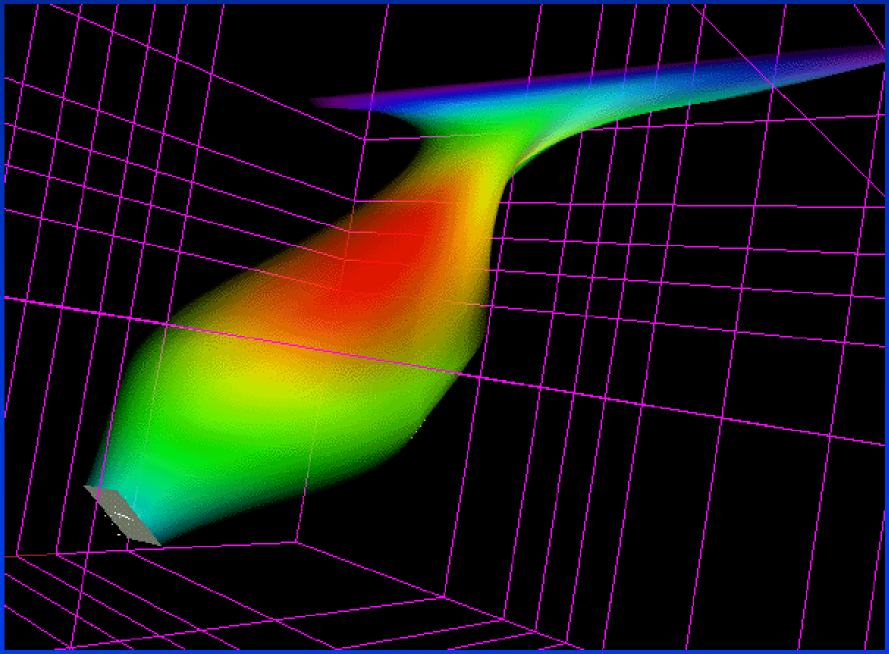
- Fast rendering on commodity hardware
- Can color the smoke to indicate other quantities

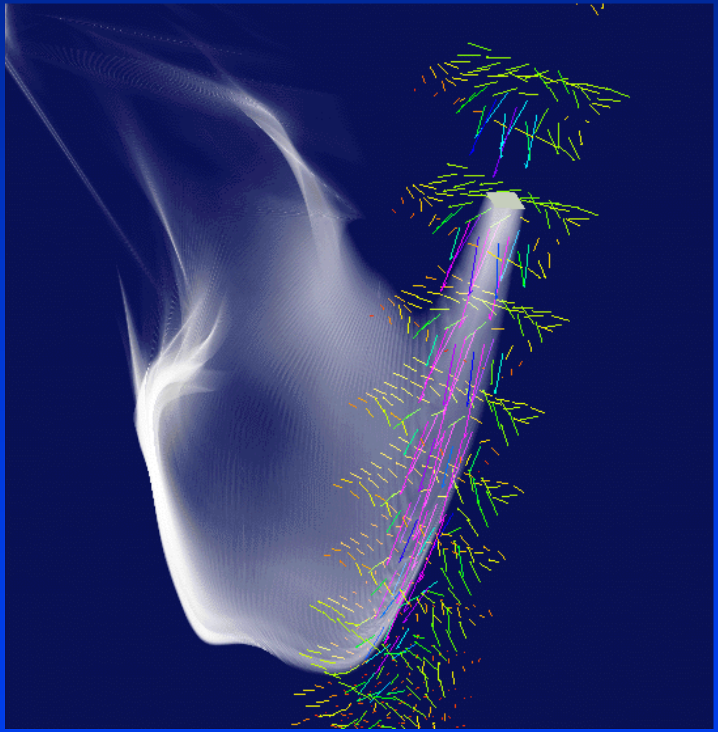




Flow Volumes

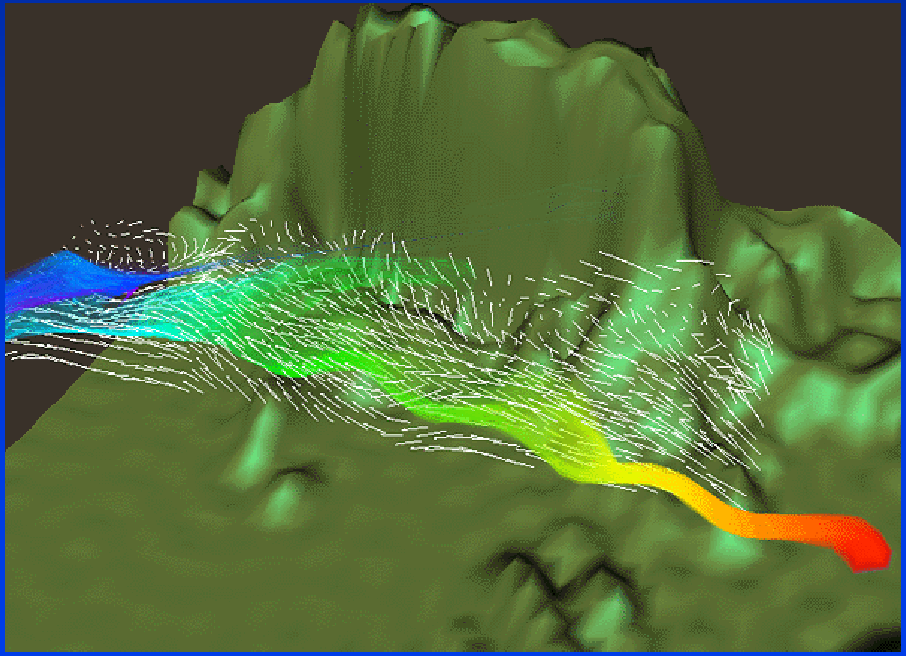
- Currently defined for regular, rectilinear, curvilinear, multigrid and unsteady meshes

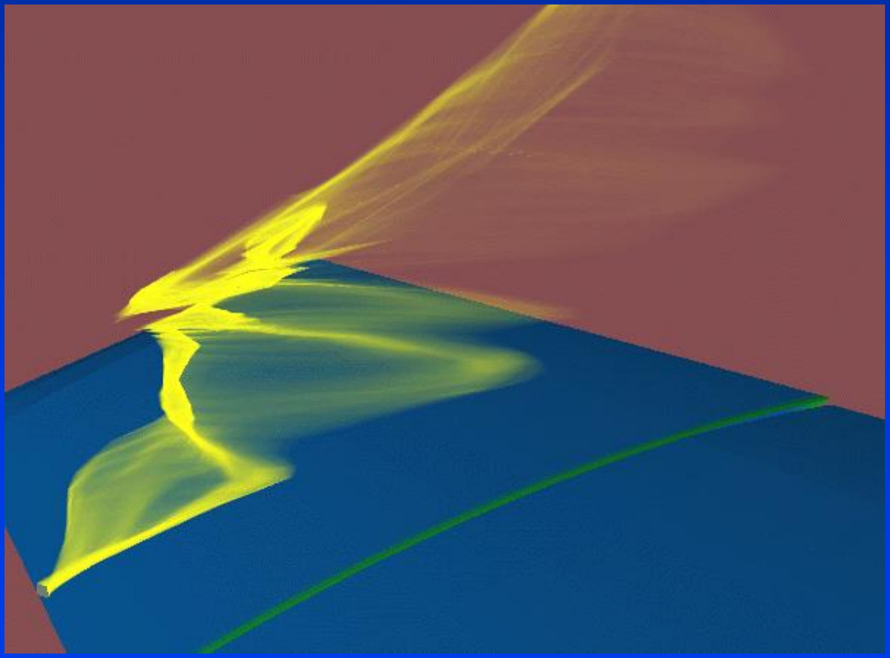




Flow Volumes – Unsteady Flows

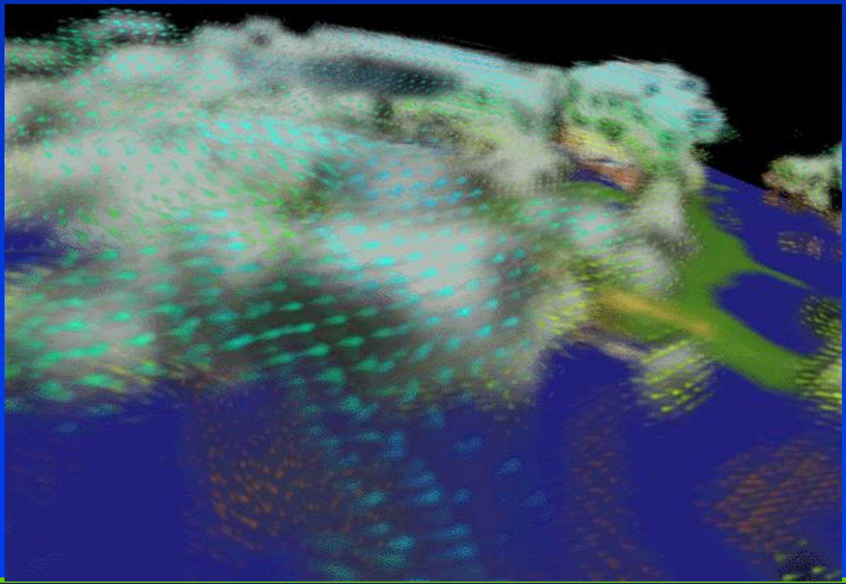
- Can work for unsteady flows for all mesh types (curvilinear, rectilinear, irregular, etc.)
- Complex twisting must be handled carefully

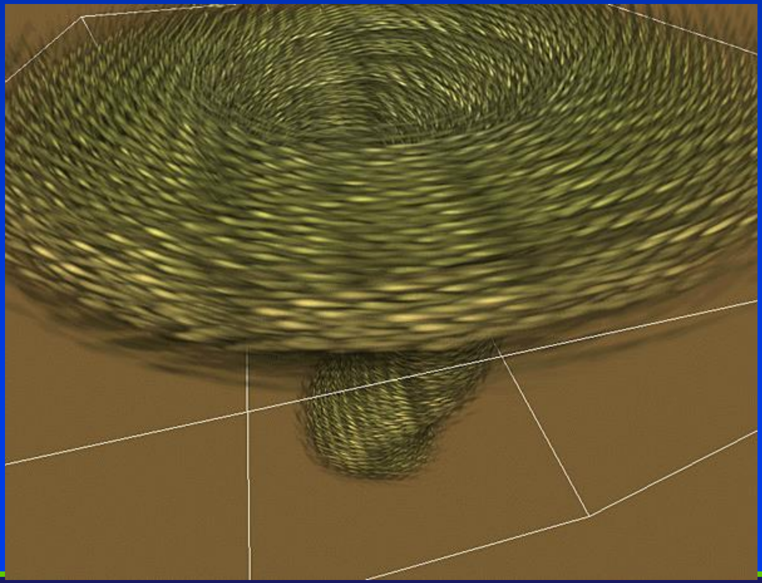




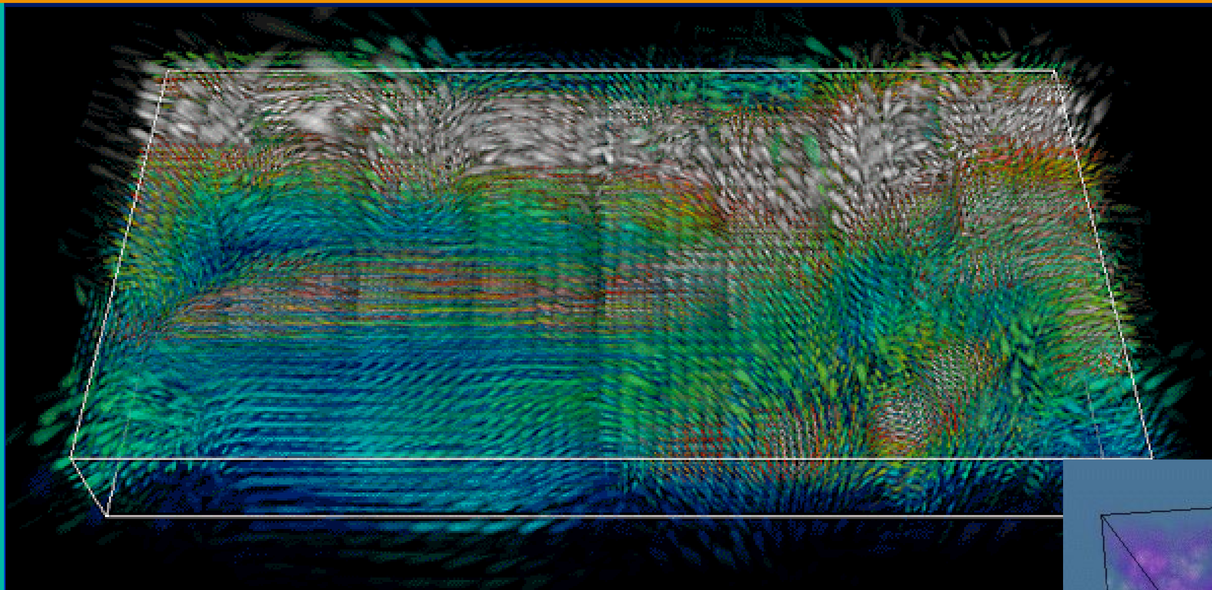
Textured Splats

- Basic idea: map reconstruction footprint from splatting to a 2D textured square
- Splat textures oriented in projected direction of flow





Textured Splats



Wind direction and magnitude

Soil conductivity