Vector and Flow Field Visualization

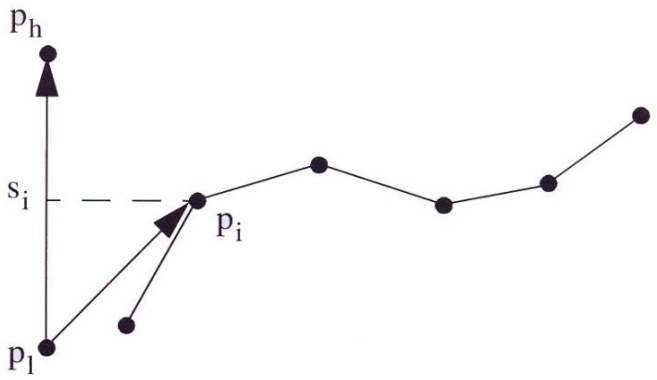
- So far, we have looked primarily at scalar field visualization
- Iso-surface extraction, volume rendering algorithms
- These algorithms do not extend to vector-valued quantities, which may have 2, 3 or more values per voxel
- What would it mean to volume-render a field of velocity vectors?
- How would we perform classification, shading, compositing, and the other stages of the pipeline?
- Interpolation seems to be the only process that generalizes directly
- When have we used linear interpolation of vectors?

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

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



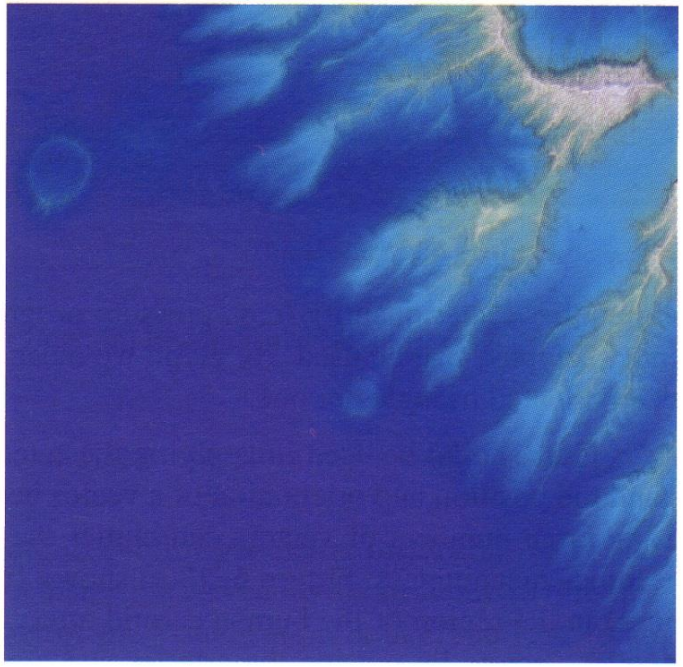


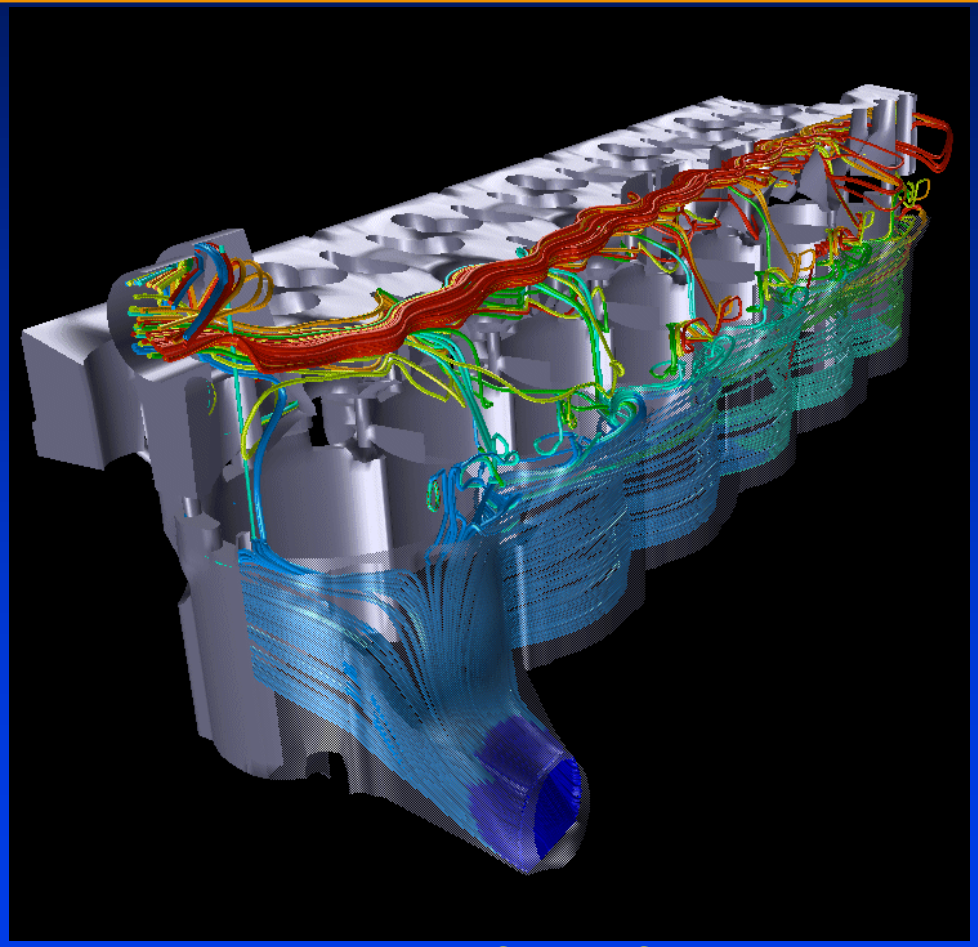
Figure 6–12 Computing scalars using normalized dot product. Bottom half of figure illustrates technique applied to terrain data from Honolulu, Hawaii (`hawaii.tcl`).

Vector and Flow Field Visualization

Vector and Flow Field Visualization

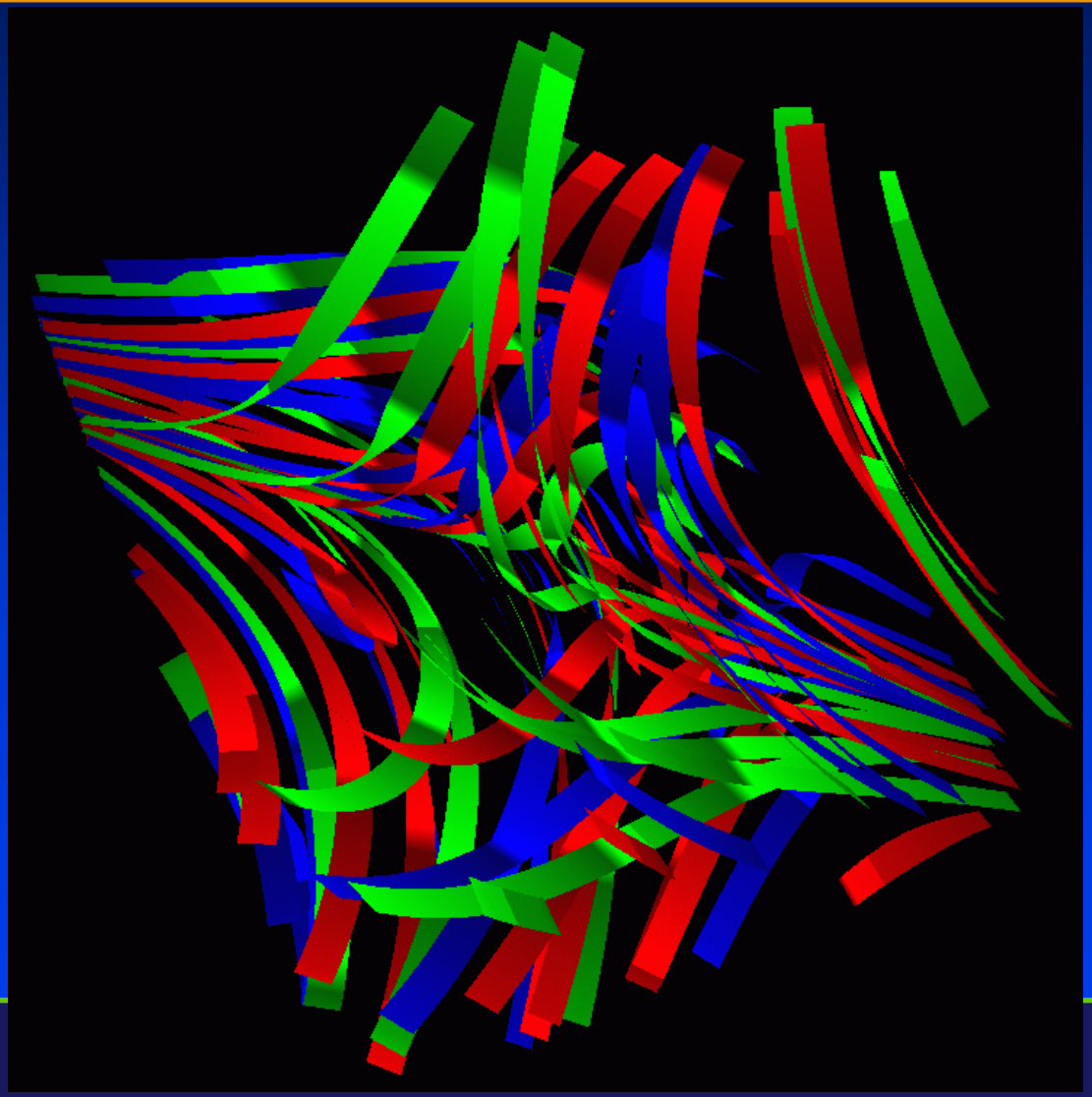
- Streamlines
  - Integration through vector field
- Stream ribbons
  - Connect two streamlines
- Streamtubes
  - Connect three or more streamlines
- Stream surfaces
  - Sweep line segment through vector field

Streamlines Example

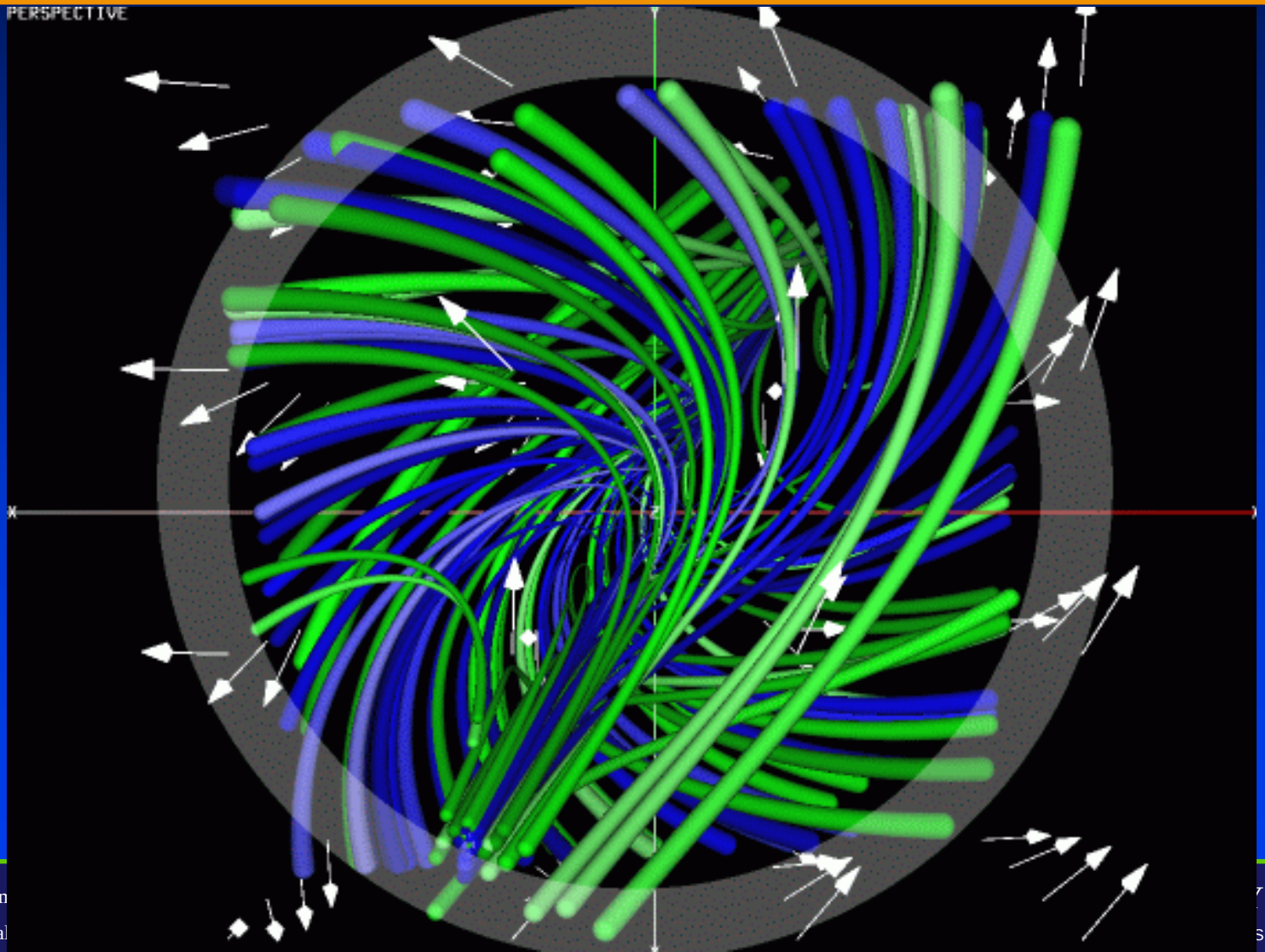


Color indicates temperature of air flowing through engine

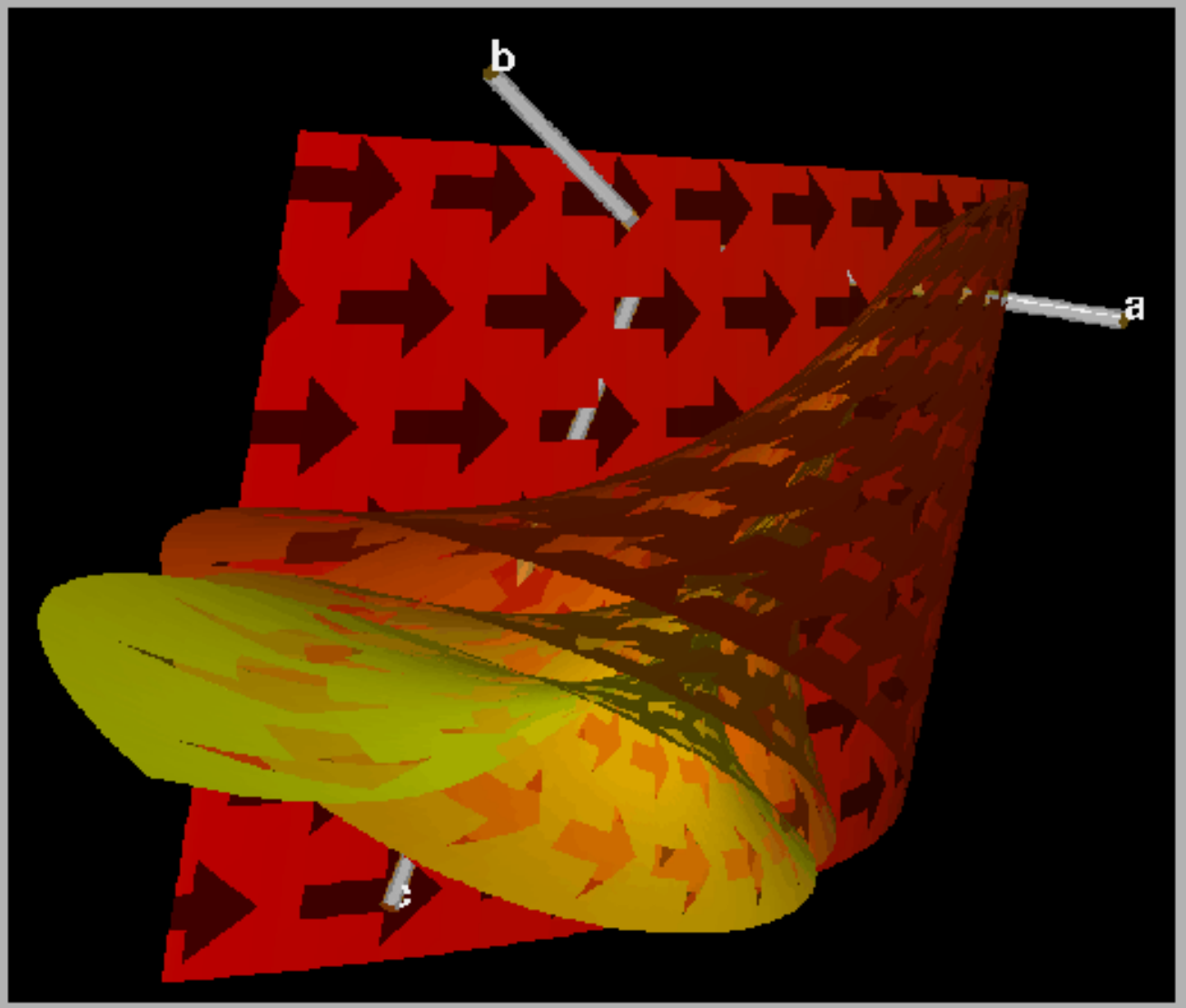
Streamribbons Example



Streamtubes Example



Streamesurfaces Example



Vector and Flow Field Visualization

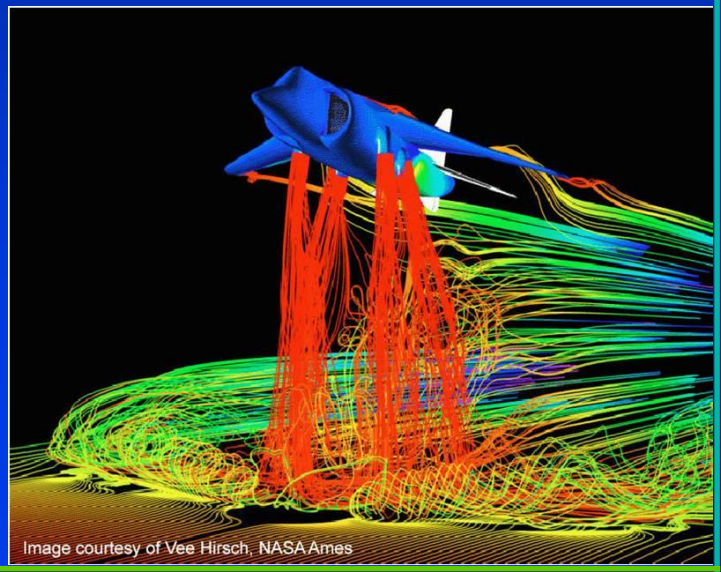
- Computational fluid dynamics (CFD) has been the classical application driving R&D in vector visualization
- Why? Many components at a given (x,y,z) position: velocity, temperature, pressure, rotation, etc.
- Finite element simulation in general
- How can we visualize a dataset that have upwards of six data values at each position?
- Vector field visualization provides some solutions
- Many vector field visualization techniques, some quite clever
- Remember goal of visualization: understand important aspects and features of potentially complex data-sets

Data Contraction

- Reduce vector-valued functions to scalar ones
- Vector magnitude
- Scalar product with a given direction vector (what does this indicate?)
- Advantage: very simple technique and uses existing volume visualization
- Disadvantage: very simple technique that discards too much information
- Can use volume rendering or iso-surface extraction (explosion simulations, etc.)

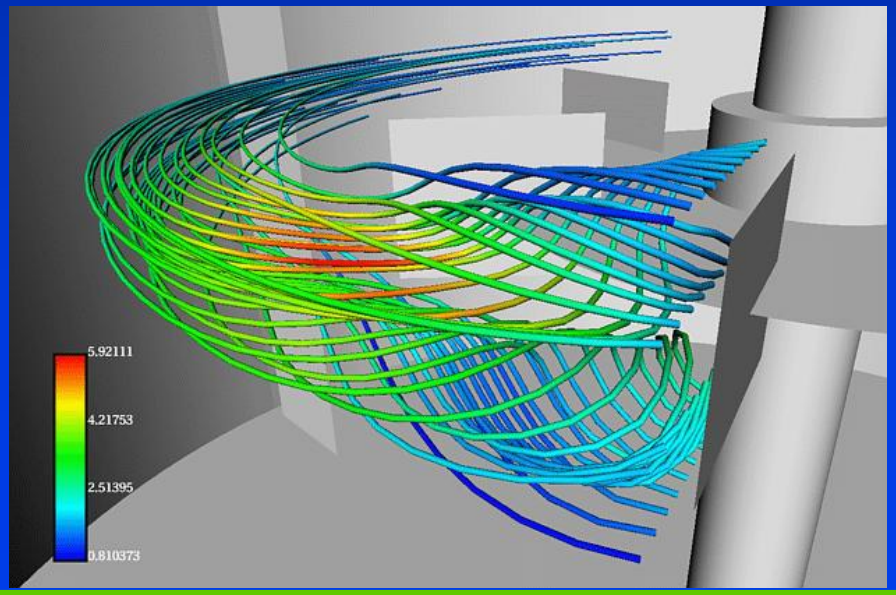
Streamlines, Pathlines, Streaklines

- 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 to display a 4^{th} value
- These streamlines capture flow character with a single snapshot



Streamlines, Pathlines, Streaklines

- 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



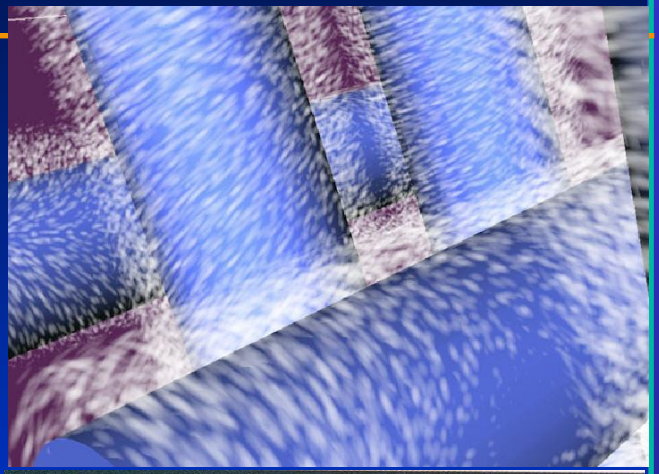
Streaklines

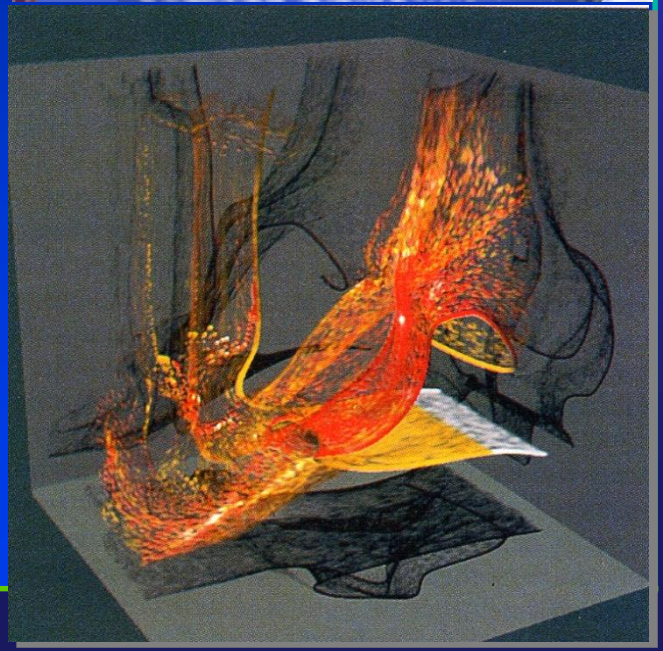
- Streakline – similar to pathline; imagine continuously releasing particles over time at a given position; connecting the resulting particles produces a streakline

- If flow is stationary, streamline, pathline and streakline will all coincide at a given position

Particle Systems

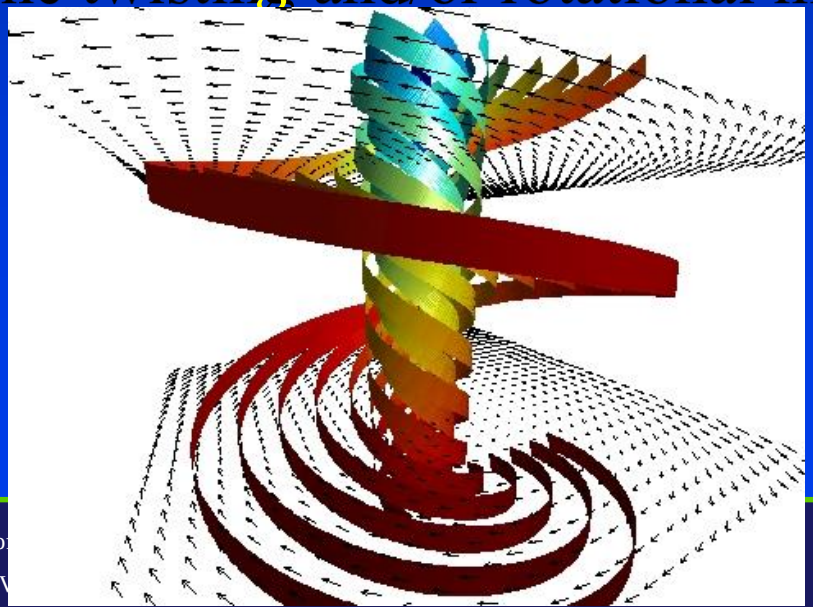
- Particles are injected into the flow field, which may be time-varying (turbulent)
- Enter, travel, leave
- Animated particles show direction and magnitude of velocity
- Can stretch particles in direction of flow to give additional visual cues
- Shadows (depth perception)

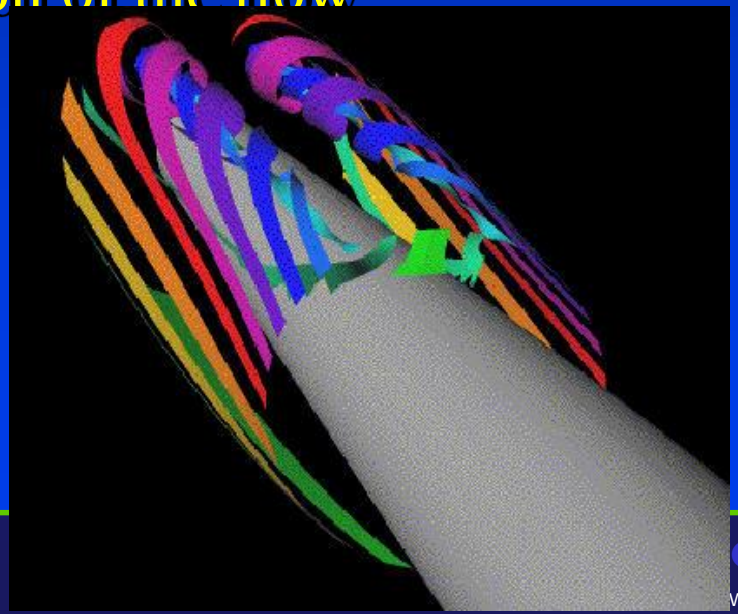




Ribbons and Tubes

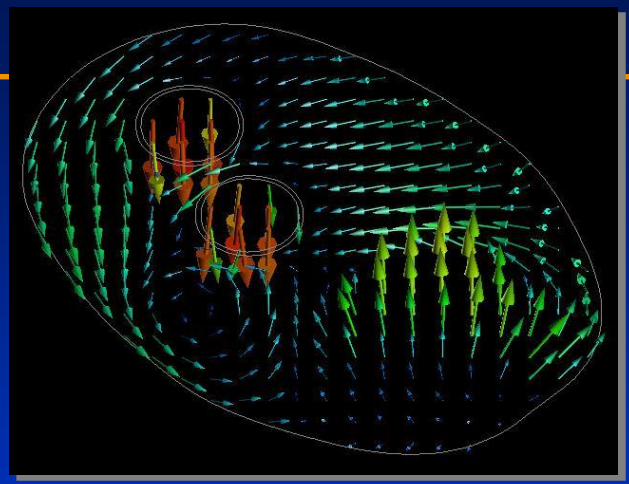
- Multiple particle advections per segment in the discretized line integration
- Connect two of them together to generate a ribbon, more to make a tube
- For ribbon, center streamline gives direction, other two indicate the twisting and/or rotational motion of the flow

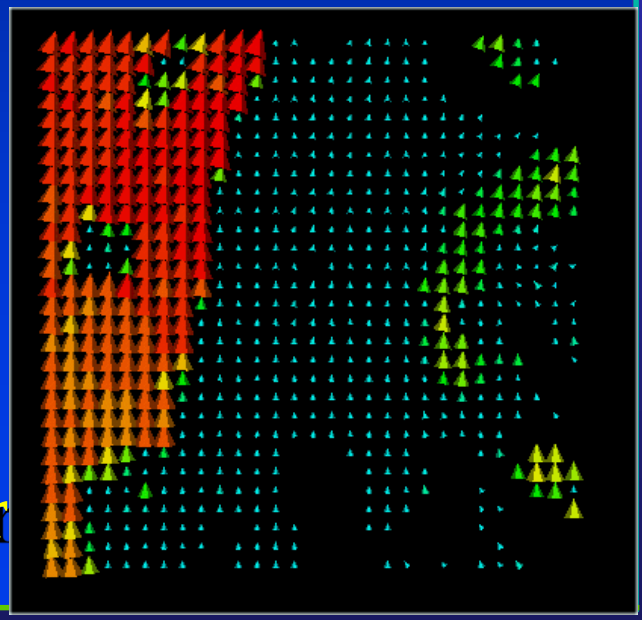




Hedgehogs

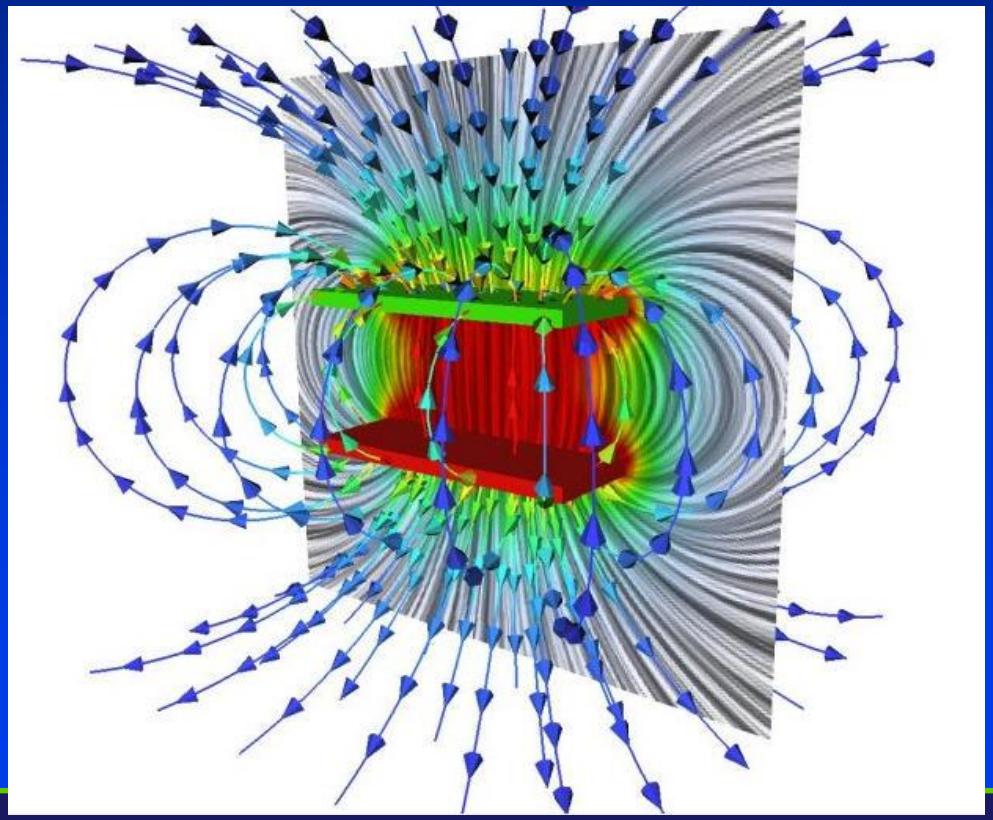
- Draw the vectors themselves
- Advantages: simple
- Disadvantages: many!
- Clutter
- Direction ambiguity (consider orthographic projection)
- Spatial ambiguity (start/end locations of arrow)
- Best used in combination with other flow visualization techniques





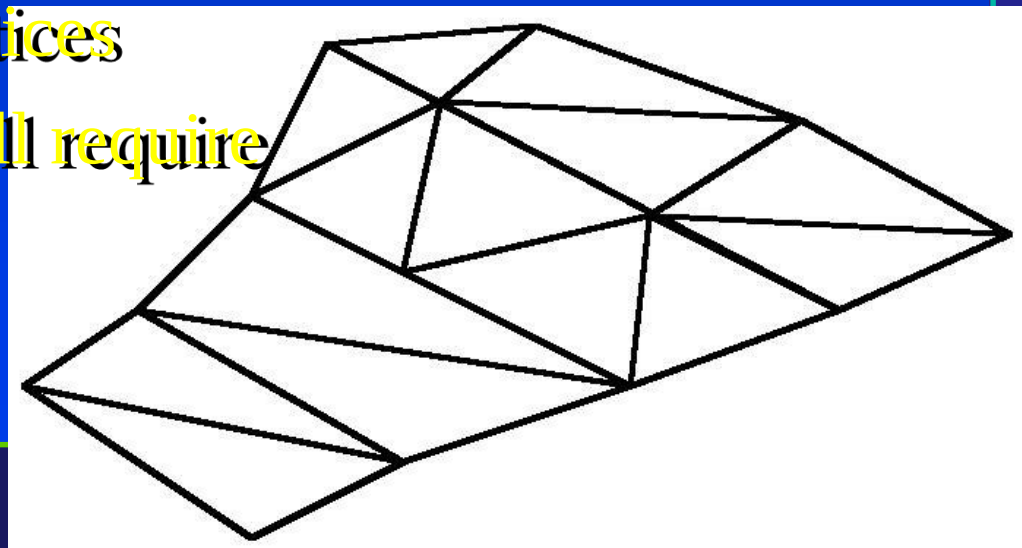
Streamlines + Hedgehogs

- Can you identify the physical phenomenon being visualized here?

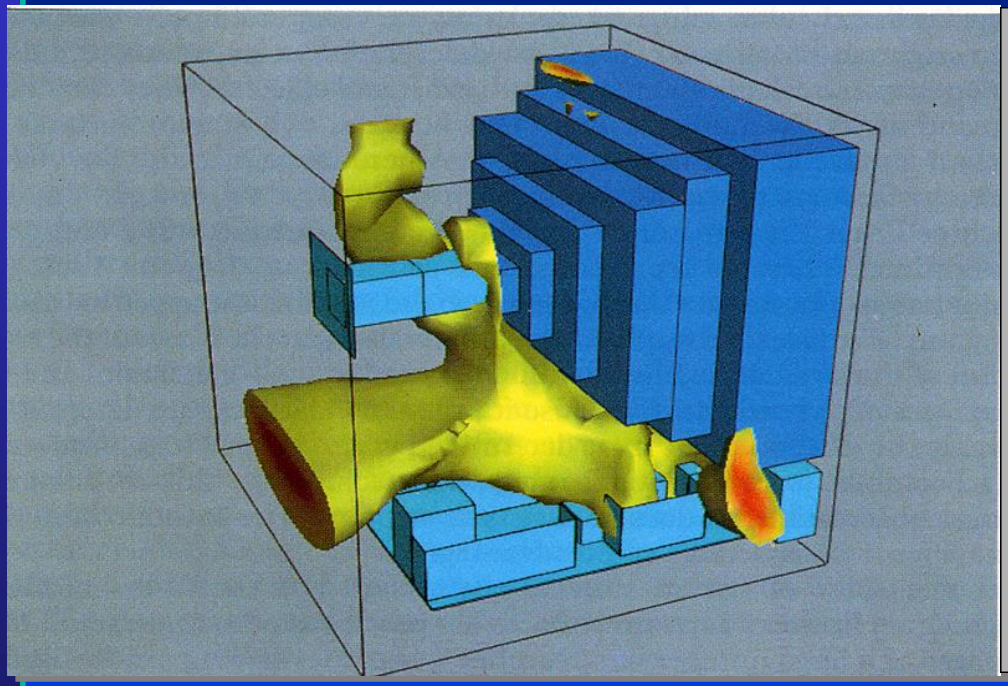


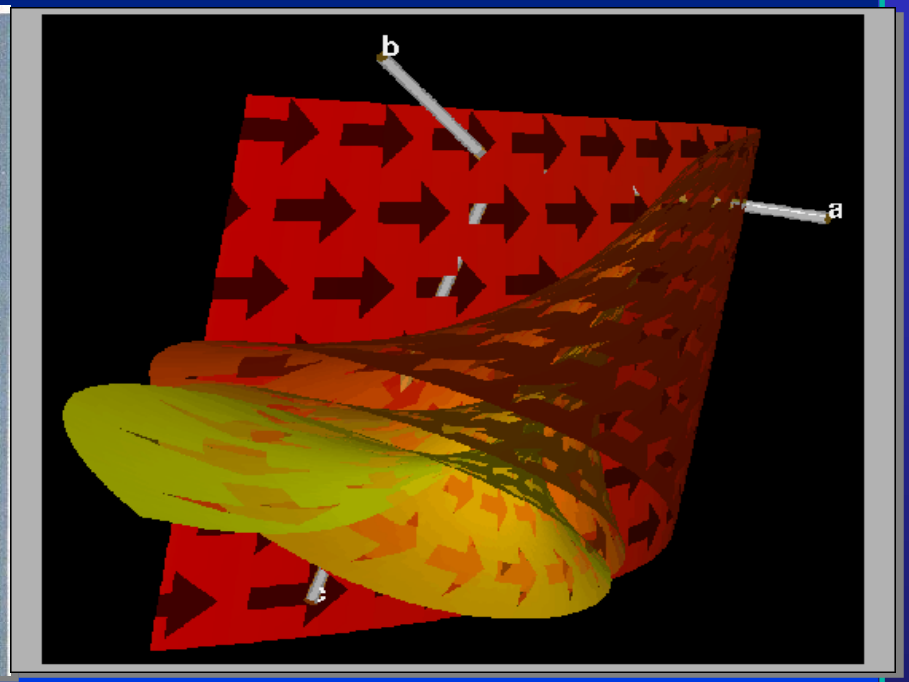
Stream Surfaces

- Calculate multiple stream lines
- Discretize
- Connect points to form triangles
- Diverging and converging flow causes problems
- Divergence: add extra vertices
- Convergence: merge vertices
- Too much divergence will require
  - a surface split
  - a tear



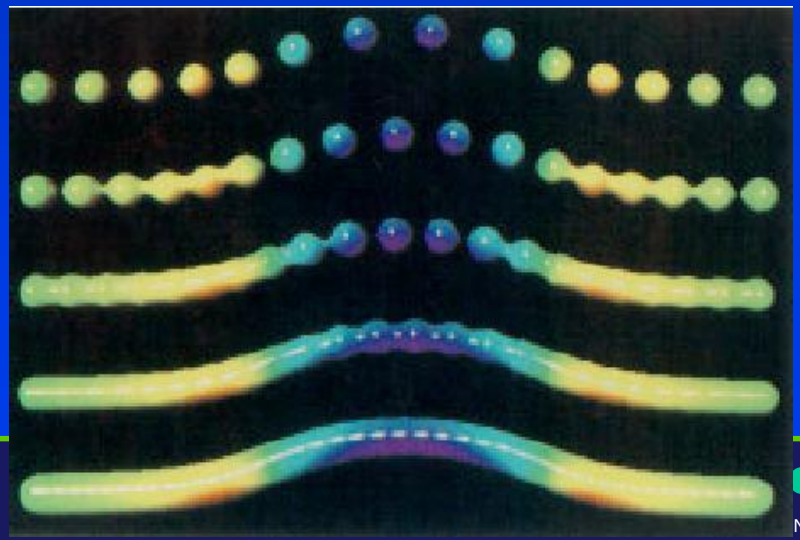
Stream Surfaces





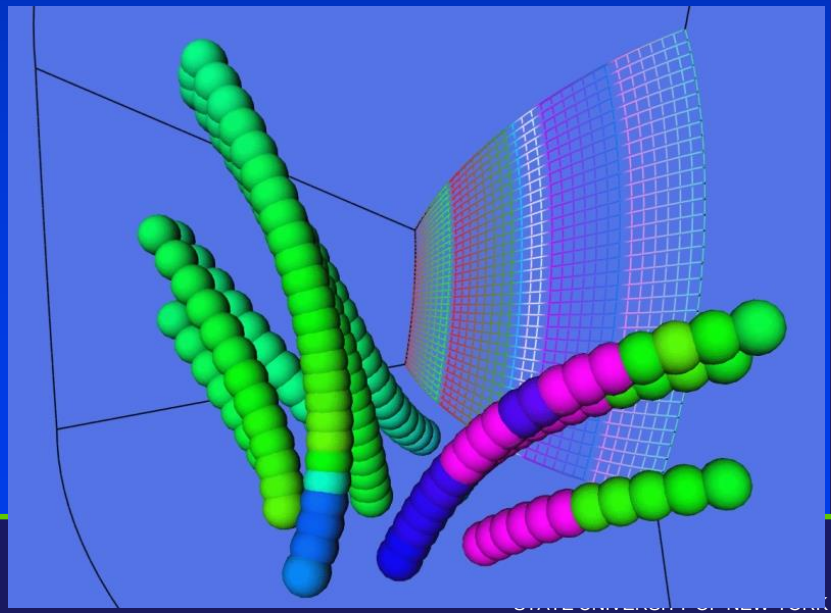
Streamballs

- 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
- Meta-balls were developed by Nishimura, Blinn, Wyvill
- Further refined by Bloomenthal and Shoemake
- Treat particles as meta-balls or use a timeline curve



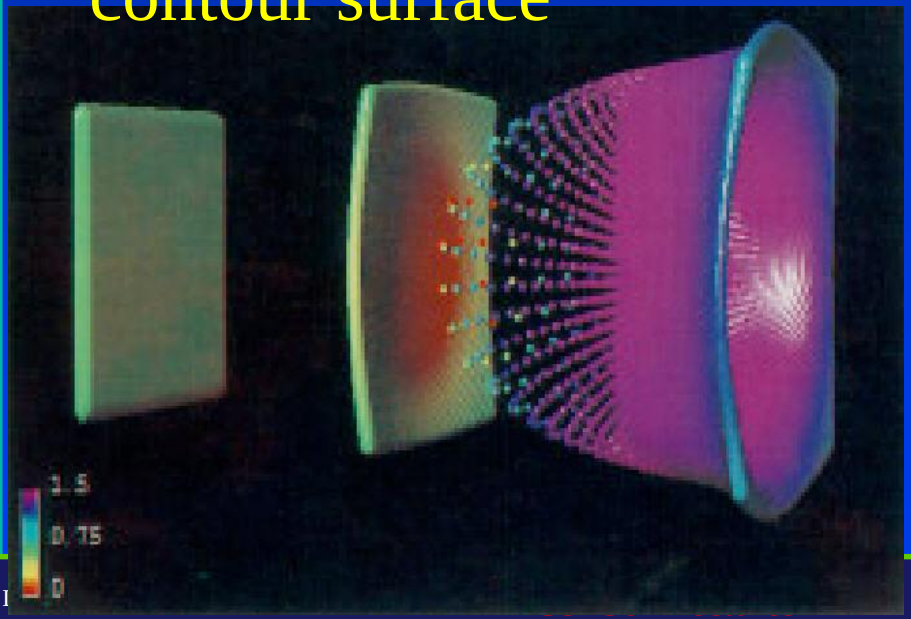
Streamballs

- Meta-balls constitute an implicit surface technique
- Implicit surface: f(x,y,z) = 0
- Advantage: easy split and merge
- Disadvantage: computationally expensive (search procedure to find the 0-level)
- Need fine mesh to do accurate isosurface extraction



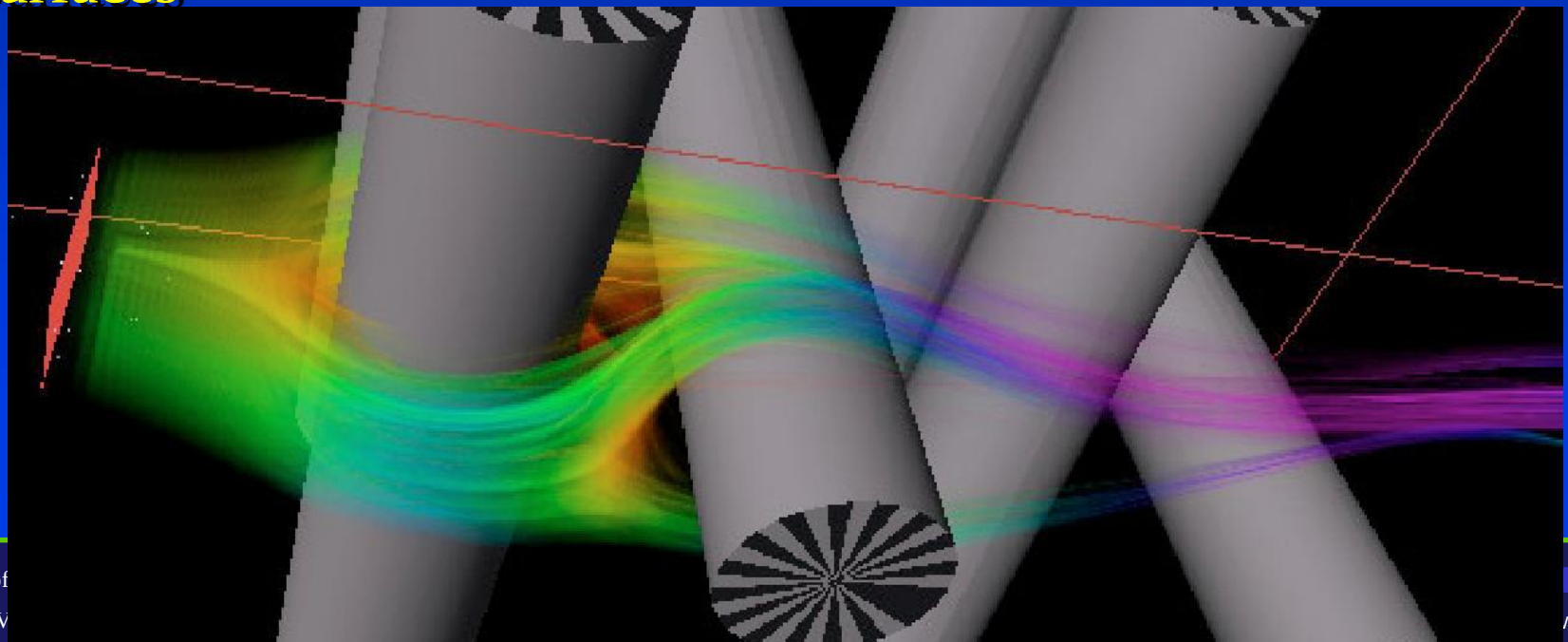
Streamballs

- A rake of particles will start out as a stream surface.
- Other variables can easily be mapped to the surface's color and texture
- Other variables can control the shape of the resulting contour surface



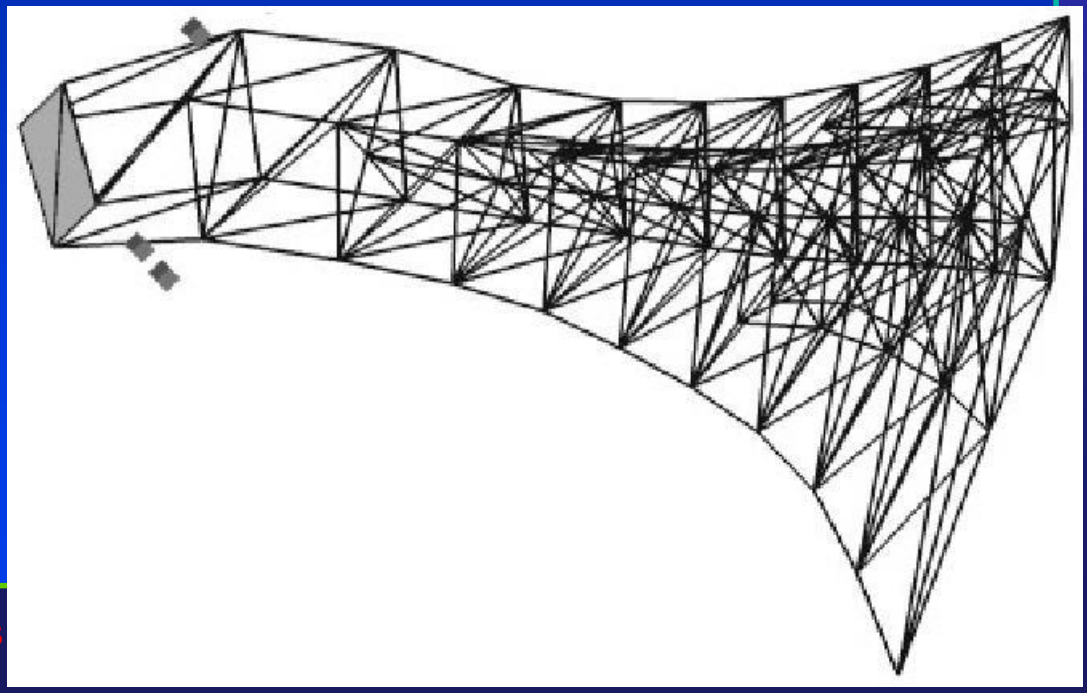
Flow Volumes

- Imagine standing outside with a smoking flare in hand
- Smoke trail guided by wind field
- This is the basic idea of flow volumes
- Volumetric flow indicator (compare with stream lines and surfaces



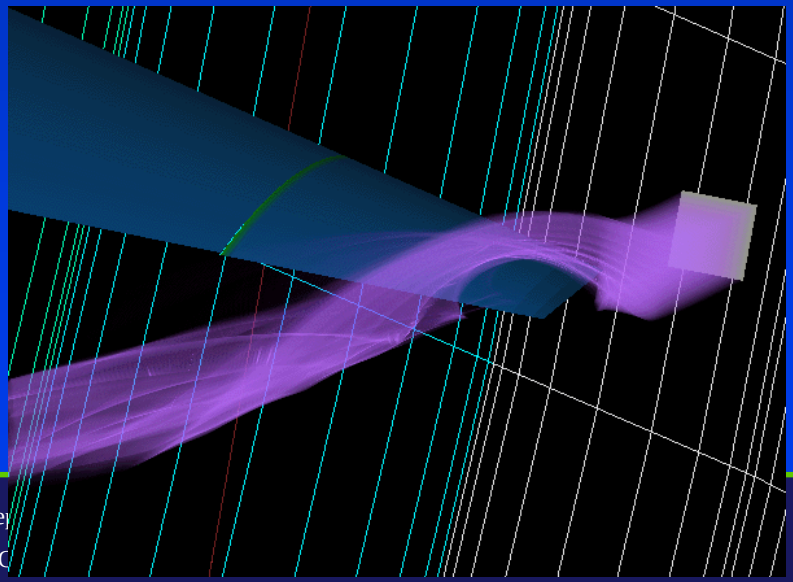
Flow Volumes

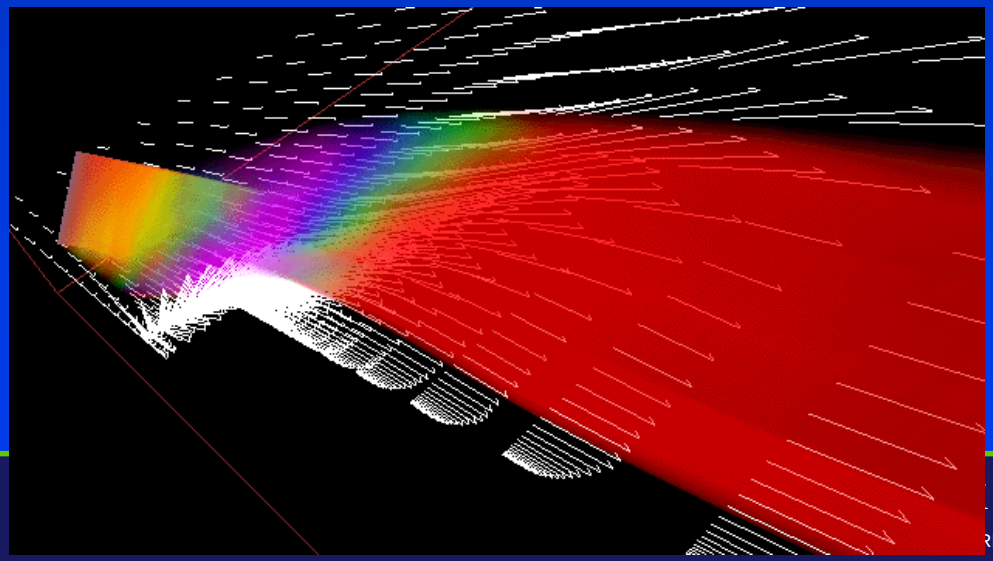
- Seed polygon (square) is used as smoke generator
- Constrained such that center is perpendicular to flow
- Square can be subdivided into a finer mesh
- Like explicit stream surfaces, the volume is adaptively subdivided in areas of high divergence
- Incremental construction of a tetrahedral grid
- Typically no merging, however



Flow Volumes

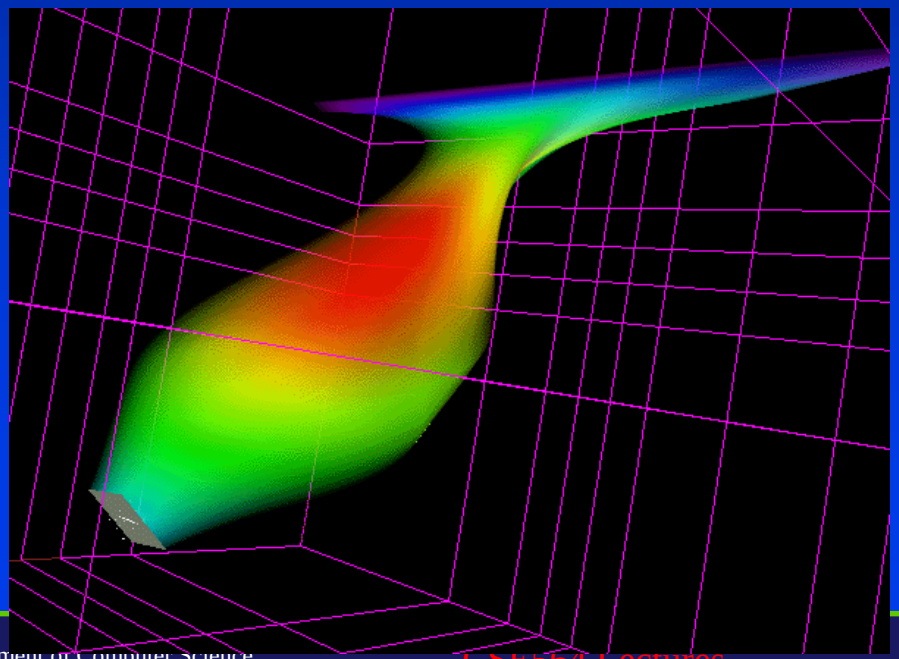
- Fast rendering on commodity hardware
- Tetrahedral rendering
- Constant smoke color → no depth sorting
- Can color the smoke to indicate other quantities
- Flow volumes of complex topologies visualized easily (thanks to efficient tetrahedral rendering algorithms, cell projection)

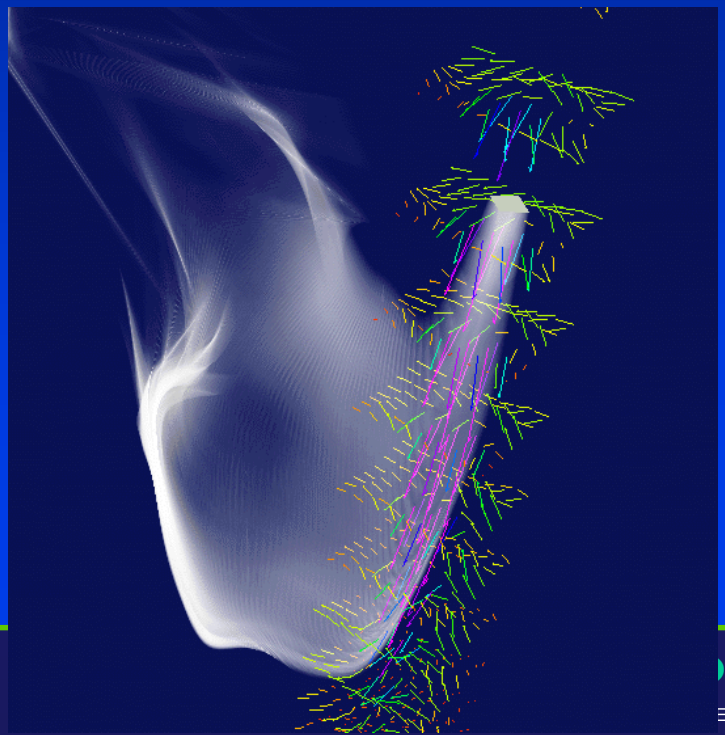




Flow Volumes

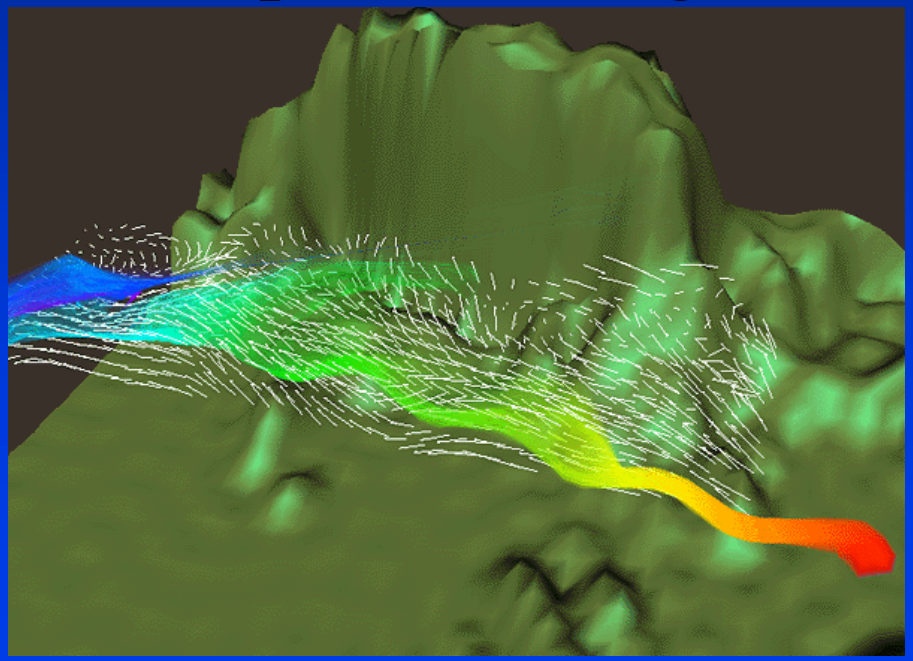
- Currently defined for regular, rectilinear, curvilinear, multigrid and unsteady meshes
- Very powerful technique
- Particularly effective when animated by moving the seed square

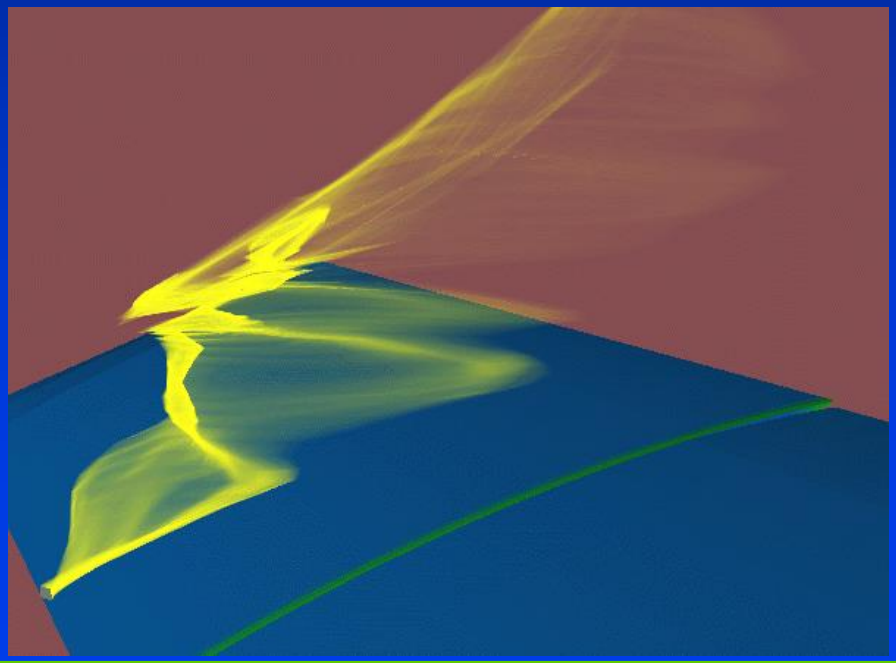




Flow Volumes – Unsteady Flows

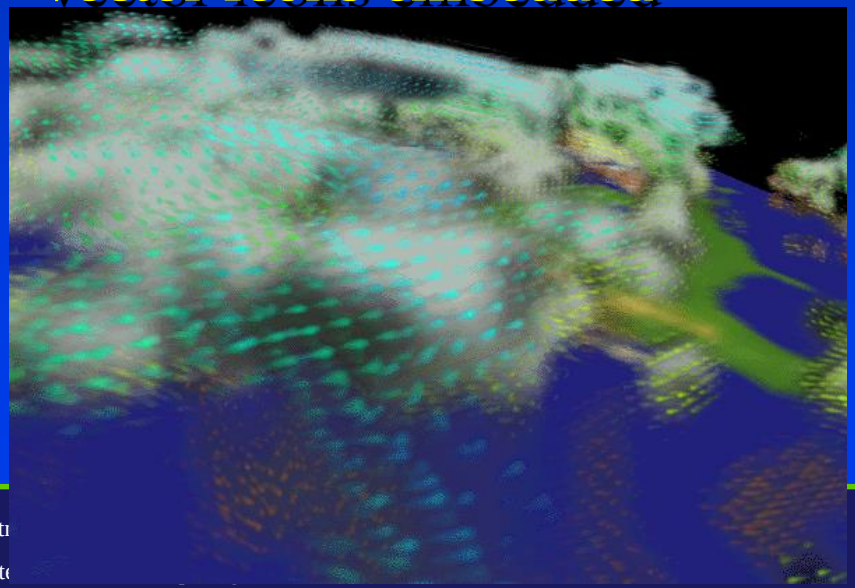
- Can work for unsteady flows for all mesh types (curvilinear, rectilinear, irregular, etc.)
- Complex twisting must be handled carefully

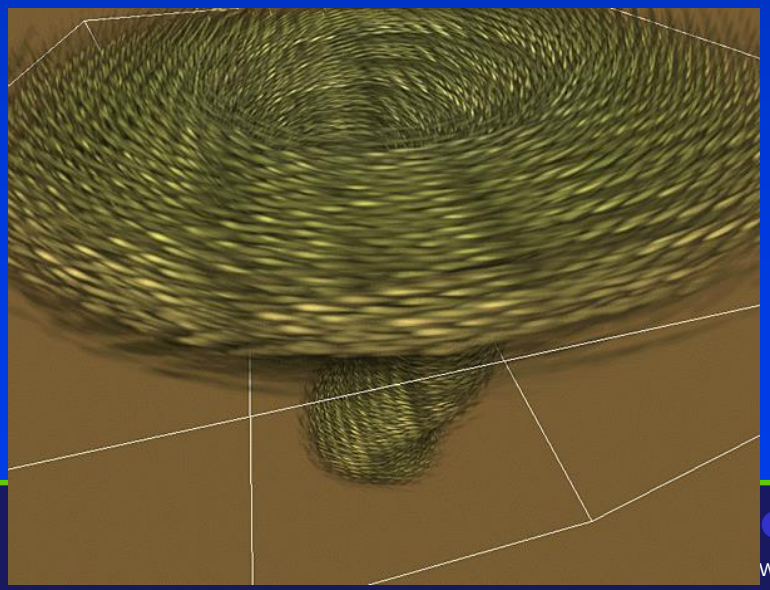




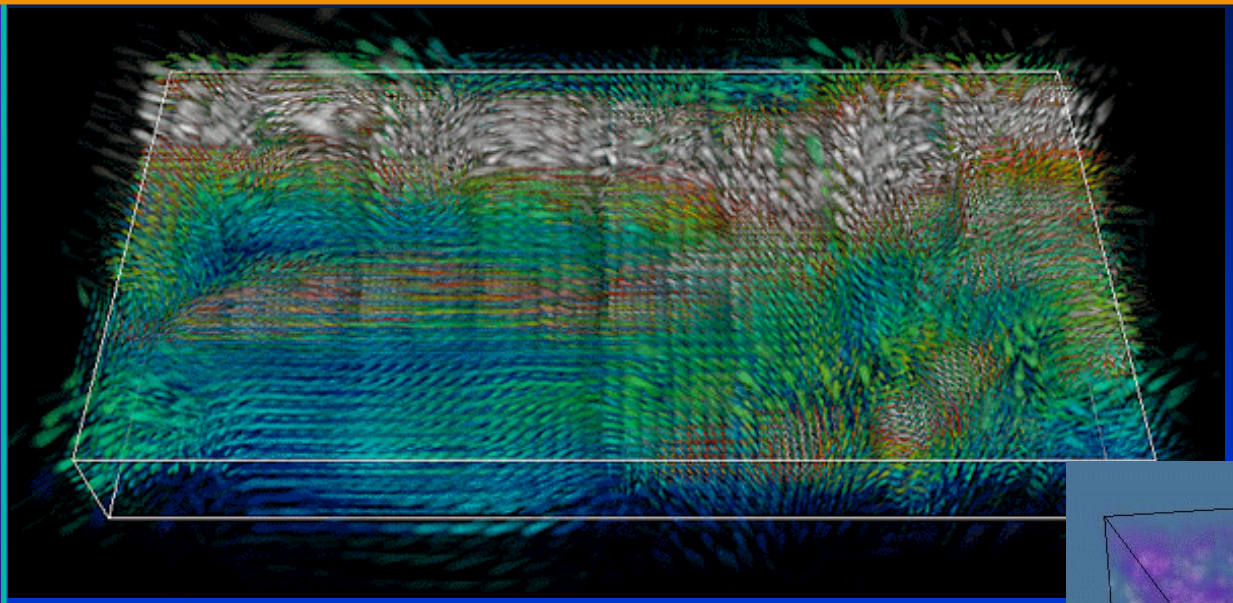
Textured Splats

- Basic idea: map reconstruction footprint from splatting to a 2D textured square
- Add anisotropic “scratches” to the texture
- Splat textures oriented in the projected direction of the flow
- The back-to-front compositing yields a volume rendering with vector icons embedded





Textured Splats



Wind direction and magnitude

Soil conductivity