Flow Visualization

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Flow Vis Goals

• See movement of fluid (direction/velocity) in instant or over time
• Applications
  – aerodynamics
  – CAD
  – airflow through/around buildings
  – ocean currents
  – fluid flow through pumps/values
  – electromagnetics
Types of Flow Data

- **Basic form**
  - Vector (tensor) at every point
- **Steady state**
  - Flow field static over visualization
- **Unsteady state**
  - Flow field changes over time
- **Implications**
  - Computational complexity
  - Representational complexity

Magnitude

- Recast as scalar vis problem
  - Compute magnitude of flow vector
    \[ |v| = \sqrt{x^2 + y^2 + z^2} \]
  - Display magnitude
Glyphs

- Techniques
  - arrows / hedgehog / tufts
  - arrows with range
  - tensor glyphs
Uncertainty Glyph

- Pang ‘97

Figure 7: Average velocity (arrow icon) and velocity distribution (ellipsoid icon) for regions with high reaction speed.
Glyph Issues

- Placement / density
- Interactive probing
- Analysis of topology
Color

- Color as auxilliary: usually magnitude

- Interactive color
  - Boring and Pang, Vis ‘96
  - color to show relationship between vec and light
  - interactive exploration
Colorwheel

- Color wheel
  - Johansen and Moorhead, CG&A ‘95
  - color angle shows orientation
  - optionally, magnitude as saturation and/or lightness
Traditional Approach

• Release markers (smoke, bubbles, dye) in flow
• Watch where it goes
• Many flow vis techniques mimic these techniques

Particle Advection

• Release weightless particles into flow, follow their paths
• Color by
  – release location
  – age
  – field characteristics: velocity, pressure, etc
Advection Issues

• Positional accuracy
  – Euler’s method: error \( \equiv O(dt^2) \)
  – Runge-Kutta: error \( \equiv O(dt^3) \)

• Speed vs accuracy trade-offs
  – method
  – step-size

Lines

• Generally
  – follow path of marker through flow
  – same speed/accuracy concerns as particles

• Types of line markers
  – streamline: path of single marker
  – streakline: path of stream of particles from single release point in changing flow

• Placement issues
  – show off interesting features
  – even spacing in merging/diverging fields
Streamline Placement

- Turk and Banks, SIGGRAPH ‘96
- Observation: hand-drawn streamlines place lines so that no region is empty of lines and no region is overpopulated

Short stream lines

- on regular grid
- on jittered grid
- optimized

Filtered Streamlines
Streamlines with centers placed regularly on grid

Streamlines placed by density-based optimization

Turk and Banks, SIGGRAPH ‘96
Tubes

• 3D entities for improved perception
• Tube = surface at constant distance from streamline
• Auxiliary information display
  – can color to show value
  – can vary radius to show value

Figure 6: Stream tubes through regions with high normalized helicity density.
Illuminated Lines

- Zöckler, Stalling, Hege, Vis ‘96
- Idea: use shaded streamlines to give better shape/depth cues
- Catch: no hardware for shaded lines

Illuminated Streamlines: Method

- Method
  - use texture-mapping hardware to do line shading
  - diffuse: 1D indexed by L*T (light * tangent)
  - specular: 2D indexed by light and view angle
  - load texture maps to give correct illumination for those lighting and viewing conditions
Stream Polygon

- Use polygon perpendicular to flow line
- Can be deformed by forces
Stream Surface

- **Method**
  - generate stream lines
  - join adjacent streamlines to form triangles
- **Issue**
  - diverging and merging flows

Texture Approaches

- Use texture to convey dense structure of field
  - Individual, independent elements
  - More sophisticated synthesis
SpotNoise

- Van Wijk, ‘91

Line Integral Convolution (LIC)

- Cabral and Leedom, ‘93; Forsell ‘96
Image-based Approaches

van Wijk, '02