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Scientific Visualization

Vector Field Visualization

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Vector Field Visualization

Data set is given by a vector component and its magnitude.

Often results from study of fluid flow or by looking at derivatives (rate of change) of some quantity.
VECTOR FIELDS
VECTOR FIELD VISUALIZATION: PROBLEM DEFINITION

Given (typically):
Physical position vector
Force vector
Electric or magnetic field vector
Velocity vector

Steady flow - vector field stays constant
Unsteady - vector field changes with time

Now, make some visualizations!
GLOBAL TECHNIQUES

Display the flow direction everywhere in the field
Hedgehogs, line integral convolution (LIC), texture splats, etc.

LOCAL TECHNIQUES (ADVECTION-BASED METHODS)

Display the trajectory starting from a particular location
Streamlines, stream ribbons, contours
GLOBAL TECHNIQUES: DISPLAY THE ENTIRE FLOW FIELD IN A SINGLE PICTURE

Minimum user intervention

Example: *hedgehogs* (global arrow plots)
PUT “ICONS” AT CERTAIN PLACES IN THE FLOW

e.g., arrows representing direction & magnitude

Other primitives are possible
PROBLEMS WITH GLYPHS?

- Clutter the image (maybe ok for 2D)
- Sometimes not very informative (complex glyphs)
- Perspective problems in 3D
ICON PLACEMENT TO DECLUTTERING THE IMAGE

Hedgehogs or arrow plots: uniform grid
COMPLEX Glyph
PERSPECTIVE PROBLEMS

In 3D, arrows suffer from perception problems:
PERSPECTIVE PROBLEMS

In 3D, arrows suffer from perception problems:

Is it this?
PERSPECTIVE PROBLEMS

In 3D, arrows suffer from perception problems:

Is it this?

Or this?
Local Techniques

Basic idea: Visualize flow directions by releasing particles and calculating a series of particle positions based on the vector field

These methods use advection
Advection is just an application of the forward Euler method

Mathematical background on advection:
http://en.wikipedia.org/wiki/Advection
LOCAL TECHNIQUES: STREAMLINES

Streamlines are a family of curves that are instantaneously tangent to the velocity vector of the flow.

Algorithm: Release a particle into the flow and trace its position over time

1. Pick point
2. Move small distance along tangent direction
3. Find new point
4. Repeat and connect to draw out streamline
LOCAL TECHNIQUES: STREAMLINES

Displaying streamlines is a local technique because you can only visualize the flow directions initiated from one or a few particles.
STREAMLINE LIMITATIONS?
**STREAMLINE LIMITATIONS**

As the number of streamlines increases, the scene becomes cluttered.
STREAMLINE LIMITATIONS

Need to know where to drop the particle seeds
STREAMLINE LIMITATIONS

computation is expensive!
Unsteady Flow

As presented, streamlines work for steady flow

We want techniques for unsteady flow

Many techniques, we’ll discuss these:

Pathlines
Timelines
Streaklines
UNSTEADY FLOW: PATHLINES & TIMELINES

Extensions of streamlines for time-varying data (unsteady flow)
**Unsteady Flow:**

**Streaklines**

Continuously inject a new particle at the same location for each time step.

Advect all existing particles and connect them together into a streakline.
FLOW ADVECTION METHOD COMPARISON

Streamlines

Streaklines

Timelines
More Complex Primitives

We really would like to see vorticities (i.e., places were the flow twists)

A point primitive or icon can hardly convey this
STREAM RIBBON

Idea: Trace neighboring particles and connect them with polygons.
Shade those polygons appropriately; can then detect twists.
STREAM TUBE

Generate a streamline and connect circular crossflow sections along the streamline.
FLOW VOLUMES

Instead of tracing a line, trace a small polyhedron
PROBLEMS?

Divergent flows
STREAM BALLS

A way to get around diverging streamlines

Simply put implicit surface primitives at particle traces

At places where they are close, they will merge elegantly
STREAM BALLS

Based on metaballs
http://en.wikipedia.org/wiki/Metaballs

+ Implicitly generated surfaces
  + Easily split and merge

- Computationally expensive
  - Need fine meshing to do accurate isocontouring/isosurfacing
STREAM BALLS

Basic idea: Create a continuos function $f(x, y, z)$ and take isosurfaces of this function.

Use metaballs to generate this function.

Metaballs developed separately by Nishimura, Blinn, and Wyvill, and further refined by Bloomenthal and Shoemake.

Treat particles as metaballs or use a timeline curve.
**STREAM BALLS**

Can easily map other variables to the surface’s color and texture

Can use other variables to control the shape of the resulting contour surface
**Contours**

Contour lines can display certain quantities by connecting identical values along a line.
LINE INTEGRAL CONVOLUTION (LIC)
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Essence of method:

Consider a white noise texture, $T(x,y)$
Set each pixel’s intensity as a function (e.g., average) of values of $T$ along a short line segment through the pixel
This has the effect of correlating the resulting pixel values along streamlines, giving a sense of the flow direction

White noise  
Flow lines  
LIC
**Line Integral Convolution (LIC)**

Rather than deposit energy on each pixel, integrate the icon weights with a white noise function.
LINE INTEGRAL

CONVOLUTION (LIC)

Rather than deposit energy on each pixel, integrate the icon weights with a white noise function.
LINE INTEGRAL
CONVOLUTION (LIC)

Rather than deposit energy on each pixel, integrate the icon weights with a white noise function.
**Line Integral Convolution (LIC)**

Rather than deposit energy on each pixel, integrate the icon weights with a white noise function.
2D LIC: What do LIC images look like?

Smooth change of color along a flow, but rough alternation perpendicular to it

Visual impression like a painting

Depiction of the directional structure of the vector field, but not the magnitude of the flow
LIC Example: 2D Airfoil (Color by Magnitude)
LIC/STREAMLINE COMPARISON
LIC AND DYE ADVECTION
LIC AND DYE ADVECTION
LIC and Dye Advection
LIC (2D on 3D surface; color by magnitude)
FLOW TOPOLOGY
FLOW TOPOLOGY

- Source
- Sink
Flow Topology

- Source
- Sink
- Sink basin
Flow Topology

Source
Sink
Source basin
FLOW TOPOLOGY – CRITICAL POINTS

- Saddle
- Spiral
- Node
- Focus
- Center
Flow Topology – Critical Points

- Saddle
- Spiral
- Node
- Focus
- Center
FLOW TOPOLOGY – CRITICAL POINTS

- Saddle
- Spiral
- Node
- Focus
- Center
Flow Topology – Topological Skeleton
**FEATURE STABILITY AND CANCELLATION**

**Robustness** is a measure that determines how much a vectorfield must be perturbed to cancel critical points.

Critical points with *low robustness* may represent *noise* in the data.

_Cancelling point with low robustness may improve interpretation._
FEATURE STABILITY AND CANCELLATION
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Visualization-by-Sketching
An Artist’s Interface for Creating Multivariate Time-Varying Data Visualizations

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