Vector Field Visualization: Computing Topology
Vector Field Topology (Recall)

• Vector field topology provides qualitative (structural) information of the underlying dynamics.

• It usually consists of certain critical features and their connectivity, which can be expressed as a graph, e.g. Entity Connection Graph (ECG) [Chen et al. 2007]
  – Fixed points
  – Periodic orbits
  – Separatrices
ECG Construction

• Two steps pipeline
  1. Extract fixed points and periodic orbits
  2. Compute connections between these features
Fixed Point Extraction

• Cell-wise
  – First, locate the cells that contain fixed points
    • Using the unique characteristics of the Poincaré index around a fixed point instead of solving a linear system
  – Second, solve for the position of the fixed point
Periodic Orbit Extraction

[Flow recurrency]

[Kalies et al. 2006]
Periodic Orbit Extraction

• Properties:
  – No guarantees to find all the cycles
  – In practice, it tends to work well
  – And it is fast
  – Can detect embedded orbits

\[ V(x, y) = \left( -x + y \cos(x) \right) \]

Synthetic field
Extract Topology

- Fixed point extraction
- Periodic orbit identification
- Compute connections
  - Separatrix computation (emitting from saddles)
  - Other connectivity
    - A source and a sink
    - A source/sink with a periodic orbit
    - A periodic orbit with other periodic orbit
Applications (1)

- Feature-aware streamline placement
  - First extract topology, then use it as the initial set of streamlines to compute seeds for later placement
Applications (2)

- CFD simulation on gas engine
- Velocity extrapolated to the boundary

- 105K polygons
- 56 fixed points
- 9 periodic orbits
- 31.58s on analysis
Applications (3)

- CFD simulation on diesel engine
- Velocity extrapolated to the boundary

- 886K polygons
- 226 fixed points
- 52 periodic orbits
- 29.15s on analysis
Application (4)

- CFD simulation on cooling jacket
- Velocity extrapolated to the boundary
Applications – Simplification

Reduce flow complexity so that people can focus on the more important structure

[Chen et al. 2007]
Applications – Data Compression

Before

After

[Theisel et al. Eurographics 2003]
EXTENSION
3D Flow Topology

• Fixed points

[Weinkauf et al. EG04]


• Periodic orbits

[Wischgoll and Scheuermann 2002]

[Weinkauf et al. VisSym 2004]

[Reich et al. TopoInVis11]
To Time-Dependent Vector Fields

- Track the Evolution of Instantaneous Topology

- Pathline-based
To Time-Dependent Vector Fields

- **FTLE**
  [Haller 2001, Shadden et al. 2005, Garth et al. CGF08, Garth et al. Vis07, Lekien et al. 2007, Sadlo and Peikert TVCG07, Fuchs et al. PG10 etc., Kuhn et al. PacificVis12, etc…]

  [Sadlo and Weiskopf EG11]

  [Uffinger et al. TVCG13]

- **Streaklines/Streak-surface based**

  [Haller 2001, Shadden et al. 2005, Garth et al. CGF08, Garth et al. Vis07, Lekien et al. 2007, Sadlo and Peikert TVCG07, Fuchs et al. PG10 etc., Kuhn et al. PacificVis12, etc…]

  [Sadlo and Weiskopf EG11]

  [Uffinger et al. TVCG13]

  [http://www.zib.de/hotz/projects/finiteTimeFlow.html]
To Uncertainty Vector Fields

[Otto et al. EG10, PacificVis11]

[Bhatia et al. PacificVis11, TVCG2012]
Additional Reading


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