Function Field Analysis for the Visualization of Flow Similarity in Time-Varying Vector Fields

ISVC 2012

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Introduction

\[ \nu : \mathbb{R}^3 \times \mathbb{R} \rightarrow \mathbb{R}^3 \]
Introduction

\[ v : \mathbb{R}^3 \times \mathbb{R} \rightarrow \mathbb{R}^3 \]
Introduction

\[ \nu : \mathbb{R}^3 \times \mathbb{R} \to \mathbb{R}^3 \]

Lagrangian analysis vs. local flow behavior
• Similarities in time-varying flow behavior:
  – Detection of (known/critical) patterns
  – Domain-centered (maps) flow comparison
  – Time-varying symmetries
Solution: reformulate field as function field

\[ v : \mathbb{R}^3 \times \mathbb{R} \rightarrow \mathbb{R}^3 \]

\[ F : \mathbb{R}^3 \rightarrow (\mathbb{R} \rightarrow \mathbb{R}^3) \]

*Flow pattern*  \( f_x = v(x, .) \)

*Flow motif*  \((f_x, [t_0, t_1])\)

In practice: Discretize data as set of vector-valued time series
Visual Similarity

• 2D: visually encode average flow direction [Hlawatsch et al. 2011]
Visual Similarity

from “Flow Radar Glyphs - Static Visualization of Unsteady Flow with Uncertainty”, Hlawatsch et al. 2011

- Basic impression of similarity
- Hard to quantify
- Not suitable for 3D function field analysis
Similarity Measures

- Quantify: What should be considered similar?
  - *Comparable* curves/velocity vector movements
  - Same *class* of flow behavior

Different levels of abstraction needed
Similarity Measures

• Formal requirements:
  – Computational efficiency
    • Fast similarity search
  – Robustness
    • Reduce impact of small scale noise
  – Flexibility
    • Invariant to local transformations
Similarity Measures

• Distance: Maximal vector dissimilarity
  – Compensate for rotation by aligning motifs in 3D

\[ d(f, g) = \max_t (\min_R (1 - f(t) \cdot Rg(t))) \]
• Behavioral similarity
  – Define predicates for abstract flow behaviors

\[ f_x \Rightarrow ([P(A), P(B), ...], [5, 10, ...]) \]
\[ d(f, g) = \| f(2) - g(2) \| \]
Applications

• Clustering
  – Automatic grouping of similar flow behaviors

• Querying in 4D
  – Manual filtering/selection / similarity search
Visualization and Interaction

- **Linked views**
  - Compound function space
  - Function field with domain geometry
Visualization and Interaction

• Function space:
  – Brushing for motif selection
  – Cluster and similarity selection/visualization
• Function field:
  – Behavior querying
    • Specify sequences of behavior predicates
  – Motif recording and querying
    • Select region of interest \( \{ x_i \} \) and time range \([t_0, t_1]\)

\[
S = \{(f_{x_1}, [t_0, t_1]), \ldots, (f_{x_n}, [t_0, t_1])\}
\]

\[
\{g = (g_x, [t_i, t_j]) \mid \exists f \in S : d(g, f) < \epsilon\}
\]
Results
Results
Summary and Conclusions

- Time-varying flow similarity and symmetry analysis
- Flow pattern detection
- Potential application in flow compression
- Integrate further flow quantities
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Thank You