Current Trends for 4D Space-Time Topology for Semantic Flow Segmentation

SemSeg

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Introduction

Recent advances in computing and simulation technology allow the simulation of time dependent flows. These are flows where underlying velocity field changes over time. The simulations of time dependent flows are a more realistic approximation of natural phenomena and they represent an invaluable tool for scientists in numerous disciplines.

Flow visualization, a subfield of scientific visualization is one of several research communities which deals with analysis of flows. There are many methods for analyzing steady flows, but the extension to the time dependent case is not straight forward. The SemSeg project is a FET Open project which tries to come closer to a universal solution for a semantic segmentation of time dependent flows, it aims at the formulation of a sound theoretical mechanism to describe structural features in time-dependent flow.

Proposed Approach

Several approaches are being pursued in the project, such as methods based on the finite time Lyapunov exponent (FTLE), Vector Field Topology (VFT) based methods, or interactive visual analysis (IVA). Uncertainty visualization and interactive evaluation of various methods are helping in evaluating current results.

Vector field topology (VFT) is a well-established methodology for analyzing and visualizing velocity field datasets. Its power lies in the automatic and parameter-free extraction of flow structures that have proven meaningful in a wide range of application domains. Its limitation is the restriction to steady flow. In order to overcome this limitation, we proposed to use moving frames of reference for local application of VFT. We defined criteria for the optimal choice of such moving frames.
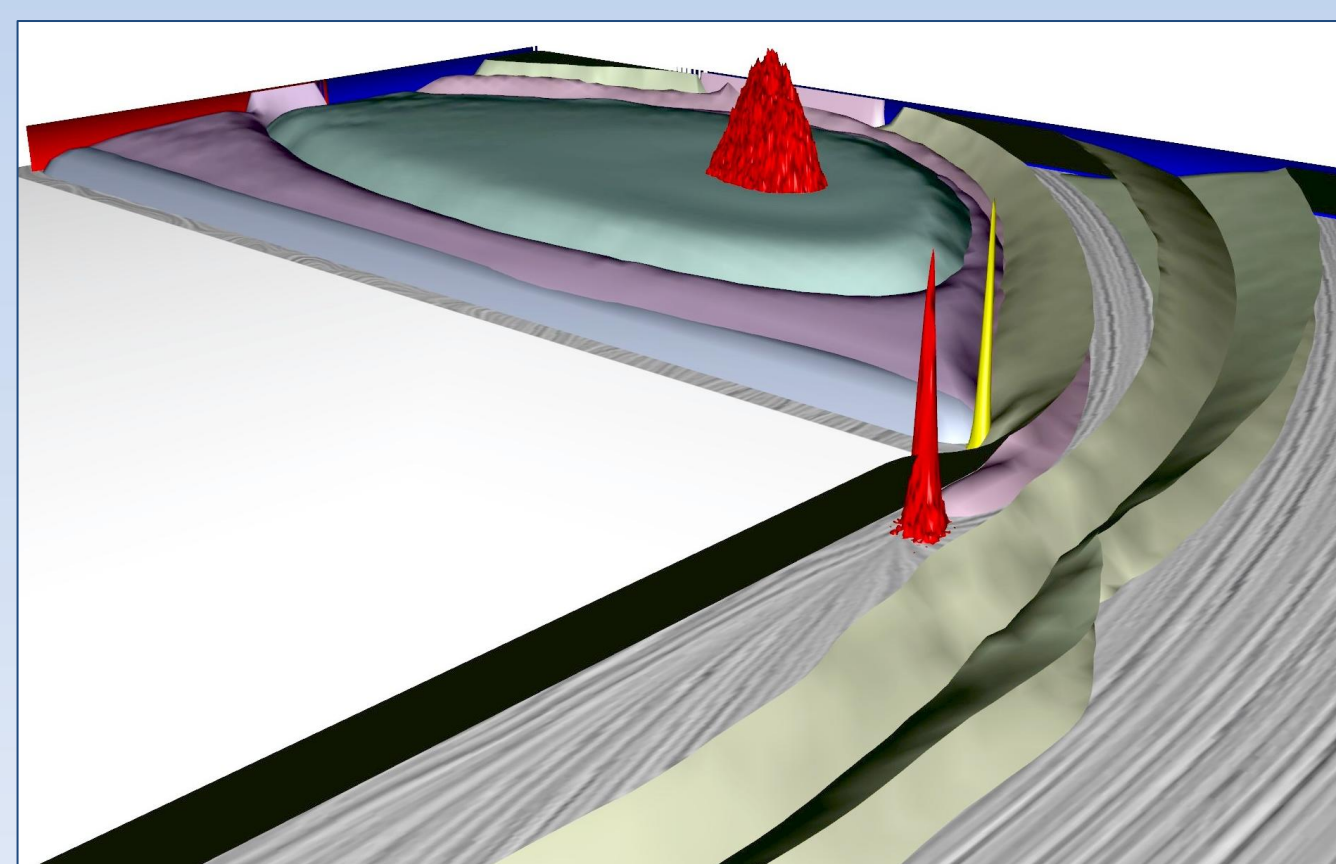
We also present a technique to visualize **global uncertainty in steady 3D vector fields using a topological approach**. We start from an existing approach for the 2D case and extend this into 3D space. In addition we develop an acceleration strategy to detect sink and source distributions. As part of the approach, we introduce uncertain saddle and boundary switch connectors and provide algorithms to extract them.

A popular alternative to VFT is based on the **finite-time Lyapunov exponent (FTLE)**, a scalar quantity that have been shown to be in close relation to flow structures, so-called **Lagrangian coherent structures (LCS)**. These structures can be visualized without an explicit ridge extraction step. Analyzing LCS and the related geometrical trajectory properties allows understanding of structure of time dependent flow phenomena. However, for further analysis such as the study of bifurcations, ridges are necessary. We compared several ridge definitions and developed a novel method which exploits properties of finite-time Lyapunov exponent fields. It avoids one order of numerical differentiation and results in higher quality ridge surfaces. In our recent work we also developed a filter that allows to distinguish between separation due to different flow directions and separation due to different flow speeds. The filter follows the geometric intuition behind the original definition of FTLE as described by Haller and uses information that is inherent to it. We demonstrate the effect of the proposed filtering on both synthetic and simulated data.

Selected Results
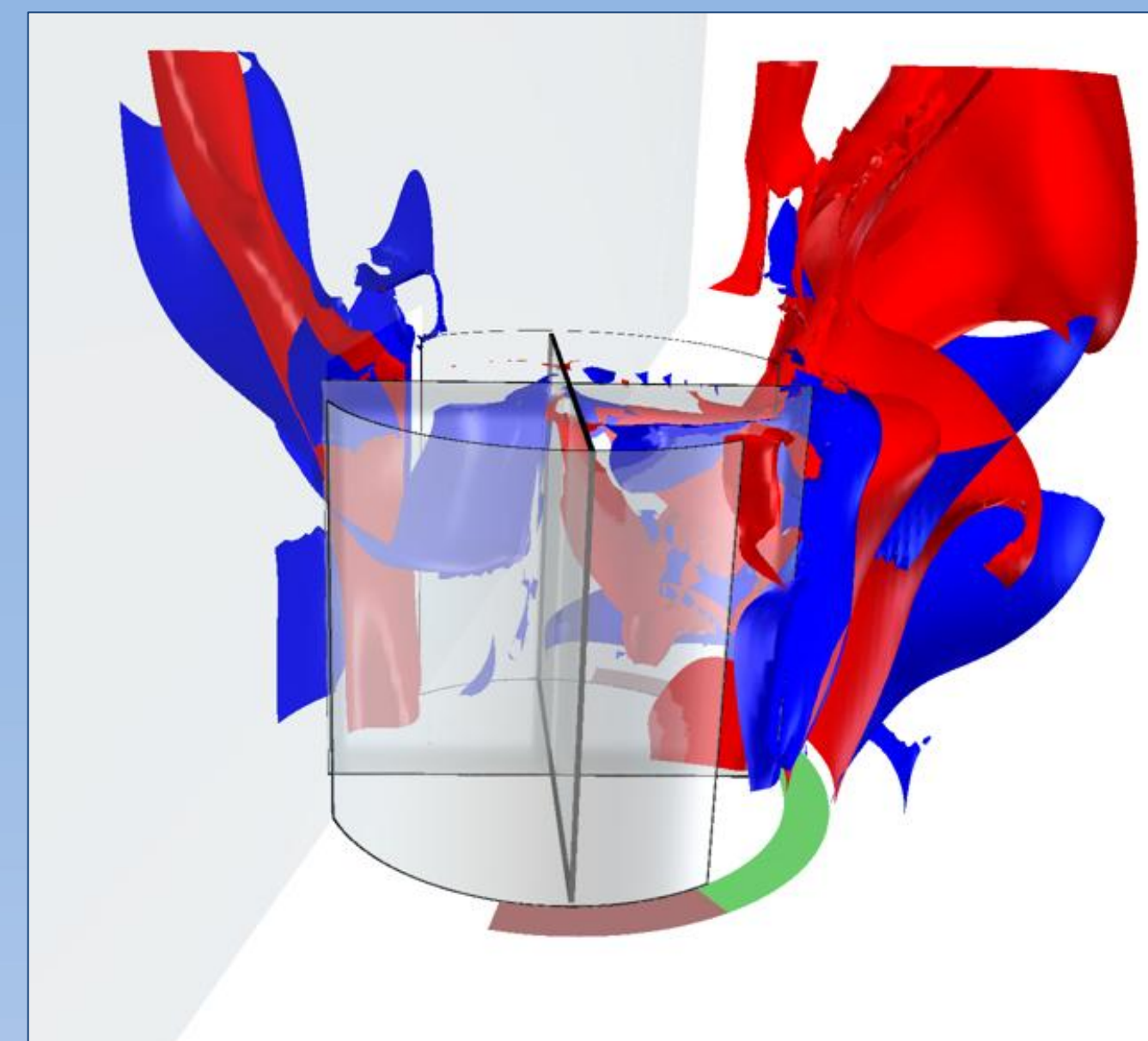
Visual analysis of the simulation results of a revolving door equipped with an air curtain. The warm air outlet (green) is placed in the floor along the interior opening of the door, two air intakes (red) are at the side of the cylinder.

Convection and the door's pumping effect add up to an interesting unsteady flow, which is visualized with Lagrangian coherent structures (LCSs). LCSs were computed as ridge surfaces of the velocity field's finite-time Lyapunov exponent, using a novel, robust ridge extraction method. For better visibility the front half of the LCSs is cut away. Both repelling (blue) and attracting (red) LCSs are good approximations of material structures and therefore indicate transport barriers. Intersections of repelling and attracting LCSs indicate saddle-like flow relative to the motion of the LCSs. Simulation data: Stefan Barp, Air Flow Consulting, Zurich. Visualization: Benjamin Schindler, ETH Zurich.

Topology of uncertain vector fields. 1024 measurements of a flow around a backward facing step were used to create an uncertain vector field. A special property of uncertain vector fields is that uncertainty is transported within the field. Thus, a global analysis is required - we extract the topology. In contrast to certain vector fields we cannot extract critical points as isolated points and separatrices as curves; instead we compute particle density distributions for critical structures and probabilities for regions with separating character. The uncertain vector field topology contains two source distributions (red height maps) and one saddle distribution (yellow height map) in our case. Probabilities for separating structures are shown by randomly colored height maps.
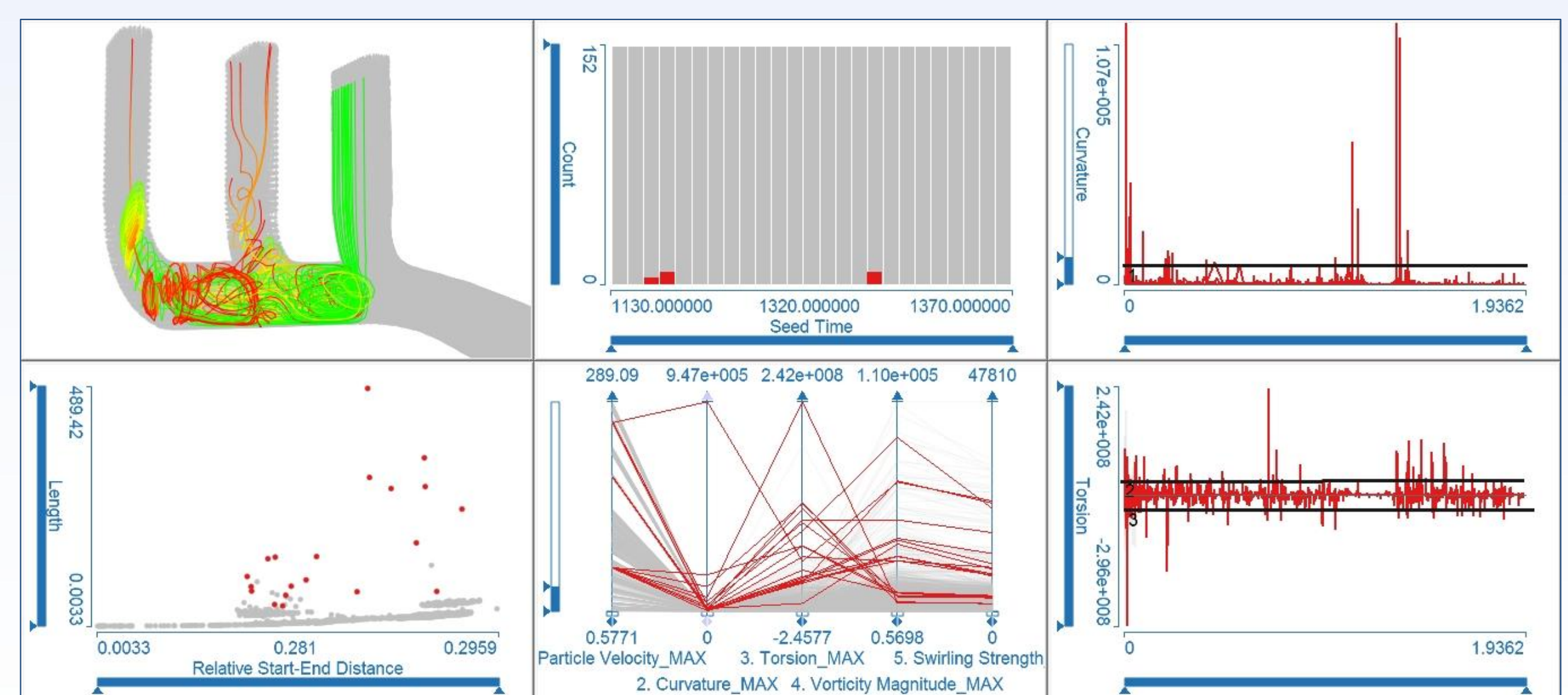
Interactive Visual Analysis. Besides automatic methods we pursue research on interactive exploration of unsteady flows. A snapshot from the analysis of an exhaust manifold data set from automotive industry is shown here.

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