Consistent Feature Extraction From Vector Fields

Combinatorial Representations and Analysis Under Local Reference Frames

HEIDELBERG LAUREATE FORUM

Harsh Bhatia, Ph.D. Candidate *(www.sci.utah.edu/~hbhatia)*
Scientific Computing and Imaging Institute, The University of Utah, USA
Center for Applied Scientific Computing, Lawrence Livermore National Laboratory, USA

Advised by
Prof. Valerio Pascucci (www.pascucci.org)
Dr. Peer-Timo Bremer (www.sci.utah.edu/people/ptbremer.html)

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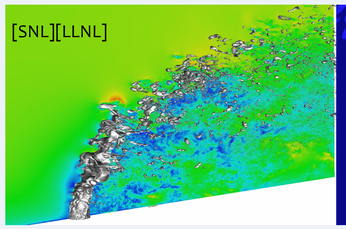
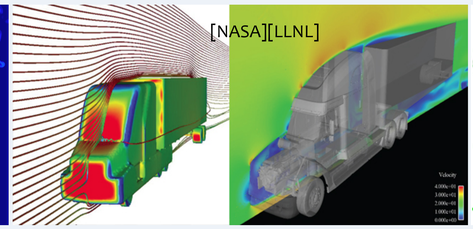
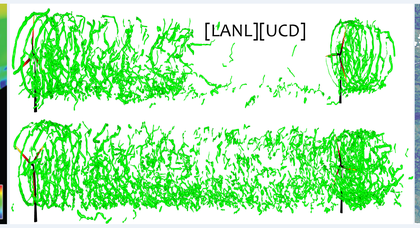
Analysis of vector fields is indispensable to many applications in science and engineering



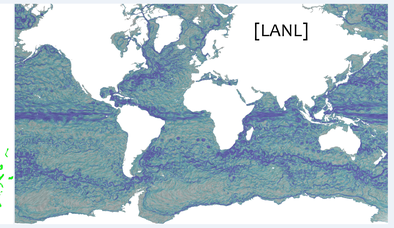
Design of fuel-efficient combustion



Aero-dynamical design of fuel-efficient automobiles

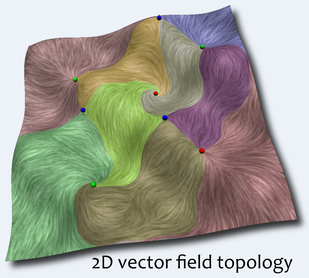


Design of high-yield renewable energy sources



Understanding climatic processes

- *Vector fields* represent important information about a variety of natural and artificial processes; gaining insights into these physical phenomena requires understanding the behavior of material particles flowing through the vector field.
- *Vector field topology* is an impactful way of studying such behavior for *steady* vector fields, but similar concepts for *unsteady* fields are not understood yet.


2D vector field topology

Combinatorial representations and algorithms provide robust and consistent analysis [*]

- Numerical adaptation of smooth theory for digital computers incurs errors and makes approximations. Tracking the resulting uncertainties is nontrivial, and the obtained results may be inconsistent, e.g., intersecting streamlines (Fig. 1).
- We develop new representations and algorithms that are combinatorial in nature, and can be implemented exactly on computers, e.g., using graphs and integers.
- This allows performing consistent extraction of topological structures (Fig. 2); the discretization errors can be computed, encoded, and visualized (Fig. 3).

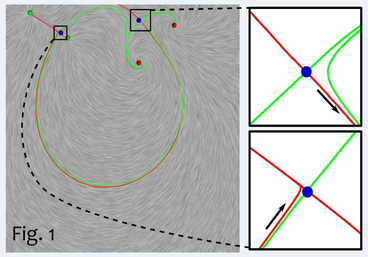


Fig. 1

Fig. 2

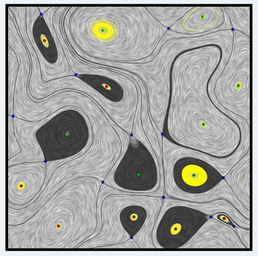
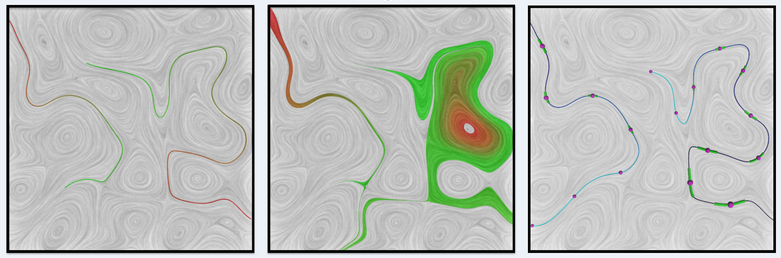


Fig. 3



Local reference frames highlight otherwise hidden features [*]

- Vector field topology is dependent upon the assumed reference frame; important features may get obscured due to an unsuitable frame (Fig. 4). This limitation also prohibits topological analysis of unsteady vector fields.
- We develop new reference frames to extract local features by performing open-boundary and multiscale analysis.
- These frames extract otherwise hidden structures (Fig. 5), and allow analyzing unsteady vector fields as sequences of steady vector fields (Fig. 6).

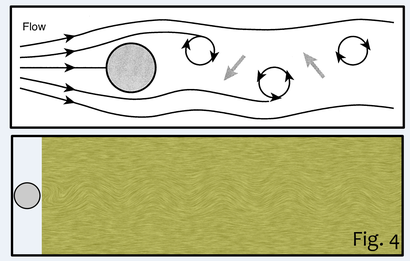
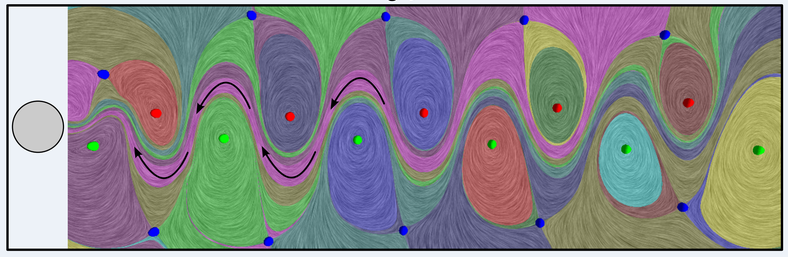


Fig. 4

Fig. 5



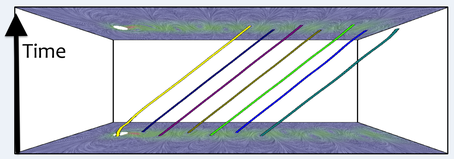
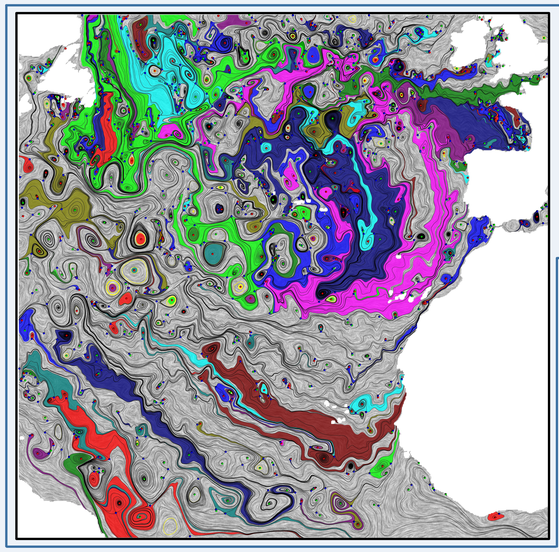
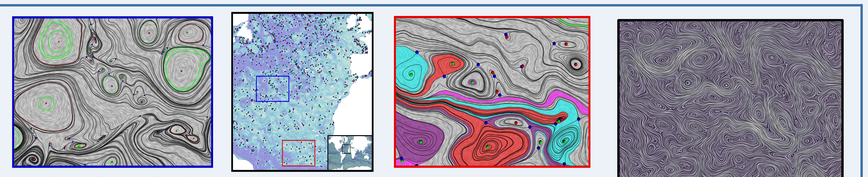


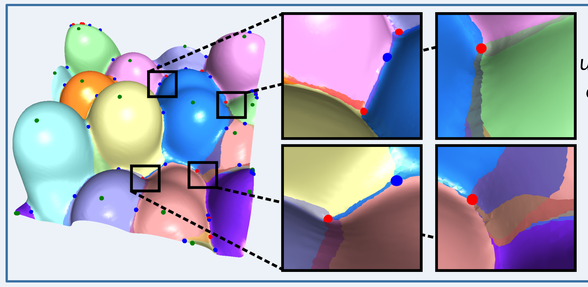
Fig. 6

Consistent topological analysis and uncertainty visualization applied under local reference frames help derive important scientific insights

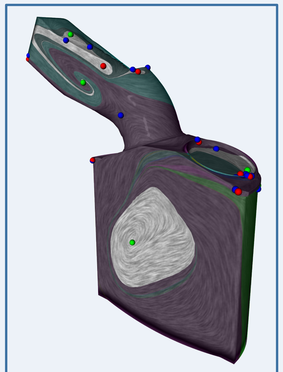




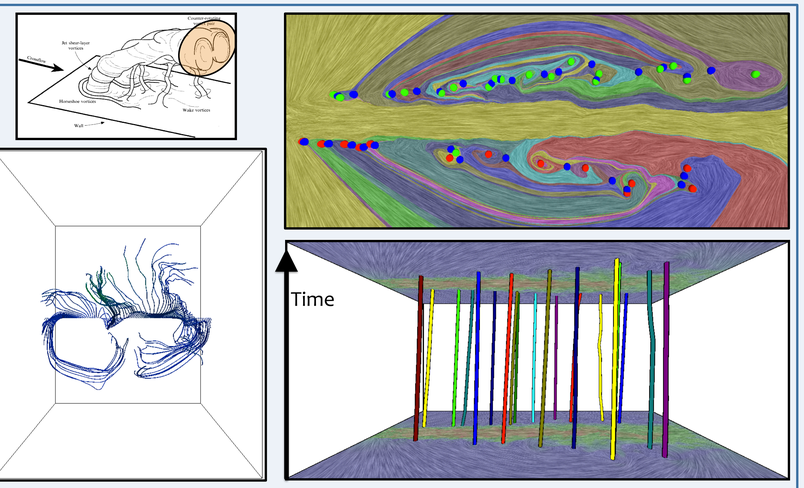
identifying the behavior of global oceanic currents helps understand global environmental factors and their impact on climate changes



understanding the structure and fuzziness in simulations of turbulent mixing sheds light on phenomena ranging from boiling water to astrophysics and nuclear fusion



investigating the flow patterns in automotive components helps improve their design and performance



identifying spatiotemporal behavior of stable but weak rotational structures in combustion simulations allows developing sources for cleaner energy

This work was performed under the auspices of the US Department of Energy (DOE) by Lawrence Livermore National Laboratory (LLNL) under contract DE-AC52-07NA27344. LLNL-POST-660070.

[*] The publications corresponding to this work can be found at the presenter's webpage.