Enabling Streamline-Based Analysis for Time-Varying Flows

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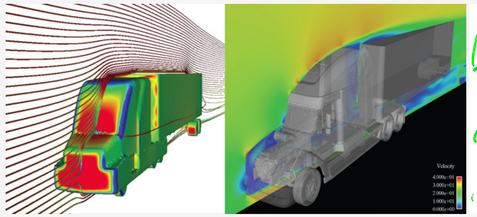
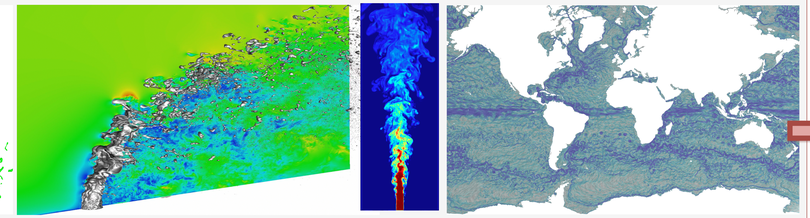
Analysis of vector fields is indispensible in many applications in science and engineering



Aero-dynamical designs of automobiles, airplanes, wind turbines, etc.

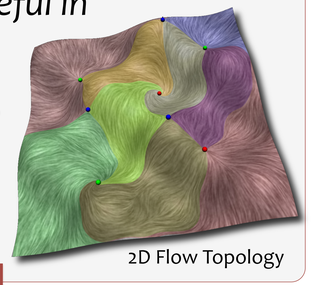


Study of mixing, transport, and circulation.

Study of wind patterns and ocean currents.

Streamline-based analysis is very useful in analyzing time-independent flows

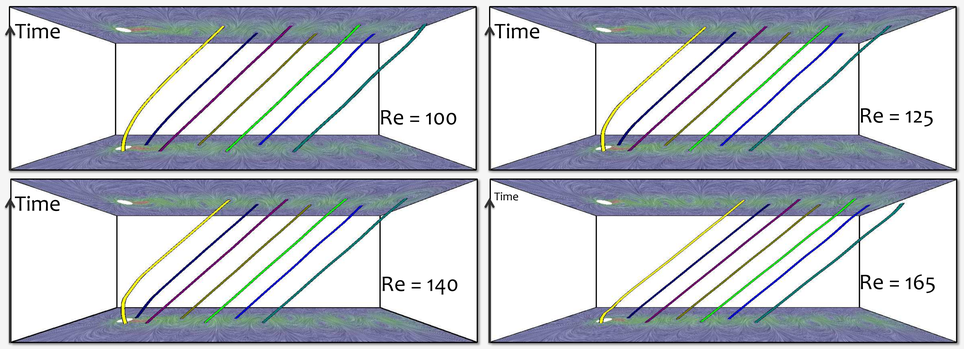
- Analysis based on *streamlines* (tangent curves to the flow) successfully captures the particle behavior in the flow
- Such techniques allow extract of meaningful features through robust, combinatorial, and higher-order analysis



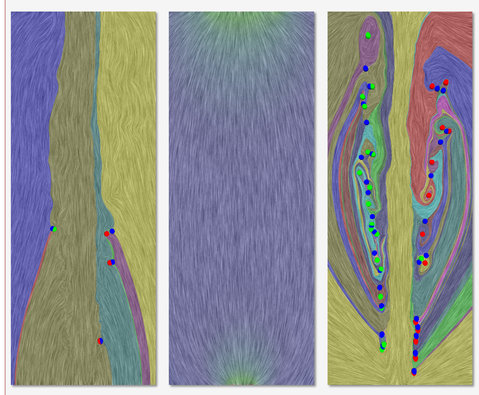
2D Flow Topology

Using streamline-based techniques to analyze time-varying flows

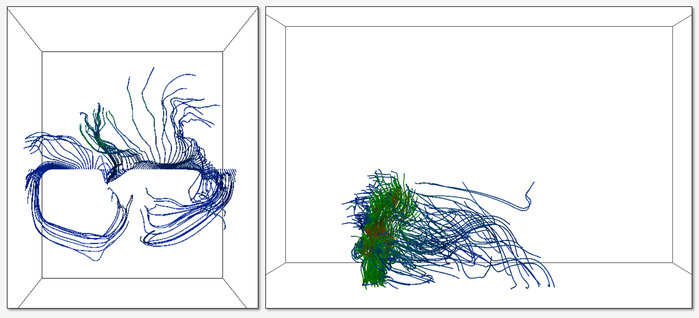
- These ideas make the well-established streamline-based techniques applicable to time-varying flows



Understanding the motion of von Karman vortex street using streamline-based techniques on individual time-steps.



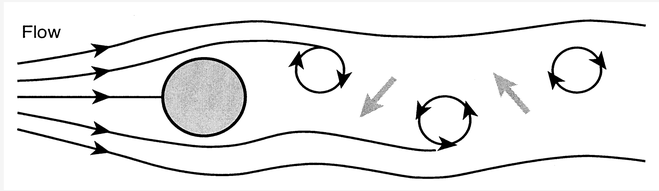
Analysis of the lifted ethylene jet flame in the internal frame (right) reveals nested vortices. None of these structures are visible in the original reference frame (left). The motion of the reference frame (middle) is more general than uniform motion.

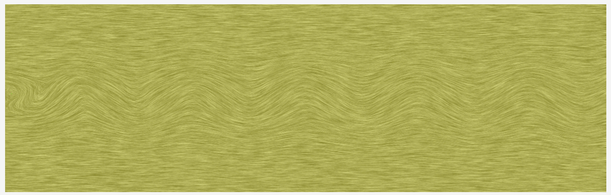


Analysis of the jet in cross-flow (bottom-left) reveals the counter rotating vortex pair (top-left) and the turbulence near the jet's orifice (top-right) as expected by the simulation model (bottom-left). The background flow (bottom-right) is non-trivial and cannot be handled using existing techniques.

But, such techniques require a "meaningful" reference frame for time-varying flows

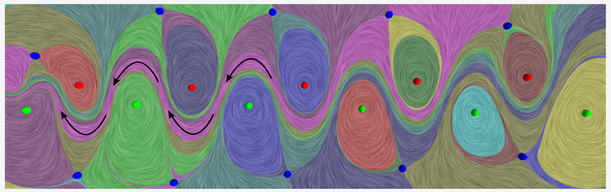
- Despite their success for time-independent flows, these techniques cannot be used for time-varying data
- The streamlines of time-varying flows are useful only in a "meaningful" reference frames
- Most existing techniques only focus on uniformly moving frames, which is not sufficient for many practical cases

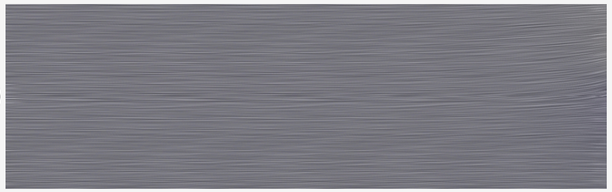




The von Karman vortex street Illustrated on the left cannot be detected in the simulated data using streamlines on the right.

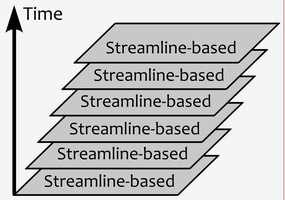
Analyzing time-varying flows per time-step using the internal reference frame [1]





Decomposing the flow highlights the internal features in the left (von Karman vortex street) and the external influences in the right.

- We decompose the flow at each time-step into meaningful components that represent
  - *internal* phenomena of the flow, e.g., combustion
  - *external* influences on the flow, e.g., fuel influx
- This decomposition creates new reference frame that
  - reveals the internal and otherwise hidden flow features
  - allows streamlines to capture particle behavior in the flow
  - simplifies the analysis by applying streamline-based techniques independently at each time-step
  - features can then be tracked in time to understand their temporal behavior
- This decomposition is computed in a data-driven manner without any assumptions
  - in a scalable and highly parallelizable manner
  - in a computationally less expensive manner than the state-of-the-art



[1] Bhatia, Pascucci, Kirby, and Bremer. Extracting Features from Time-Varying Vector Fields using Internal Reference Frames. Computer Graphics Forum, 33, Jun 2014.

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