Topology based feature extraction and analysis

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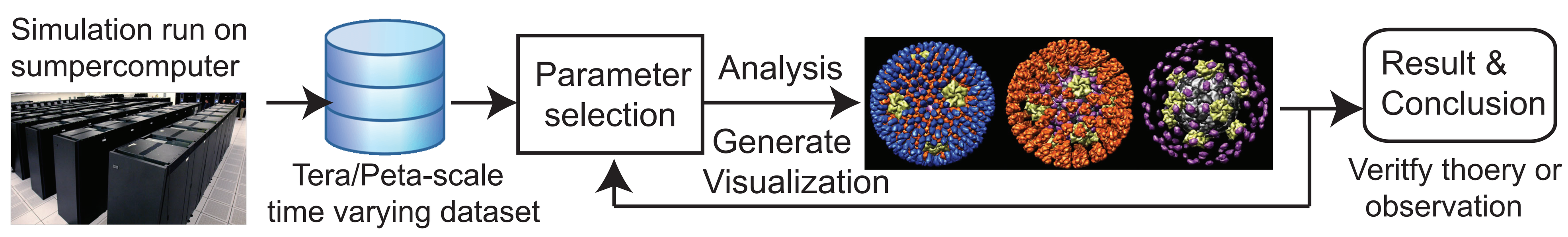
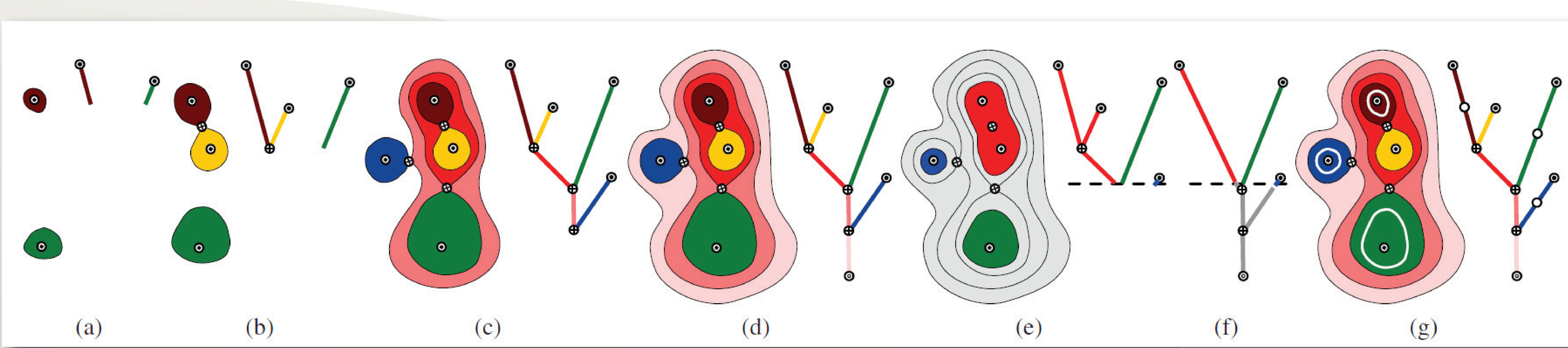
Challenges of understanding large-scale simulation



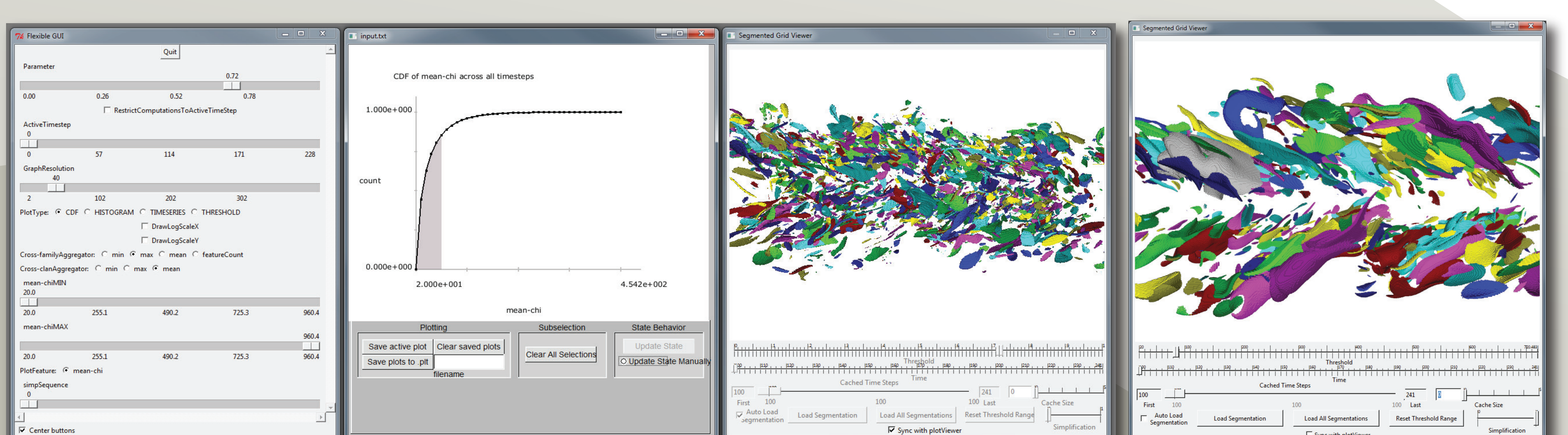
Large-scale simulations are increasingly being used to study complex scientific and engineering phenomena. Often, a key step in extracting insight from these large simulations involves the definition, extraction, and evaluation of features in the space and time coordinates. Due to the shear amount (Peta-scale) of raw simulation data and the repetitive parameter selection required by analysis and visualization it becoming increasing difficult to make sense of large simulation.

Topology based analysis framework

We present a new topological framework that in a single pass extracts and encodes entire families of possible features definitions as well as their statistical properties. We construct a hierarchical merge tree (construction process showed below), a highly compact, yet flexible feature representation. It allows us to extract a set of feature for any given parameter instantly without any recomputation. The compact data format(orders of magnitude smaller) and flexible structure enable interactive feature analysis and visualization of large scale simulation on a commodity desktop or laptop.



For the above figure, each color represents one "arc" or the merge tree. the image sequence (a-d) shows steps in a top-down construction of the tree. (e-f) shows how thresholds can be used to extract features from the tree, (g) shows relative thresholds.



The core component of our analysis framework is an interactive viewer consists of a feature segment viewer(show on the right), a statistic viewer (shows on the left linked with the segment viewer), and a graph track viewer (not showed above). The linking between different view provides a natural and intuitive workflow for the exploration of global trends in feature-based statistics. For example in the statistic viewer a CDF function is show, we can pick a certain range in the CDF, since the segment viewer is linked, only the feature comply with the selected statistic range will show up in the viewer. This provide a huge flexibility for the user compare to previous works.

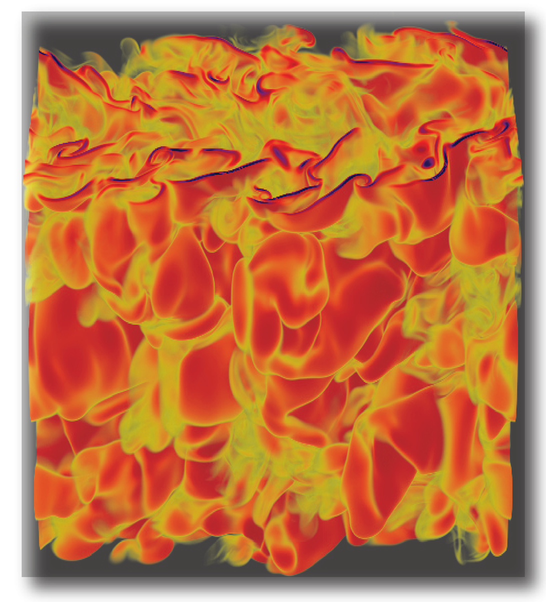
References & Acknowledgement

Feature-Based Statistical Analysis of Combustion Simulation Data, Janine Bennett, Vadiynanathan K, Shusen Liu, Ray Grout, Jackie Chen, Bremer Timo, Valerio Pascucci

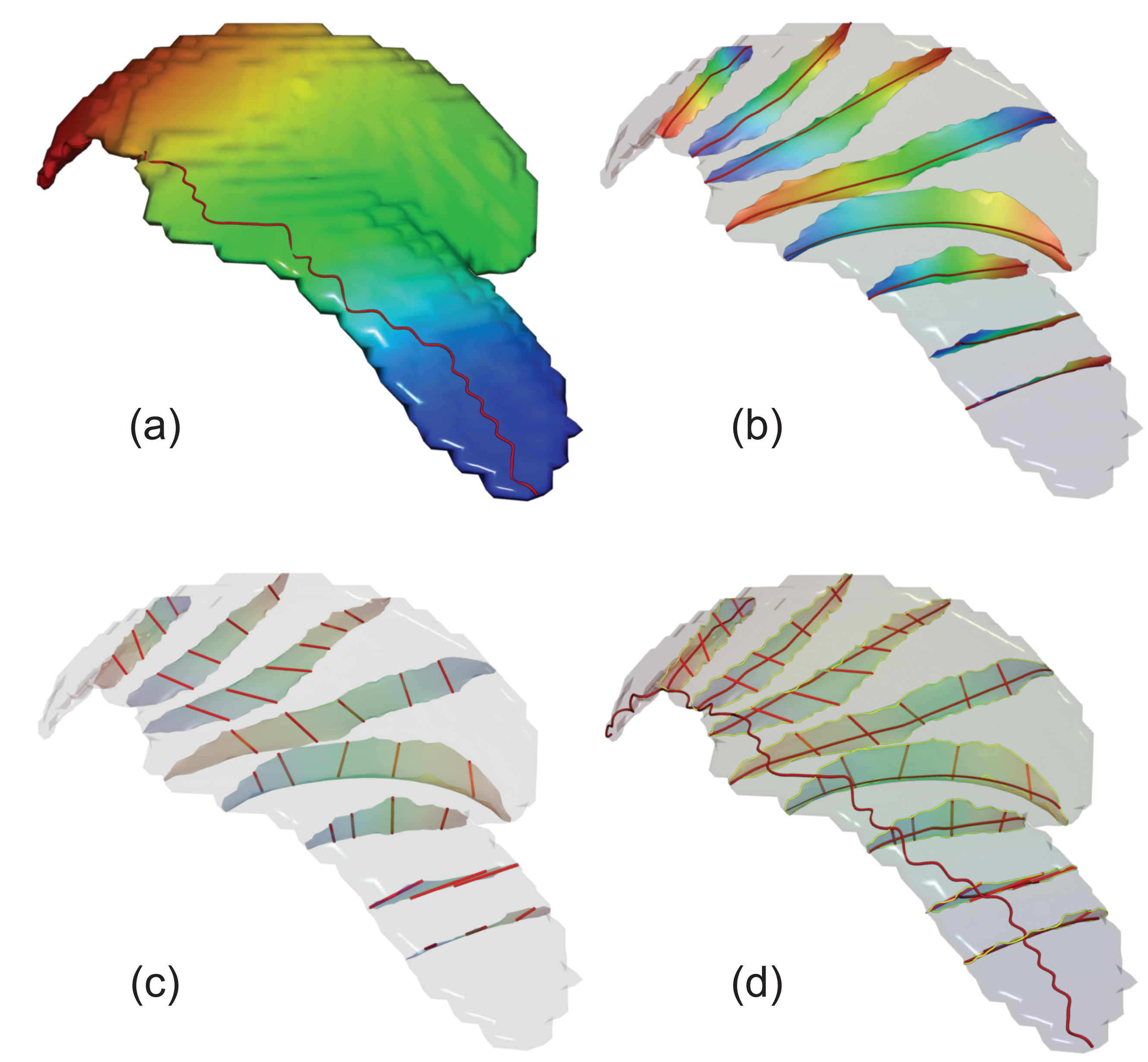
Interactive Exploration and Analysis of Large-Scale Simulations Using Topology-Based Data Segmentation, Peer-Timo Bremer,Gunther H. Weber, Julien Tierny, Valerio Pascucci,Marcus S. Day, and John B. Bell

Analyzing and Tracking Burning Structures in Lean Premixed Hydrogen Flames. Peer-Timo Bremer,Gunther H. Weber, Valerio Pascucci, Marcus S. Day, and John B. Bell

Application in combustion science

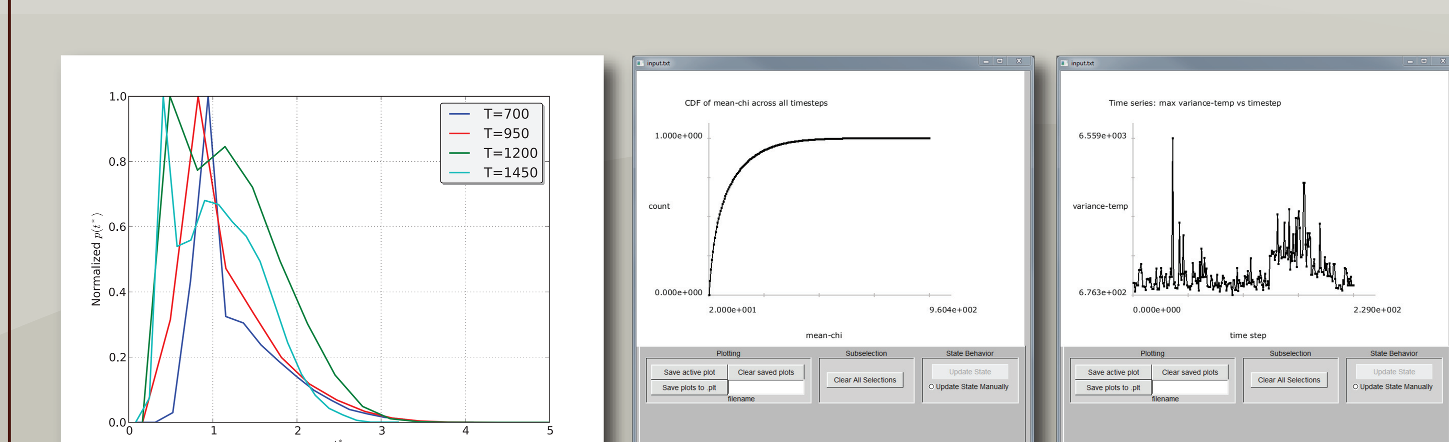


Combustion provides the vast majority of the world's energy needs and in an effort to reduce our reliance on fossil fuels, in order to predict efficiency and pollutant emissions for potential new fuel sources coupled with advanced combustor designs. Scientists use Direct Numerical Simulations (DNS) of turbulent flames to better understand the combustion process. The image on the left shows a volume visualization from the turbulent flames simulation.



One of the primary drivers of auto-ignition and extinction is the rate of turbulent mixing, characterized locally by the scalar dissipation rate. Compressive strain in directions aligned to scalar gradients, creates thin pancake-like regions (showed above as (a)) in the simulation whose thickness provides a direct measure of the local mixing lengthscale and its scaling with turbulence length scales.

In the figure above each shape is parametrized according to its first non-trivial eigenvector to compute its length (a), and the same technique is performed recursively on iso-contours of the first eigenvector to compute the width (b) and thickness (c). (d) showed all three scale together.



The primary scientific insights are captured in the distributions of the plot on the left. It shows the distribution of thicknesses, at a relevance of 0.85, computed for structures grouped by the mean temperature in the segment for four bins, each 250 Kelvin wide. The PDFs show a trend consistent with experimental observations: the thickness distribution conditional on temperature is asymmetric, with faster rise and shorter tail than lognormal, and shifts towards larger thickness with a broader distribution with increasing temperature. Three different statistic plots can be generated by our tool include: species distribution (middle figure) and time-series (right figure) and parameter study.

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