Design and Implementation of a System for Interactive Higher Dimensional Vector Field Visualization

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Abstract

Although the challenge of 2D flow visualization is deemed virtually solved as a result of the tremendous amount of effort invested into this problem, higher-dimensional flow visualization, (e.g. the visualization of flow on surfaces in 3D (2.5D), volumetric flow (3D), and flow with multiple attributes (nD)), still holds many challenges which need to be addressed. We describe the design and implementation of a generic framework incorporating a selection of related scientific and information visualization techniques which are interactively integrated to provide tools for effective visualization of the higher dimensional CFD (Computational Fluid Dynamics) simulation data. In contrast to the most research prototypes, the system we present handles real-world, unstructured simulation data. Our framework involves direct, vector field clustering and geometric flow visualization techniques. Information visualization approaches, such as a tabular histogram, velocity histogram, and parallel coordinate plot are also integrated. In order to enable a smooth and efficient user interaction, these visualization options are systematically combined on a multi-threading platform which ensures responsiveness even when processing large data.

1. Introduction

Over the last three decades, computational fluid dynamics (CFD) has developed rapidly. Its applications range widely from the automotive industry to medicine [LEG*08]. Since the size, complexity and dimensionality of the CFD simulation data has dramatically increased, the need for visualizations which provide quick and effective insight into the data also increases [PL09]. In order to present a visualization toolkit which is capable of dealing with large, unstructured, and high dimensional CFD simulation data, a comprehensive and versatile visualization framework is needed. In this poster we focus on the design and implementation of a generic visualization framework which provides the user solutions for effective visualization of the higher dimensional CFD simulation data by interactively combining scientific and information visualization techniques. This visualization framework yields following benefits:

- The framework handles versatile real-world, unstructured 2.5D, 3D, and *n*D CFD simulation data.
- Direct, vector field clustering and geometric flow visualization techniques are integrated in order to support the CFD engineer with an intuitive and rich visualization for effective visual analysis.
- Information visualization approaches, such as tabular histogram, velocity histogram, and parallel coordinate plot (PCP), are incorporated to enable engineers to gain a deeper understanding of the simulation data and thus focus on parts they deem interesting.
- A smooth and efficient user interaction is ensured by our multi-threading platform, even when large data is being processed.

2. Related Work

In this section, we discuss related works in visualization design and implementation. In order to guarantee quick responsiveness for user interaction even when dealing with large data, Piringer et al. [PTMB09] present a generic multi-threading architecture which enables early cancellation of the visualization thread due to user interaction without common pitfalls of multi-threading. Fisher et al. [FDFR10] present a framework called WebCharts. Existing information visualizations can be plugged into various host applications. WebCharts enables users do visualization locally, yet new visualizations can be updated and obtained via the API from related websites. Peng et al. [PGSC10] present a multi-linked framework which provides customized visualization techniques for engineers to gain a fast overview and intuitive insight into the flow past the marine turbine.

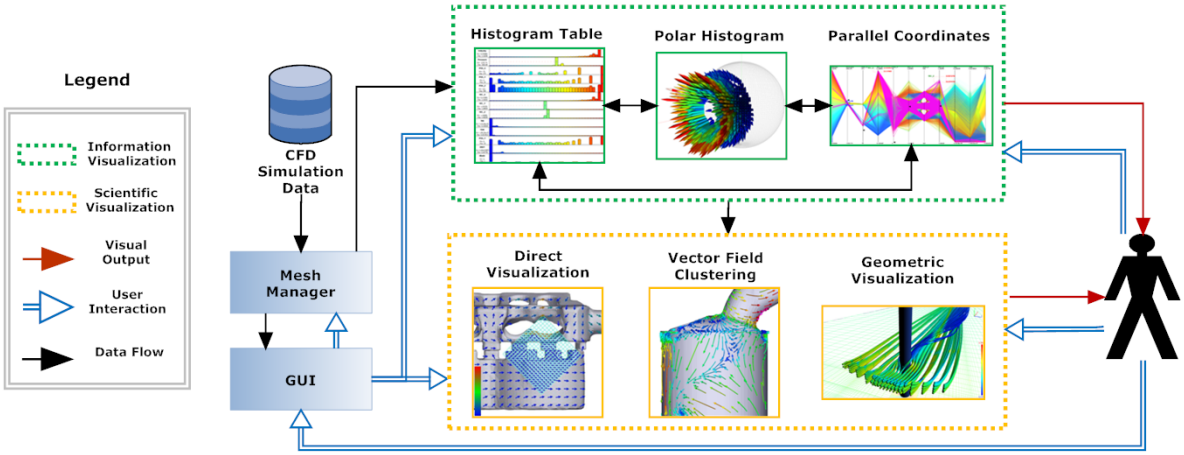

Figure 1: *An overview shows the pipeline of the application framework.*

3. System

Figure 1 illustrates an overview of the framework. The input is the flow simulation CFD mesh. It is associated with high dimensional information which includes position, velocity vectors and other various simulation attributes such as pressure. Since the mesh is often unstructured and adaptive resolution, the mesh manager is used to compute the mesh adjacency information as a preprocessing step. After the mesh topology is constructed, various information visualization approaches are employed to gain insight into the data. The histogram table provides an intuitive overview of the multi-dimensional attributes of the whole simulation. Based on the histogram table, the user can focus on attributes they deem interesting, while the polar histogram and PCP simultaneously depict the details of the focus attributes. The polar histogram presents an intuitive description of the flow velocity distribution. The PCP highlights the relationship between CFD attributes to support exploration. Several flow visualization approaches are applied to provide rich visual analysis. Interactive glyph visualization provides a quick and direct hands-on exploration on the vector field, while a continuous and complete view can be obtained by geometric flow visualization such as streamlines. The automatic vector field clustering [PGL*10] produces intuitive and insightful images of vector fields. The user can interact between different information visualization approaches to obtain the final scientific visualization result. Figure 2 shows our application based on this framework.

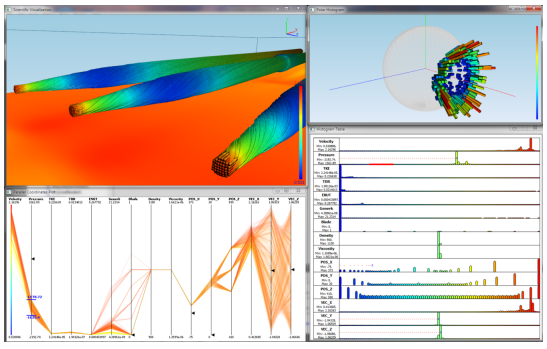

Figure 2: *A screen shot of our application being used to visualize the flow past by marine turbines.*

4. Conclusion

We describe the design and implementation of a generic framework which incorporates information and scientific visualization approaches to provide effective visual analysis of higher dimensional CFD flow simulation data. We discuss the motivation and the benefits of this framework. The feedback we have received from CFD experts has been very positive. We believe the principle outlines here can be applied to a more general way to other similar projects

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