Doctoral thesis position

In-situ visualization of volume data from large-scale simulation

Hosting institute: University of Strasbourg, ICube lab, IGG team (Computer Graphics and Geometry), Strasbourg, France

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Keywords: Volume rendering, high performance/in-situ visualization, large-scale simulation data.

Desired skills:
- Visualization
- Volume data
- GPU programming
- HPC

Contexte and motivations:

Access to increasingly powerful computing machines allows scientists to simulate increasingly complex phenomenon. However, large-scale numerical simulations produce data that are complex in terms of their size and their geometric, topological and physical characteristics. Specifically, such simulations can generate multi-variate volume meshes of large spatial dimension at each time step. Moreover, these meshes can be unstructured, high order, heterogeneous, with non-convex cells, non-planar faces etc.

On the other hand, modern visualisation methods are essential for several stages of numerical simulations: design, validation... Efficient visualisation of volume data is possible today with the ray-tracing algorithm on GPU offering good performance for a good rendering quality. However, interactive and in-situ visualisation algorithms need to adapt to the complexity of data from large-scale numerical simulations. The memory of GPUs is still too limited and their parallel SIMD architecture is not adapted to complex unstructured data. Moreover, the in-situ visualisation approaches proposed in the scientific literature are not adapted to HPC environments with storage capacities in RAM lower than the data set of a whole simulation.

In this context, it is necessary to focus on the evolution of interactive and in-situ visualisation algorithms so that they are able to provide an abstraction of the complexity and size of the input data. These issues are at the heart of the ANR LUM-Vis is project led by the IGG team of the ICube laboratory and to which this thesis is attached.

PhD Objectives:

The objective of this thesis is to address the scientific challenges outlined above, at the intersection of rendering and HPC for scientific visualisation in the application domain of numerical simulation.

From a state of the art that covers i) visualization of unstructured volume grids, ii) visualization of large volume data and iii) in-situ visualization, the identified objectives are the following:

- To address the different stages of sampling, interpolation and classification of direct volume rendering in order to propose a method for efficient rendering [1, 8] by providing a visualization faithful to the degree of accuracy of numerical simulations [6, 7].
- To explore the possibilities of interactive visualization of large volumes of dynamic data in an HPC environment, based on the combination of out-of-core rendering methods [2, 3] and in-situ methods [4, 5]. It will be necessary to consider the evolution in time of the data to be visualised, both in terms of topological and geometrical changes and in the scalar/vector field(s). This objective will also cover aspects of parallel and distributed rendering.

Work environment:

The thesis will take place at the Laboratory of Engineering, Computer Science and Imaging (ICube) of the University of Strasbourg. The candidate will be integrated into the Geometric and Graphic Informatics team (IGG). Moreover, with the support of the partners involved in the LUM-Vis project, we will have the advantage during this thesis to have access to:
- real data from numerical simulations from the Advanced Mathematics Laboratory of Strasbourg (IRMA) and the French Atomic Energy Commission (CEA), as well as direct support from the researchers in charge of developing these simulations.
- resources for large-scale tests via the computing (ROMEO) and visualization (CENTRE IMAGE) platforms of the simulation centre of the University of Reims Champagne-Ardenne.

During the thesis, it will also be possible to participate in teaching missions, either at the UFR de mathématique et d'informatique of Strasbourg, or at the Computer Science Department of the IUT Robert Shuman of Illkirch.

References:

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[3] J. Sarton, Y. Remion, et L. Lucas, « Distributed Out-of-Core Approach for In-Situ Volume Rendering of Massive Dataset », in *High Performance Computing*, Cham, 2019, p. 623-633. doi: 10.1007/978-3-030-34356-9_47.

[4] J. Kress *et al.*, « Comparing the Efficiency of In Situ Visualization Paradigms at Scale », in *High Performance Computing*, Cham, 2019, p. 99-117. doi: 10.1007/978-3-030-20656-7_6.

[5] H. Childs *et al.*, « A terminology for in situ visualization and analysis systems », *The International Journal of High Performance Computing Applications*, p. 1094342020935991, août 2020, doi: 10.1177/1094342020935991.

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[7] B. Nelson, E. Liu, R. M. Kirby, et R. Haimes, « ElVis: A System for the Accurate and Interactive Visualization of High-Order Finite Element Solutions », *IEEE Transactions on Visualization and Computer Graphics*, vol. 18, n° 12, p. 2325-2334, déc. 2012, doi: 10.1109/TVCG.2012.218.

[8] P. Muigg, M. Hadwiger, H. Doleisch, et E. Groller, « Interactive Volume Visualization of General Polyhedral Grids », *IEEE Trans. Visual. Comput. Graphics*, vol. 17, n° 12, p. 2115-2124, déc. 2011, doi: 10.1109/TVCG.2011.216.

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