Design and study of a Lattice Boltzmann Method kernel for real-time and immersive educational simulation software.

Laboratoire DynFluid EA-92, Conservatoire National des Arts et Métiers.

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1 General Context

Numerical tools play an essential role in nowadays educational frameworks. Numerical computational and visualization tools are entirely embedded in the learning process. Basic programming environments or complex visualization software are often of crucial help for students to better understand advanced physical concepts.

The educational tools currently used in aerodynamics training are mainly of two kinds. Experimental tools (such as wind tunnels and test benches) allow for the rapid identification of critical aerodynamic phenomena through the use of data from sensors. However, their educational use can lead to cumbersome setup and imperfect or absence of flow visualizations. On the other hand, numerical tools using simulation software allow for complete visualization of the flow. However, restitution times and software learning constraints often require many iterations between the learner and the teacher. These delays often blur the pedagogical goal focusing on the physical phenomena.

Associating the direct visualization capabilities of numerical simulations to the interactive and fast feedback provided by experiments could be game-changing in teaching aerodynamics. The PhD is an attempt in creating a virtual laboratory of fluid mechanics combining the immersive and interactive environment of virtual reality (VR) with accurate and fast numerical simulation tools. It will allow, for instance, the study of airflow simulation around a virtual plane with real-time interaction with learner inputs.

The main goal of this research work will be to develop a numerical simulation kernel for real-time and immersive simulations. The design of such a computing kernel relies on solving three main scientific challenges:

- To develop algorithms combining execution speed and accuracy. Current techniques used in 3D rendering of a fluid environment use computational methods far from the needed accuracy for physically relevant simulations.

- To consider complex geometry with interactive modifications at the user level. The inclusion of any geometry that the user can modify in the numerical calculation requires adapted algorithms ensuring a good precision in the vicinity of the wall.

- To ensure real-time visualization of the results in an immersive and interactive framework. Data generated by the computational kernel will have to be efficiently translated into data compatible with the virtual environment.

Lattice Boltzmann methods [5] currently developed in DynFluid laboratory are known for their high-speed and straightforward algorithm. It is an excellent candidate for developing a real-time computational kernel for aerodynamic simulations when combined with the well-identified breakthrough in GPU node-level overall speed compared with x86 one. However, the development of an accurate and fast LBM kernel on a GPU environment is still an open subject [4, 6]. In particular, the underlying physical model such as wall treatment and turbulent modelling will have to be carefully designed to maintain computational efficiency.

2 PhD objectives

Regardless of the hardware architecture considered, real-time simulation constraints of the VR environment preclude the use of double-precision arithmetic and favour simple or mixed precision [1]. The PhD objectives will be to adapt an existing x86 LBM solver to new GPU architectures while simultaneously considering:

- (re-)formulation of the LBM algorithm to compile with modern GPU architectures requirements (e.g. memory management, task scheduling on Streaming Multiprocessors, tackle the problem of new tensor-cores needs and potential benefit,...),
- performing in-depth analysis of the use of reduced floating-point precision arithmetic on the numerical stability and accuracy of LBM simulations,
- ensuring that the numerical ingredients (e.g. boundary condition treatments, numerical stability technics) necessary to reach applications relevant for VR teaching scenarios (e.g. external aerodynamic) meet the efficiency requirements.

3 Scheduled Program

This work will be based on the experience of the DynFluid laboratory in LBM [2] and HPC [3]. The basic steps of the work are presented in the following:

Year 1:

- Bibliographical study on the optimization of LBM performance on GPU.
- Adaptation of the present code to GPU architecture (openACC or openCL)
- Performance Optimization on the modern architectures.
- Study of different collision models impact on the computational performances.

Year 2:

- Bibliographical study of fast and accurate LBM immersed boundary conditions.
- Adaptation of IBC to the chosen GPU architecture.
- Validation of the code on GPU architecture for academic test cases

Year 3:

- Bibliographical study of real time graphics visualization with VR.
- Definition of a 3D test case for real-time simulation
- Validation of accuracy and performances of the code for the chosen 3D test case.

4 Skills

+ Strong programming knowledge in one or two programming languages: C, Fortran, Cuda, OpenCL.
+ Knowledge of Python
+ Some knowledge in fluid mechanics
+ Basic knowledge in computer graphics would be appreciated.

5 Contact

To apply to this position, please send your CV and letter to:

simon.marie@cnam.fr and **nicolas.alferez@lecnam.net**

References

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