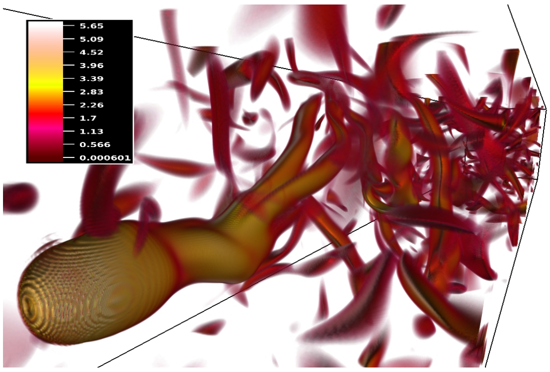
High Performance Computing for Fluids



SUMMARY.
Numerical simulations are an indispensable tool in studying astrophysical problems. The development of new algorithms and the increasing computational power of supercomputers consisting nowadays of millions of computing units allow for realistic simulations of complex environments. This meteor provides the fundamental know-how that is behind these demanding simulations. The students will learn to code numerical schemes for compressible fluids such as the interstellar medium. For this, a modern algorithm called Discontinuous Galerkin (DG) will be introduced. The students turn theory into practice and implement short but challenging applications.

OBJECTIVES

- Studying numerical schemes employed in modern codes to simulate gases include finite difference (FD), finite volume (FV), discontinuous Galerkin (DG) methods. **The students will understand the main differences between numerical methods**.
- C++ is a computing language that is not only used in scientific computing but also in many other performance critical applications. It allows user friendly abstractions while keeping optimal performance. **The students will learn modern C++ through practice**.
- Today's supercomputers are massive parallel. They contain fast-interconnected nodes equipped with several multi-core CPUs and accelerators such as graphics processing units (GPU). **The students will learn how to use supercomputers** by adapting theirs algorithms for parallel computing.

PREREQUISITES

☒ S1. Numerical methods

THEORY

by Holger Homann

Numerical methods have to be fast and precise. The students will understand why the order of convergence matters. Why high-order (complicated) methods (such as discontinuous Galerkin) are faster than low-order (simple) methods. The students will understand critical ingredients of numerical schemes such as conservation, Riemann problems and dissipation.

Fast codes run on fast hardware. The students will learn the architectural differences of modern computing hardware. What does object-oriented and data-oriented design mean? How can we reconcile both to get the optimal code?

APPLICATIONS

by Holger Homann

Astrophysical problems often involve smooth flow and regions where the formation and dynamics of shocks is important. The students will understand main properties by studying two one-dimensional model problems: the Burgers equation and the isothermal gas equations.

The students will themselves implement from scratch a modern numerical scheme for such equations. A focus can either be on the modern algorithms (such as discontinuous Galerkin) or on modern hardware (such as graphic cards (GPUs)).

Today's supercomputer consist of a mixture of CPUs and GPUs

MAIN PROGRESSION STEPS

- Recalling finite difference and finite volume methods
- Introduction to discontinuous Galerkin methods
- Introduction to Riemann solvers
- Study of relevance of DG schemes for astrophysical applications (study of paper).
- Introduction of C++ for scientific computing
- Project: Students choose a scientific coding project among
  - High-order discontinuous Galerkin methods
  - Comparison of Riemann solvers
  - Compressible gas simulations
  - Parallelization for supercomputers

EVALUATION

- `Theory grade [30%]`
  - Oral exam : theoretical questions on numerical methods and programming, base calculus from lectures
- `Practice grade [30%]`
  - Coding project: initiative, progress, quality of code, autonomy
- `Defense grade [40%]`
  - Oral and slides quality
  - Context
  - Project / Personal work
  - Answers to questions

BIBLIOGRAPHY & RESOURCES

- Nair-Lauritzen-Levy(2011)
- Colella-Pucket(1994)
- Schaal-etal.(2015)

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