jh160055-NAHI

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Cerebrospinal Fluid Flow Analysis in Subarachnoid Space

JHPCN

Background

A better understanding of the hydrodynamics of the Cerebrospinal fluid (CSF) is important for the understanding of diseases related to the brain and spine. An accurate assessment of hydrodynamics of the CSF in complex geometries of subarachnoid spaces (SAS) is possible by means of fully resolved direct numerical simulation that results in meshes consisting of up to 2 billion. The simulation requires large computational resources and an efficient implementation of the underlying algorithms.

Team Organization

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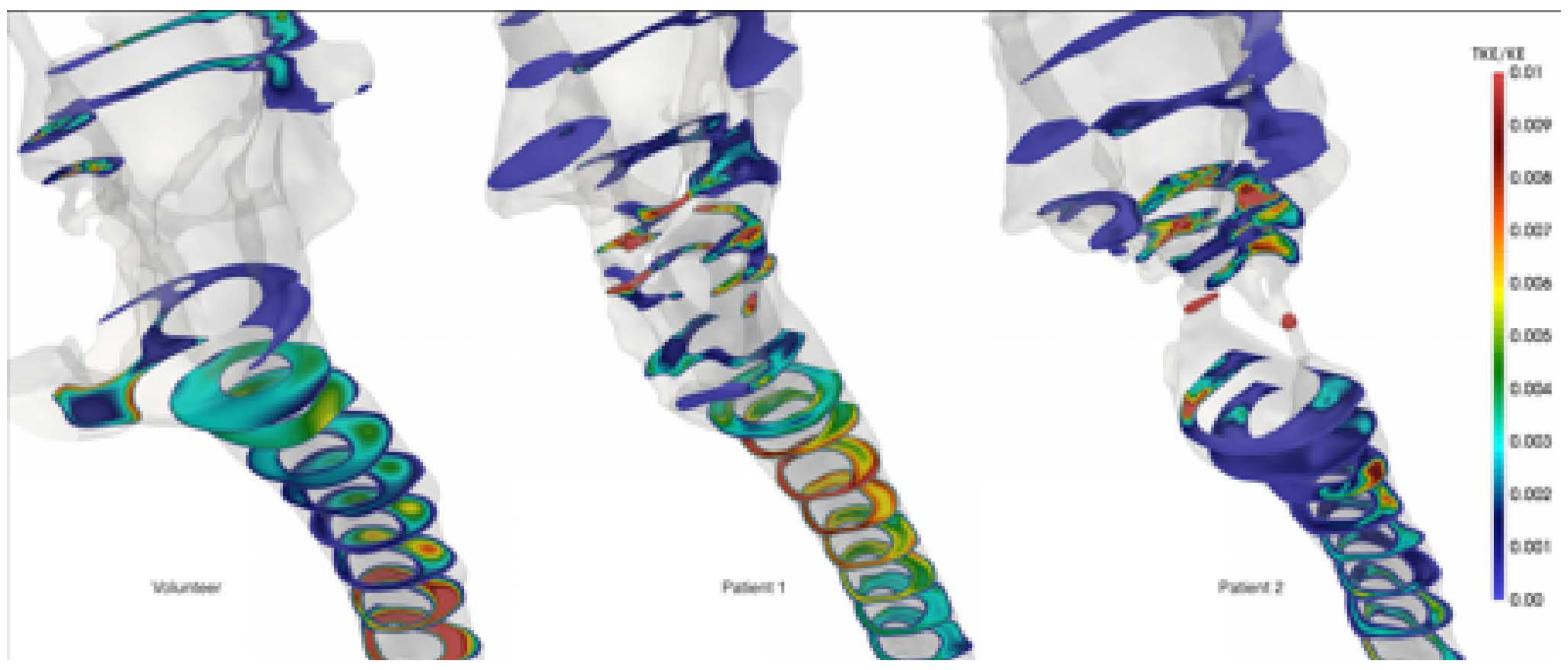
Motivation and Goals

Overall goals of this research are

- **Simulating the CSF in subject specific SAS, with employment of high spatial and temporal resolutions using modern vector parallel supercomputer SX-ACE.**
- **Carrying out quantitative performance analysis using cutting edge supercomputers in Germany and Japan.**

Our target code is a Lattice-Boltzmann method(LBM) solver named MUSUBI of the APEs framework. To simulate the incompressible flow, LBM has some favorable features for large scale, transient, incompressible flow simulations in complex geometries. It offers a relatively simple kernel with few operations that can be easily vectorized, and it also requires a relatively high Byte/FLOP ratio. Hence an implementation on SX-ACE would offer an efficient execution.



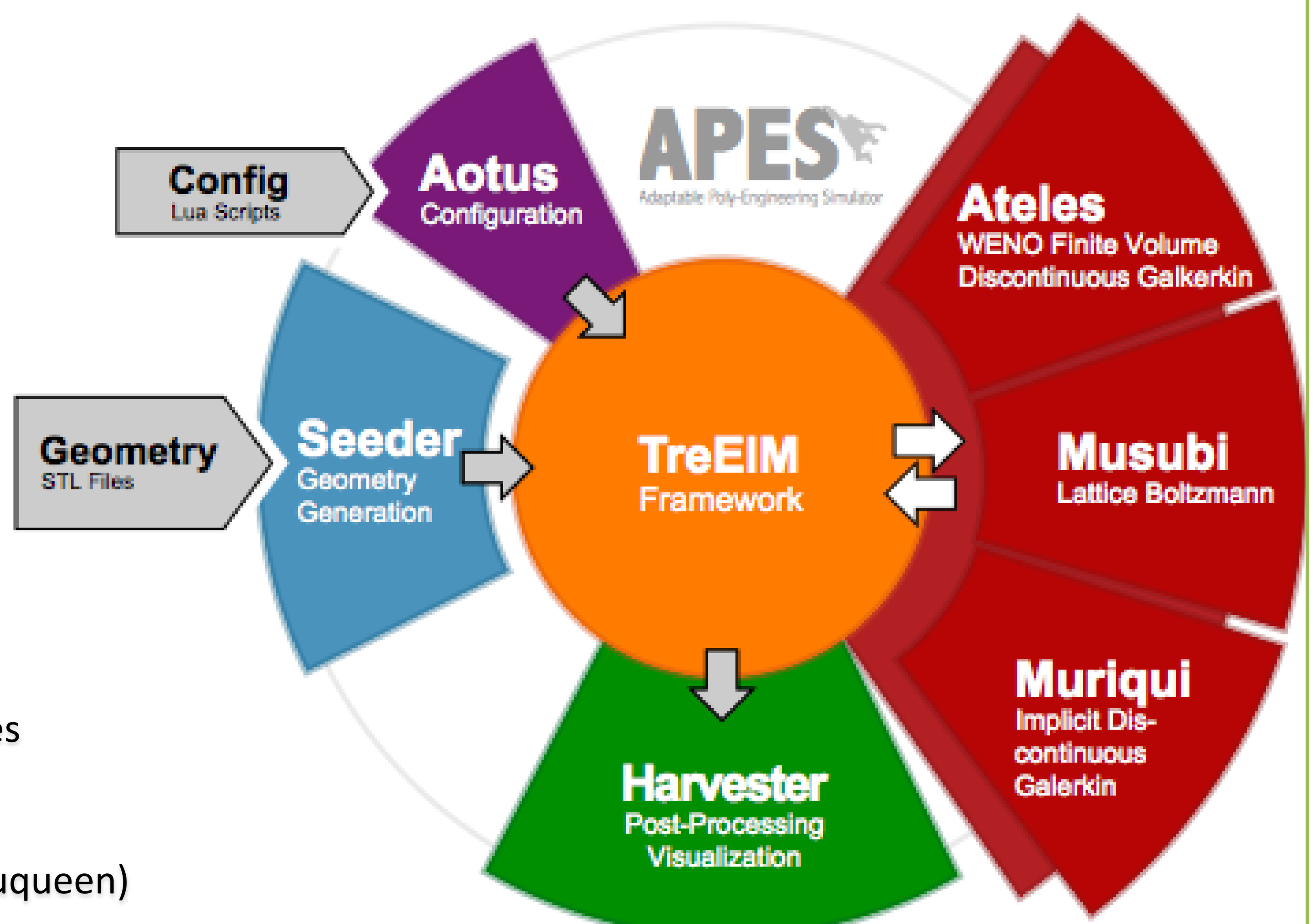
Turbulence intensity across axial planes in the SAS of a healthy volunteer and two Chiari patients. As can be observed, the flow is evenly distributed in the volunteer, minor fluctuations develop in the Patient1 that are highly localized in the Patient2, due to impingement of flow in areas near the cranio-vertebral junction.

APES

Adaptable Poly-Engineering Simulator

Suite of mesh based simulation tools

- Written in Fortran 2003
  - Compiles with gfortran, Intel, IBM and Cray compilers
- Two solvers on a common basis:
  - Lattice-Boltzmann Solver : Musubi
  - Discontinuous Galerkin Solver : Ateles
  - Scalable on cluster resources
- Utilizing more than 100,000 cores (Juqueen)
  - Unstructured meshes (indirect addressing)



Musubi in the APES tool chain

- All tools based on Treelm Mesh format
- Octree structure
- Space-Filling Curve Ordering
- Scalable distributed processing of meshes
- Mesh generation by Seeder
- STL geometry as inputs
- Voxelized meshes with LBM specific higher order boundary information (q-values) as outputs
- Simulation with Musubi
- Post-processing with dedicated tool

Musubi is the multi-level parallel lattice Boltzmann solver within the APES suite. It is working on a linearized octree and uses efficient data structures allowing adaptive parallel simulations.

Early Performance Evaluation

Since MUSUBI has been running on the intel based systems and JUQUEEN, We have ported MUSUBI to the SX-ACE with simple optimizations. We will perform advanced intra/inter node optimizations to exploit the potential of SX-ACE. Then, based on the quantitative performance analysis among supercomputers in Germany, we will carry out design space exploration of a future HPC system design.

Evaluation Environments



SX-ACE	SuperMUC	JUQUEEN	Hornet
NEC SX-ACE Processor	Intel Xeon	IBM Bluegene	Intel Xeon
2,560 nodes	9,216 nodes	28,672 nodes	3,944 nodes
707 Tflop/s	3,200 Tflop/s	5,900 Tflop/s	3,786 Tflop/s
130 TB Mem	288 TB Mem	488 TB Mem	493 TB Mem