Steering Supercomputers to Simulate Interaction of Blood Flow and Blood Vessel in Real Time

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ABSTRACT

Fluid Structure Interaction (FSI) studies the complex interplay between fluids and elastic/flexible immersed structures. FSI can be found in both natural industrial environments, e.g., parachutes dropping from aircrafts and blood cells flowing past human vessels. This project focuses on scientific computing of how arterial vessels interact with blood flow. As FSI simulations require extreme computational resources, we designed and implemented a software framework to realize real-time simulation of inflation of a blood vessel via parallelization techniques for use of the 1 Petaflops supercomputer of Big Red II at IU. The software framework consists of four components: 1) an FSI Application Programming Interface (API) provided by OOMPH-lib featuring convenient abstractions such as meshes and pressure pinning, 2) a parallelization wrapper provided by OOMPH-lib featuring domain decomposition and optimized cross-processor communication, 3) a parallel visualization library and API named Libsim, and 4) an in-situ visualization of the FSI simulation via the library and API named VisIt. Since OOMPH-Lib is able to take various types of input from different science and engineering domains, we will generalize the framework for simulation of any FSI problem featuring in-situ visualization. The final software framework will be made available on virtual machines and released to FSI-related communities on the NSF Jetstream cloud platform.

METHODS

(i) (ii) (iii)

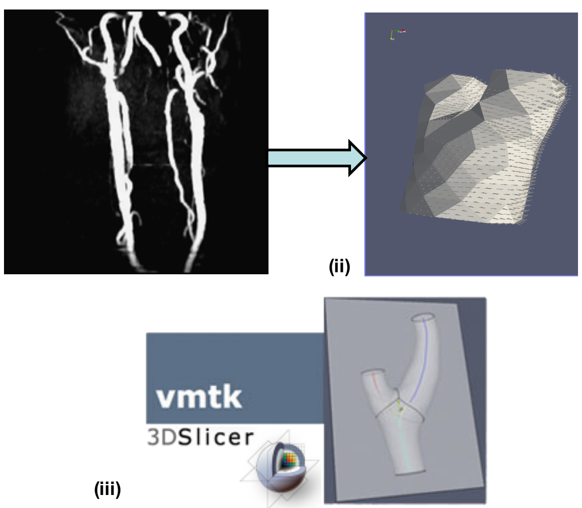

Figure 1: Conversion of MRI image of artery (i) to unstructured mesh via VMTK, the "Vascular Modeling ToolKkit" (iii).

METHODS (CONT.)

(i) (ii)

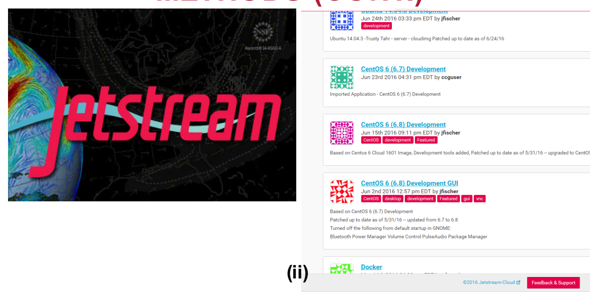

Figure 2: Jetstream (i) will provide a much easier-to-use ecosystem for non-computer science domain users, due to its intuitive user interface (ii).

RESULTS

A. The pressure pinning and constant drop of flow created uniform, maximum turbulence perpendicular to the expected direction of turbulence: i.e., against the artery's length instead of against the fork.

(i) (ii) (iii) (iv) (v)

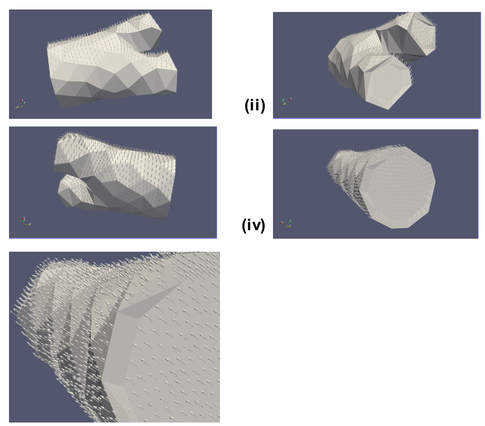

Figure 3: (I, ii, iii, iv) images of the unstructured mesh, consisting of a fork. (v) close-up of pressure arrows indicating pressure perpendicular to mesh length.

CONCLUSIONS

- Fluid-structure interactions can be better studied via computer simulations because they are too complex for humans to solve.
- Although in-situ visualization offers the benefit of visualization prior to completion of the simulation, it requires significant effort compared to post-simulation visualization, due to increased risk of fatal errors and the requirement for significant modification to the source code.
- Converting MRI images to unstructured meshes in serial on a Windows installation via VMTK, then on a Linux installation simulating fluid-structure interactions, and visualizing on a Linux installation these meshes, is the ideal workflow for fluid-structure interaction experiments involving real arteries.
- For larger datasets- i.e., larger or more refined meshes- parallelization techniques are significantly more important than for smaller datasets.
- Our experience with a few open-source libraries show that the parallel software's portability and ease-of-use needs to be improved.

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