Computational Personal Medicine In The Multicore/Manycore Era

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The Health Application

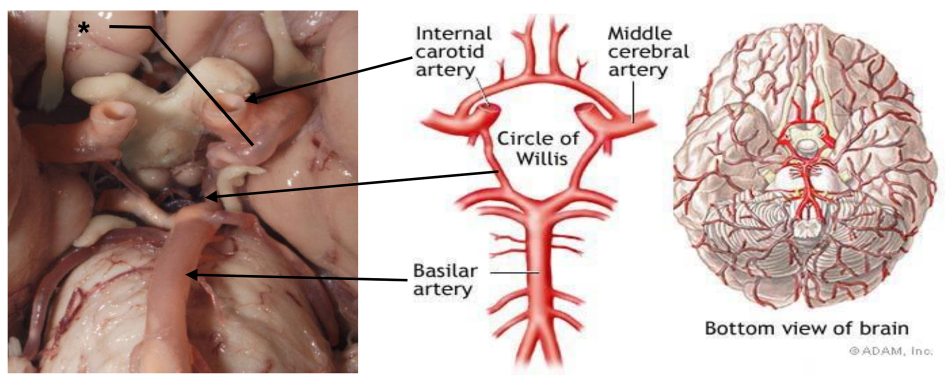
800k strokes per year in the U.S.

•1 stroke per 40 seconds

•~25% concurrent

•150k deaths per year

•Third leading cause of mortality



•Develop a **rapid computational tool** to help surgeons and radiologists interpret three-dimensional medical imaging modalities as computed tomography (CT) and magnetic resonance (MR) for surgical planning and critical decision-making.

•Improve patient care, reduce healthcare costs and save lives of strokes victims.

Biomechanical Analysis

•Developing our own one-dimensional code to perform a comprehensive parameter study on the biomechanics of blood flow in the circle of Willis in order to inform our more detailed 3D modeling.
•Our code solves a one-dimensional version of the incompressible form of Navier-Stokes equation for a network of arteries.
• Arteries are modeled as incompressible, isotropic, and elastic.
•The code will simulate the circle of Willis arteries and any smaller downstream arteries (which are truncated in the model) as an electrical circuit, using one of two types of circuits: RCR (Resistor-Capacitor-Resistor) and R (Resistor).
•The one-dimensional analysis contains solid-fluid interactions.
•This work will help us determine the best multi-resolution path to adopt.

Computational Fluid Dynamics

•The **circle of Willis inflow conditions are both time and space dependent** and can be represented as a combination of pulsating sine wave components. This representation for pulsatile flow in a rigid wall tube is known as a Womersley Flow profile.

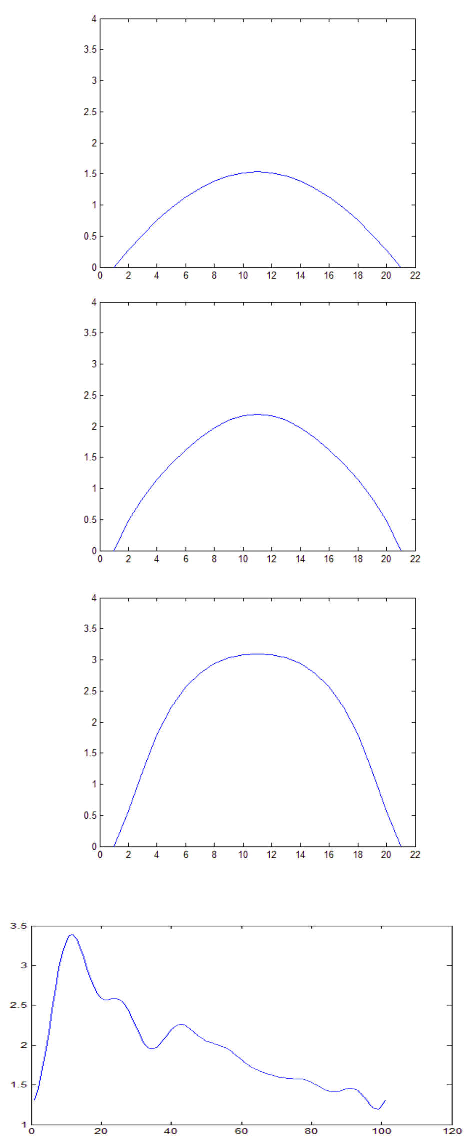
•Based on a literature review of the types of inflow conditions, it was decided that the pulsatile blood flow in the arteries entering the circle of willis can be represented by **Womersley flow profiles** at the internal carotid and vertebral arteries with general “common” profiles available from patient surveys.

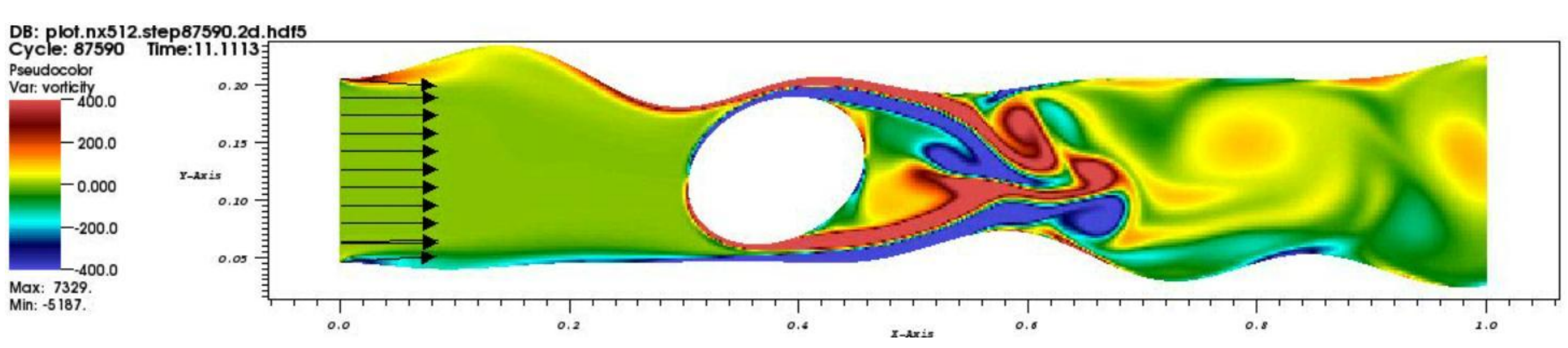
•While the profiles themselves do not represent a perfect copy of an individuals flow profile within the arteries the general profile is present for all individuals and can be easily be made more **“patient-specific”** by the addition of a single piece of information as average flow velocity.

•The previous status of the Chombo framework was a single option for inflow conditions namely a constant time and space inflow velocity.

•The framework of Chombo has been extended to incorporate a time-varying inflow condition with the profile initially tried being the common carotid artery Womersley Flow profile.

•The simulation ran with the time varying carotid artery inflow velocity shows that the pseudo-steady state that arises with constant inflow is changed when a pulsatile flow is introduced.





Work in Progress &Future Work

•Finish developing the one-dimensional biomechanical analysis and test it for different patient cases.
•Study of the performance of tetrahedral elements for finite element simulations.
•Use of non-uniform tetrahedral meshing.
•Combination of the new inflow conditions with a full 3d simulation of the circle of Willis for a given patient geometry
•Creation of a specific study on the influences of variation in inflow velocity profiles on the outflow parts of the circle of Willis.
•Analysis of two-dimensional and three-dimensional solid-fluid interaction partitioned algorithms.

Computational Geometry

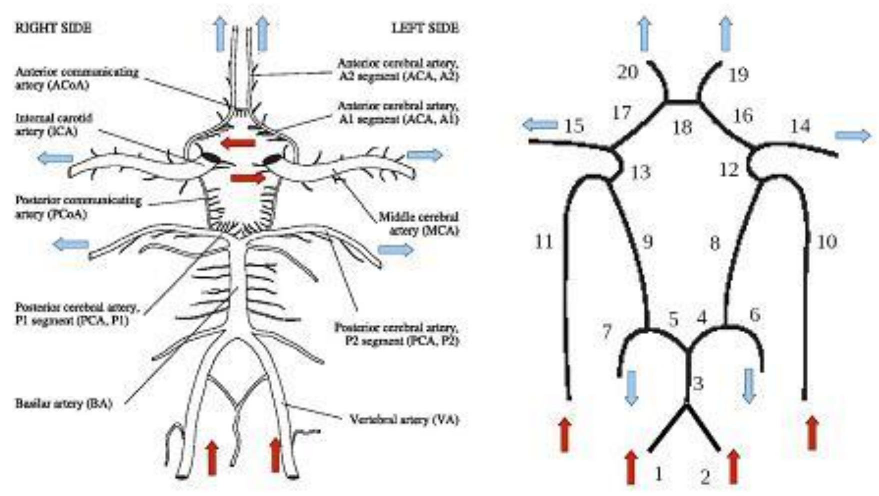
•The medical images processing is patient specific but not automated yet.

•The vasculature geometry is obtained from **patient specific CT scans.**

•Extraction of the domain of interest using medical images processing software.

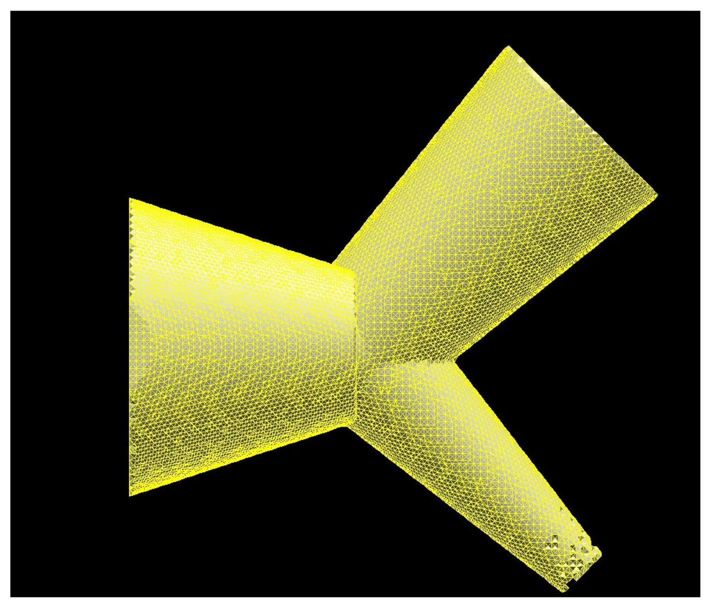
•Modeling of a **tree structure** characterized by input, ouput and bifurcation points as well as segement diameters.

•Sine distance functions distinguish between the internal and external domain of the artery.



•Conversion to a **uniform three-dimensional mesh** using an iso-stuffing algorithm.

•**Improving of mesh quality** using Stellar for more suitable finite element analysis: vertex smoothing by nonsmooth optimization, vertex insertion, and edge contraction etc.



Computational Fluid-Solid-Interaction

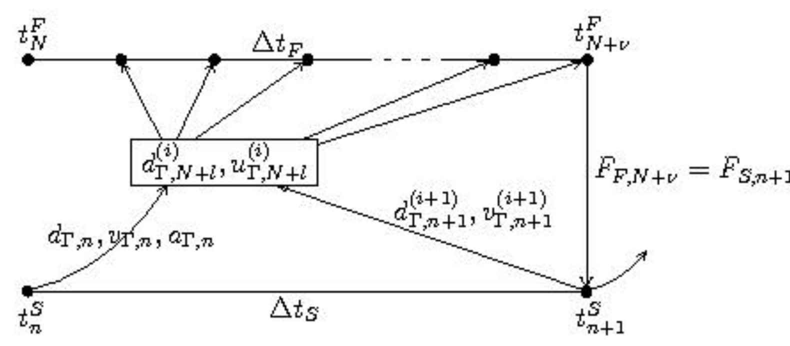
•Two separate, independent and existing parallel software packages have been chosen for modeling the blood flow in the circle of Willis: **Chombo** models the blood flow. **Olympus** simulates the deformation of the artery.

•The deformation of the artery influences the blood flow and vice versa, which has to be modeled through **coupling of the two parallel softwares**.

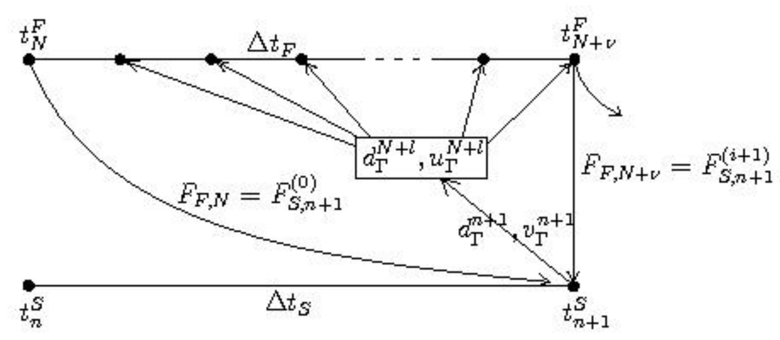
•**One dimensional** computational and mathematical analyis of **partitioned approaches** for modeling fluid-solid interaction.

Basic Algorithm:

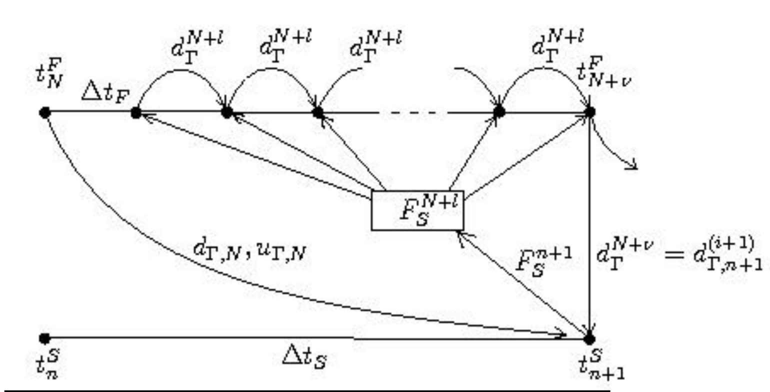
•Loop over time
•Predict solution for the current time step
•Iterate until convergence
- Solve Fluid and Solid Problem (multiple fluid time steps for one solid time step)



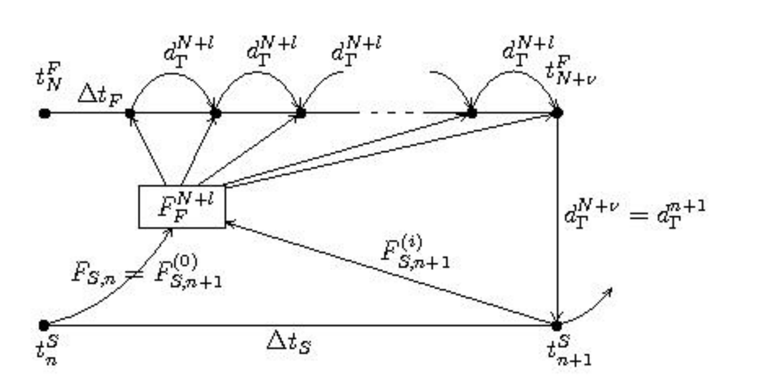
1st Algorithm:
1. Solid Solve (Neumann Problem)
2. Fluid Solve (Dirichlet Problem)



2nd Algorithm:
1. Fluid Solve (Dirichlet Problem)
2. Solid Solve (Neumann Problem)



3rd Algorithm:
1. Solid Solve (Dirichlet Problem)
2. Fluid Solve (Neumann Problem)



4th Algorithm:
1. Fluid Solve (Neumann Problem)
2. Solid Solve (Dirichlet Problem)

Research Team

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