MATDAT18: Materials and Data Science Hackathon

Team Composition (2 people max.)

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Project Title

Quantifying rupture risk of brain aneurysms by combining morphological descriptors and blood flow data from large-scale lattice Boltzmann simulations

Project Synopsis (approx. 100 words)

Brain aneurysms can cause brain bleeding which is known to have severe consequences with high rates of disability and mortality. However, most aneurysms are asymptomatic and clinical decision-making needs to weigh the risk of rupture against the not insignificant risk of surgical intervention. The precise mechanisms of aneurysms pathophysiology are not fully understood thus making it difficult to assess the rupture risk. Recent advances in CFD have made it feasible to simulate patient-specific blood flow thus opening a way to provide more quantitative risk measures. This project seeks to apply machine learning to morphological and blood flow data to provide quantitative predictions of rupture risk.

Identified Data-Science Collaborative Need (approx. 100 words)

The lattice Boltzmann simulations generate a considerable amount of data in 4D space-time. Given the large amount of flow field data for a relatively small number of samples, we will attempt to perform dimensionality reduction and feature selection to extract descriptors from the flow field data. We shall investigate, for example, the effect of spatial or temporal averaging of wall shear stresses which is often applied in CFD studies. We are specifically interested if and how commonly used physical observables can be correlated with the risk of aneurysm rupture. Moreover, we seek to find descriptors that can be used for machine learning, e.g., as inputs to a neural network that shall be trained to predict the probability of aneurysm rupture. To this end, we intend to combine morphological descriptors (obtained by image analysis) and hemodynamic descriptors (obtained from the flow fields).

Data Origin and Access (*data must be available and sharable with data science teams* – please address: data source/origin, access privileges, sharing privileges)

The simulation data is currently stored on Clemson University's Palmetto cluster. The Schiller Research Group owns a 10TB storage volume (ZFS file system) and we can request access for external collaborators (unaffiliated with Clemson University) to our group resource.

The angiographic images are available from the AneuriskWeb repository http://ecm2.mathcs.emory.edu/aneuriskweb under a Creative Commons license (CC BY-NC 3.0). Use of the data in the repository has been authorized by the Ethical Committee of the Ca'Granada Niguarda Hospital.

Project Description (approx. 1.5 pages, plus figures and references; please describe data size, form, dimensionality, uncertainties, number of examples, etc.)

Cerebrovascular diseases such as brain aneurysms are a primary cause of adult disability, morbidity, and mortality. Strokes are the no. 5 cause of death in the U.S., killing nearly 130,000 people a year. About 13% of strokes are cause by subarachnoid hemorrhage, i.e., bleeding in the brain due to ruptured blood vessels. However, most brain aneurysms are asymptomatic and the underlying mechanisms triggering rupture are not fully understood. An estimated 6 million people (or 1 in 50) in the U.S. have an unruptured brain aneurysm. This poses a quandary in clinical decision making since surgical treatments of unruptured aneurysms carry significant risks as well, including neurologic deficits and mortality. Therefore, there is a pressing need to develop quantitative risk assessments that can reliably predict the probability of aneurysm rupture.
Factors that are commonly considered in the decision to treat aneurysms are the size and shape of the aneurysm and the morphology of the affected vessel which can be assessed through neurovascular imaging [1]. In addition, there is evidence that hemodynamics, i.e., the blood flow in the affected vessel, plays a major role in the pathophysiology of aneurysms. The associated features include, *inter alia*, wall shear stress (WSS), oscillatory shear index (OSI), vorticity, and flow impingement regions. However, there is yet no consensus what the specific indicators of rupture risk are [2], largely due to the fact that these factors are difficult to assess *in vivo.*
To this end, computational fluid dynamics methods have gained in popularity as tools to simulate hemodynamics in complex geometries [3,4]. For instance, the lattice Boltzmann method can be used to simulate blood flow in patient-specific models of arteries that are reconstructed from three-dimensional angiographic images of the vasculature [5,6]. The simulations can generate the flow fields for varying cardiac states, i.e., for periods of rest and increased activity. While hemodynamic properties such as blood pressure and wall shear stress can be calculated from the

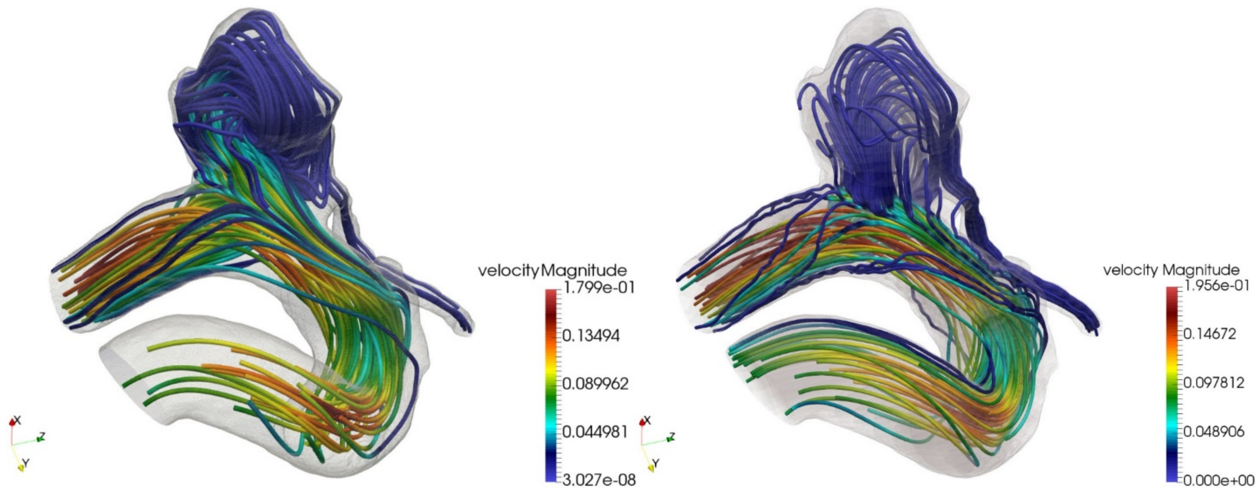

Figure 1: Visualization of velocity streamlines of blood flow through a middle cerebral artery affected by an aneurysm with and without a stent-mesh flow diverter.

in silico flow fields, it is not always clear how to extract meaningful indicators from the 4D space-time data. Due to the variability of aneurysm geometries and the complex flow patterns and the limited understanding of the relevant mechanisms it is unclear how to correlate the physical observables with the probability of bleeding and rupture.

The availability of angiographic image sets and the possibility to generate hemodynamics data for patient-specific morphologies constitute a promising basis for data science approaches. Here we propose to apply machine learning to a set of 25 aneurysm cases in the middle cerebral artery (MCA) for which blood flow data can be generated using large-scale lattice Boltzmann simulations. The aneurysm geometries are obtained from the AneuriskWeb repository [7]. The geometries are stored as triangulated surfaces in the STL file format. Lattice Boltzmann simulations of blood flow in the segmented geometries are performed on Clemson University's HPC cluster Palmetto. A typical simulation output comprises the flow field in the form of a three-dimensional vector field that is written every 100 time steps. The vector field is written in the form (id, x, y, z, vx, vy, vz) where id is a voxel id, x, y, and z are the coordinates of the voxel, and vx, vy, vz are the components of the velocity vector. In addition, the wall shear stresses for each flow configuration are written to a separate file in the form (id, x, y, z, wss). The geometries comprise in the range of 100 to 200 million voxels such that an estimated 500GB of data is generated per aneurysm geometry per cardiac cycle.

Post-processing of the hemodynamics data typically involves computing spatial or temporal averages and WSS-related parameters such as oscillatory shear index and relative residence time (RRT) [6,8]. While these parameters can be correlated with the geometry and the rupture risk, they are not necessarily involved in the underlying causal mechanism of rupture, and there may be other, hitherto unknown factors. We propose to use dimensionality reduction and feature extraction to explore the possibility of using a larger set of descriptors to quantify the rupture risk. The aneurysm set comprises 16 unruptured and 9 ruptured cases which can be used to train a neural network using both the morphological descriptors and the hemodynamics features as inputs and the binary ruptured/not ruptured as target output.

Another interesting opportunity for this project is to attempt to use machine learning to predict certain flow features based on morphological parameters of the vasculature. This has the

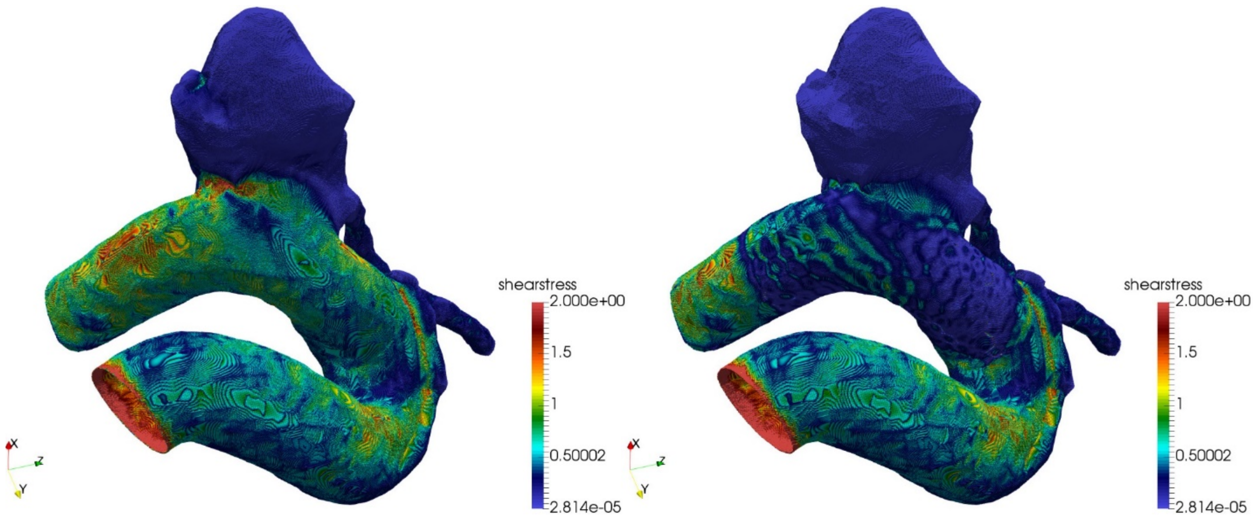

Figure 2: Visualization of the time-averaged wall shear stress in a middle cerebral artery affected by an aneurysm with and without a stent-mesh flow diverter.

potential to reduce the need for costly CFD simulations. For instance, it may be possible to extrapolate the effect of varying cardiac activity corresponding to different inlet boundary conditions in the simulation. This can be used to predict changes to the flow patterns for increased exercise activity, which in turn can be used to assess the associated risk in patients with aneurysms.

Future directions for this project include investigations of the effect of stents and flow diverters. We have implemented a virtual stent deployment algorithm that can be used to insert a stent *in silico* into the aneurysm geometries [9,10]. This will make it possible to obtain simulation data for stented arteries which can then be included in the data analysis which may ultimately provide new insights into the mechanisms that influence aneurysm pathophysiology. Such insights will pave the way to data-driven optimization of stent designs which promises to significantly improve clinical treatment options of patients with brain aneurysms.

References

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