Topological data analysis for classification of vascular flows: overcoming irregular geometry

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ABSTRACT

Classification of vascular flows on regular domains has been developed using topological data analysis. This work is to develop a methodology for projecting the velocity field from irregular, curved vascular geometries to a coordinate system that makes the velocity field more consistent with regular geometry. This is done with the goal of using theoretical results developed with simulations of regular geometries on the geometries present in actual human anatomy.

DIAGNOSIS OF VASCULAR DISEASE

Cardiovascular disease is the leading cause of death world-wide; about 17.3 million deaths per year (2011), expected about 23.6 million by 2030 (CDC). Nearly $787,000$ people in the US died from heart disease, stroke and other cardiovascular diseases in 2011 (one of every three deaths in America). $2,150$ Americans die each day from these disease, one every 40 seconds. For heart disease, once every 90 seconds.

When a blood vessel has developed stenosis, it can be treated by inserting a stint. It is important to only do this if it is absolutely necessary, as stints can eventually disintegrate, leaving tiny pieces of metal in the blood stream. These fragments can travel to the brain and cause aneurysm and death.

In order to help medical professionals make more informed decisions in these scenarios, we wish to employ computational models and advanced classification methodologies.

We use CFD to simulate the flow in real geometry of blood vessels captured with medical imaging. Then we use TDA to classify these flows as healthy or atypical. Current methods rely only on pressure differentials.

TOPOLOGICAL DATA ANALYSIS

S^2 projection The velocities are normalized $\tilde{\boldsymbol{w}} = \frac{\boldsymbol{w}}{\|\boldsymbol{w}\|}$ so that the magnitude of every vector is 1. This makes them all sit on the unit sphere and is the preliminary step before applying TDA.

Barcodes and persistence The barcode for a point cloud is the graph of the generators of the homology of the complex against the filtration parameter t. The barcode will vary depending on the method used to generate the complex. The barcode displays not only the Betti numbers at each time value, but actually graphs how long each generator remains non-trivial. The length of an interval gives information about the correctness of the interval, a concept referred to as persistence.

The barcodes of the projected velocity fields have been shown to be valuable in classifying turbulent from laminar flows.

Figures

Each figure shows a vessel rendered, as well as the corresponding sphereical projection from two angles.

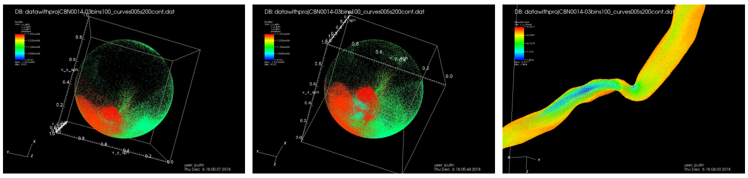

Figure 1: Vessel 14, spherical projection with pressure as color variable, and pseudocolor plot of velocity on primary axis

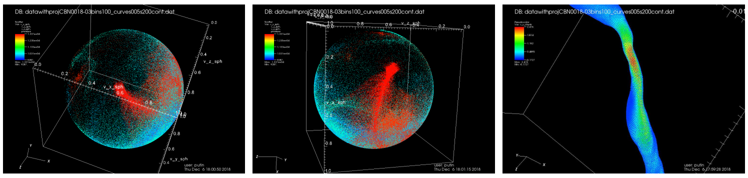

Figure 2: Vessel 18, spherical projection with pressure as color variable, and pseudocolor plot of velocity on primary axis

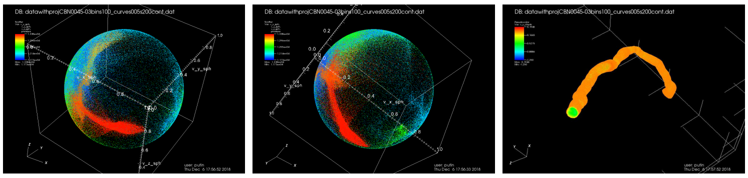

Figure 3: Vessel 45, spherical projection with pressure as color variable, and psudocolor plot of velocity on primary axis

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