Advances in patient-specific IGA-based cardiovascular simulation

David Joseph Gunderman
Purdue University, Stanford University
dgunderm@purdue.edu

Patient-specific simulations are an important, growing tool for biomedical research. In order to customize models for specific patients, anatomical structures are extracted from medical images, creating a geometric model that serves as the computational domain for simulation of physics phenomena. A common application is the numerical modelling of blood flow, tissue mechanics, or blood-tissue interaction in the cardiovascular system. These models can then be used to assess patient-specific disease condition, risk of complications, and test surgical interventions *in silico*.

Segmentation of medical image data for model geometry specification typically results in a discrete, flat-faced, triangulated boundary representation (surface mesh) of the segmented structure [3]. This geometry representation is suitable for low-order, classical finite element simulations of the physics. However, it has been shown that isogeometric analysis (IGA)-based modelling of cardiovascular geometries yields more accurate, robust, and efficient results in comparison to traditional low-order, FEM-based simulations [2]. Moreover, curved surface representations of the model facilitate systematic manipulation and optimization of the geometry. For example, the model can be unioned with a medical device, the geometry can be virtually altered to virtually plan a surgery, and the high-order mesh nodes can be used as degrees of freedom to optimize artificial vasculature design. Recently, higher medical image quality, streamlined image-to-model pipelines, and faster computational algorithms have eased the difficulties associated with simulating cardiovascular phenomena on patient-specific cardiovascular geometries [3]. However, these methods typically do not support high-order, curved surface geometry specifications.

The SimVascular team has shown that curved, analysis-suitable geometries can be extracted from labelled, low-order, patient-specific cardiovascular datasets [1]. In this presentation, I will discuss the state-of-the-field in applications of IGA to the cardiovascular system, present preliminary work demonstrating the steps in an image-to-analysis pipeline for IGA-based numerical simulations of cardiovascular dynamics on a open-source dataset of labeled patient-specific models, and pose future directions and challenges associated with IGA simulation of multiphysics problems associated with image-based cardiovascular fluid-structure interaction problems.

Joint work with: Alison L. Marsden, Hector Gomez, Craig J. Goergen.

References

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