jh190074-MDHI

下川辺 隆史（東京大学）

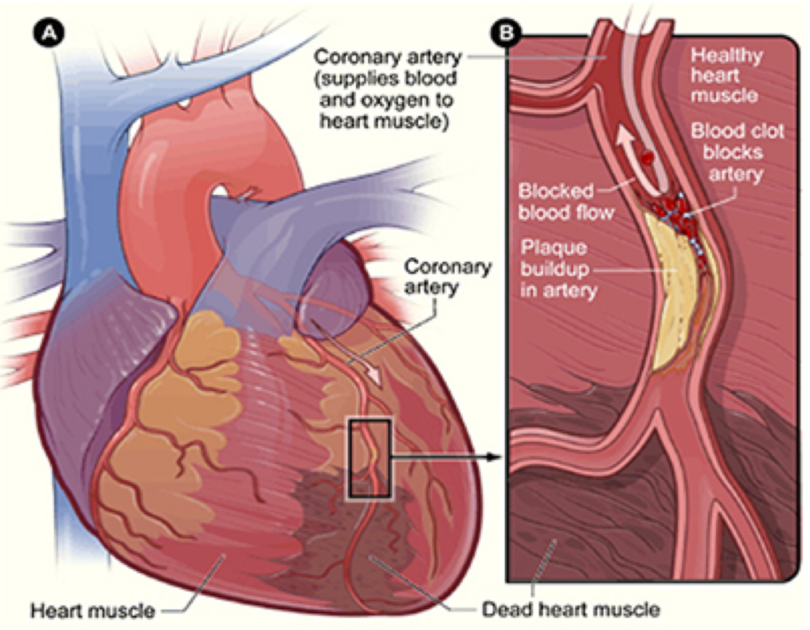
Development of Fast Surrogate for Approximating Large-scale 3D Blood Flow Simulation

1 Background and Motivation

Coronary heart disease is a leading cause of death worldwide. The main cause of coronary heart disease is coronary stenosis, which is mainly due to atherosclerosis. In the normal situation, coronary arteries supply oxygenated blood to heart muscle. When atherosclerotic plaque appears on the artery wall, the corresponding artery wall becomes narrow. This stenosis reduces the amount of oxygenated blood delivered to heart muscles and thus cause myocardial ischemia. Fractional flow reserve (FFR) is defined as the ratio between distal pressure and proximal pressure and has been used as a standard tool to diagnose the severity of coronary stenosis [1].

Recently, computational fluid dynamics (CFD) has been used to compute the blood flow and FFR for patient-specific artery. In this method, patient specific artery geometries are extracted from medical images and used as wall boundaries in the subsequent simulation. Some clinical trials demonstrated that the method combining CFD and medical image is better than the method using medical image solely in diagnosing ischemic stenosis [1]. However, this method can be computationally demanding because it may take hours to perform CFD simulation [1, 2]. This drawback may limit the usage of this method in clinic practice. Therefore, it is indispensable to accelerate the process of CFD analysis.

In this study, we will use geometric deep learning to build a fast surrogate for approximating the large-scale 3D blood flow simulation.



Coronary Artery Disease

Adapted from https://www.drsureshbhagia.com/patient-guide/overview-of-coronary-artery-disease/

[1] Zhang J-M, Zhong L, Luo T, Lomarda AM, Huo Y, Yap J, et al. (2016) Simplified Models of Non-Invasive Fractional Flow Reserve Based on CT Images. PLoS ONE 11(5): e0153070.
[2] Itu, L., Rapaka, S., Passerini, T., Georgescu, B., Schwemmer, C., Schoebinger, M., . . . Comaniciu, D. (2016). A machine-learning approach for computation of fractional flow reserve from coronary computed tomography. Journal of Applied Physiology,121(1), 42-52

2 Challenges and Goals

Real Time Diagnostic Tool for Coronary Heart Disease

This study provides fast surrogate, which approximates the FFR distribution of coronary artery, to assist the diagnosis of coronary stenosis.

Application of Geometric Deep Learning on Irregular Data

Although several previous works tried to use deep learning to approximate CFD simulation result, most of them are restricted to regular data. In this study, both geometry data and simulation data are irregular data. Therefore, instead of conventional deep learning methods, geometric deep learning, which considers neural network on manifold, should be considered. Geometric deep learning has drawn great attention in recent years and has been applied on 3D image classification and segmentation. This study is the first attempt to apply geometric deep learning to construct surrogate for 3D CFD simulation.

Development of a Method for Predicting Large-scale Simulation Results

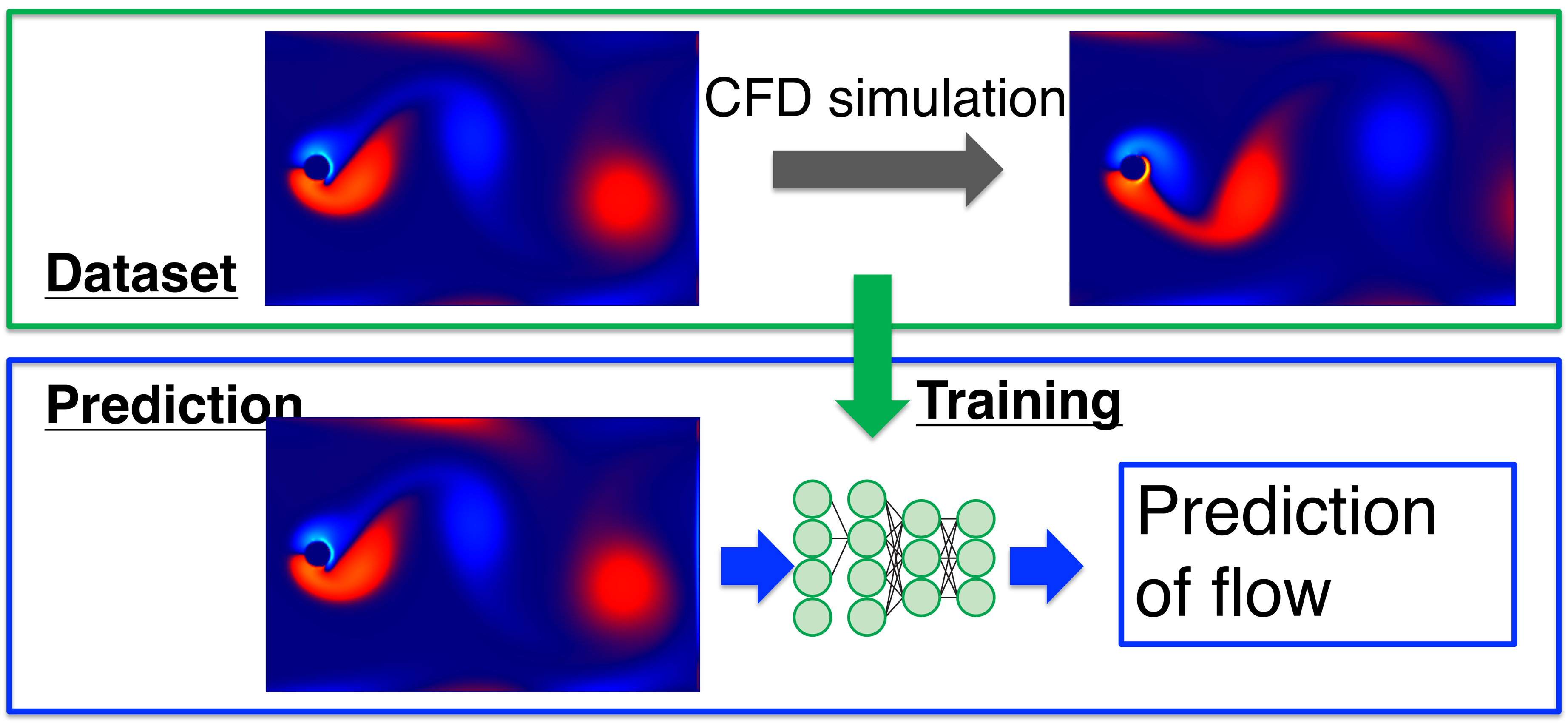
In deep learning, it is difficult to construct a large neural network due to the memory size limitation of GPU and Xeon Phi. For this reason, the size of the input data is often limited. In the previous research for image recognition, model parallel computing is adopted to handle the large-scale input data. Unlike this, in this joint research, we will develop a prediction method for large-scale simulation results by dividing the input geometry into multiple parts and applying a single small neural network to each part in parallel. This method is developed based on considering the characteristics of CFD simulation and the consistency of the boundary condition of each divided subdomain.

3 Research plan

(1) Deep Learning Surrogate for Steady State Model:
- (1-1) Building construct surrogate for simple artery shapes as a trial stage
- (1-2) Development of the deep learning surrogate for real artery simulation

(2) Development of a Method for Predicting Large-scale CFD Simulation Results:
- (2-1) Development a method to predict the inner computational domain for any given boundary condition
- (2-2) Building a method to predict the simulation results of the entire large-scale computational domain by applying deep learning to multiple divided subdomains in parallel

(3) Development of Predictor for Large-scale 3D Blood Flow Simulation based on (1) and (2)



4 Members

- Takashi Shimokawabe (The University of Tokyo)
- Weichung Wang (National Taiwan University)
- Naoyuki Onodera (Japan Atomic Energy Agency)
- Kengo Nakajima (The University of Tokyo)
- Toshihiro Hanawa (The University of Tokyo)
- Masashi Imano (The University of Tokyo)
- Shlok Mohta (The University of Tokyo)
- Sora Hatayama (The University of Tokyo)
- Atsushi Hasegawa (The University of Tokyo)
- Cheng-Ying Chou (National Taiwan Normal University)
- Che-Yu Hsu (National Taiwan University Hospital)
- Yikai Kan (National Taiwan University)
- Mei-Heng Yueh (National Taiwan Normal University)
- Wanyun Yang (National Taiwan University)
- Yuehchou Lee (National Taiwan University)