Neural Network Finite Element Approaches for Cardiac Simulations

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Comprehensive image-based computational modeling pipelines are being actively developed for high-fidelity patient-specific cardiac simulations. However, conventional simulation techniques pose a challenge in this regard, primarily because of their excessively slow performance. We have developed a Neural Network Finite Element (NNFE) approach for high-speed cardiac mechanics simulations that can produce accurate simulation results within seconds (Journal of Biomechanical Engineering 144.12 (2022): 121010.). The method utilized neural networks to learn the displacement solution; and finite elements for defining the problem domain, specifying the boundary conditions, and performing numerical integrations. The NNFE method does not rely on use of traditional FEM simulations, experimental data, or reduced order modeling approaches, and has been successfully applied to hyperelastic boundary value problems using a potential energy formulation. In the present work we extended the NNFE approach to a prolate spheroid model of the left ventricle as a starting point for more complex cardiac simulations. We incorporated spatially varying fiber structures and utilized a Fung-type material model that included active contraction along the local myofiber axis. As cardiac mechanics are non-conservative problems with path-dependent pressure boundary conditions, we developed a new NNFE formulation based on classical virtual work principles. Importantly, the resultant NNFE cardiac NNFE cardiac model was trained over the complete physiological functional range of pressure, volume, and myofiber active stress. The final trained cardiac model predicted the displacement solution over the cardiac cycle for any physiological condition without retraining with a mean nodal displacement error of 0.023 ± 0.019 mm. Similar agreement accuracy was found for the stress and strain results. The NNFE model trained within 2.25 hours and predicted the complete pressure-volume response within 30 seconds, whereas the FE model took approximately 5 hours. This study successfully demonstrates the potential of the NNFE method to simulate cardiac mechanics with high speed and accuracy over the complete physiological functional space. Future work includes real heart geometries and infarct simulations.

ABOUT the SPEAKER

Professor Sacks is a world authority on cardiovascular modeling and simulation, particularly on developing patient-specific, simulation-based approaches for the understanding and treatment of heart and heart valve diseases. His research is based on multi-scale modeling, quantification, and simulation of the biophysical behavior of the constituent cells and tissues and translation to the organ level in health, disease, and treatment. For example, he has developed novel non-invasive methods to quantify pre- and post-surgical state of the mitral valve from pre-surgical clinical images. He has determined the how local stress environments of heart valve interstitial cells alter their biosynthetic responses in the context of altered heart and valvular organ-level responses. His research also includes developing novel cardiac models to simulate growth and remodeling of the myocardium in pulmonary hypertension, the first full 3D approach for left ventricular myocardium mechanical behavior. Dr. Sacks is also active in modeling replacement heart valve materials and in understanding the in-vivo remodeling processes.

Monday, September 16 at Noon
1003 Engineering Centers (Tong Auditorium)