KTH SOLID MECHANICS KEYNOTE SEMINAR; Thursday, June 24th, 16.15; https://kth-se.zoom.us/j/65992559126

Michael Sacks' KEYNOTE seminar "Neural Network-based Surrogate Computational Modeling of Myocardium: A new look at an old problem"

Professor Sacks is Professor of Biomedical Engineering at the Oden Institute for Computational Engineering and Sciences at The University of Texas at Austin. He works on cardiovascular modeling and simulation, particularly on developing patient-specific, simulation-based approaches for the understanding and treatment of heart and heart valve diseases. With a h-index of 85 (Google scholar) he is amongst the highest cited researchers in the field. He holds a PhD in Biomedical Engineering from the University of Texas Southwestern Medical Center at Dallas and received M.S. and B.S. in Engineering Mechanics from Michigan State University. He is a fellow of American Heart Association, American Society of Mechanical Engineers, Biomedical Engineering Society (Inaugural), American Institute for Medical and Biological Engineering and holds many other academic awards.

The full characterization and modeling of three-dimensional (3D) mechanical behaviour the myocardium is essential in understanding the function of the heart in health and disease. The hierarchical structure of the myocardium results in their highly anisotropic mechanical behaviors, with the spatial variations in fiber structure giving rise to heterogeneity. We have developed a novel numerical-experimental approach to determine the optimal parameters for 3D constitutive models of the myocardium using optimal design of full 3D kinematically controlled (triaxial) experiments coupled to an inverse model of the experiment and local fibrous structure. Due to the natural variations in structures, the mechanical behaviors of myocardium can vary dramatically within the heart. Thus, to obtain the responses of the myocardium with different realizations of structures, the resulting hyperelastic problem needs to be solved with spatially varying parameters and in certain cases different boundary conditions. To alleviate the associated computational costs at the time of simulation, we have developed a neural network-based direct PDE solution method. The solution $\mathbf{u}(\mathbf{x})$ was discretized as $\mathbf{u}(\mathbf{x}) = \mathbf{CN}(\mathbf{x})$ where $\mathbf{C}_i$ are weight matrix, $\mathbf{N}_i$ are basis functions, x are spatial variables, so was the parameter $\mathbf{m}(\mathbf{x}) = \mathbf{DN}(\mathbf{x})$ that describe fiber structures and loading path boundary conditions. The neural network represents the solutions of the form $\mathbf{D} = f_{NN}(\mathbf{x}, \mathrm{C}; \boldsymbol{\theta})$ where $\boldsymbol{\theta}$ are parameters of the (fully connected) neural network. The resulting neural network was then trained in a physics-informed approach by searching for $\boldsymbol{\theta}$ that minimizes the potential energy $\boldsymbol{\Pi}(\mathbf{u}(\mathbf{x}), \mathbf{m}(\mathbf{x}))$ of the hyperelastic problem on the training dataset generated by sampling x in a given domain and m for a range of parameters. The present method is intended for the low data problem; it does not require generating a large, labelled training datasets, which are also computationally intractable. The neural network model was trained with satisfactory convergence, it can be used to give fast predictions of complex 3D deformations in full kinematic space with population-based fiber structures by forward passes in the neural network. Due to their transfer learnability characteristics, the neural network on subsequent specimens more quickly. This approach is currently being scaled up for complete organ-level models to provide efficient and robust computational models for clinical evaluation to improve patient outcomes.