<u>Hi</u>erarchical <u>De</u>ep-Learning <u>N</u>eural <u>N</u>etworks (HiDeNN) for Physics-Based Simulation, Design, and Optimization: A Proposed Artificial Intelligence (AI) Framework for Plasticity

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Abstract

Challenges encountered in the application of artificial intelligence (AI) methods to computational science and engineering can be divided into three categories: (1) mechanistically known problems with incomplete models, (2) purely data-driven problems with lack of mechanistic knowledge, and (3) computationally expensive problems. We propose a general AI framework named **Hi**erarchical **De**ep-learning **N**eural **N**etwork (HiDeNN) for physics-based simulation, discovery, and design optimization. HiDeNN has the capability to combine computational simulation results such as the Integrated Computational Materials Engineering (ICME) with data-driven models to address data-scarcity for the aforementioned challenges.

The general framework and essential components of HiDeNN as an AI framework are first presented which leads to the demystification of mathematical preliminaries. The process of augmentation of traditional finite element method (FEM) and beyond (e.g., iso-geometric analysis and meshfree methods) with HiDeNN can lead to more accurate solutions. Next, we will show how the HiDeNN framework can be extended to include our developing reduced order methods (e.g., proper generalized decomposition (PGD) and self-consistent clustering analysis (SCA) methods) to increase the flexibility, accuracy, and performance of the proposed HiDeNN AI software system. This is demonstrated by some representative problems, including additive manufacturing, mechanics of materials science, biomedical engineering, fracture and fatigue predictions, design optimization and uncertainty quantification. The outlook of HiDeNN will be discussed, with particular focus on how HiDeNN can be incorporated within proprietary and other commercial software platforms.

Vita

Professor Wing Kam Liu is the Walter P. Murphy Professor of Northwestern University, Director of Global Center on Advanced Material Systems and Simulation, Past President (2018-present) and President (2014-2018) of the International Association for Computational Mechanics (IACM), Past Chair (2017-2018) and Chair (2015-2016) of the US National Committee on TAM and Member of Board of International Scientific Organizations, both within the US National Academies. Selected synergistic activities includes the development of ICME multiscale and data-driven theories, methods, hierarchical deep learning neural networks, and software with experimental validations for the design and analysis of engineering material systems, materials design, advanced and additive manufacturing; and technology transfer. He is Cited by Institute for Scientific Information (ISI) as one of the most highly cited, influential researchers in Engineering (2001) and Computer Science (2014). He has over 40 years of engineering and manufacturing consulting, including a broad array of companies and industries, small businesses, and international corporations.