Advanced Deep Learning Strategies for Forward and Inverse Problems

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Abstract: The field of Machine Learning (ML) refers to computational and statistical methods for automated detection of meaningful patterns in data. Deep learning (DL), a subset of machine learning, learns data representations using artificial neural networks (NNs). While deep learning approaches have proved to be state-of-the-art methods in the fields of computer vision, speech recognition, natural language processing, etc., its success is limited in the scientific computing community. Unlike numerical methods, such as finite element methods, in which solution accuracy and reliability are guaranteed under regularity conditions, DL results are often far from providing reasonably accurate results. The reason is that though approximation capability of NNs is as good as classical methods in approximation theory, NN accuracy is not attainable in general due to limitation in training. Though the past decade has seen tremendous advances in both theories and computational algorithms for machine learning, training NN remains a grand challenging problem facing the machine learning community. Thus, there is a critical need to develop advanced strategies to tackle this crucial challenge in order to enable the potential of deep NNs for computational sciences and engineering applications.

Our long-term goal is to establish a research program that addresses advanced optimization methods, automatic hyperparameter determination, and uncertainty quantification techniques for deep learnings. We have a track record of developing scalable algorithms for large-scale uncertainty quantifications, large-scale PDE-constrained optimization, and large-scale model and data reduction methods. Our objective for the Moncrief Grand Challenge Faculty project is to focus on developing effective deep learning methods for magnetohydrodynamics (MHD) simulations and magnetic resonance elastography (MRE). An important product of this project is the development of scalable optimization methods for training deep NNs. Below are the brief descriptions of MHD and MRE, their challenges, and our deep learning strategies to address the challenges.