

# Preface

Electromagnetic (EM) scattering is a widely seen physical phenomenon, which results from the interaction between EM wave and an isolate object or set of objects (termed as scatterer hereafter). Numerical modeling of either static or dynamical process of scattering finds numerous applications in physical and engineering science, with practical impact on wave physics, geophysical sensing, stealth aircraft designs, biomedical imaging and so on. Conventional wisdom in helping formulate the modeling process is originated from applied mathematics view, from which a set of computational tools, such as finite element method, method of moment and finite difference method, were developed to solve integral or differential equations derived from the first principle physics of system under interest (e.g., Maxwell equations). However, all these methods face a same dilemma when they come into real computational scenarios/applications. In this case, the governing equations of problem at hand are generally discretized into a complicated matrix system which is often in high-dimensional space and characterized by millions of unknowns. Conventional tools might provide feasibility to solve, but the computational efficiency lags behind. Hours or even days of calculation prevent us from handling large-scale EM problems or applications requiring real-time response.

Deeping learning then comes at the right time into the stage of scientific computing. The direct idea behind is data-driven modeling, where the traditional numerical tools for problem solving only serve to provide sufficient data (not necessarily a complete set of solutions) from which deep learning algorithms learn the underlying dynamics and try to generalize. In essence, the function relation in any forward EM modeling problems with multiple variables can be faithfully approximated via network training, rather than time-consuming numerical integration or differentiation. At an intuitive level, this ability of function approximation originates from layers of networks consisting of up to millions of trainable weights followed by nonlinear activation. For EM scattering modeling, the training is supervised by the prepared dataset and it may take a few hours to reach the convergent stability, but as long as being well-trained, the deep learning algorithms excel in forward analysis with orders of magnitude acceleration compared to the conventional numerical methods.

Deep learning appears as a transformative method with astonishing performance in scientific computing, modeling and data analysis, but it is never an obscure and prohibitive method to be applied in different research areas where we mainly focus on EM scattering here. Instead, to get a grasp of the knowledge behind, all you need to add on top of your domain expertise (e.g., math, physics, chemistry, biology) is a systematical view into consecutive parts of data-driven modeling. **This book is here to provide comprehensive insights and practical guidance for you to build up a sophisticated EM scattering solver using deep learning approach, to help you put deep learning into your daily research practice.** The intended audience includes anyone who is interested in applying machine learning into research of computational physics, especially for forward EM wave modeling.

Throughout the book, we start from the introduction to the EM wave scattering. The formulation of physics behind and conventional wisdom in problem solving are articulate. The second chapter exposes readers with the basic concepts of deep learning and principles for constructing a proper network configuration. The training and testing techniques are given in detail so that readers can expect to get hands-on experience with practical philosophy of how can machine learning be integrated into the EM research. In the following chapter, a closer look is taken into another important part of deep learning research, which is the preparation of data. The numerical method (FDFD) which we relied on to generate dataset is formally introduced in this chapter with proper depth. Practical techniques including the geometry generator and format for physical quantity are also covered. Up to this chapter, techniques behind the topics of this book are provided completely.

Then, we demonstrate the original and concrete experimental results in the following two chapters to showcase how the complete procedure can be done to build a 2D/3D EM scattering solver via deep learning. Readers are expected to enjoy a holistic view of problem solving in data-driven scheme and are encouraged to transfer the basic ideas behind into their own domain of research.

Applying deep learning into the modeling of EM wave propagation or wider range of physics is gradually going from a spark of research practice into mainstream trend of study, and it now has been called widely as scientific machine learning where mathematician, physicist, computer scientist, etc., work together to crackle down complex multiscale and multiphysics problem, across science, engineering and medicine. In this background, the authors believe all the readers will benefit from this book.

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