Internship Position F/M Multilevel and distributed Physics-Informed Neural Networks for the Helmholtz equation

Contract type: Internship
Level of qualifications required: Graduate degree or equivalent
Other valued qualifications: Master in applied mathematics or scientific computing
Function: Internship Research

About the research centre or Inria department

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Context

Numerical simulations of electromagnetic wave propagation problems primarily rely on a space discretization of the system of Maxwell’s equations using methods such as finite differences or finite elements. For complex and realistic three-dimensional situations, such a process can be computationally prohibitive, especially when the end goal consists in many-query analyses (e.g., optimization design and uncertainty quantification). Therefore, developing cost-effective surrogate models is of great practical significance.

There exist different possible ways of building surrogate models for a given system of partial differential equations (PDEs) in a non-intrusive way (i.e., with minimal modifications to an existing discretization-based simulation methodology). In recent years, approaches based on neural networks (NNs) and Deep Learning (DL) have shown much promise, thanks to their capability of handling nonlinear or/and high dimensional problems. Model-based neural networks, as opposed to purely data-driven neural networks, are currently the subject of intense research for devising high-performance surrogate models of parametric PDEs.

The concept of Physics-Informed Neural Networks (PINNs) introduced in [1], and later revisited in [2], is one typical example. PINNs are neural networks trained to solve supervised learning tasks while respecting some given physical laws, described by a (possibly nonlinear) PDE system. PINNs can be seen as a continuous approximation of the solution to the PDE. They seamlessly integrate information from both data and PDEs by embedding the PDEs into the loss function of a neural network. Automatic differentiation is then used to actually differentiate the network and compute the loss function.

This internship is a preliminary to the PhD project described in the offer #2023-06769.

Assignment

The main challenge when devising scalable physics-based DNNs for realistic applications is the computational cost of network training, especially when they are only used for forward modeling. Another important issue lies in their capacity to accurately deal with high frequency and/or multiscale problems. In particular, it has been observed that, when higher frequencies and multiscale features are present in the PDE solution, the accuracy of PINNs usually rapidly decreases, while the cost of training and evaluation drastically increases. There are multiple reasons for this behavior. One is the spectral bias of NNs, which is the well-studied property that NNs have difficulties learning high frequencies. Another reason is that, as high frequencies and multiscale features are added, more collocation points as well as a larger NN with significantly more free parameters, are typically required to accurately approximate the solution. This leads to an increase in the complexity of the optimization problem to be solved when training the NN.

Recently, in [3], multilevel distributed (domain decomposition-based) PINNs architectures have been
proposed to address the above-mentioned issues. In this internship, we propose to conduct a more
detailed study of such multilevel distributed PINNs for frequency-domain acoustic wave propagation
problems, considering various scenarios of boundary conditions, source field and heterogeneity of the
propagation medium.


framework for solving forward and inverse problems involving nonlinear partial differential equations. J.

https://doi.org/10.48550/arXiv.2306.05486

Main activities

1. Bibliographical study for a review of (1) physics-based DNNs for wave propagation type models and
   (2) strategies for designing multilevel and distributed physics-based DNNs.
2. Study in 2d case by considering wave propagation modeled by a Helmholtz-type PDE
3. Software development activities
4. Numerical assessment of the proposed NN-based physics-based multilevel surrogate models
5. Publications

Skills

Technical skills and level required

- Sound knowledge of numerical analysis for PDEs
- Sound knowledge of Machine Learning / Deep Learning with Artificial Neural Networks
- Basic knowledge of PDE models of wave propagation

Software development skills : Python programming, TensorFlow, Pytorch

Relational skills : team worker (verbal communication, active listening, motivation and commitment)

Other valued appreciated : good level of spoken and written english

General Information

- Theme/Domain : Numerical schemes and simulations
  Scientific computing (BAP E)
- Town/city : Sophia Antipolis
- Inria Center : Centre Inria d’Université Côte d’Azur
- Starting date : 2024-03-01
- Duration of contract : 6 months
- Deadline to apply : 2024-06-30

Contacts

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About Inria

Inria is the French national research institute dedicated to digital science and technology. It employs
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than 3,500 scientists and engineers working to meet the challenges of digital technology, often at the
interface with other disciplines. The Institute also employs numerous talents in over forty different
professions. 900 research support staff contribute to the preparation and development of scientific and
entrepreneurial projects that have a worldwide impact.

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not guaranteed.

Instruction to apply

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to the protection of national scientific and technical potential (PPST). Authorisation to enter an area is
granted by the director of the unit, following a favourable Ministerial decision, as defined in the decree
of 3 July 2012 relating to the PPST. An unfavourable Ministerial decision in respect of a position situated
in a ZRR would result in the cancellation of the appointment.

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