Internship Opportunity: Integration of Causality in High-Performance Computing for Seismic Wave Propagation Analysis

Subject: Finite Element Method, Causality, HPC, AI, ML

Context: Utilizing causality – *a machine learning method that explores cause-and-effect relationships* – in conjunction with finite element methods (FEM) – *a numerical approach for modeling physics* – holds the potential to enhance numerical analysis by improving result interpretations, deriving data driven models for faster computations, and improving computational accuracy and speed. This internship aims to investigate the same in context of seismic modeling (earthquake physics), we intend to integrate causality–FEM coupling to improve the analysis of seismic wave propagation [1]. The selected candidate will work on developing algorithms and implementing them in scientific computing tools that can then harness the capabilities of both approaches. The primary goal is to leverage causality techniques to determine and quantify the cause-effect relationship between different spatial locations within the earthquake FEM simulation measured over time. For this purpose, we aim at developing a causal graph based on the Pearl framework [3] and adapted to heterogeneous time series [4] data procured from FEM simulation. After learning the causal graphs – *process of detecting relevant patterns in the data* – acceleration for various stages of the FEM analysis, such as model setup, parameter estimation, solver preconditioning, and result interpretation is expected.

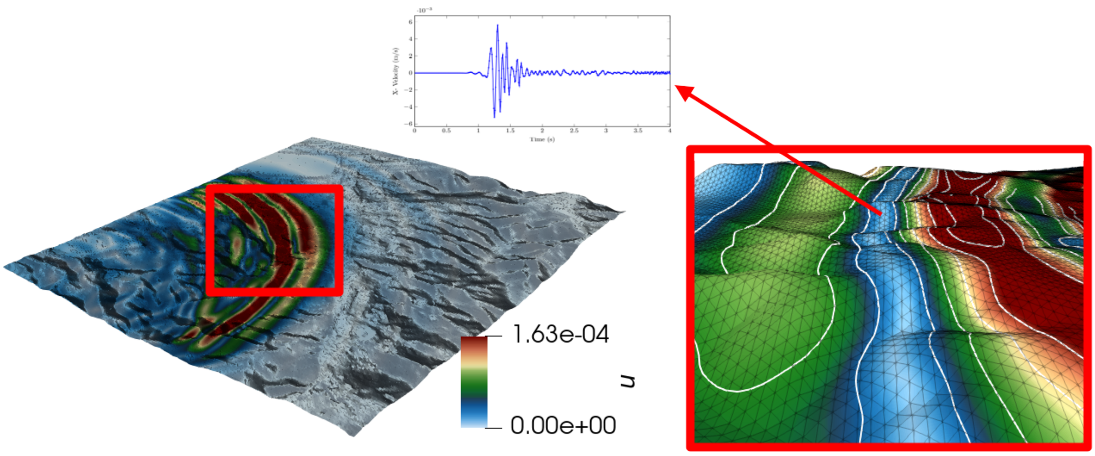

Figure 1: FEM solution for earthquake wave propagation obtained via a parallel code (PSD[2]) based on CPU parallelism. More than twelve thousand CPUs were used to obtain these results.

At CEA, we have been developing HPC finite element codes for seismic modeling – ArcaneFEM[1] and PSD[2] – which are designed to solve large-scale problem arising in seismic wave propagation. These simulations are of utmost importance as they play a key role in risk and disaster management. We believe that incorporating causality with in-place FEM solvers will significantly enhance the performance of the solver and perhaps better understand the uncertainties involved in the numerical simulations.

We believe this internship will provide a unique opportunity for individuals passionate about scientific computing, numerical simulations, and machine learning to contribute to cutting-edge research and gain valuable experience within a prestigious organization like CEA.

[1] FEM code based on Arcane [2] a C++ HPC framework dedicated to scientific computing `https://github.com/arcaneframework/arcanefem`

[2] PSD, acronym for Parallel Solid/Structural/Seismic Dynamics is an inhouse CEA code for seismic studies

Objectives: During the internship, the selected candidate will have the opportunity to collaborate with experts from the LESIM laboratory and LIAD laboratory. The main responsibilities will include:

- Conducting research on HPC-compatible FEM methods and causality algorithms for seismic wave propagation analysis.
- Developing/implementing/benchmarking algorithms to integrate FEM and causality techniques.
- Collaborating with the research team to analyze and interpret results.
- Documenting research findings and presenting them.

Requested knowledge: We are seeking a candidate who possesses a background in **Scientific Computing**, **Machine Learning**, **C++**, **Python**... The ideal candidate should have a solid understanding of numerical method principles, methodologies, and informatics.

Profile: BAC+5 – master

Locality: CEA Paris-Saclay

PhD after internship: No

To apply: Send your CV, grades, and motivation letter to

- Mohd Afeef BADRI : mohd-afeef.badri@cea.fr
- Aurore LOMET : aurore.lomet@cea.fr

References:

[1] T. Ali, M. N. Eldin, & W. Haider, (2023). The Effect of Soil-Structure Interaction on the Seismic Response of Structures Using Machine Learning, Finite Element Modeling and ASCE 7-16 Methods. Sensors, 23(4), 2047.

[2] G. Grospellier, B. Lelandais (2009). The Arcane development framework. POOSC'09.

[3] J. Pearl. Causality (2009). Cambridge university press.

[4] A.Arsac, A.Lomet, JP. Poli (2023). Causal discovery for time series with constraint-based model and PMIME measure. ArXiv preprint arXiv:2305.19695