Postdoc Opportunity: Exascale Earthquake Simulation using ArcaneFEM on GPGPU Architectures

Subject: Exascale Computing, GPU, Parallel Computing, Linear Solvers, AMG, HPC, FEM, `C++`

Context: General-purpose GPU (GPGPU)[1]-based numerical simulations are a key enabler in the transition to the exascale computing[2] era. As large-scale numerical simulations increasingly rely on GPU power, existing solvers must evolve to harvest the massive parallelism offered via modern hardware. In this context, `ArcaneFEM` [1] – a massively parallel finite element solver – has been steadily developed to support GPGPU computations for a wide range of physics problems, including earthquake modeling (fig. 1-right), linear elasticity, diffusion, heat transfer, and aerodynamics (fig. 1-left). Built on top of the `Arcane Framework` [2], a `C++` environment for parallel simulation codes, `ArcaneFEM` supports a variety of parallelization paradigms across CPUs, GPUs, threads, and more. Designed to scale to thousands of compute units, `ArcaneFEM` is a strong candidate for European future exascale platforms. The focus of this postdoctoral project is to build and run earthquake exascale-scale simulations on the forthcoming European exascale supercomputer, Alice Recoque [3].

A major computational challenge in finite element simulations is solving large, sparse linear systems — often containing billions of unknowns, particularly in earthquake modeling. `ArcaneFEM` currently leverages Algebraic Multigrid (AMG) preconditioned iterative solvers on thousands of GPUs to address this. While this already provides substantial speed-ups, there remains significant room for optimization: enhancing convergence for hyperbolic PDEs – expected in earthquake simulations, improving robustness, tuning performance, and ensuring adaptability to next-generation GPU architectures. Beyond solver efficiency, the project faces several additional exascale-era challenges: adapting CPU-oriented meshing and partitioning tools (e.g., `top-ii-vol`) for GPU use and porting non-linear transient dynamics kernel in `ArcaneFEM` on GPGPU architectures. The selected postdoctoral researcher will play a key role in tackling these challenges — from developing exascale-ready solver components and optimizing GPU performance, to rigorously benchmarking the full pipeline on future systems like Alice Recoque. These efforts will ensure that `ArcaneFEM` is capable of delivering scalable, accurate, and efficient simulations for full-scale seismic events on heterogeneous exascale platforms.

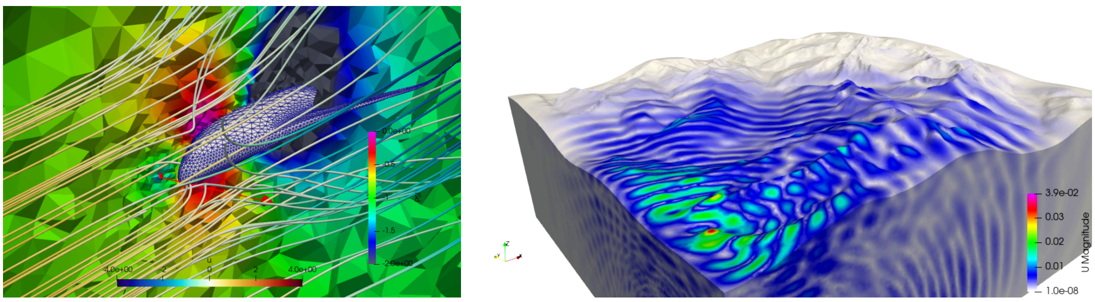

Figure 1: Illustrations of aerodynamics (left) and earthquake (right) simulations using `ArcaneFEM`.

[1] GPGPU: General-purpose computing on graphics processing units — using GPUs, traditionally for graphics rendering, for scientific and engineering computations.

[2] Exascale Computing: A class of supercomputers capable of executing over 10^{18} floating-point operations per second (exaFLOP).

The selected postdoctoral researcher will join the SGLS (Service de Génie Logiciel pour la Simulation) team at CEA Paris-Saclay, where `ArcaneFEM` is actively developed. The project will be co-supervised by experts from CEA DAM (Direction des Applications Militaires). The researcher will work alongside a team of specialists in HPC, numerical methods, and performance optimization, with access to powerful computing clusters. The work will emphasize testing, tuning, and benchmarking solvers on real GPGPU HPC systems, ensuring scalability and robustness across various applications.

Objectives: The postdoctoral research will involve the following tasks:

- Develop and deploy an exascale-ready, non-linear FEM solver for earthquake simulations on GPGPU architectures.
- Advance and optimize multi-grid linear system solver preconditioners for hyperbolic PDEs on GPUs, targeting earthquake simulations.
- Benchmark solver performance and scalability across multiple HPC GPU platforms.

Requested Knowledge:

- Strong motivation to work with HPC systems and interest in scientific software development.
- Solid knowledge of `C++` programming in a high-performance or scientific computing context.
- Experience with GPU programming (`CUDA`, `HIP`, or equivalent) is highly desirable.
- Good understanding of linear solvers and iterative methods (e.g., Krylov methods, AMG).
- Knowledge of finite element methods (FEM) and their application to mechanics problems is a plus.
- Experience with profiling and performance tuning on HPC architectures is a plus.
- Ability to work collaboratively in a multidisciplinary team of engineers and researchers.
- Good communication skills (written and oral) in English;

Period: 1 year starting in 2025, with possibility of +1 year

Profile: Doctoral degree (PhD)

Locality: CEA Paris-Saclay, at (SGLS/LESIM Lab)

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

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References:

[1] M. A. Badri, et. al., (2025). ArcaneFEM: Massively parallel FEM solver on CPU-GPU. GitHub. https://github.com/arcaneframework/arcanefem

[2] G. Grospellier, et. al., (2009). The Arcane development framework. POOSC'09. https://doi.org/10.1145/1595655.1595659

[3] https://www.cea.fr/english/Pages/News/signature-hosting-agreement-second-european-exascale-supercomputer-Alice-Recoque.aspx

[4] J. Bolz, et. al., (2020). Sparse matrix solvers on the GPU: conjugate gradients and multigrid. ACM Journals. ACM Transactions on Graphics. Vol. 22, No. 3 https://doi.org/10.1145/882262.882364