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FRANCE 2030
PROGRAMME DE RECHERCHE
NUMÉRIQUE POUR L'EXASCALE

Samurai : An innovative Structured Adaptive mesh and Multiresolution library

Exa-MA Annual Meeting

S. Dubois & A. Hoffmann (Research Eng.)
A. Simon (PhD student)

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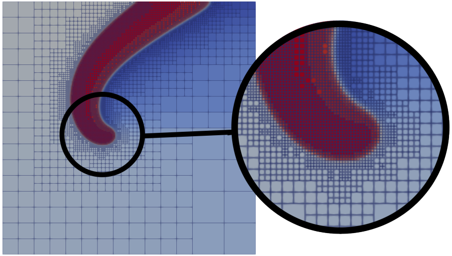
Team HPC@Maths, CMAP - Ecole Polytechnique

Samurai : Structured Adaptive mesh and Multiresolution based on Algebra of Intervals -- NumPEx - Quantstack - CEA

Two research engineers - Code development

Samurai: Main Idea

1. Compress the mesh according to the level-wise spatial connectivity along each Cartesian axis.
2. Achieve fast look-up for a cell into the structure, especially for parents and neighbors.
3. Maximize the memory contiguity of the stored data to allow for caching and vectorization.
4. Facilitate inter-level operations, which are common in many numerical techniques.



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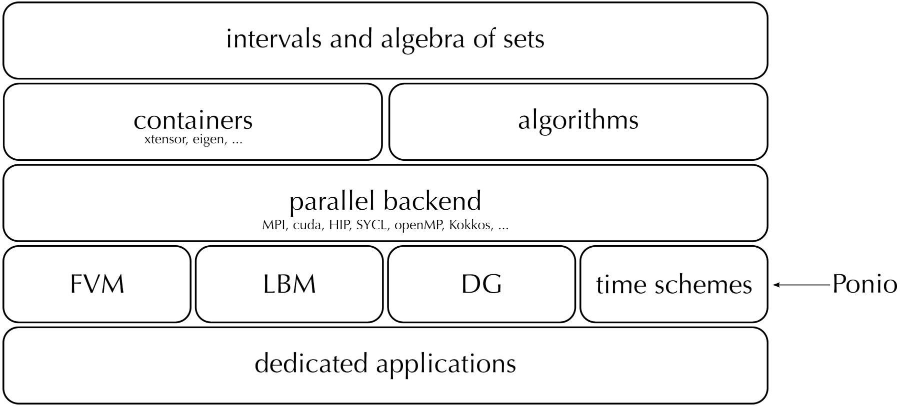
Samurai: Roadmap



Samurai: Toward the Exascale

- Benchmarks with other libraries (AMReX for example)
- Optimize Single node performance for maximum efficiency
- Improve the dynamic MPI load balancing
- Provide support for GPU through the `Kokkos` library
- Improve `xtensor` library and its parallel capabilities
- Non-regression performance tests
- `spack` and `guix` packaging

Questions?

GitHub project available here : `https://github.com/hpc-maths/samurai`

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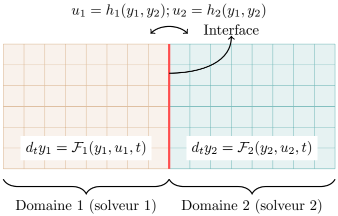
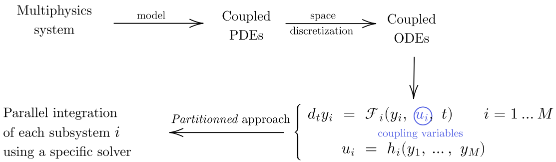
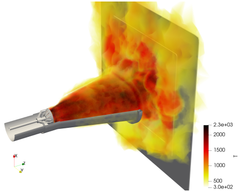
High-order adaptive coupling – PhD Thesis NumPEx – ONERA

Collaboration CMAP / ONERA / CORIA / SafranTech

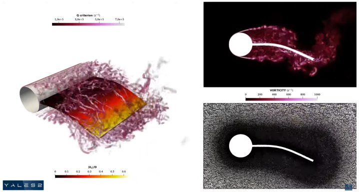
Context : multiphysics simulations and code coupling







Fluid – solid [SafranTech]



Fluid – structure [T. Fabbri, Coria]

The multistep coupling scheme

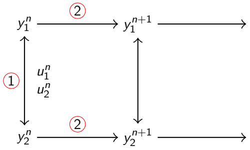
- Usually:

Integration of the

$d_t y_i = \mathcal{F}_i(y_i, u_i^n, t)$

constant

$\Rightarrow$ Convergence **at order 1**



Conventional Parallel Staggered scheme

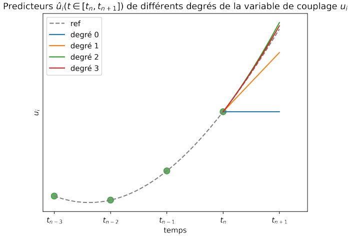
- High-order multistep scheme (explicit):

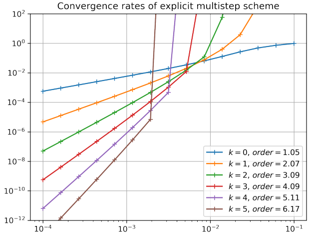
Integration of the

$d_t y_i = \mathcal{F}_i(y_i, \hat{u}_i^n, t)$

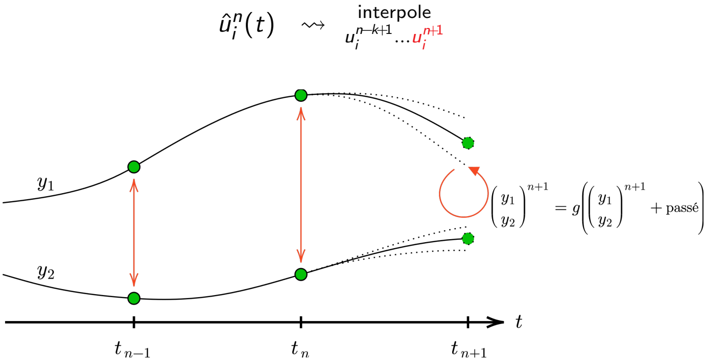
polynomial extrapolates the past $u_i^{n-k} \dots u_i^n$

$\Longrightarrow$ Convergence **at order k+1**





Implicitation of the multistep coupling scheme



Resolution of a fixed point problem

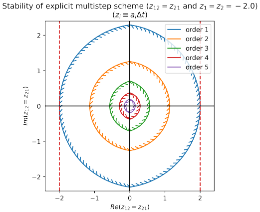
Results

- Proof of convergence = zero-stability + consistency

- Coupling model equation

$$\begin{cases} d_t y_1 = a_1 y_1 + a_{12} y_2 \\ d_t y_2 = a_{21} y_1 + a_2 y_2 \end{cases}$$

- Stability analysis



Perspectives

Ongoing work (PhD Thesis started November 12th 2024):

- Stability analysis
- Publication in *Comptes Rendus Mécanique* (Académie des Sciences - 2025) Proc. Journée Scientifique ONERA dedicated to numerical simulation environments
- Link model equation – PDE system
- HPC implementation in CWIPI

Collaborations:

- ONERA applications fluid – plasma, fluid – structure etc
- Industrial collaboration with CORIA and SafranTech: fluid – solid thermal coupling
- Modeling Summer Program 2025 at NASA Ames Research Center with HPC@Maths team (CMAP): fluid – solid – ablation