Chair of Scientific Computing
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Efficient Time Stepping in Partitioned Multi-Physics

Challenges in Fluid-Structure-Acoustics Interaction

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ExaFSA in a Nutshell

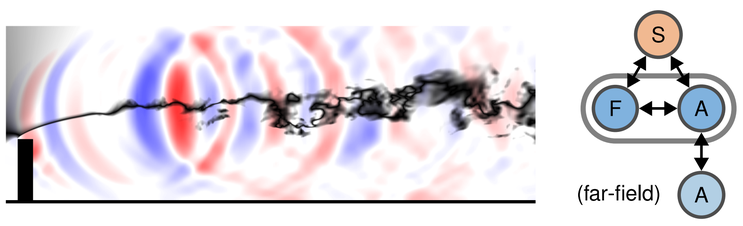
Project Framework

SPPEXA is the DFG priority program for the development of *Software for Exascale Computing*.

ExaFSA is part of SPPEXA with contributions from University of Stuttgart, University of Siegen, Tohoku University, TUM, TU Delft, TU Darmstadt. The goal of ExaFSA (running from 2013-2019) is to perform efficient and scalable simulations of Fluid-Structure-Acoustics (FSA) interaction problems.

preCICE is an open source library developed at University of Stuttgart and TUM used in the scope of ExaFSA.

Coupled Problem: FSA



Fluid-Structure-Acoustics simulation and partitioned setup (Images: T.Reimann [1])

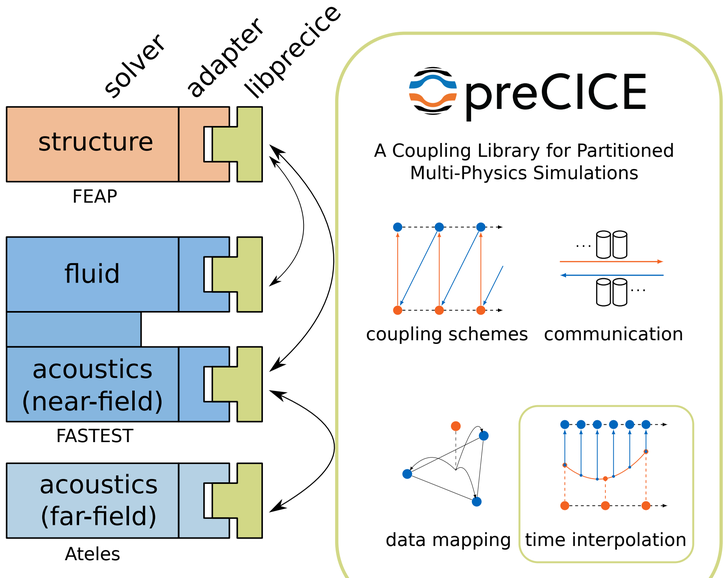
Fluid-Structure-Acoustics (FSA) is a multiscale problem, where different scales in time and space are considered. The physical phenomena of fluid (F), structure (S) and acoustics (A) are solved using three different solvers.

physics	timescale	solver	scheme	order
(S)	large	FEAP	N-β	1 or 2
(F)	medium	FASTEST	CN	2
(A)	small	FASTEST	EE	1
(A)	small	Ateles	RK	2 or 4

The partitioned approach allows us to (1) reuse existing solvers and (2) run them in parallel.

Coupling Tool: preCICE

The coupling library preCICE [2] is used for realization of the partitioned approach. A library approach allows minimally invasive coupling, where the solvers are treated as black-boxes. The solvers are extended by a simple adapter; implementation details of the solver remain hidden.

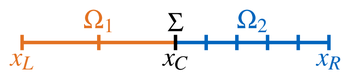


Subcycling for preCICE

Reproduce order degradation and reach high order.

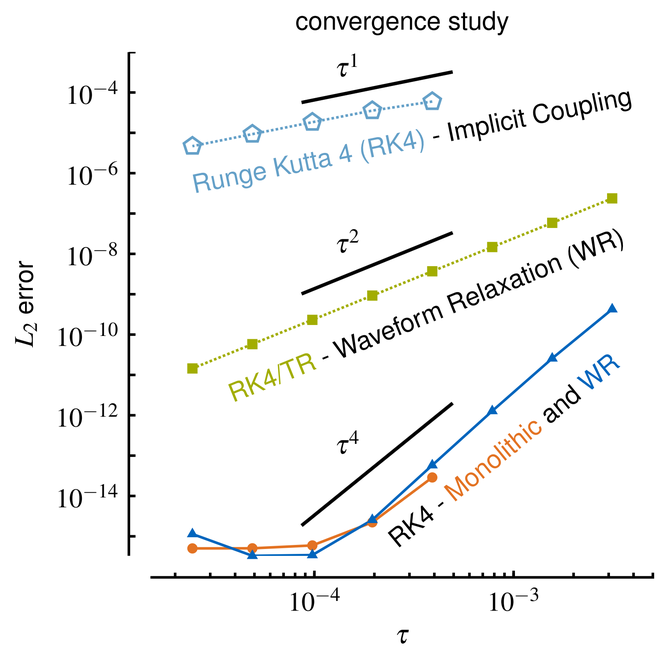
Partitioned Heat Transport [5]

Comparison of monolithic (M) approach with implicit coupling (Im) and waveform relaxation (WR). Trapezoidal rule (TR) and Runge Kutta 4 (RK4) are used for time stepping.



Partitioning of domain Ω at coupling interface Σ.

scheme	time step	order	stable
RK4 - Im	$\tau_1 = \tau_2$	$\mathcal{O}(\tau)$	small τ_2
RK4/TR - WR	$\tau_1 = \tau_2$	$\mathcal{O}(\tau^2)$	$\forall \tau_2$
RK4 - M	$\tau_1 = \tau_2$	$\mathcal{O}(\tau^4)$	small τ_2
RK4 - WR	$\tau_1 > \tau_2$	$\mathcal{O}(\tau^4)$	small τ_2



Research Focus

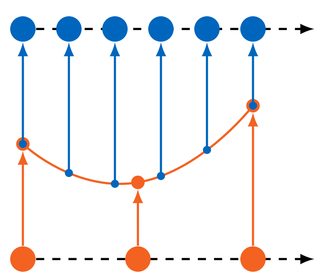
Engineering:

How can we combine FASTEST and Ateles with ideal timestep and order?

Informatics:

How can we provide a flexible interface following the black-box approach of preCICE?

Subcycling



Challenges and Next Steps

Engineering:

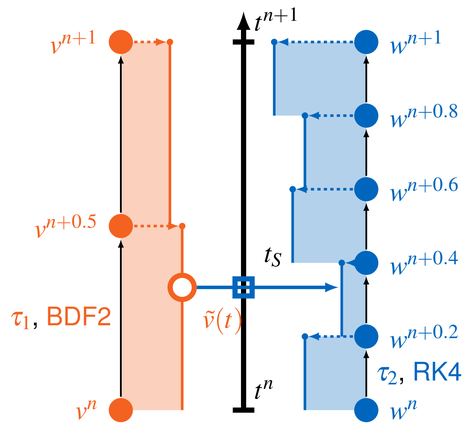
We want to test the waveform relaxation method on a **more complex scenario** such as FSA. Here, we can compare to **literature**. We will see how our method affects the results and whether it can be used for **real applications**.

Informatics:

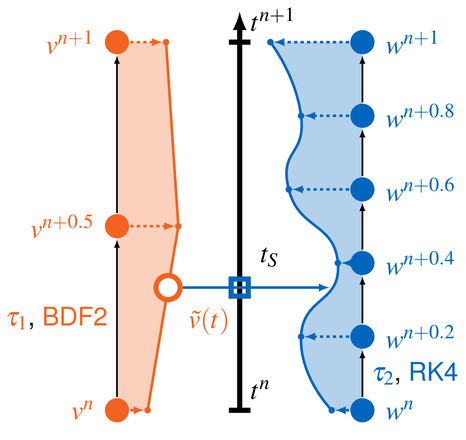
The **prototype implementation** should be extended to a **general approach based on preCICE**. This allows us to investigate the effects on **parallel performance** and **convergence speed**. We also have to extend preCICE to be able to communicate the **interpolants** across the interface, since currently **only nodal data** may be exchanged.

Develop coupling schemes supporting subcycling.

Implicit Coupling [3]



Waveform relaxation [4]



Only nodal data $v^{n+\cdots}, w^{n+\cdots}$ is used to create an interpolation polynomial on the window $T = \left[t^n, t^{n+1}\right]$. A combination of different solvers and time step sizes τ_1, τ_2 is possible.

References:
[1] Reimann, T., Ali, A., & Sternel, D. C. (2017). Aspects of FSI with aeroacoustics in turbulent flow. In 7th GACM Colloquium on Computational Mechanics.
[2] Bungartz, H.-J., Lindner, F., Gatzhammer, B., Mehl, M., Scheufele, K., Shukaev, A., & Uekermann, B. (2016). preCICE – A fully parallel library for multi-physics surface coupling. Comput. & Fluids, 141(Supplement C), 250–258.
[3] Uekermann, B. (2016). Partitioned Fluid-Structure Interaction on Massively Parallel Systems. PhD Thesis. Technical University of Munich.
[4] Schöps, S., De Gersem, H., & Bartel, A. (2012). Higher-order cosimulation of field/circuit coupled problems. IEEE Transactions on Magnetics, 48(2), 535–538.
[5] Leiva, J. S., Blanco, P. J., & Buscaglia, G. C. (2010). Iterative strong coupling of dimensionally heterogeneous models. International Journal for Numerical Methods in Engineering, 81(12), 1558–1580.

www.precice.org github.com/precice rueth@in.tum.de