Chair of Scientific Computing
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Scalable coupled simulations with OpenFOAM® and other solvers

Setting up Multi-Physics simulations like playing LEGO®, without stepping on the pieces

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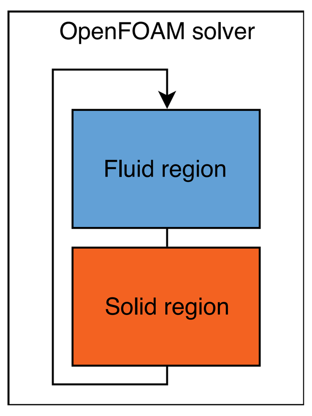
Multi-Physics in OpenFOAM

Approaches and problems

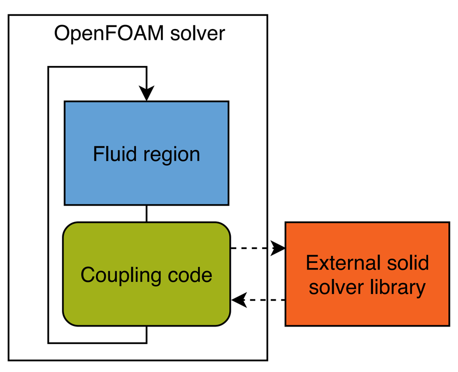
Framework approach: Two different regions in an OpenFOAM solver, solved sequentially. Examples: chtMultiRegionFoam (intrinsic), fsiFoam (only in foam-extend) [1].

+ Everything inside OpenFOAM
– Limited to specific, OpenFOAM-only solvers
– Limited coupling numerics
– Limited scalability
– Partitioned numerics, but monolithic software



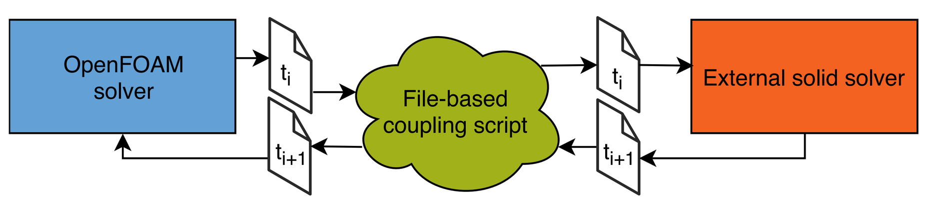
Master - Slave approach: The OpenFOAM solver calls an external solver library. Example: OpenFPCI [2].

+ Not limited to OpenFOAM solvers
– Invasive (convert solver to library)
– Difficult extension to > 2 solvers
– Limited scalability
– Tight setup, difficult to maintain



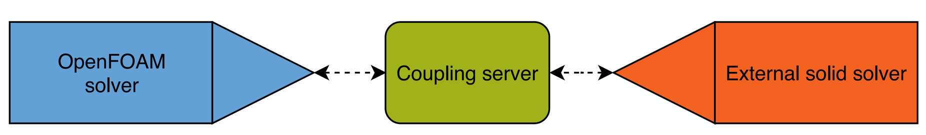
Files-based approach: Every solver works independently, solving every coupling timestep as a complete simulation. An external script (often in-house) processes their results files and adjusts their configuration files, restarting them. Example: Galanin et. al. [3].

+ Non-invasive
+ Intuitive and easy to debug
– Very slow



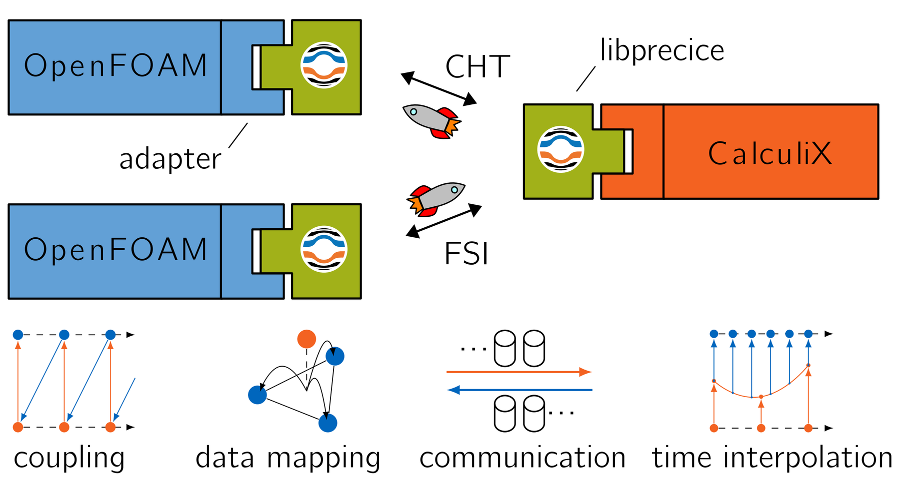
Server library approach: Every solver calls an external library, which couples them. The solvers do not communicate directly. Examples: MpCCI (commercial) [4], EMPIRE [5], ifls [6].

+ Flexible
+ Advanced coupling numerics
– Limited scalability
– Additional executable to handle



Solution: preCICE coupling library

preCICE (www.precice.org) [7] follows a completely parallel, peer-to-peer approach [8]. preCICE treats each solver as a "black-box" and handles all the functionality required for the coupling. Each participating solver loads the preCICE library through an "adapter" [9].



preCICE supports (parallel) implicit coupling with Quasi-Newton acceleration, RBF mapping, and communication via MPI or TCP/IP sockets. Time interpolation schemes are under development.

OpenFOAM adapter for preCICE [10]

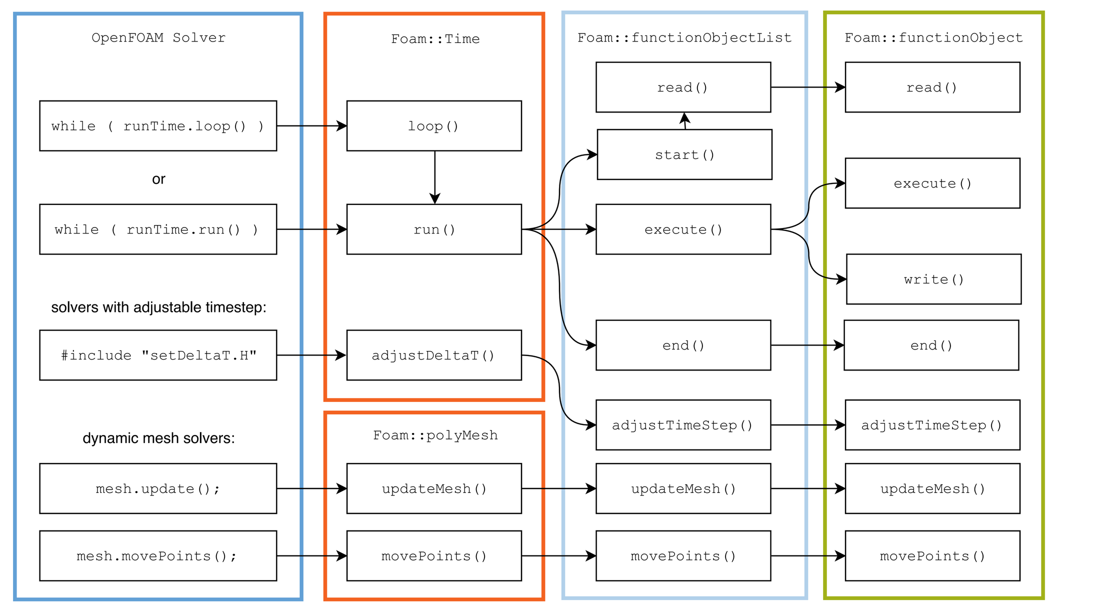
One adapter, no changes in the solver

Previous approach: Modify the solver to add calls to preCICE → solver-specific. Examples: FOAM-FSI [11], L. Cheung [12], K. Rave [13], D. Schneider [14].

OpenFOAM function objects: Inject code at specific, pre-defined points, without modifying the solver's code or re-compiling.

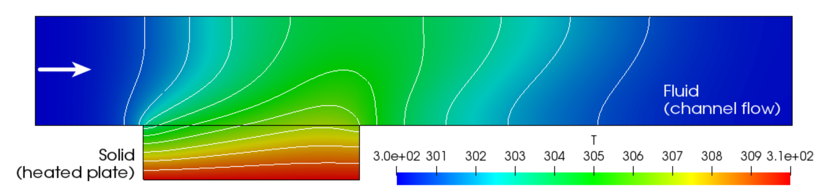
Compatible: Designed for current versions of openfoam.com and openfoam.org.

Challenges: Access everything through the objects' registry and keep the code general.

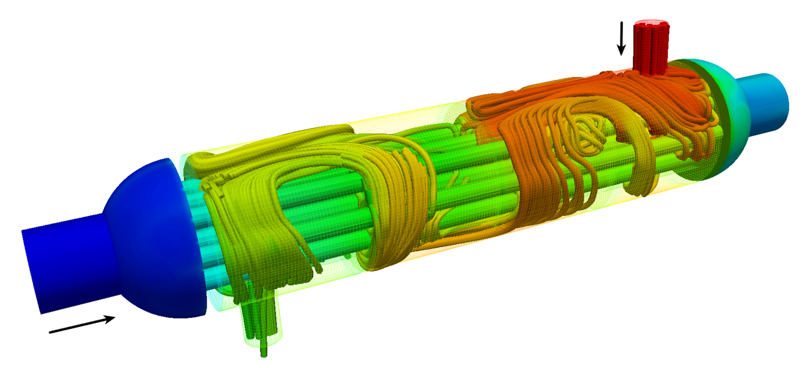


Results & Tutorials

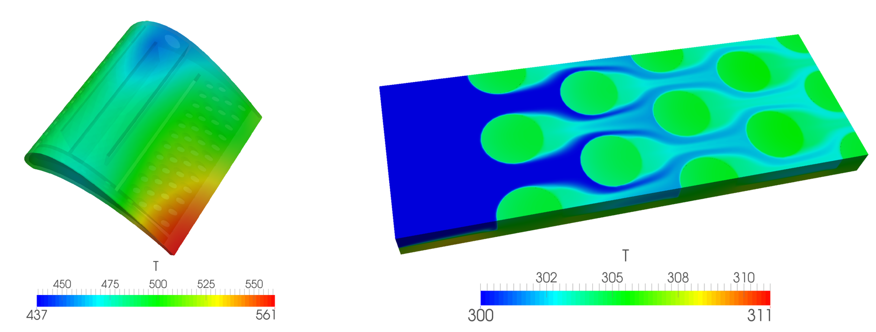
Flow over a heat plate: CHT tutorial, validated.



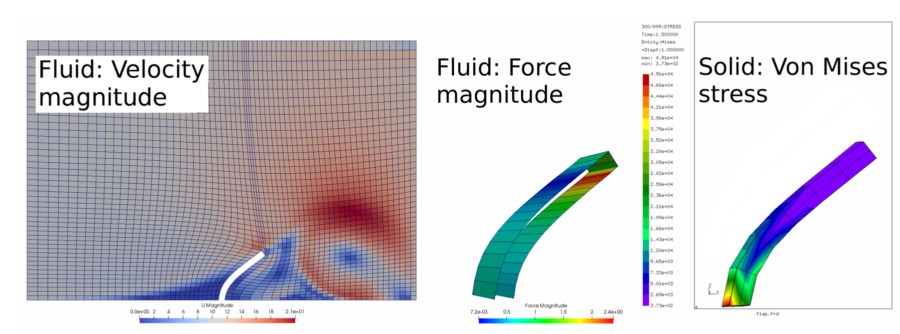
Shell-and-tubes heat exchanger: Multi-coupling CHT tutorial with OpenFOAM and CalculiX (calculix.de). Compared to chtMultiRegionFoam, a performance benefit has been observed for this scenario. A rigorous performance study is future work.



More CHT scenarios: Turbine blade cooling and pin-fin cooling (simulations by L. Cheung [12])

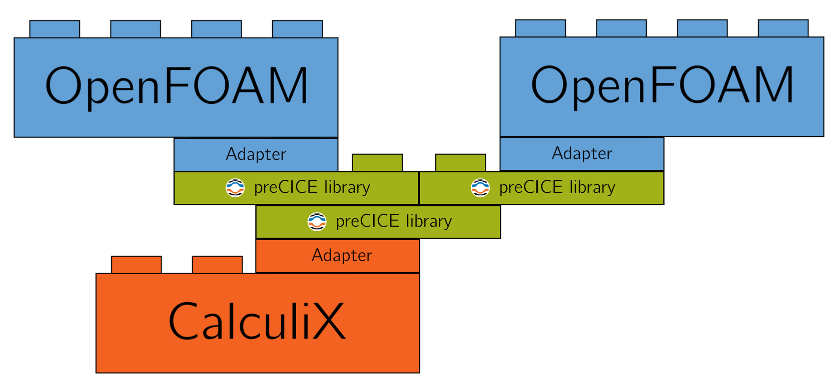


Initial FSI results: Flap perpendicular to the flow with OpenFOAM (left, center) and CalculiX (right)



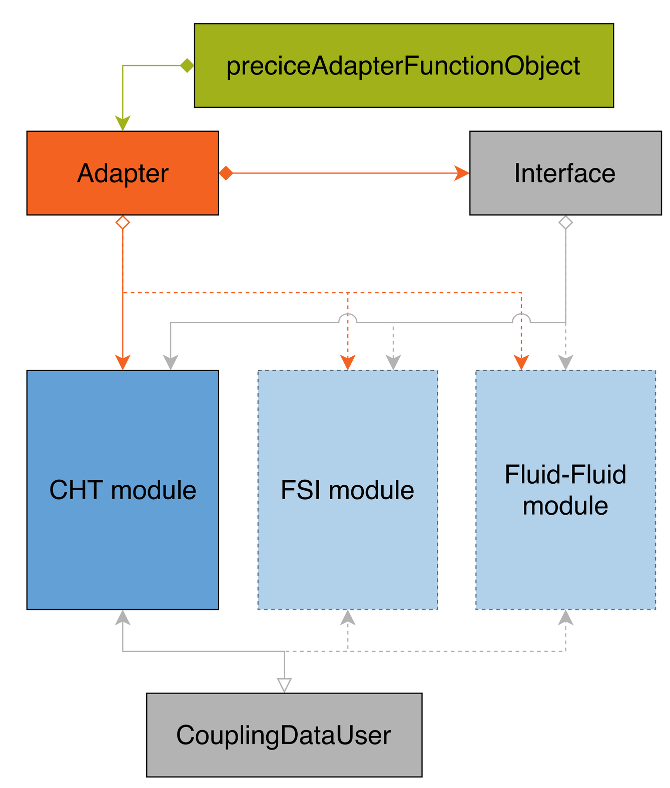
Easy to use

+ **Load at runtime:** Add 3 lines in your `system/controlDict`
+ **Easy to configure:** Small (approx. 7 lines) YAML file (plan to replace it with an OpenFOAM dictionary)
+ **No matter which partner:** The adapter only knows about preCICE.



Next steps

The adapter can be extended to support other problem types, such as Fluid-Fluid multi-model coupling.



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