Coupling 1D thermohydraulics with 3D CFD via preCICE

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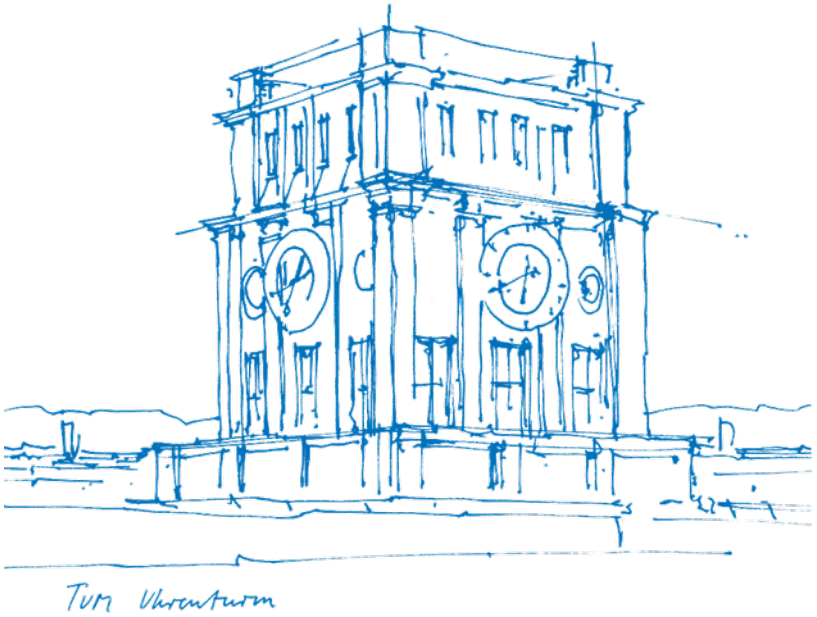
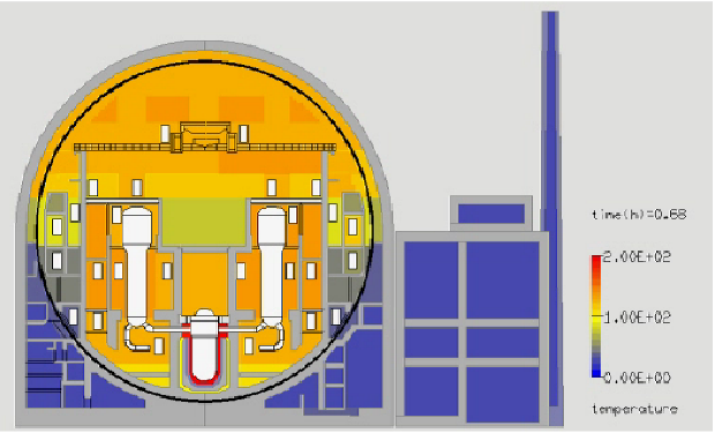
Institute for Parallel and Distributed Systems (IPVS)
Chair of Usability and Sustainability of Simulation Software

ECCOMAS Congress 2022
Oslo, June 9, 2022



How would you simulate a
nuclear reactor?



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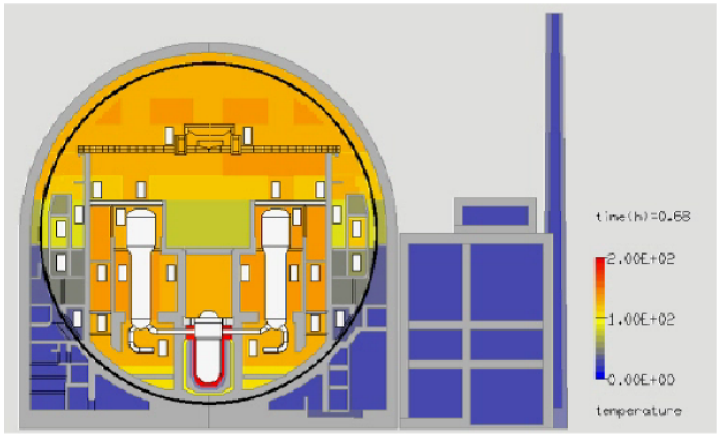
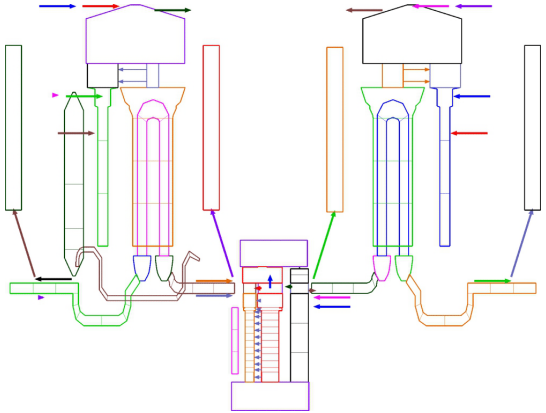
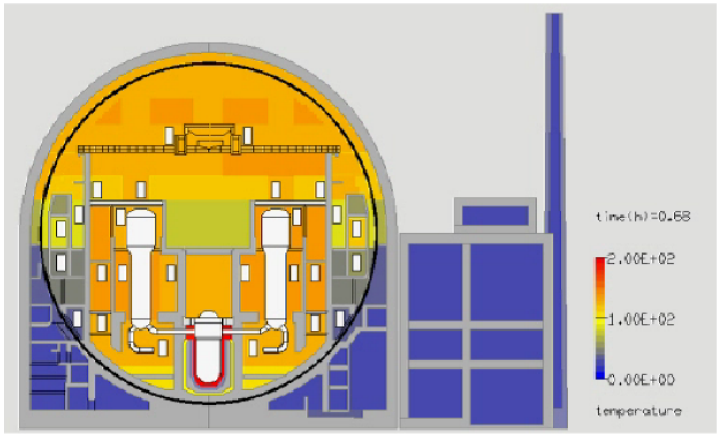
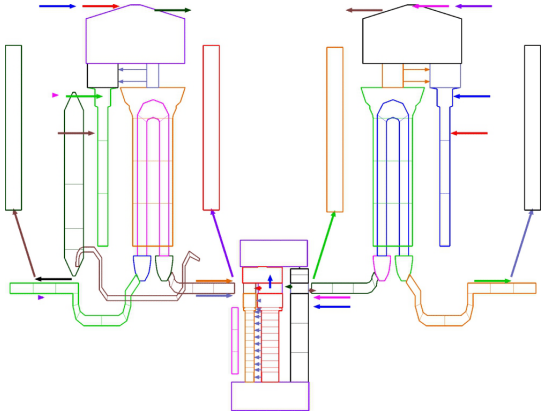




ATHLET

How would you simulate a nuclear reactor?

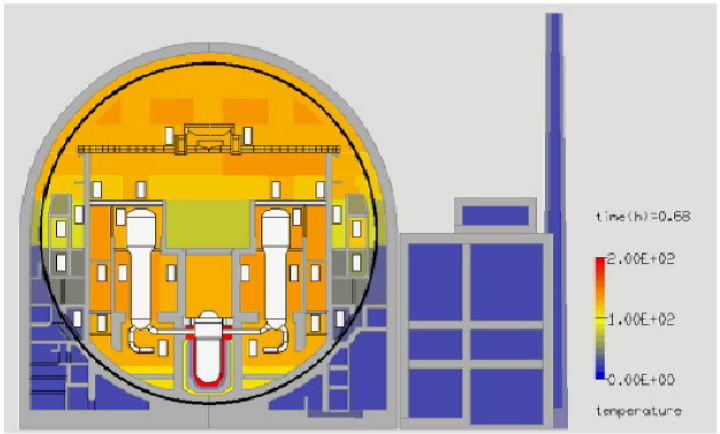


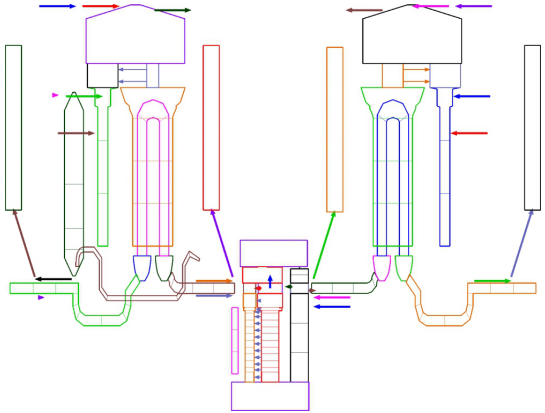


ATHLET

What if we could integrate higher dimension models? (in a plug-and-play way)

How would you simulate a nuclear reactor?





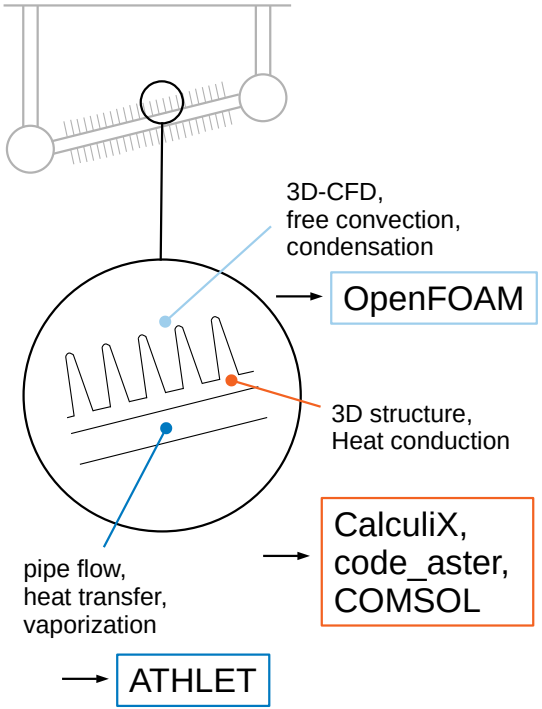
ATHLET

What if we could integrate higher dimension models? (in a plug-and-play way)

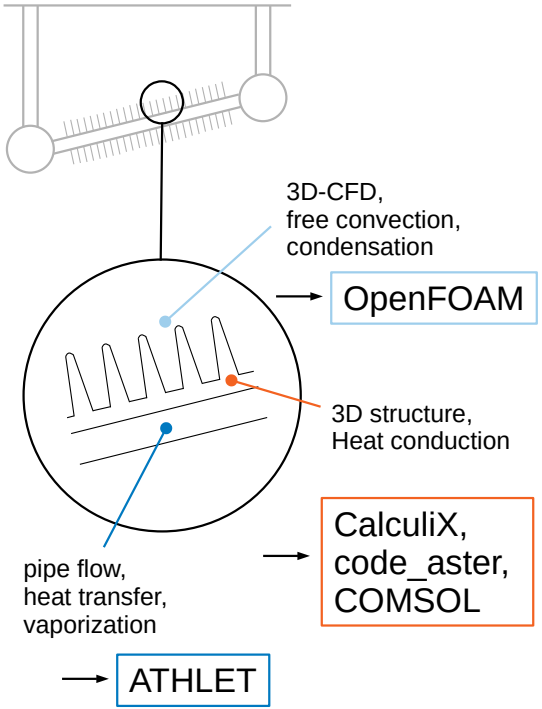
OpenFOAM

Pictures by GRS, available on `http://grs.de/`. OpenFOAM logo of OpenCFD, `www.openfoam.com`.

Nuclear reactor themohydraulics



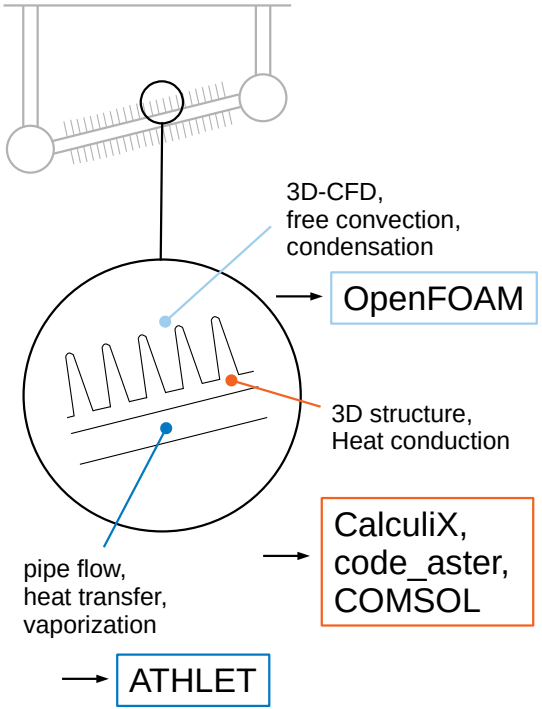
Nuclear reactor themohydraulics



Currently:
in-house coupling to OpenFOAM, ANSYS CFX, ...

J. Herb (2014). *Coupling OpenFOAM with thermo-hydraulic simulation code ATHLET*. 9th OpenFOAM Workshop, Zagreb.

Nuclear reactor themohydraulics



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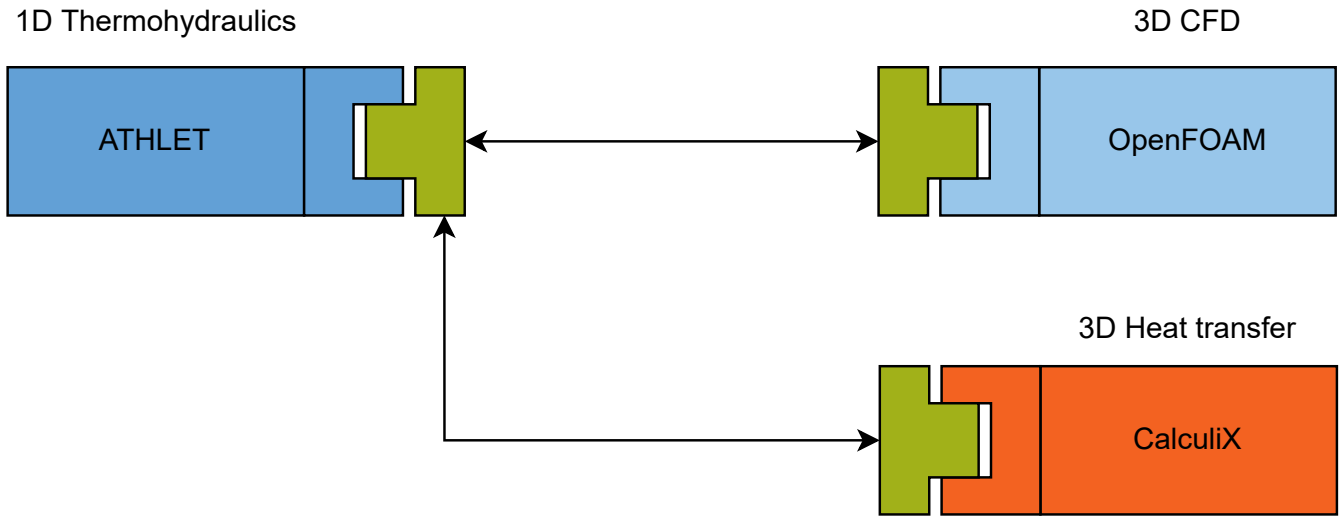
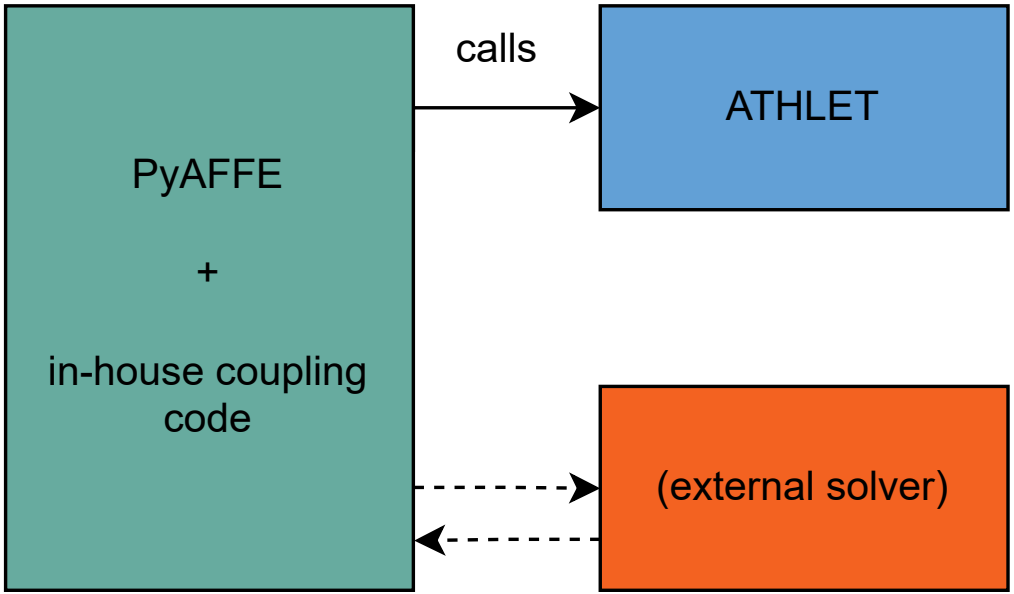
Long-term goal:
replace several existing coupling systems with a sustainable approach.

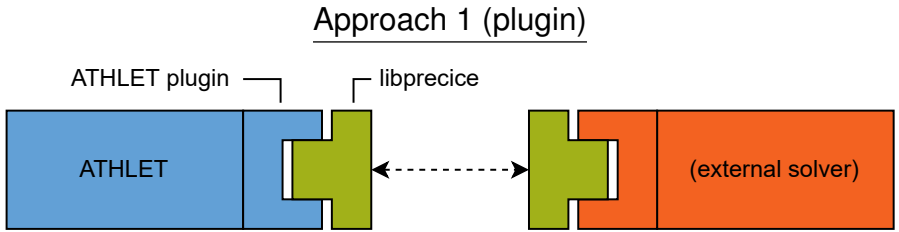
ATHLET + preCICE: ATHLET + many other solvers



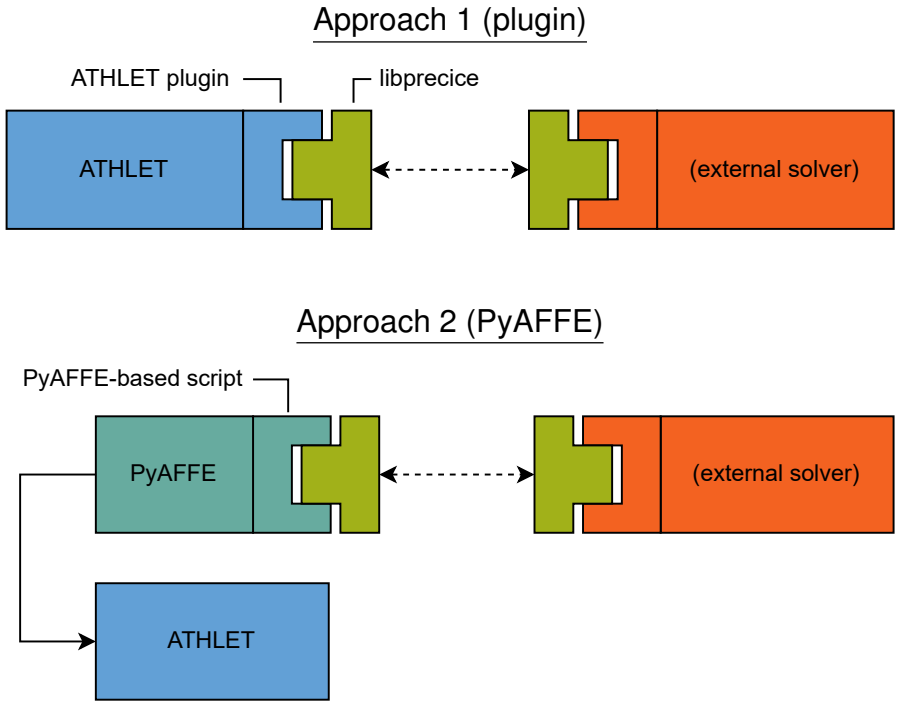
Architecture: In-house coupling (previous)



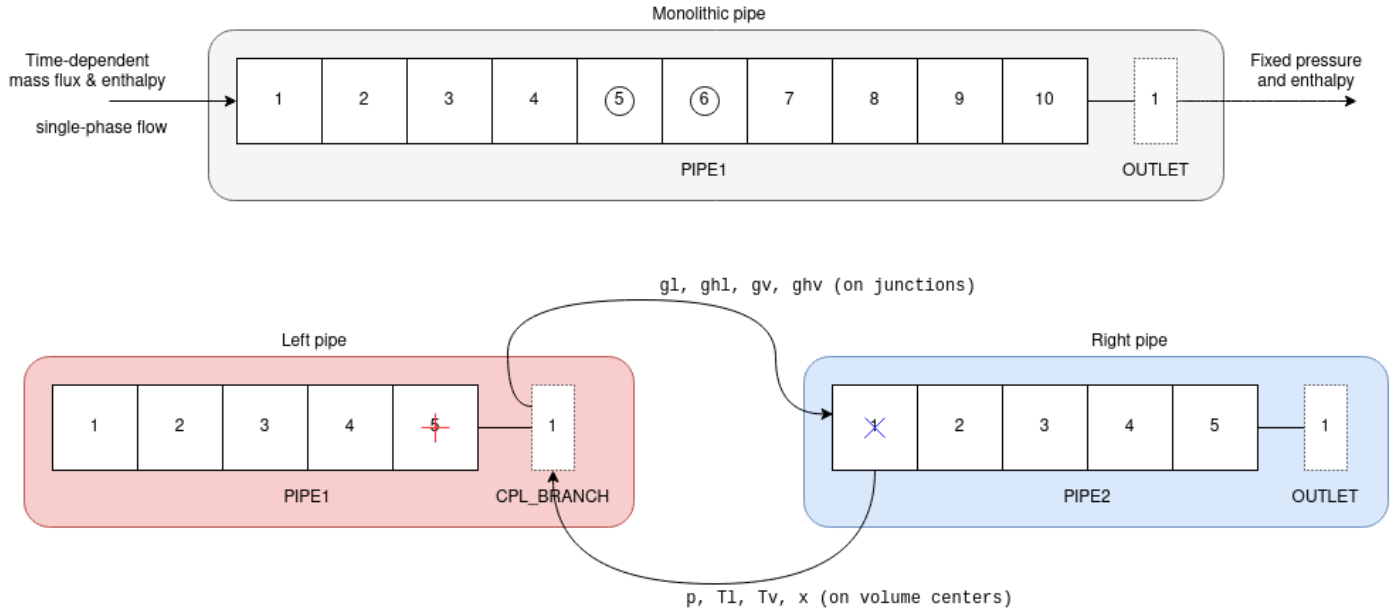
Architecture: Coupling with preCICE



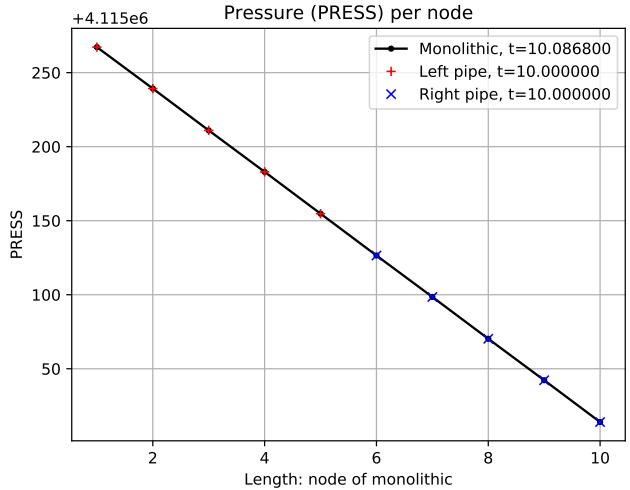
Architecture: Coupling with preCICE

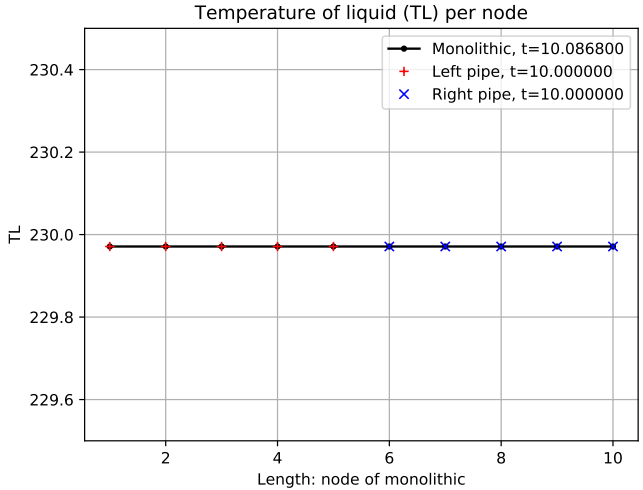


First step: Coupling ATHLET with ATHLET

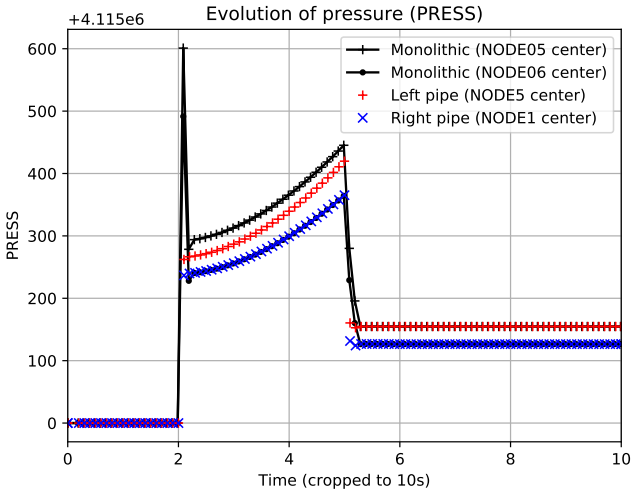


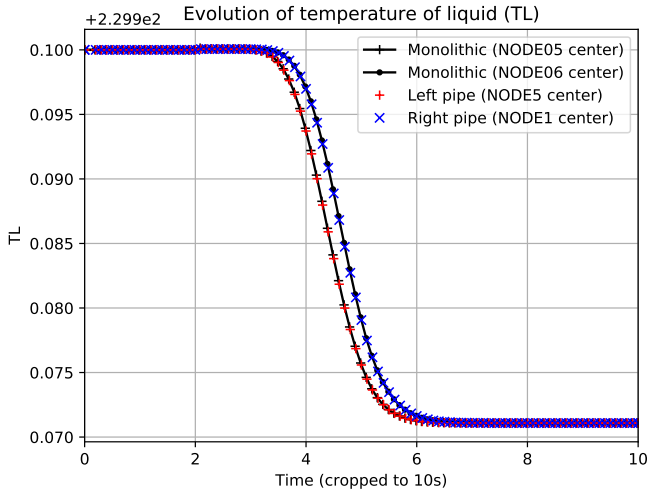
ATHLET-ATHLET: Looks good (per space)

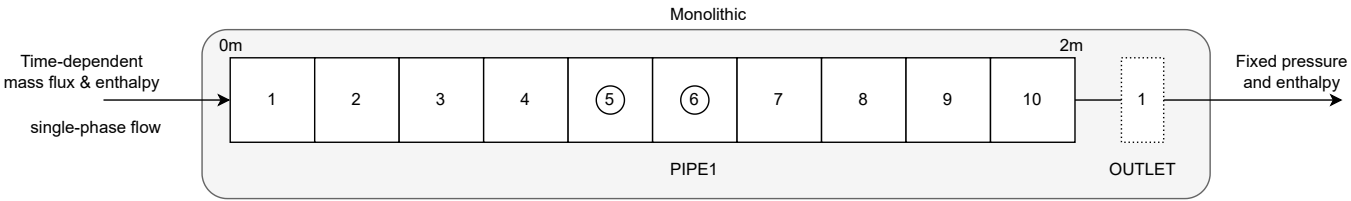




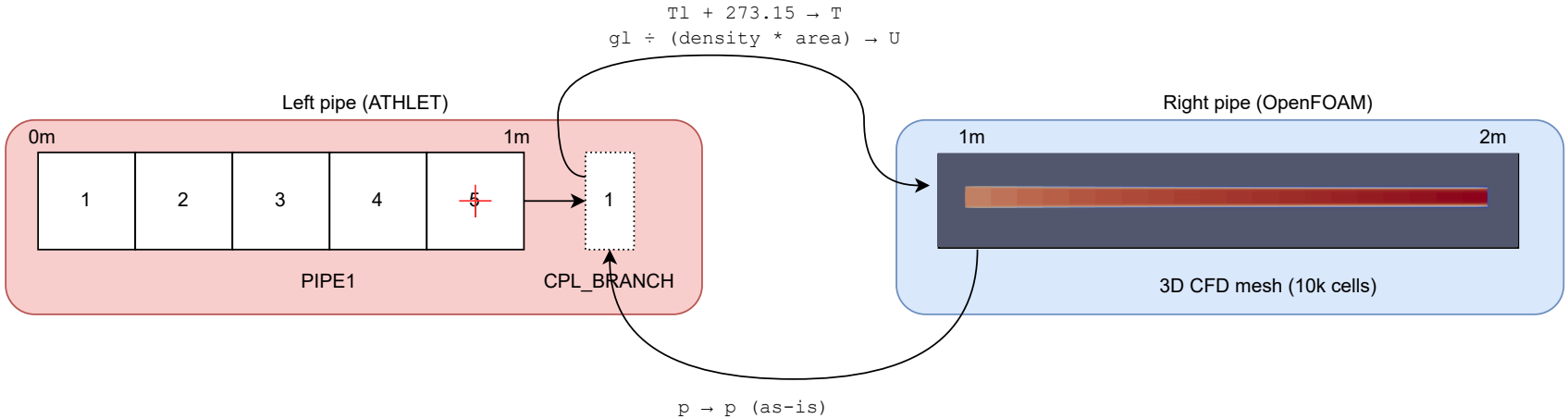
ATHLET-ATHLET: Looks good (per time as well)







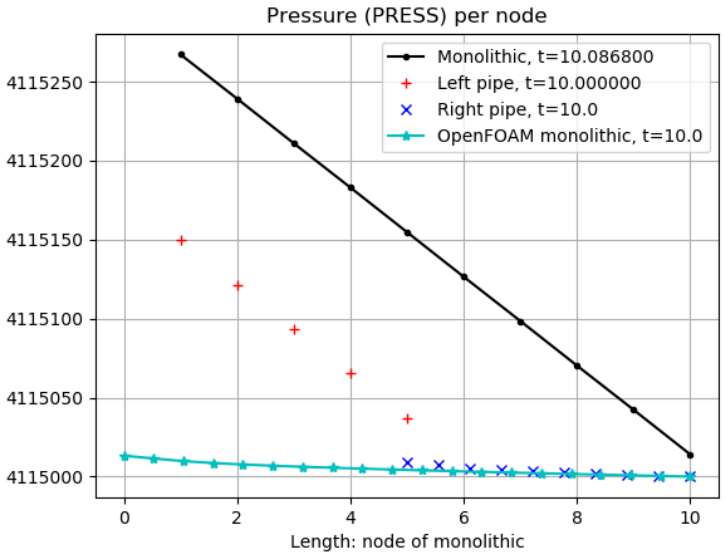
Coupling ATHLET with OpenFOAM

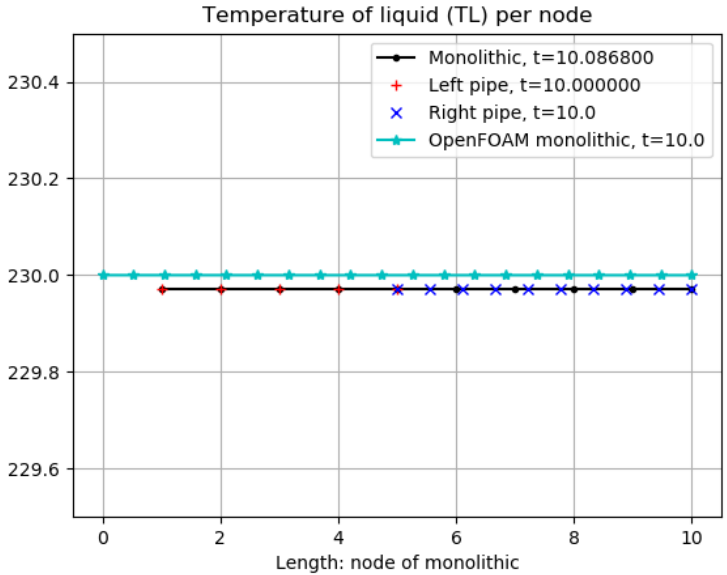


A few issues:

- Single-physics models need alignment (e.g., friction model in ATHLET)
- Different state variables: mass flux (1D) $\rightarrow$ velocity (3D)
- Material parameters: computed vs constant
- Temperature units: $^{\circ}\mathrm{C} \rightarrow ^{\circ}\mathrm{K}$

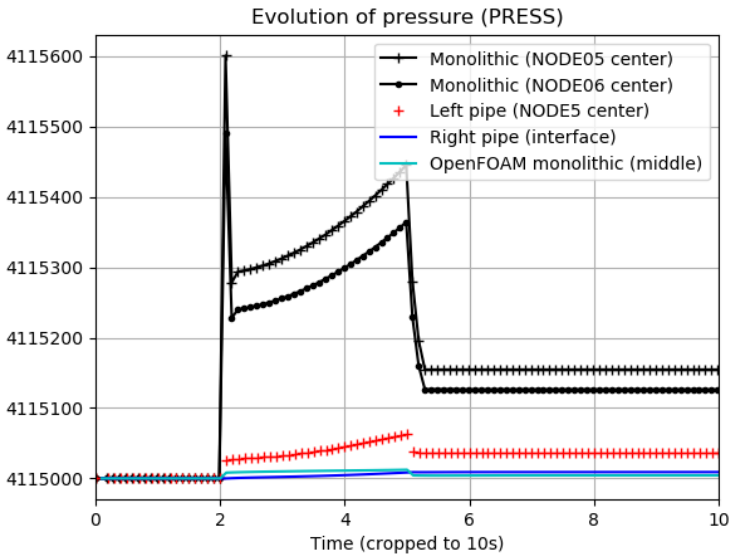
ATHLET-OpenFOAM: Results per space

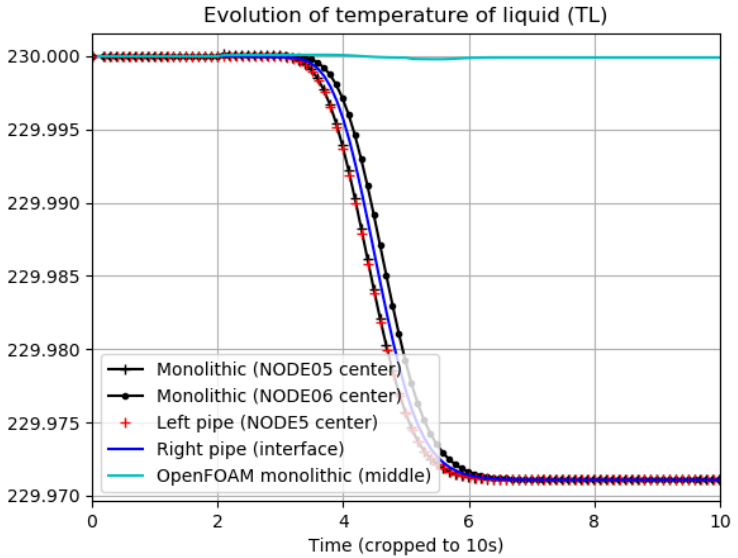




The two single-physics models are not exactly aligned (not an issue at the moment), but the coupling works.

ATHLET-OpenFOAM: Results per time





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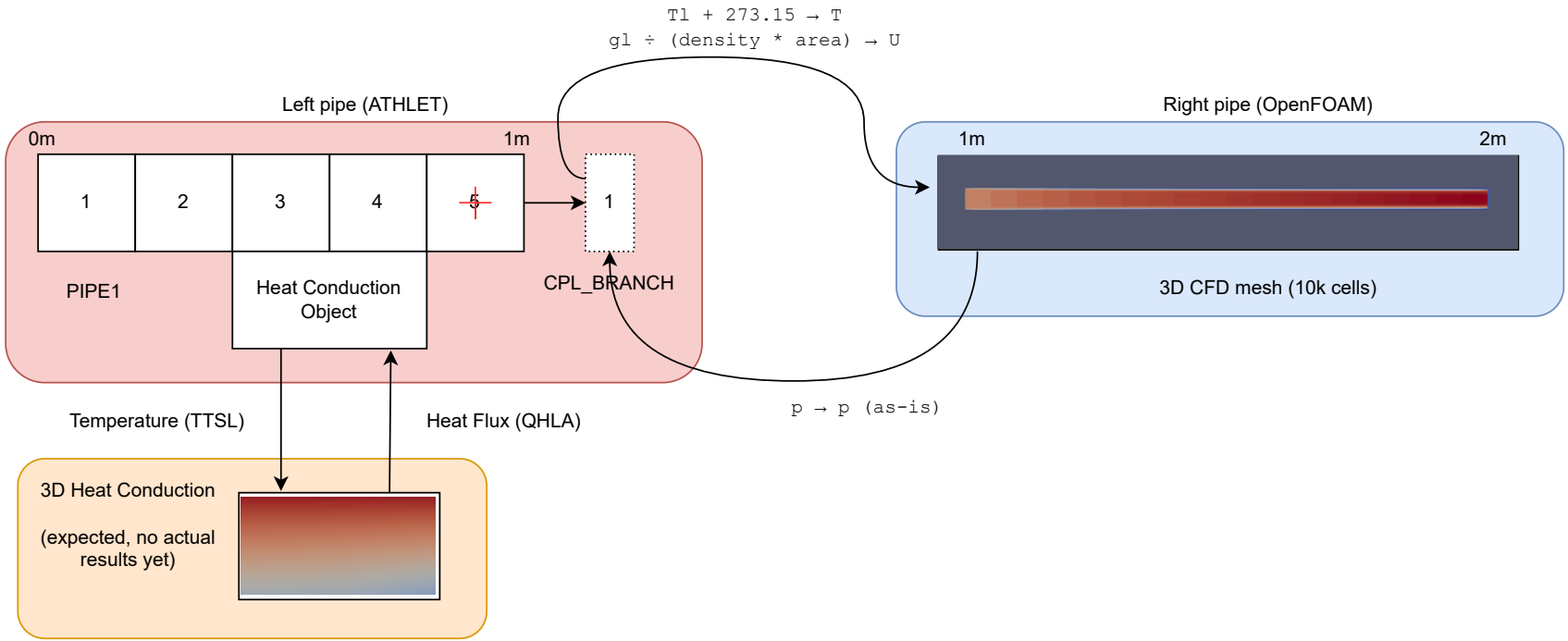
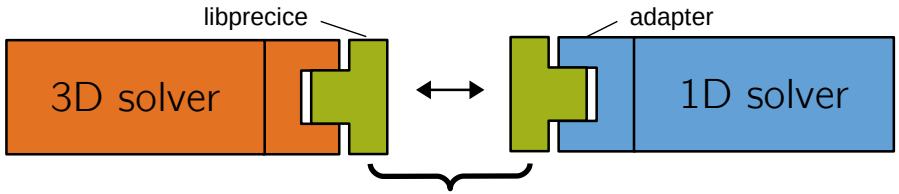
Next step: Coupling for Conjugate Heat Transfer



Bigger picture: Geometric multi-scale mapping in preCICE



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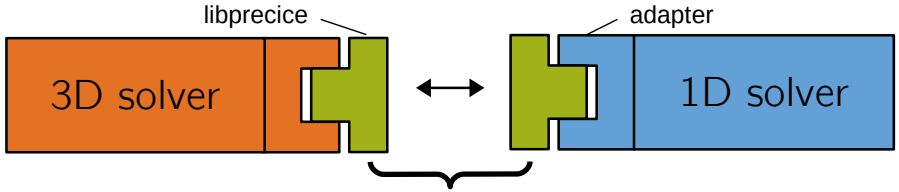
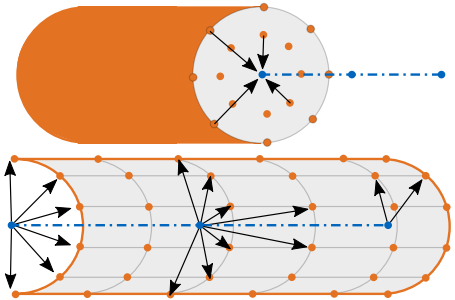




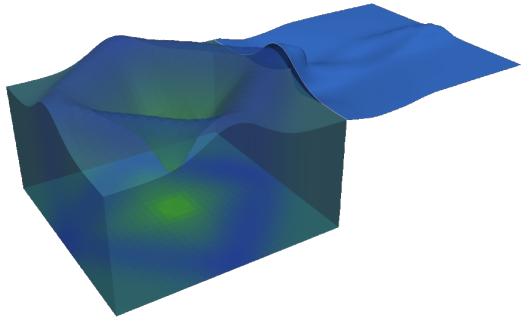
G. Chourdakis, B. Uekermann, G. van Zwieten, H. van Brummelen (2019). Coupling OpenFOAM to different solvers, physics, models, and dimensions using preCICE. 14th OpenFOAM Workshop.

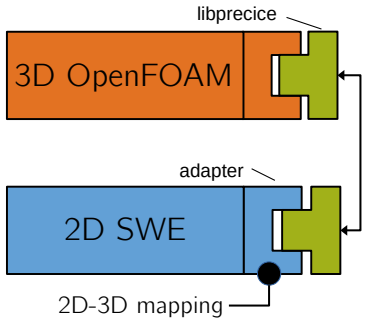
G. Chourdakis, Q. Huang, F. J. Espinosa Pelaez, F. Weyermann, B. Uekermann. *Geometric multi-scale coupling prototypes with preCICE*. Poster at SIAM CSE21.

Further geometric multi-scale examples

A quick flight over some prototypes

Tsunami near coast (2D-3D FF)

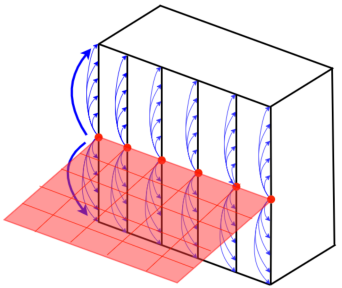




2D-3D two-phase flow

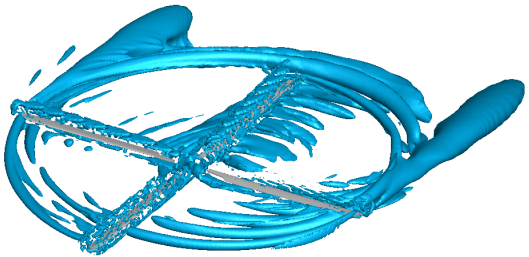
- 2D flow in large regions, shallow-water equations
- 3D flow in critical regions, Navier-Stokes equations

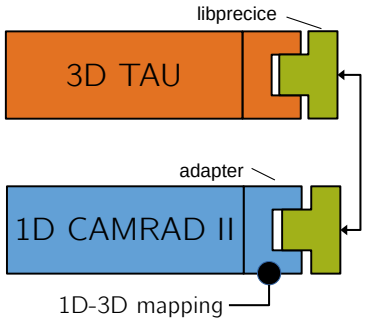
$\rightarrow$ axial 2D-3D mapping



F.J. Espinosa Pelaez (2020). *A flexible approach to 2D-3D coupling of a Shallow-Water Equation solver to OpenFOAM*.
Master's Thesis. Technical University of Munich.

Helicopter blades (1D-3D FSI)

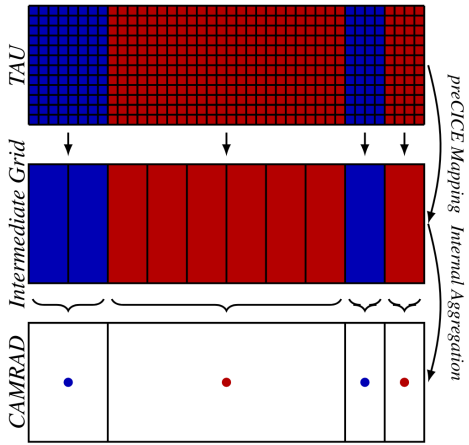




1D-3D FSI

- 1D helicopter blade shape (CAMRAD II)
- 3D flow around the blade (DLR TAU)

$\rightarrow$ radial 1D-3D mapping



Q. Huang, A. Abdelmoula, G. Chourdakis, J. Rauleder, B. Uekermann (2021). *CFD/CSD Coupling for an Isolated Rotor using preCICE*. Proceedings of the ECCOMAS WCCM 2020.

Funding preCICE

Supported by:

Federal Ministry
for the Environment, Nature Conservation,
Nuclear Safety and Consumer Protection

based on a decision of
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DFG

- Research Software Sustainability
- EXC 2075 SimTech

EuroTech Universities

SPPEXA

KONWIHR

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 754462

Summary

Goal:	Flexible coupling of ATHLET with other codes via preCICE
Challenges:	Programming interface, single-physics models, different state descriptions
Next steps:	Conjugate heat transfer, validation, more complex scenarios
Big picture:	General-purpose geometric multi-scale mapping in preCICE

Contact me: I am looking for use cases for geometric multiscale coupling

gerasimos.chourdakis@tum.de

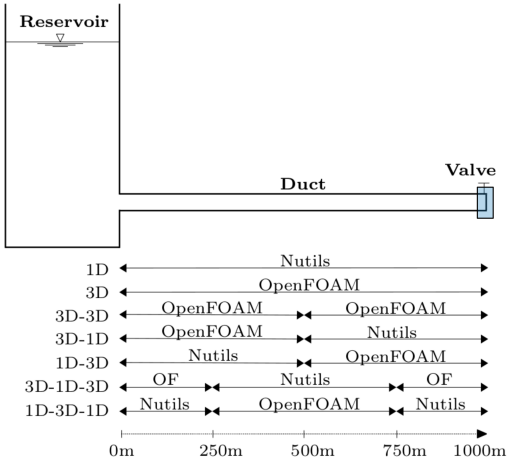
- precice.org
- github.com/precice
- @_makCh, @preCICE_org
- precice.discourse.group
  gitter.im/precice

Slides & feedback:

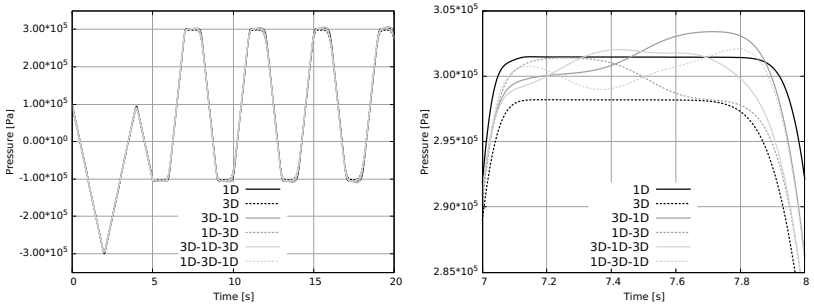
go.tum.de/120326

preCICE

Water hammer (1D-3D fluid-fluid coupling)



1D single-phase flow in a pipe, opening-closing valve, axial mapping



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14th OpenFOAM Workshop, Duisburg.

Proof-of-concept:
feasibility, workbench for developing methods.
OpenFOAM + Nutils (`www.nutils.org`, Python), mapping directly in preCICE