

Coupling OpenFOAM with 1D thermohydraulics via preCICE

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Chair of Scientific Computing in Computer Science (SCCS)

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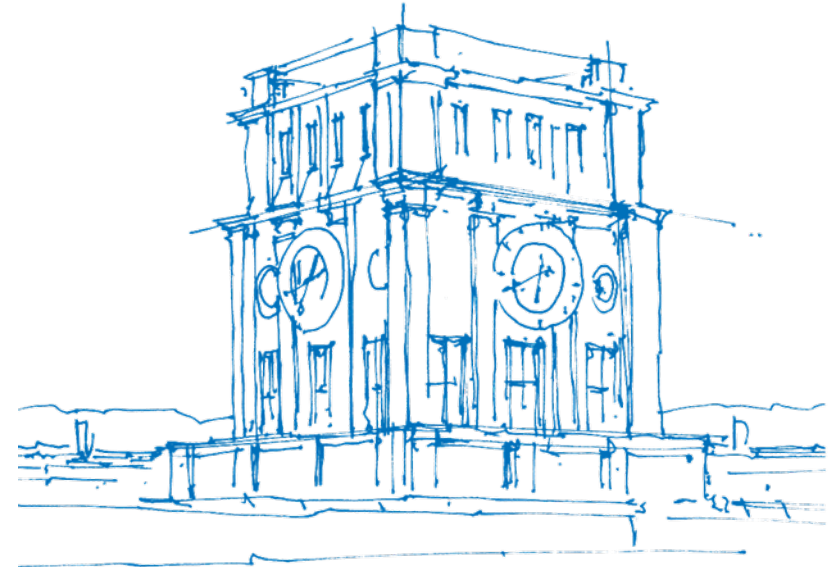
³University of Stuttgart

Institute for Parallel and Distributed Systems (IPVS)

Chair of Usability and Sustainability of Simulation Software

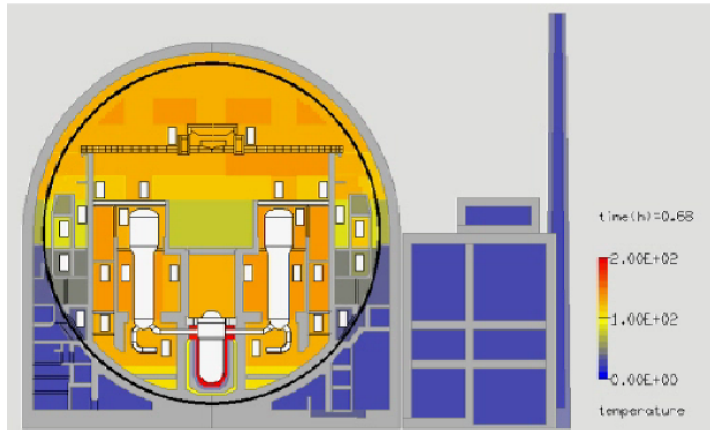
17th OpenFOAM Workshop

Cambridge, July 14, 2022

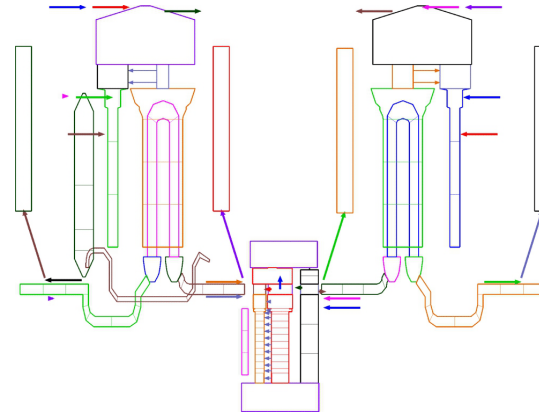
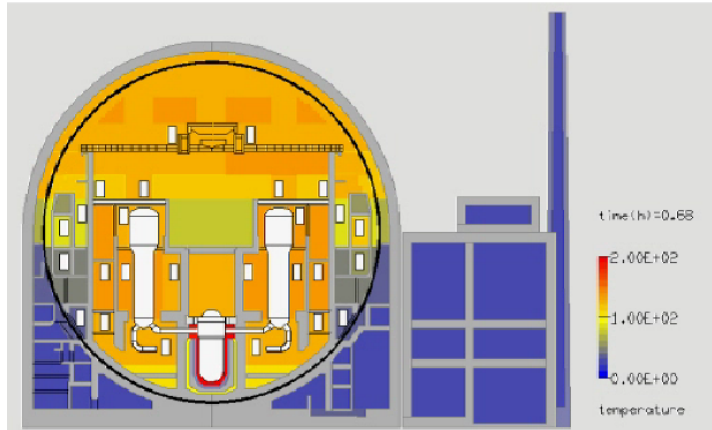


TUM Uhrenturm

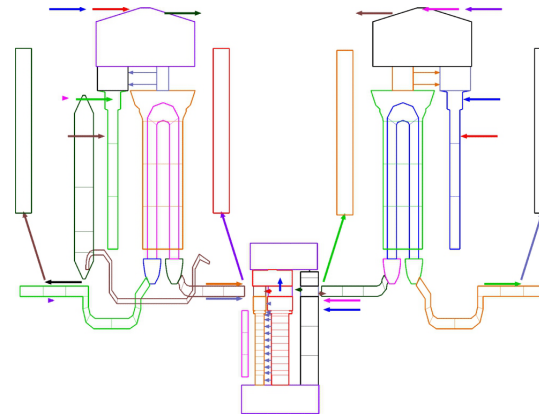
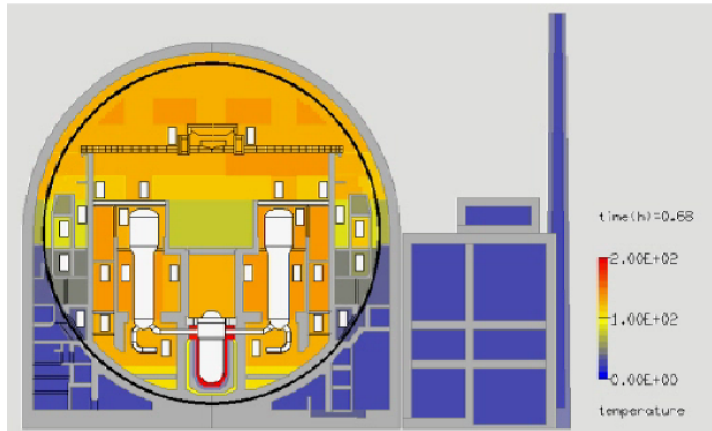
How would you simulate a nuclear reactor?



How would you simulate a nuclear reactor?



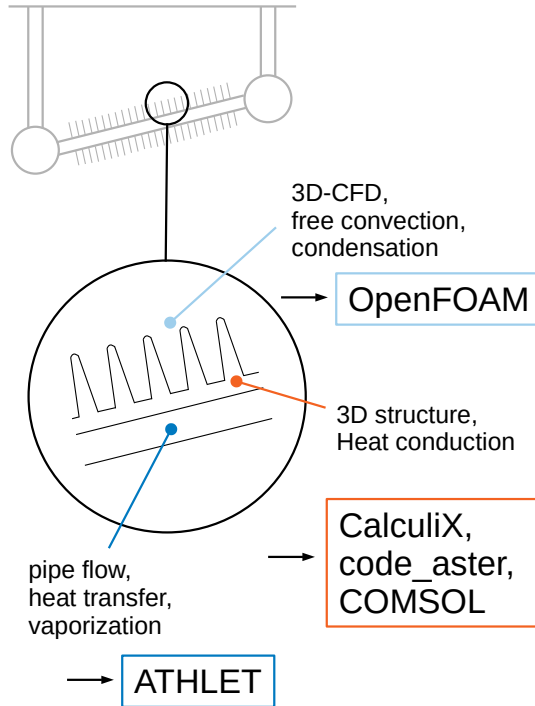
How would you simulate a nuclear reactor?



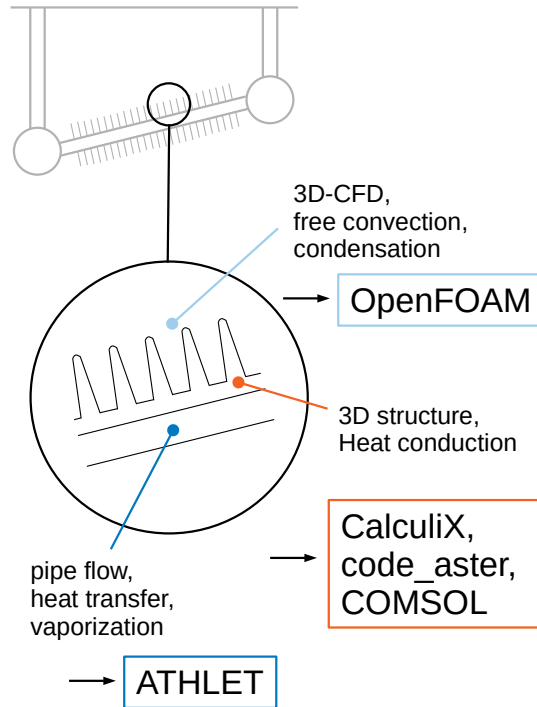
What if we could integrate higher dimension models? (in a plug-and-play way)



Nuclear reactor themohydraulics



Nuclear reactor themohydraulics

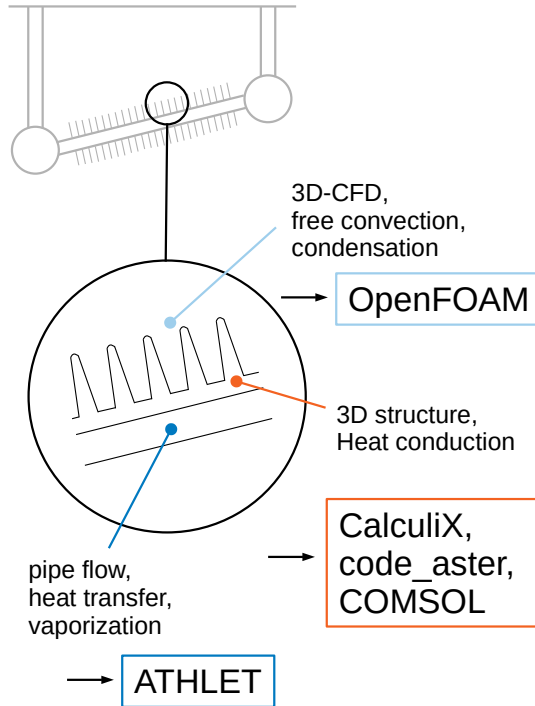


Previously:

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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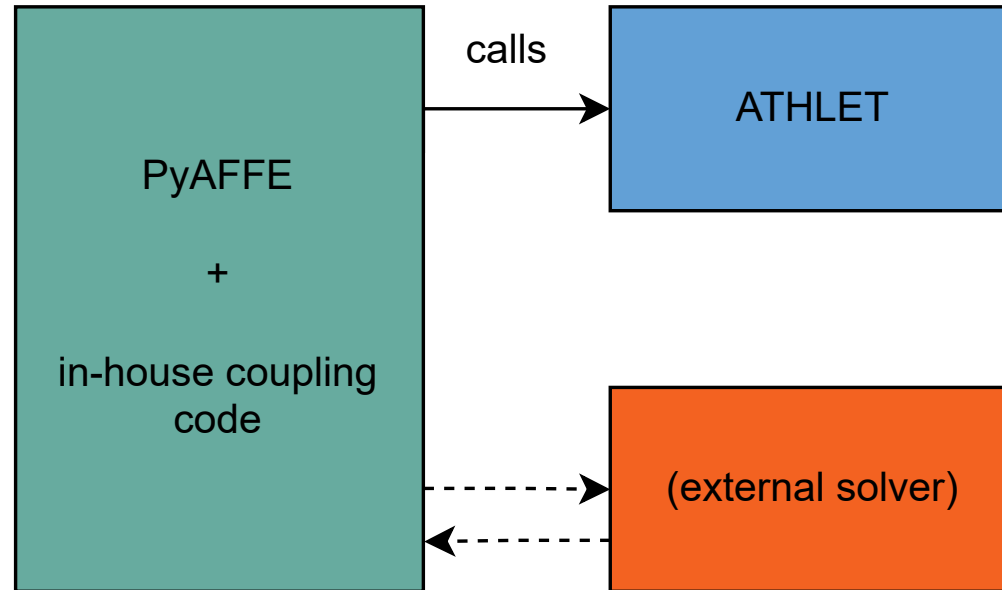
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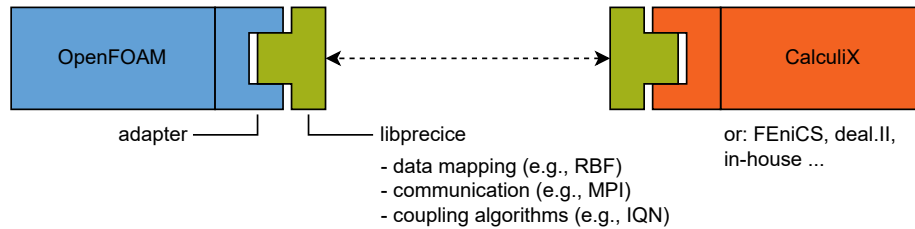
Long-term goal:

replace several existing coupling systems
with a sustainable approach.

Previously: In-house coupling

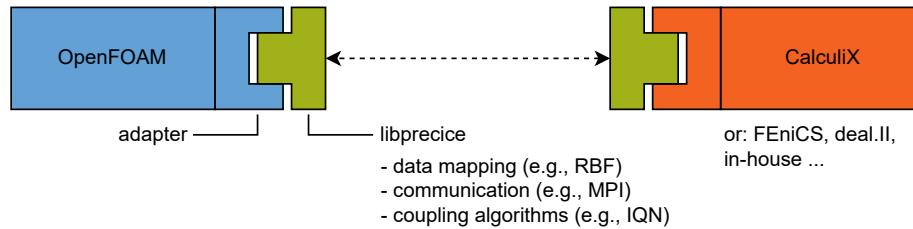


preCICE: a coupling library for partitioned multi-physics



```
while (t < t_end){
    solve(dt);
    precice.write_data(force);
    max_dt = precice.advance(dt);
    precice.read_data(displacement);
}
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preCICE: a coupling library for partitioned multi-physics



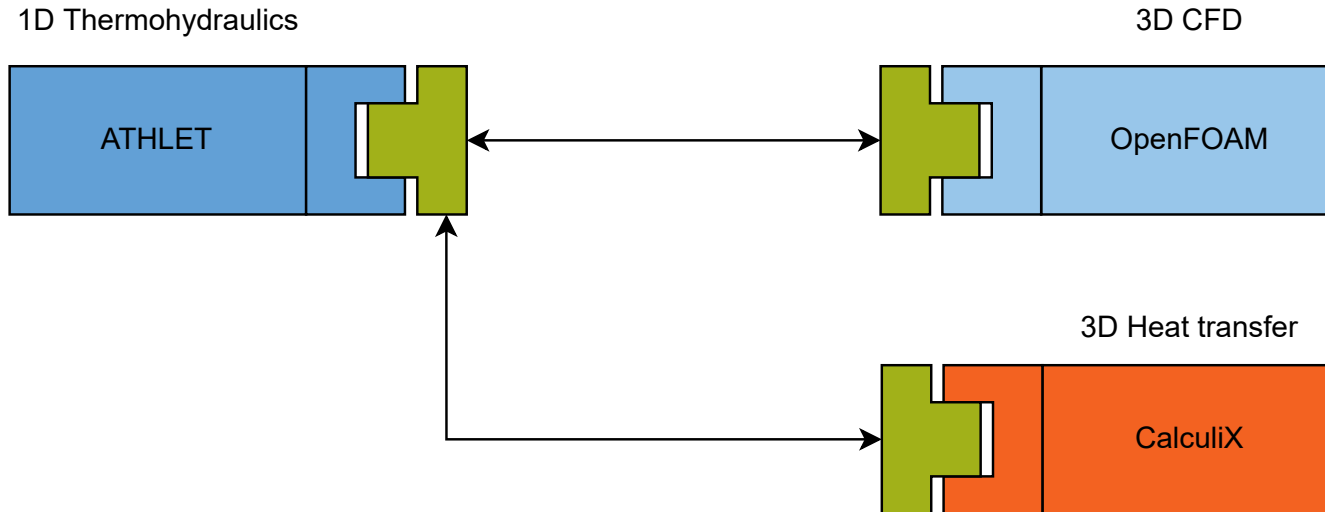
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}
```

Adapters and examples for: OpenFOAM, SU2, CalculiX, deal.II, FEniCS, DUNE, Nutils, code_aster ...

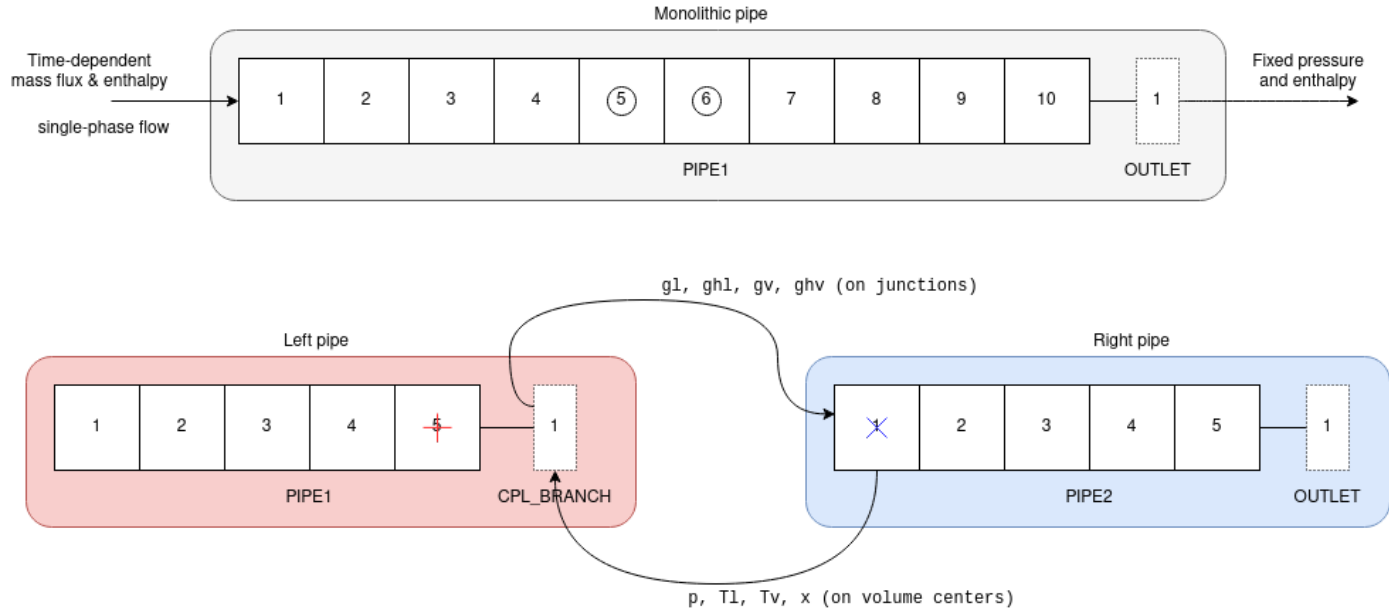
API in C++, C, Fortran, Python, Matlab, Julia

Community in fluid-structure interaction, conjugate heat transfer, porous media, ...

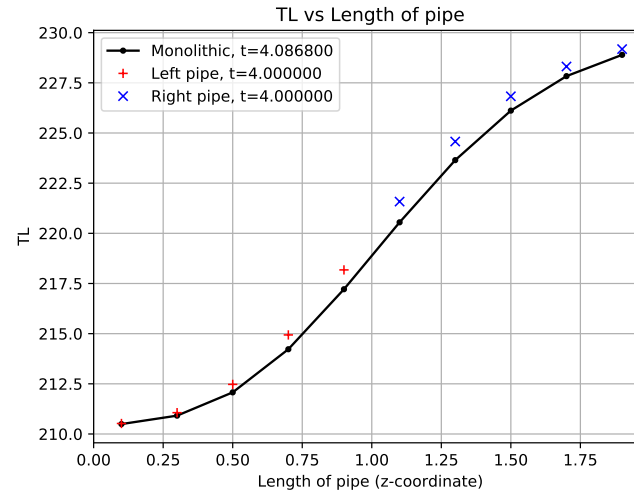
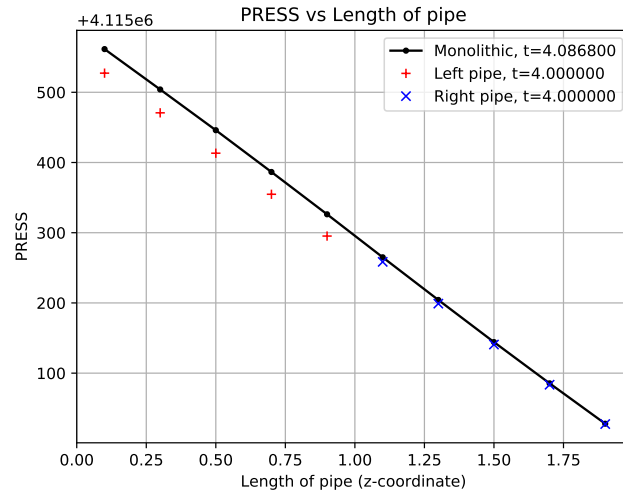
ATHLET + preCICE: ATHLET + many other solvers



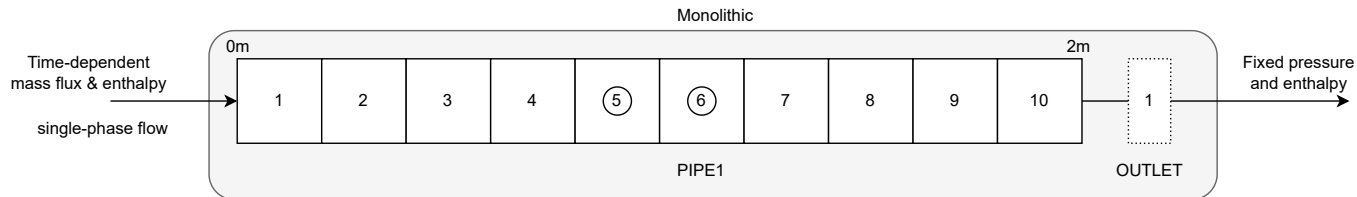
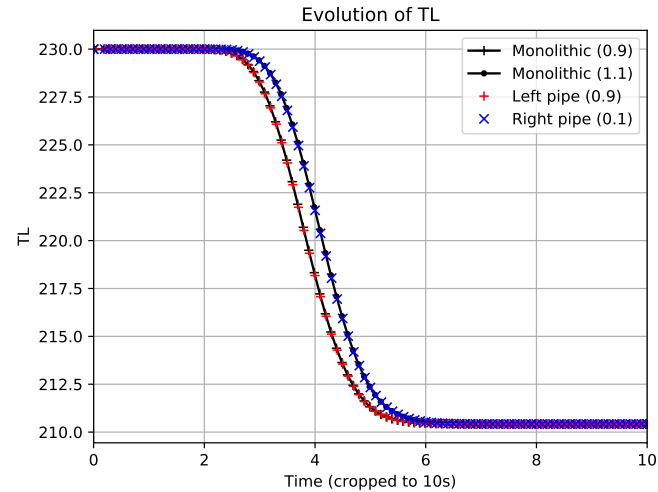
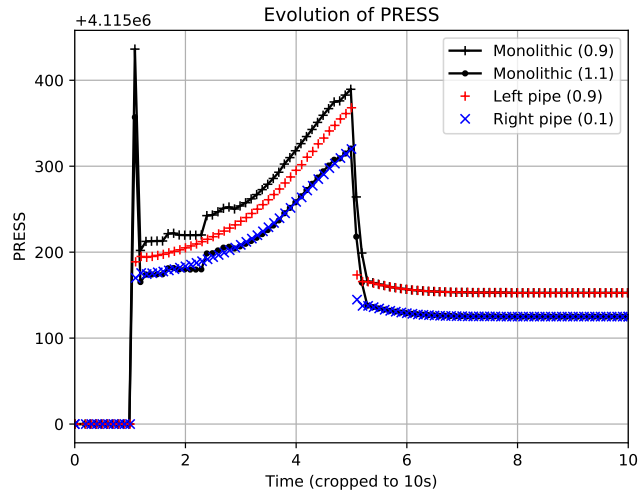
First step: Coupling ATHLET with ATHLET



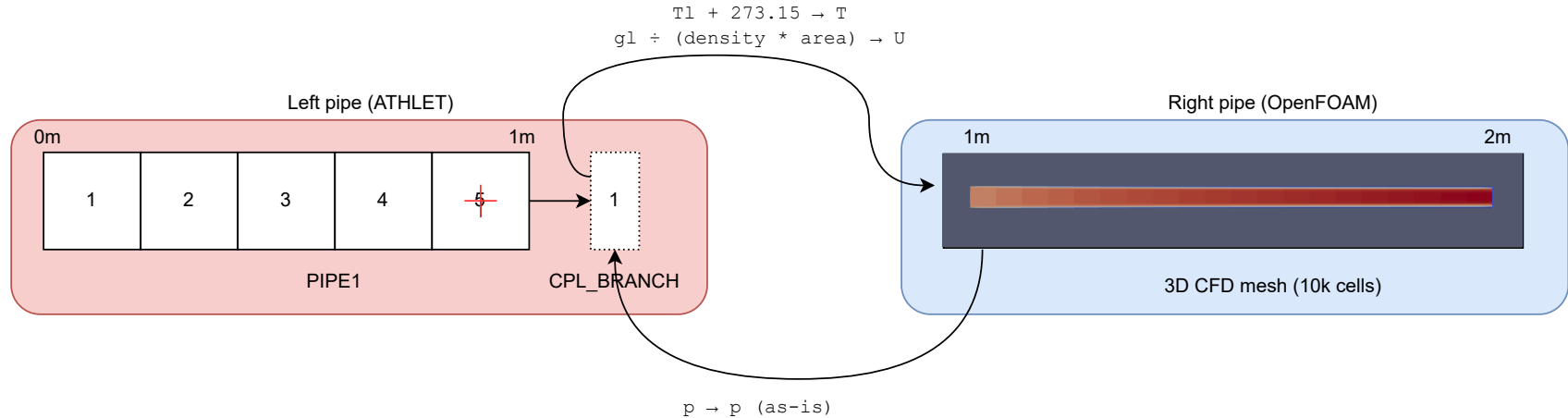
ATHLET-ATHLET: Looks good (per space)



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



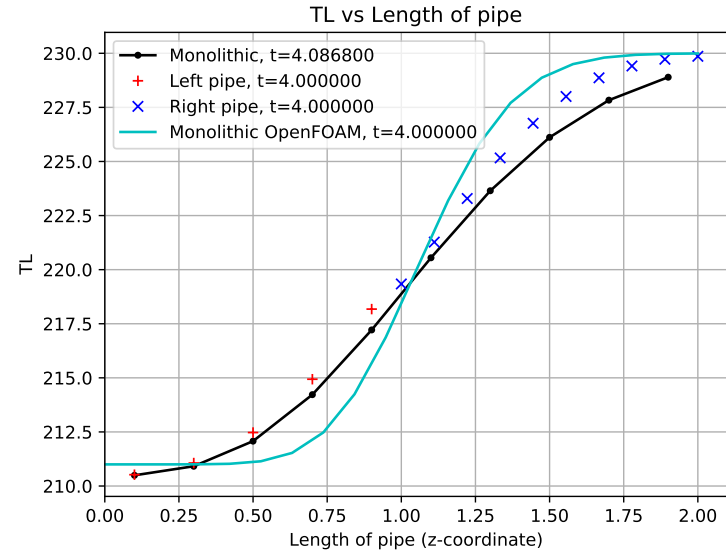
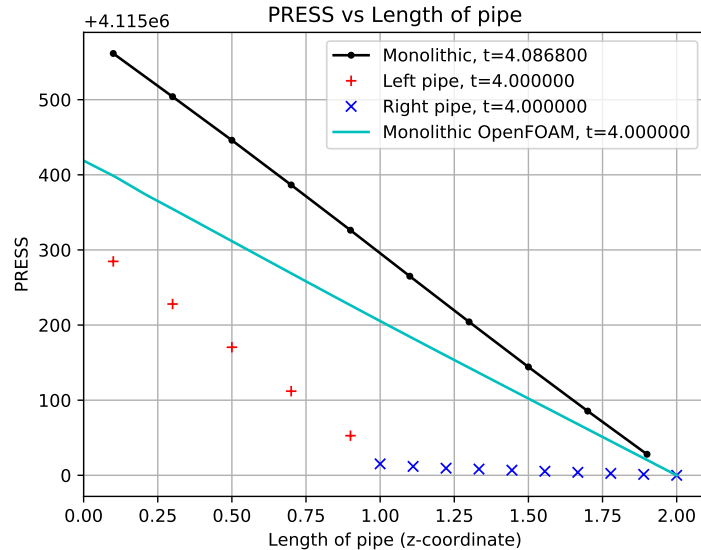
Coupling ATHLET with OpenFOAM



A few issues:

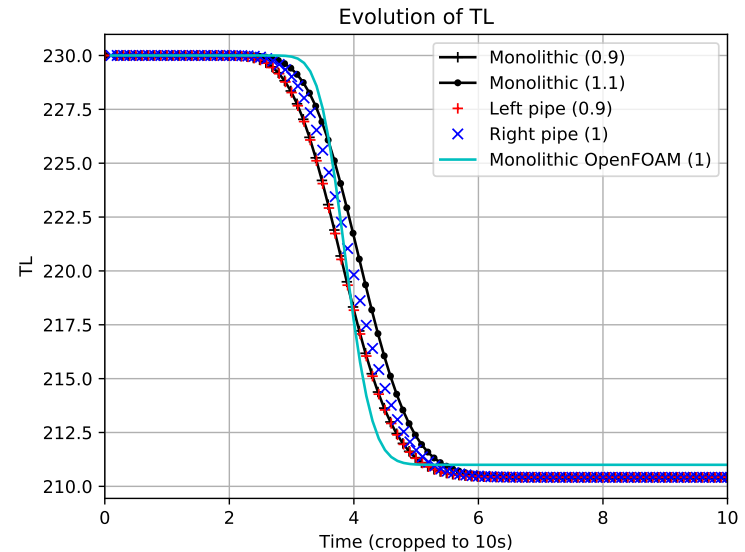
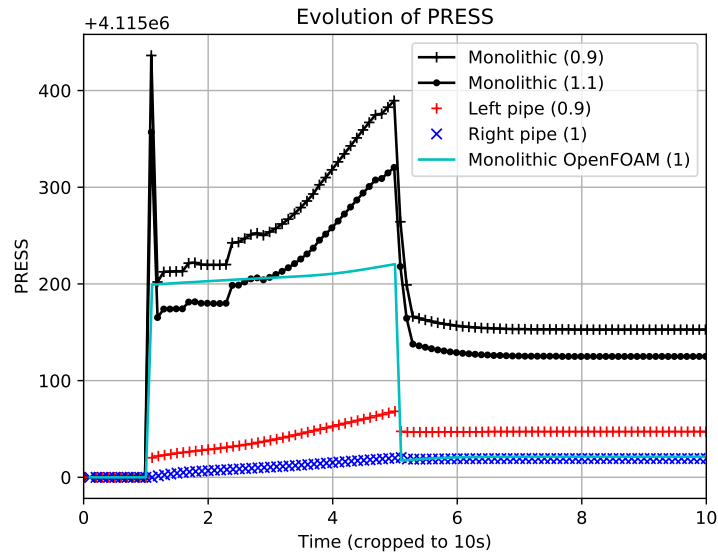
- Single-physics models need alignment (e.g., friction model in ATHLET)
- Different state variables: mass flux (1D) \rightarrow velocity (3D)
- Material parameters: computed vs constant
- Temperature units: $^{\circ}\text{C} \rightarrow ^{\circ}\text{K}$

ATHLET-OpenFOAM: Results per space



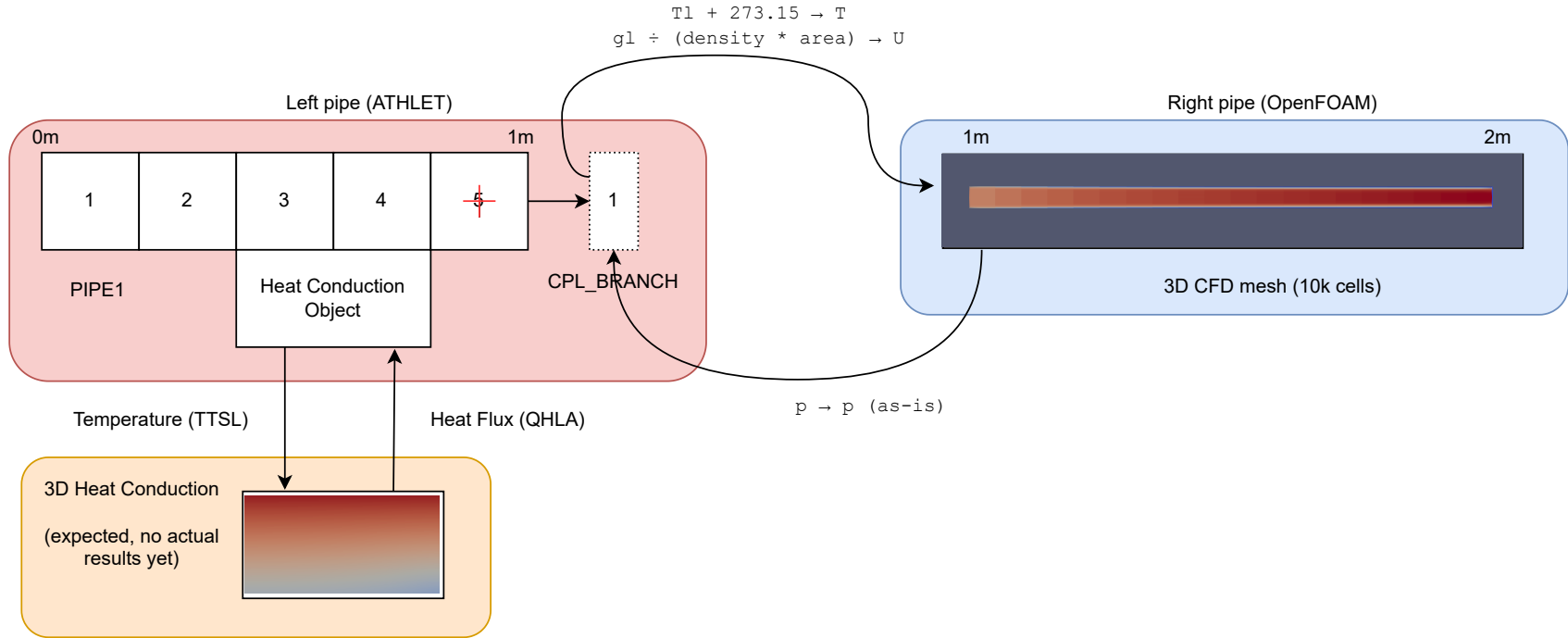
The two single-physics models are not exactly aligned (not an issue at the moment), but the coupling works.

ATHLET-OpenFOAM: Results per time

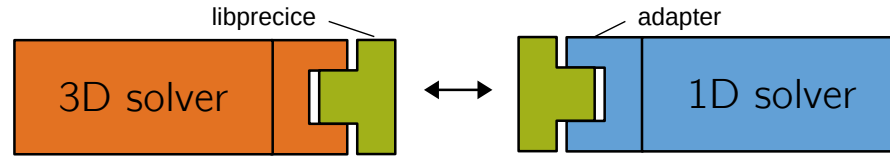


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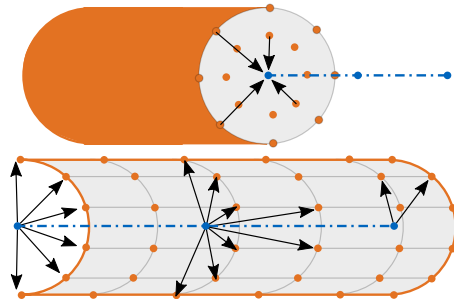
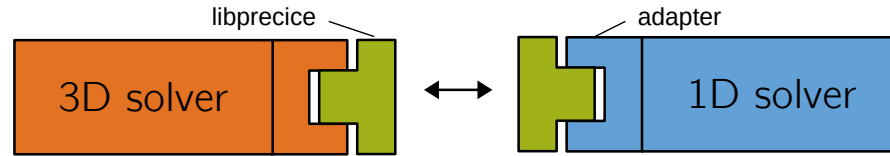
Next step: Coupling for Conjugate Heat Transfer



Bigger picture: Geometric multi-scale mapping in preCICE



Bigger picture: Geometric multi-scale mapping in preCICE



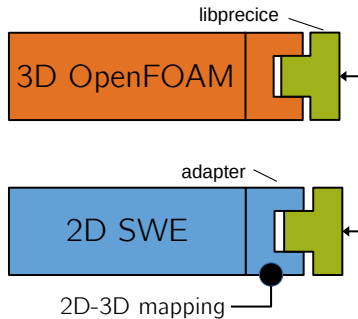
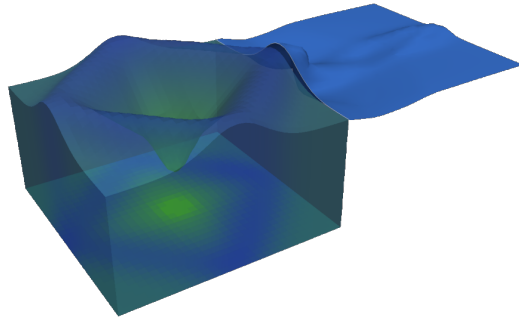
G. Chourdakis, B. Uekermann, G. van Zwieten, H. van Brummelen (2019). Coupling OpenFOAM to different solvers, physics, models, and dimensions using preCICE. 14th OpenFOAM Workshop.

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

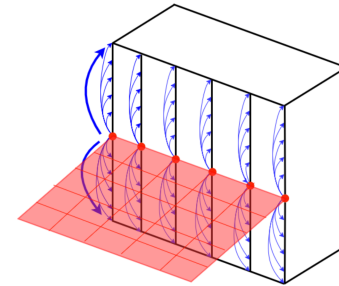
Tsunami near coast (2D-3D FF)



2D-3D two-phase flow

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

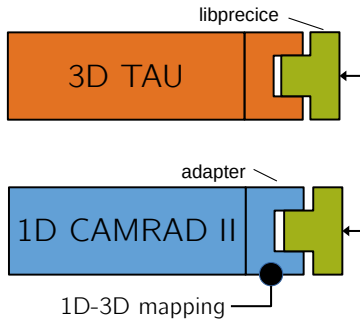
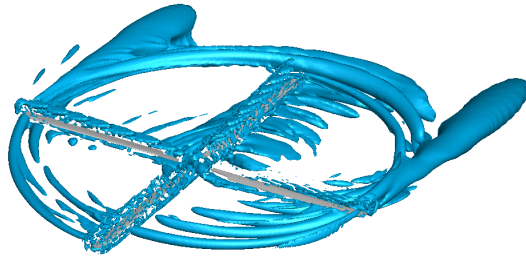
→ axial 2D-3D mapping



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.

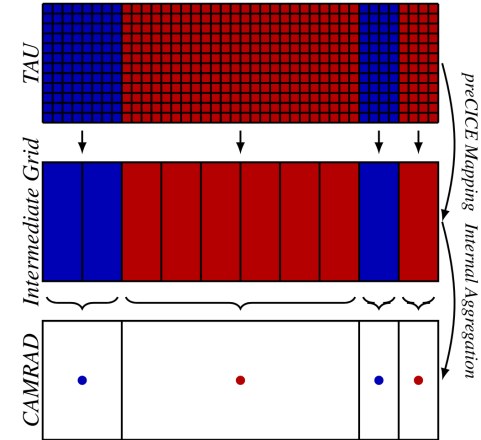
Helicopter blades (1D-3D FSI)



1D-3D FSI

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

→ 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:



based on a decision of
the German Bundestag



- Research Software Sustainability
- EXC 2075 SimTech



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



New preCICE v2 reference paper


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SOFTWARE TOOL ARTICLE

preCICE v2: A sustainable and user-friendly coupling library [version 1; peer review: 2 approved]

Gerasimos Chourdakis, Kyle Davis, Benjamin Rodenberg, Miriam Schulte, Frédéric Simonis, Benjamin Uekermann, Georg Abrams, Hans-Joachim Bungartz, Lucia Cheung Yau, Ishaan Desai, Konrad Eder, Richard Hertrich, Florian Lindner, Alexander Rusch, Dmytro Sashko, David Schneider, Amin Totounferoush, Dominik Volland, Peter Vollmer, Oguz Ziya Koseomur

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Open Peer Review

Approval Status ✓✓

	1	2
Version 1 29 Apr 22	✓ view	✓ view

- Axelle Viré, Delft University of Technology, Delft, The Netherlands
- Garth Wells, University of Cambridge, Cambridge, UK

Comments on this article

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

See also: Prof. Gavin Tabor: *“Coupled Fluid Structure Modelling of a Wind Turbine Blade”*
(Today at 13:00, Turbomachinery I, Wolfson Hall)

 precice.org
 github.com/precice
 [@_makCh, @preCICE_org](https://twitter.com/_makCh)
 precice.discourse.group
 gitter.im/precice

Slides & feedback:



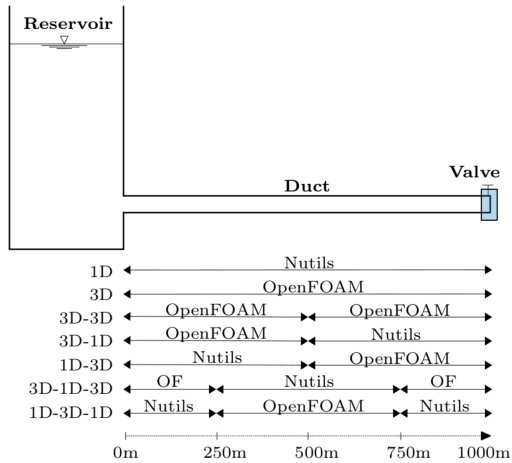
go.tum.de/613308

(Note: looking for a research stay abroad in 2023)

 preCICE

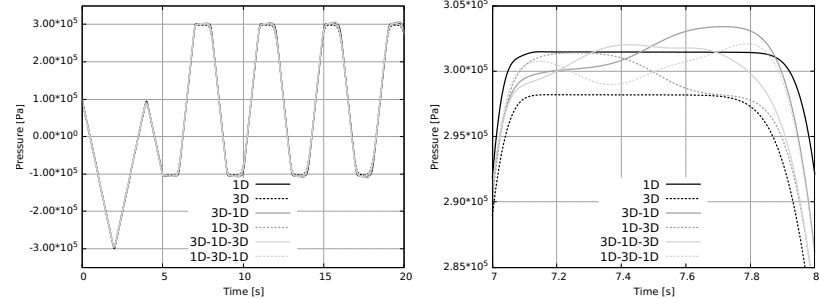


Water hammer (1D-3D fluid-fluid coupling)



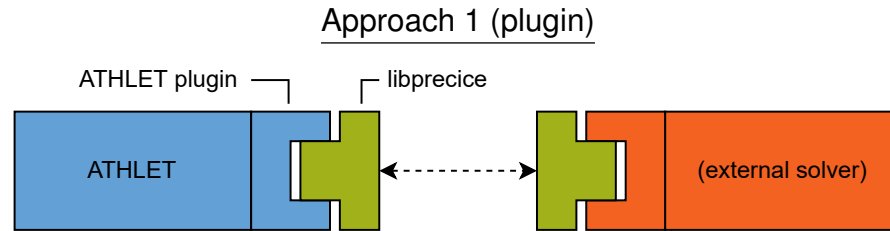
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1D single-phase flow in a pipe, opening-closing valve, axial mapping



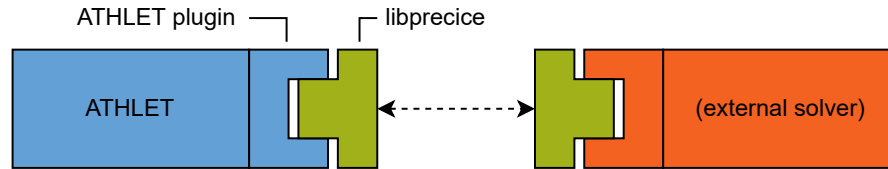
Proof-of-concept:
 feasibility, workbench for developing methods.
 OpenFOAM + Nutils (www.nutils.org, Python),
 mapping directly in preCICE

Architecture: Coupling with preCICE

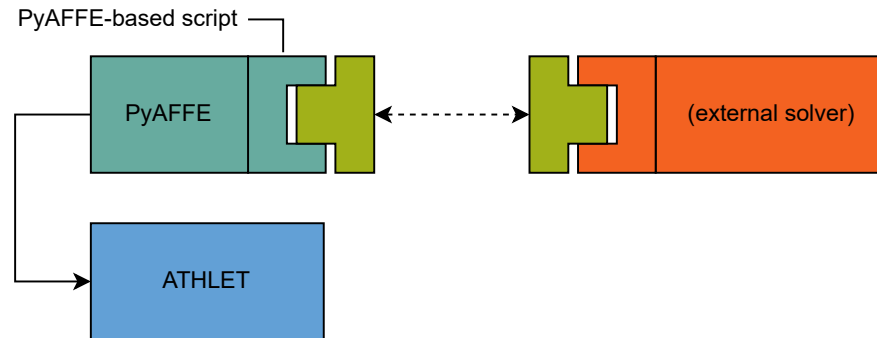


Architecture: Coupling with preCICE

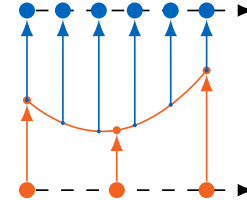
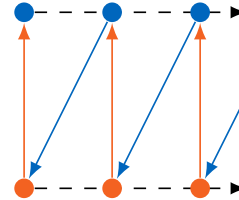
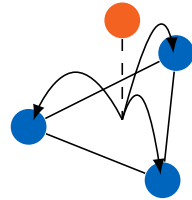
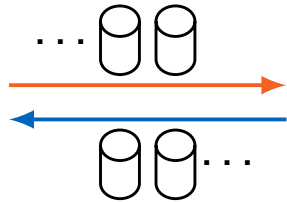
Approach 1 (plugin)



Approach 2 (PyAFFE)



Main features



Communication

- Options:
- MPI ports (fast)
 - TCP sockets (robust)

Fully-parallel, peer-to-peer

Data mapping

- Options:
- radial-basis functions
 - projection-based
 - conservative/consistent
 - direct mesh access

Compute on any side

Coupling schemes

- Options:
- serial / parallel
 - explicit / implicit
 - compositional, multi
 - IQN, Aitken, ...

Same high-level API
Configurable at runtime

Time interpolation

- Options:
- waveform iteration

Experimental since v2.4.0