

# Partitioned Fluid-Structure Interaction with the Coupling Library preCICE

CCP-WSI  
Code Developers' Workshop 2  
April 8, 2021

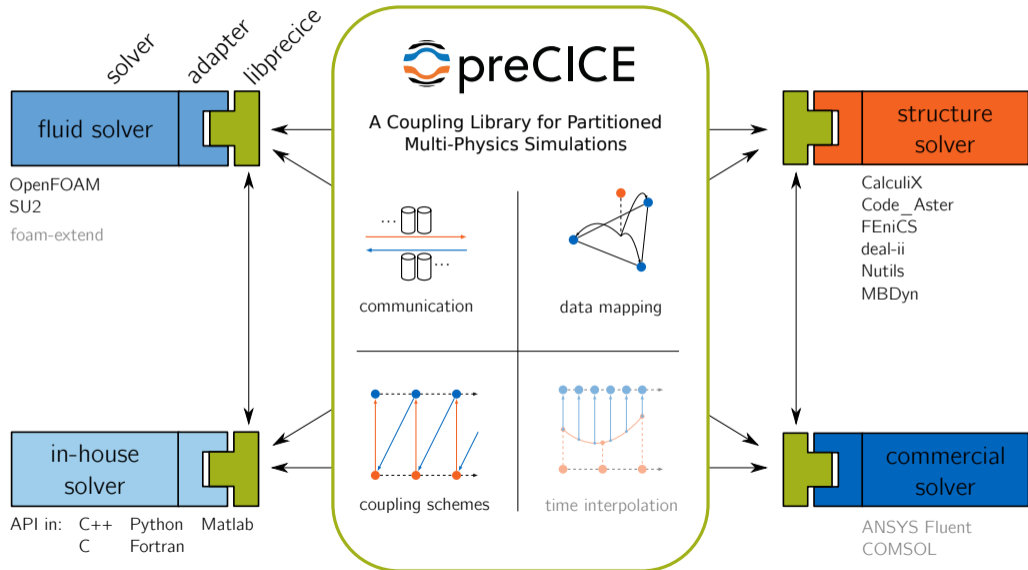
Gerasimos Chourdakis (TUM), Benjamin Uekermann (U Stuttgart)

## Outline

1. Fundamentals
2. Live Demo
3. What is an Adapter?
4. Resources
5. Coupling Schemes

# 1. Fundamentals

# The Big Picture



# Who uses preCICE?

- ▶ We know of  $\approx 80$  groups that use preCICE
- ▶ 50% academia, 25% non-academic research centers, 25% industry
- ▶ Many different applications: aerodynamics, astronautics, automotive manufacturing, wind energy, biomechanics, marine engineering, nuclear fusion, reactor safety, . . .
- ▶ 50% fluid-structure interaction



Oden Institute  
USA



CIRA  
Italy



Fluid Mechanics  
Germany



Applied Mechanics  
Germany



STS  
Germany



Aerodynamics  
Netherlands



Heat and Mass Transfer  
TC  
Spain



IFL  
Germany



Scientific Computing  
Germany



University of the Free  
State  
South Africa



A\*STAR  
Singapore



NRG  
Netherlands



DHCAE  
Germany



EuroCFD  
France



Global Research for  
Safety  
Germany



MPI-IPP  
Germany



Helicopter Technology  
Germany



FNB  
Germany



IWS  
Germany



Wind Energy  
Netherlands



CFD & FSI  
United Kingdom



Bitron  
Italy



AIT  
Austria



Fluid Mechanics  
Luxembourg



FAST  
Germany



Noise & Vibration  
Belgium



Aerodynamics  
United Kingdom



MTU Aero Engines  
Germany



University of Split  
Croatia



IIT  
India



Nuclear Engineering  
Sweden



IAG  
Germany

# Who develops preCICE?

Still 100% academia



# Funding

**SimTech**

**SPPEXA**

**DFG**



Bundesministerium  
für Wirtschaft  
und Energie

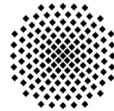


H2020 grant 754462

**KONWIHR**

**TUM**

**TU/e**

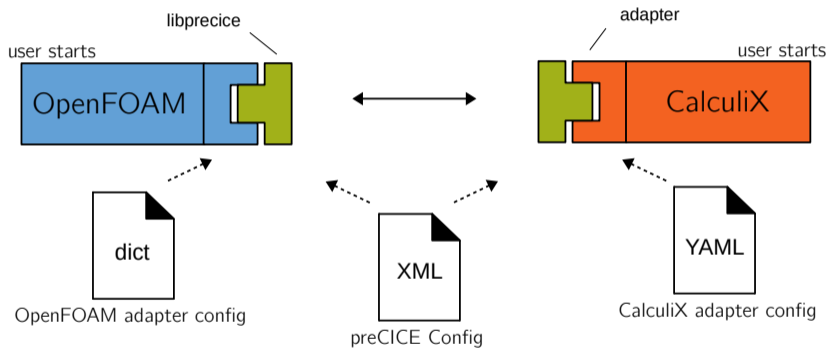


**Universität  
Stuttgart**

## 2. Live Demo

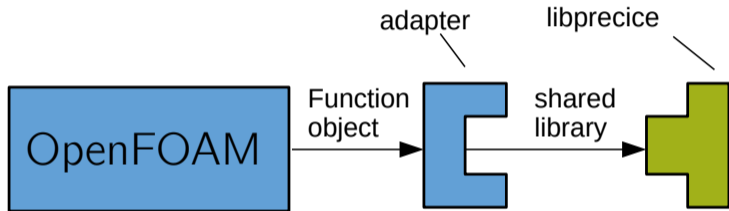


# How does it look like?

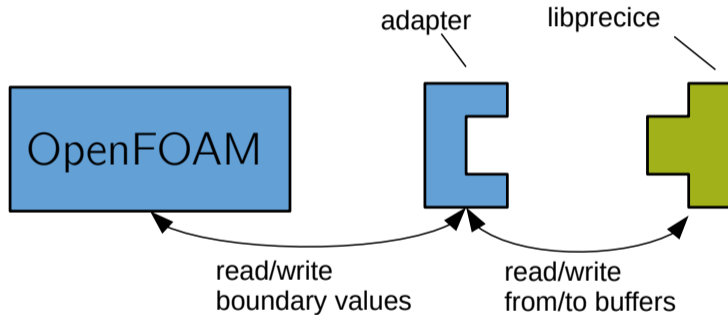


### 3. What is an Adapter?

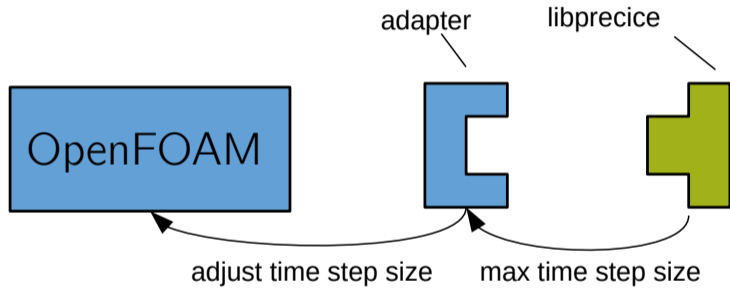
## What is an adapter?



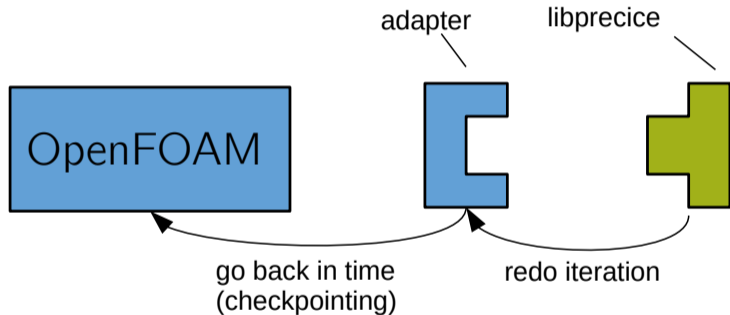
## What is an adapter?



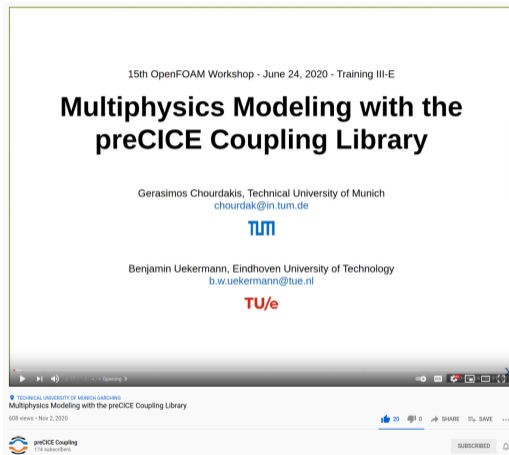
## What is an adapter?



## What is an adapter?



# Learn more about preCICE and OpenFOAM



Watch the recording of our OpenFOAM Workshop 2020 training session on YouTube (or join the next one at OFW16: 8-11 June, 2021)

## 4. Resources



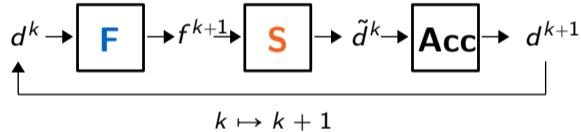
# Resources

*Live demo: preCICE website (<https://www.precice.org/>)  
and forum (<https://precice.discourse.group/>)*

## 5. Coupling Schemes

# Serial-Implicit Coupling

- ▶ Fluid solver  $F : d \mapsto f$
- ▶ Solid solver  $S : f \mapsto d$

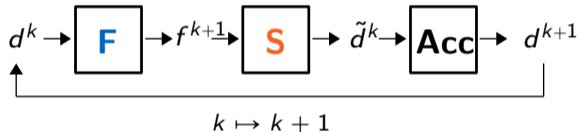


<sup>1</sup>Mehl et al. Parallel Coupling Numerics for Partitioned Fluid-Structure Interaction Simulations. (2016)

<sup>2</sup>Bungartz et al. A Plug-and-Play Coupling Approach for Parallel Multi-Field Simulations. (2015)

# Serial-Implicit Coupling

- ▶ Fluid solver  $F : d \mapsto f$
- ▶ Solid solver  $S : f \mapsto d$



- ▶ There is also explicit coupling
- ▶ There is also parallel coupling<sup>1</sup>
- ▶ Can be generalized to multiple coupled codes<sup>2</sup>

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## Aitken Acceleration

- ▶ Coupled problem:  $F : d \mapsto f, S : f \mapsto d \rightsquigarrow (S \circ F)(d) \stackrel{!}{=} d$
- ▶ General fixed-point equation:  $H(x) = x$

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- ▶ General fixed-point equation:  $H(x) = x$
- ▶ Fixed-point iteration:  $x^{k+1} = H(x^k)$
- ▶ Underrelaxation:  $x^{k+1} = \omega H(x^k) + (1 - \omega)x^k, \omega \in (0; 1)$
- ▶ Aitken underrelaxation: compute adaptive  $\omega^k$

# Quasi-Newton Acceleration

- ▶ Non-linear problem:  $H(x) = x \Leftrightarrow R(x) := H(x) - x \stackrel{!}{=} 0$

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<sup>3</sup>Degroote et al. Performance of a New Partitioned Procedure versus a Monolithic Procedure in FSI. (2009)

<sup>4</sup>Lindner et al. A Comparison of Various Quasi-Newton Schemes for Partitioned FSI. (2015)

<sup>5</sup>Haelterman et al. Improving the Performance of the Partitioned QN-ILS Procedure for FSI Problems: Filtering. (2016)



# Quasi-Newton Acceleration

- ▶ Non-linear problem:  $H(x) = x \Leftrightarrow R(x) := H(x) - x \stackrel{!}{=} 0$
- ▶ Newton:  $J_R \Delta x^k = -R(x^k)$  and  $x^{k+1} = x^k + \Delta x^k$

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- ▶ Different variants IQN-ILS<sup>3</sup> (explicit information from previous time windows) and IQN-IMVJ<sup>4</sup> (implicit information from previous time windows)

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- ▶ Different variants IQN-ILS<sup>3</sup> (explicit information from previous time windows) and IQN-IMVJ<sup>4</sup> (implicit information from previous time windows)
- ▶ Can be improved with a filter<sup>5</sup>

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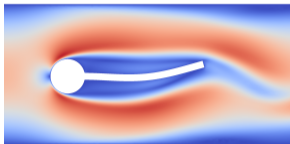
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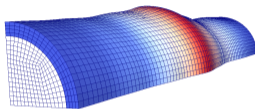
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# Numerical Results

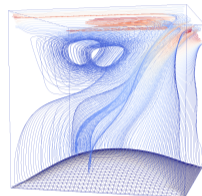
FSI3



3D-Tube



Driven Cavity









<b>Mean Iterations<sup>6</sup></b>	Aitken	Quasi-Newton
FSI3	17.0	3.7
3D-Tube	Div.	7.5
Driven Cavity	7.4	3.0

<sup>6</sup>Uekermann. Partitioned FSI on Massively Parallel Systems. (2016)

# Summary

- ▶ Minimally invasive integration (library approach, API in C++, C, Fortran, Python, Matlab)
- ▶ Many ready-to-use adapters available (OpenFOAM, FEniCS, Nutils, deal.II, SU2, ...)
- ▶ Coupling of arbitrary many programs
- ▶ Extensive documentation and testcases
- ▶ State-of-the-art numerical methods (quasi-Newton coupling, radial-basis function mapping)
- ▶ Scalability up to complete supercomputers
- ▶ Fast growing and active community

## Links

- ▶  <https://www.precice.org/>
- ▶  <https://github.com/precice/>
- ▶  <https://precice.discourse.group>
- ▶  @preCICE\_org
- ▶  <https://www.youtube.com/c/preCICECoupling>
- ▶  [chourdak@in.tum.de](mailto:chourdak@in.tum.de), [benjamin.uekermann@ipvs.uni-stuttgart.de](mailto:benjamin.uekermann@ipvs.uni-stuttgart.de)