

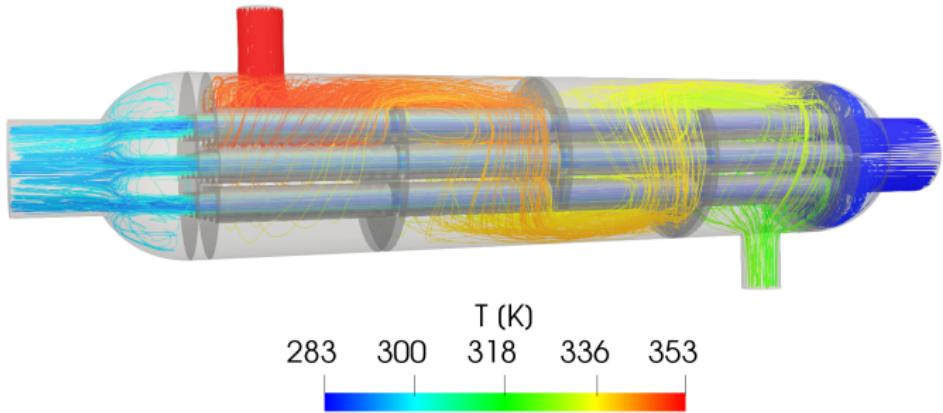


A Coupling Library  
for Partitioned Multi-Physics  
Simulations

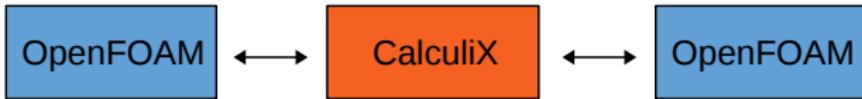
- 1.** What is preCICE?
- 2.** How to get started?
- 3.** How can I couple my own code?

## 1. What is preCICE?

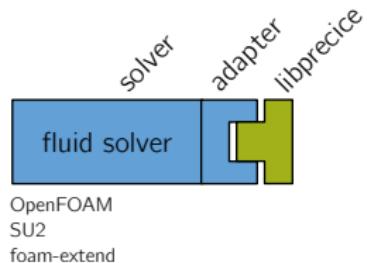
## Example: Shell-And-Tube Heat Exchanger



- ▶ Partitioned coupling: Usage of three independent solvers
- ▶ Reuse of existing solvers



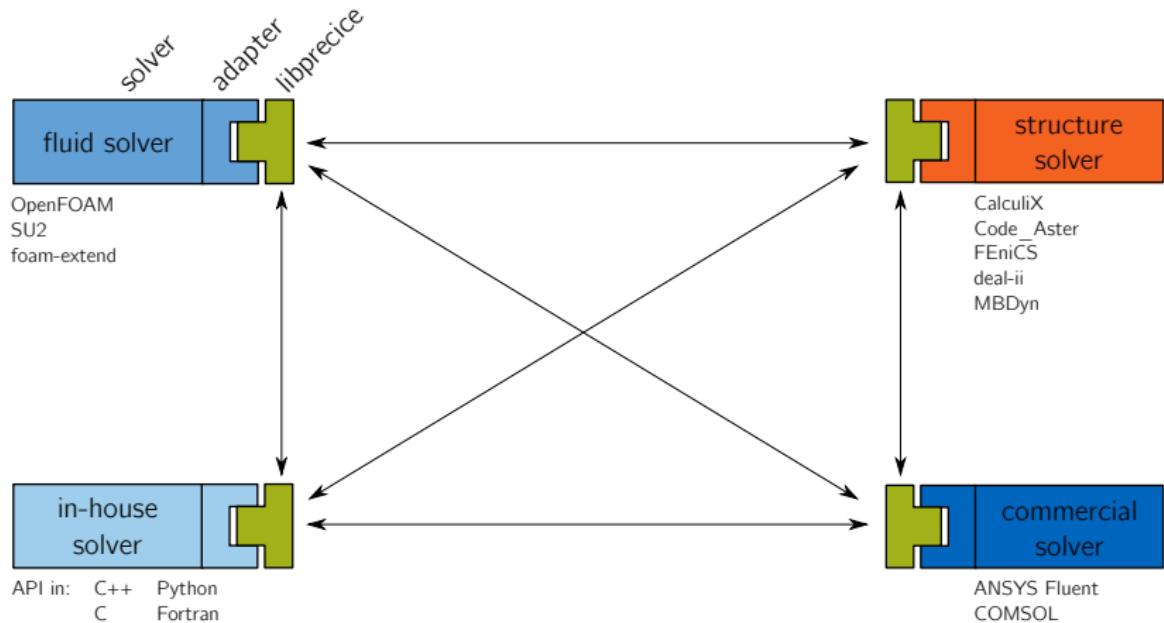
# preCICE – A Plug-and-Play Coupling Library



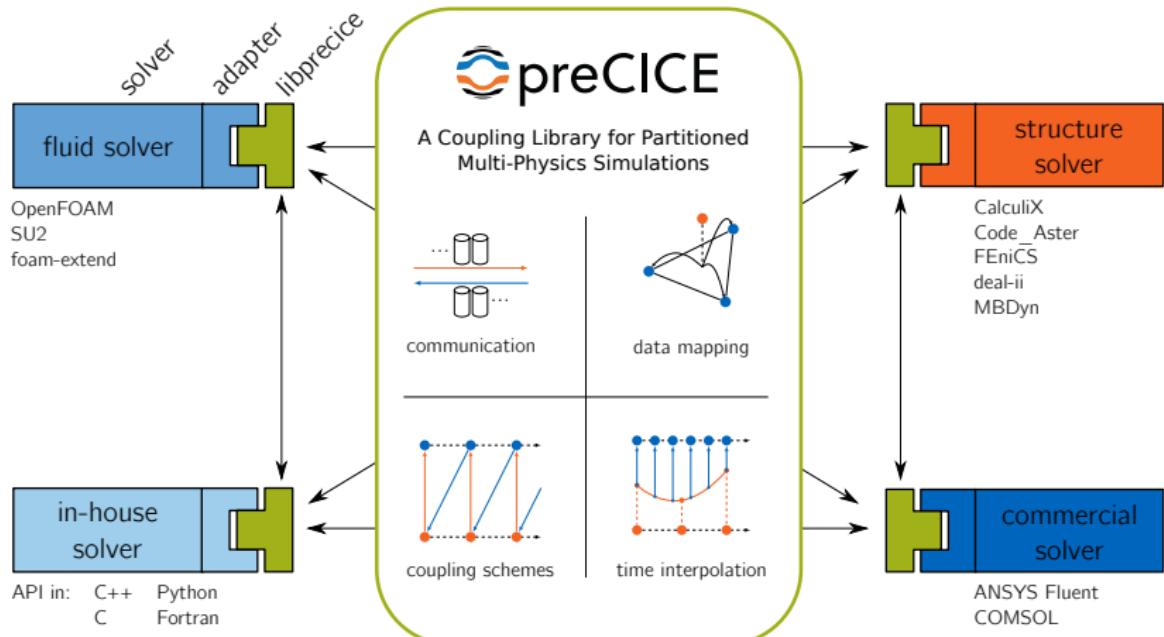
# preCICE – A Plug-and-Play Coupling Library



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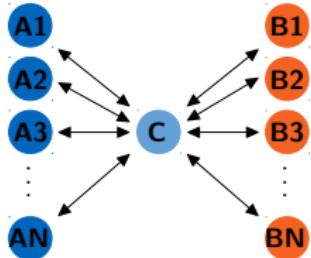


## Unique Selling Points (USPs)

1. Scalability
2. Robust quasi-Newton coupling
3. Coupling of arbitrary many components  
*(arbitrary many = more than two)*
4. Minimally-invasive coupling
5. Open-source, community

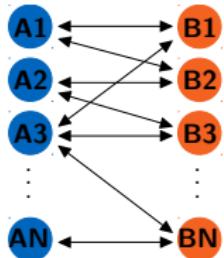
## USP 1: Scalability

### Server-Based Concept



- ▶ Complete communication through central server process
- ▶ Interface computations on server (in sequential)
- ▶ ⇒ Coupling becomes bottleneck for overall simulation already on moderate parallel systems

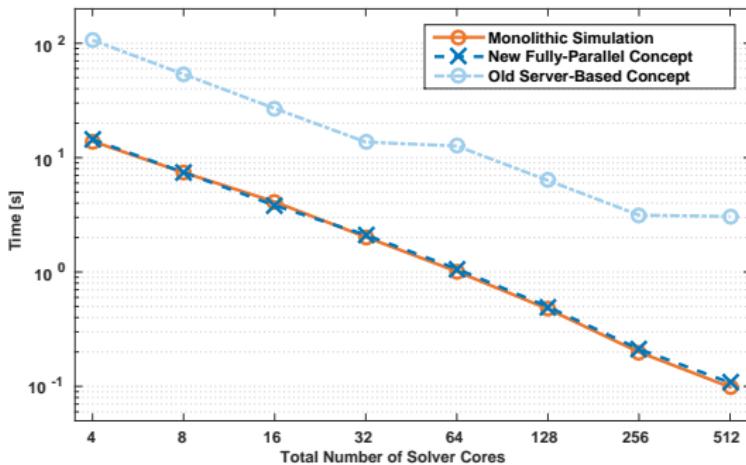
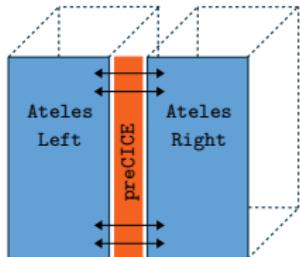
### Our Peer-To-Peer Concept



- ▶ No central entity
- ▶ ⇒ Easier to handle (user does not need to care about server)
- ▶ ⇒ No scaling issues

## USP 1: Scalability

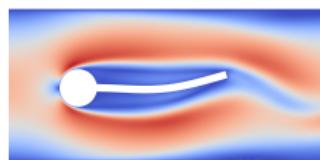
- ▶ Travelling density pulse (Euler equations) through artificial coupling interface
- ▶ DG solver Ateles (U Siegen),  $7.1 \cdot 10^6$  dofs
- ▶ Nearest neighbor mapping and communication



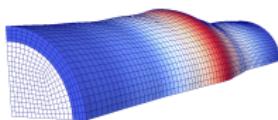
## USP 2: Quasi-Newton Coupling

Coupled problem:  $F : d \mapsto f$ ,  $S : f \mapsto d \rightsquigarrow (S \circ F)(d) \stackrel{!}{=} d$

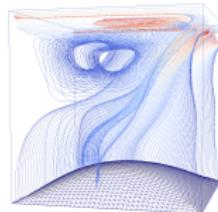
FSI3



3D-Tube



Driven Cavity



Mean Iterations	Aitken	Quasi-Newton
FSI3	17.0	3.3
3D-Tube	Div.	7.5
Driven Cavity	7.4	2.0

## USP 2: Quasi-Newton Coupling

- ▶ Quasi-Newton can even handle biomedical applications, such as an Aortic bloodflow
- ▶ Stable coupling (no added-mass instabilities)
- ▶ Six times less iterations than Aitken



- 
- ▶ Joint work with Juan-Carlos Cajas (Barcelona Supercomputing Center)
  - ▶ Geometry by Jordi Martorell

# Contributors



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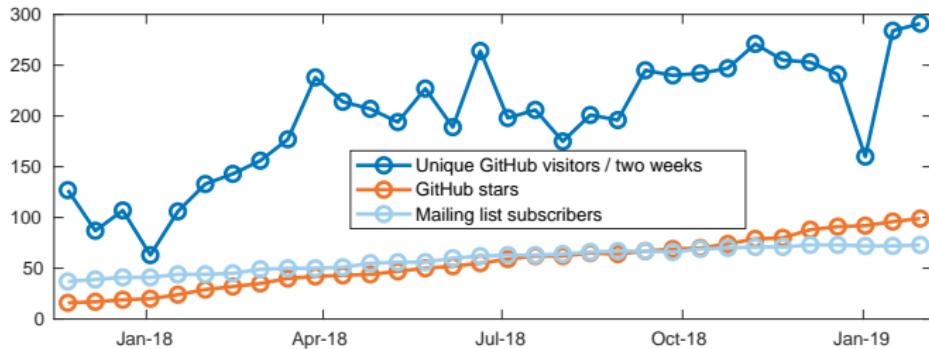
# Users

- ▶ LSM & STS, U Siegen, Germany
- ▶ SC & FNB, TU Darmstadt, Germany
- ▶ SCpA, CIRA, Italy
- ▶ Cardiothoracic Surgery, UFS, South Africa
- ▶ A\*STAR, Singapore
- ▶ NRG, Petten, The Netherlands
- ▶ Aerodynamics &Wind Energy (KITE Power), TU Delft, The Netherlands
- ▶ Mechanical and Aeronautical Eng., University of Manchester, UK
- ▶ University of Strathclyde, Glasgow, UK
- ▶ FAST, KIT, Germany
- ▶ AIT, Vienna, Austria

- ▶ IAG, University of Stuttgart, Germany
- ▶ CTTC UPC, Barcelona, Spain
- ▶ Amirkabir U. of Technology, Iran

## Upcoming:

- ▶ GRS, Garching, Germany
- ▶ MTU Aero Engines, Munich, Germany
- ▶ Numerical Analysis, Lund, Sweden
- ▶ Helicopter Technology & Astronautics, TUM, Germany
- ▶ ATA Engineering Inc., USA
- ▶ BITS Pilani, India
- ▶ Aviation, MSU Denver, USA



## **2.** How to get started?

# Infrastructure

We are on GitHub: <https://github.com/precice>

The screenshot shows the GitHub repository page for the preCICE project. At the top, there's a search bar and navigation links for Pull requests, Issues, Marketplace, and Explore. Below the header is the project logo, which is a stylized orange and blue wave-like shape, followed by the text "preCICE" and a subtitle "A Coupling Library for Partitioned Multi-Physics Simulations on Massively Parallel Systems". A pinned repository card for "precice" is displayed, showing its description, language (C++), stars (52), and forks (17). The main repository card for "precice" follows, featuring its name, description, tags (Simulation, high-performance-computing, openfoam, multiphysics), and stats (52 stars, 17 forks, 1 issue, updated 5 days ago). To the right, there are sections for Top languages (C++, C, Python, HTML) and Most used topics (fluid-structure-interaction, precice, co-simulation, multi-physics, conjugate-heat-transfer). A People section shows a grid of user profiles. At the bottom, there are standard GitHub navigation icons.

# Building

## Dependencies

- ▶ Eigen, Boost (version  $\geq$  1.65), libxml2
- ▶ Optional: PETSc, Python (incl. Numpy), MPI

## The easy way

- ▶ Ubuntu 18.04: All dependencies available through distribution
- ▶ Ubuntu 16.04: All dependencies available except Boost

## Still doable

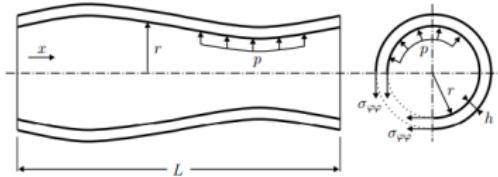
- ▶ macOS
- ▶ Other Linux distributions

## Experimental

- ▶ Conda, Docker, Debian package, Spack
- ▶ Windows

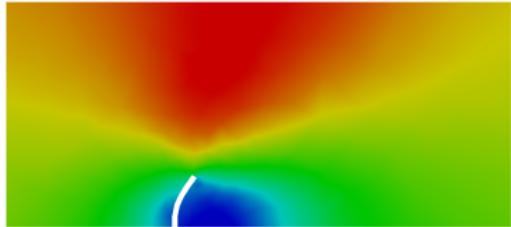
## 1D Elastic Tube

- ▶ Simple provided solvers
- ▶ Learn about API and configuration



## Flexible beam

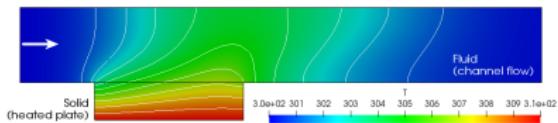
- ▶ Fluid-structure interaction
- ▶ Couple SU2 or OpenFOAM to CalculiX
- ▶ Learn about coupling schemes
- ▶ Also interactive version available in browser <http://run.coplon.de/>



# Tutorials

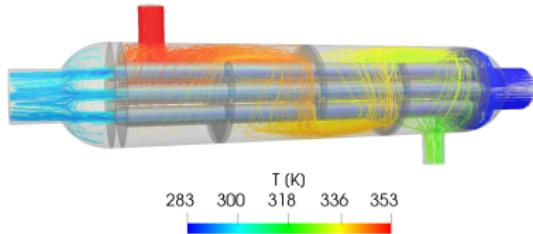
## Flow over a Heated Plate

- ▶ Conjugate-heat transfer
- ▶ Couple two OpenFOAM solvers
- ▶ Learn about OpenFOAM adapter



## Heat exchanger

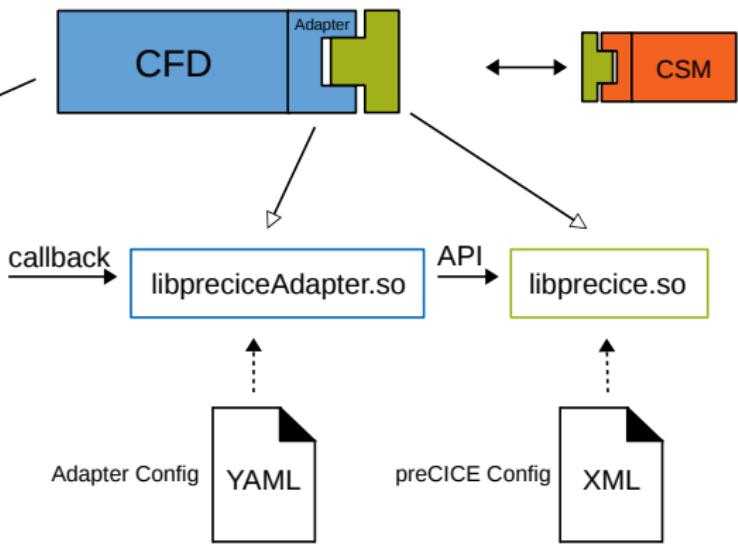
- ▶ Conjugate-heat transfer
- ▶ Couple two OpenFOAM instances with CalculiX
- ▶ Learn about multi coupling



# The OpenFOAM Adapter

```
int main(int argc, char *argv[])
{
    #include "setFoamLibPaths.h"
    #include "createTime"
    #include "createMesh.h"
    ...
    while (runTime.loop())
    {
        Info<< "Time = " << endl;
        #include "CourantNo.H"
        // Momentum predictor
        fvVectorMatrix UEqn
        (
            fvm::ddt(U)
            + fvm::div(phi, U)
            - fvm::laplacian(nu, U)
        );
    }
}
```

myFoam



## Flow over a Heated Plate

Load adapter at runtime in system/controlDict:

```
1 functions
2 {
3     preCICE_Adapter
4     {
5         type preciceAdapterFunctionObject;
6         libs ("libpreciceAdapterFunctionObject.so");
7     }
8 }
```

Define coupling boundary in system/blockMeshDict:

```
1 interface
2 {
3     type wall;
4     faces
5     (
6         (4 0 1 5)
7     );
8 }
```

# Flow over a Heated Plate

Configure adapter in precice-adapter-config.yml:

```
1 participant: Fluid
2
3 precice-config-file: /path/to/precice-config.xml
4
5 interfaces:
6 - mesh: Fluid-Mesh
7   patches: [interface]
8   write-data: Temperature
9   read-data: Heat-Flux
```

# Flow over a Heated Plate

```
/bin/bash 83x50
[preciceAdapter] [DEBUG]     write-data :
[preciceAdapter] [DEBUG]       HeatFlux
[preciceAdapter] [DEBUG]     read-data :
[preciceAdapter] [DEBUG]       Temperature
[preciceAdapter] [DEBUG]     subcycling : 1
[preciceAdapter] [DEBUG]     prevent early exit : 1
[preciceAdapter] [DEBUG]     evaluate boundaries : 1
[preciceAdapter] [DEBUG]     disable checkpointing : 0
[preciceAdapter] [DEBUG]     CHT mode enabled : 1
[preciceAdapter] [DEBUG] Configuring the CHT module...
[preciceAdapter] [DEBUG]     user-defined solver type : none
[preciceAdapter] [DEBUG]     temperature field name : T
[preciceAdapter] [DEBUG]     transportProperties name : transportProperties
[preciceAdapter] [DEBUG]     conductivity name for basic solvers : k
[preciceAdapter] [DEBUG]     density name for incompressible solvers : rho
[preciceAdapter] [DEBUG]     heat capacity name for incompressible solvers : Cp
[preciceAdapter] [DEBUG]     Prandtl number name for incompressible solvers : Pr
[preciceAdapter] [DEBUG]     turbulent thermal diffusivity field name for incomp
possible solvers : alphaT
[preciceAdapter] [DEBUG] Determining the solver type...
[preciceAdapter] [DEBUG] Found the transportProperties dictionary.
[preciceAdapter] [DEBUG] Did not find the turbulenceProperties dictionary.
[preciceAdapter] [DEBUG] Did not find the thermophysicalProperties dictionary.
[preciceAdapter] [DEBUG] This is a basic solver, as transport properties are provided, while turbulence or transport properties are not provided.
[preciceAdapter] [DEBUG] Checking the timestep type (fixed vs adjustable)...
[preciceAdapter] [DEBUG] Timestep type: fixed.
[preciceAdapter] [DEBUG] Creating the preICE solver interface...
[preciceAdapter] [DEBUG] Number of processes: 1
[preciceAdapter] [DEBUG] MPI rank: 0
[preciceAdapter] [DEBUG] preICE solver interface was created.
[preciceAdapter] [DEBUG] Configuring preICE...
(0) 16:10:32 [impl::SolverInterfaceImpl]:119 in configure: Configuring preICE with configuration: "precice-config.xml"
(0) 16:10:32 [impl::SolverInterfaceImpl]:153 in configure: Run in coupling mode
[preciceAdapter] [DEBUG] preICE was configured.
[preciceAdapter] [DEBUG] Creating interfaces...
[preciceAdapter] [DEBUG] Interface created on meshSolid-Mesh
[preciceAdapter] [DEBUG] Adding coupling data writers...
[preciceAdapter] [DEBUG] Constructed KappaEff_Basic.
[preciceAdapter] [DEBUG] Name of transportProperties: transportProperties
[preciceAdapter] [DEBUG] Name of conductivity: k
[preciceAdapter] [DEBUG] k = 100_000000
[preciceAdapter] [DEBUG] Added writer: Heat Flux for basic solvers.
[preciceAdapter] [DEBUG] Adding coupling data readers...
[preciceAdapter] [DEBUG] Added reader: Temperature
[preciceAdapter] [DEBUG] Initializing the preICE solver interface...
(0) 16:10:32 [impl::SolverInterfaceImpl]:216 in initialize: Setting up master communication to coupling partner/s
] ]
```

Solid: waiting...

```
/bin/bash 83x50
Create mesh for time = 0
PIMPLE: Operating solver in PISO mode
Reading thermophysical properties
Selecting thermodynamics package
(
    type          heRhoThermo;
    mixture      pureMixture;
    transport    const;
    thermo       hConst;
    equationOfState perfectGas;
    specie       specie;
    energy        sensibleEnthalpy;
)
Reading field U
Reading/calculating face flux field phi
Creating turbulence model
Selecting turbulence model type laminar
Selecting laminar stress model Stokes
Reading g
Reading hRef
Calculating field g.h
Reading field p_rgh
Creating field dpdt
Creating field kinetic energy K
No MRF models present
Radiation model not active: radiationProperties not found
Selecting radiationModel none
No finite volume options present
Courant Number mean: 0.0837143 max: 0.403668
Starting time loop
] ]
```

Fluid: preparing...

### **3.** How can I couple my own code?

## How to couple my own code?

```
1     precice::SolverInterface precice("FluidSolver",rank,size);
2     precice.configure("precice-config.xml");
3     precice.setMeshVertices();
4     precice.initialize();
5
6     while (precice.isCouplingOngoing()) { // main time loop
7         solve();
8
9         precice.writeBlockVectorData();
10        precice.advance();
11        precice.readBlockVectorData();
12
13        endTimeStep(); // e.g. write results, increase time
14    }
15
16    precice.finalize();
```

- ▶ Timesteps, most arguments, and less important methods omitted.
- ▶ Full example in the wiki.
- ▶ API in C++, C, Fortran, and Python

# Roadmap

## Current Developments v1.4

- ▶ Debian package
- ▶ Building with cmake

## Current Developments Adapters

- ▶ Fluid-fluid module for the OpenFOAM adapter
- ▶ Update of Fluent adapter
- ▶ Official adapters for dealii, FEniCS, and Nutils

## Long-term Goals v2.0

- ▶ 3D-1D and 3D-2D data mapping
- ▶ Parallel initialization → support of very large cases
- ▶ Support of re-meshing and dynamically changing coupling interfaces
- ▶ Consistent time interpolation

## Funding



TUM TU/e





**Flexible:** Couple your own solver with any other

**Easy:** Add a few lines to your code

**Ready:** Out-of-the box support for many solvers

**Fast:** Fully parallel, peer-to-peer, designed for HPC

**Stable:** Implicit coupling, accelerated with Quasi-Newton

**Multi-coupling:** Couple more than two solvers

**Free:** LGPL3, source on GitHub

- [www.precice.org](http://www.precice.org)
- [github.com/precice](https://github.com/precice)
- [@precice.org](https://@precice.org)
- Mailing-list, Gitter
- Literature Guide on wiki

