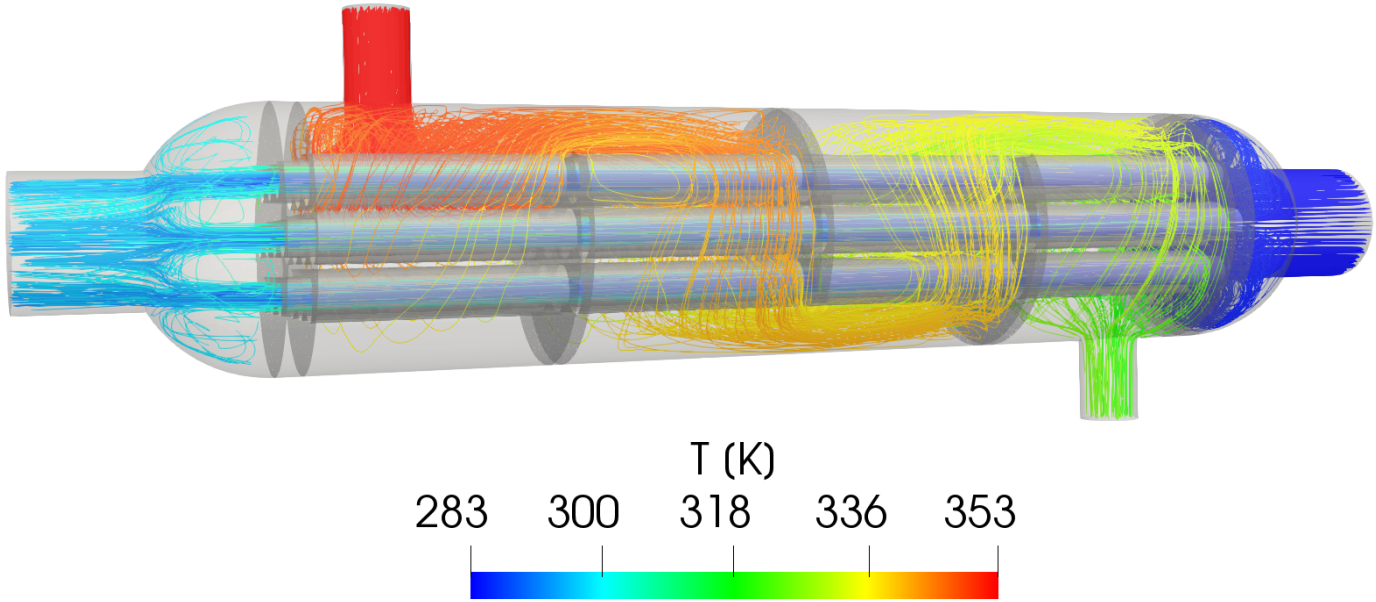
A Coupling Library for Partitioned Multi-Physics Simulations

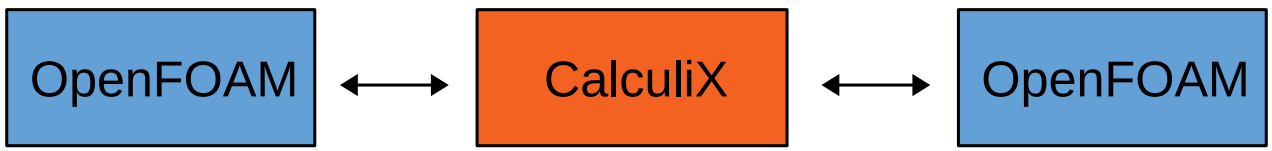
1. What is preCICE?
2. How to get started?
3. How can I couple my own code?

1. What is preCICE?

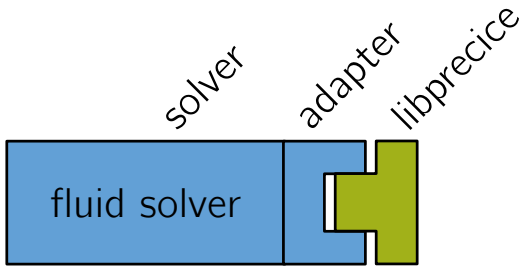
Example: Shell-And-Tube Heat Exchanger



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



preCICE – A Plug-and-Play Coupling Library



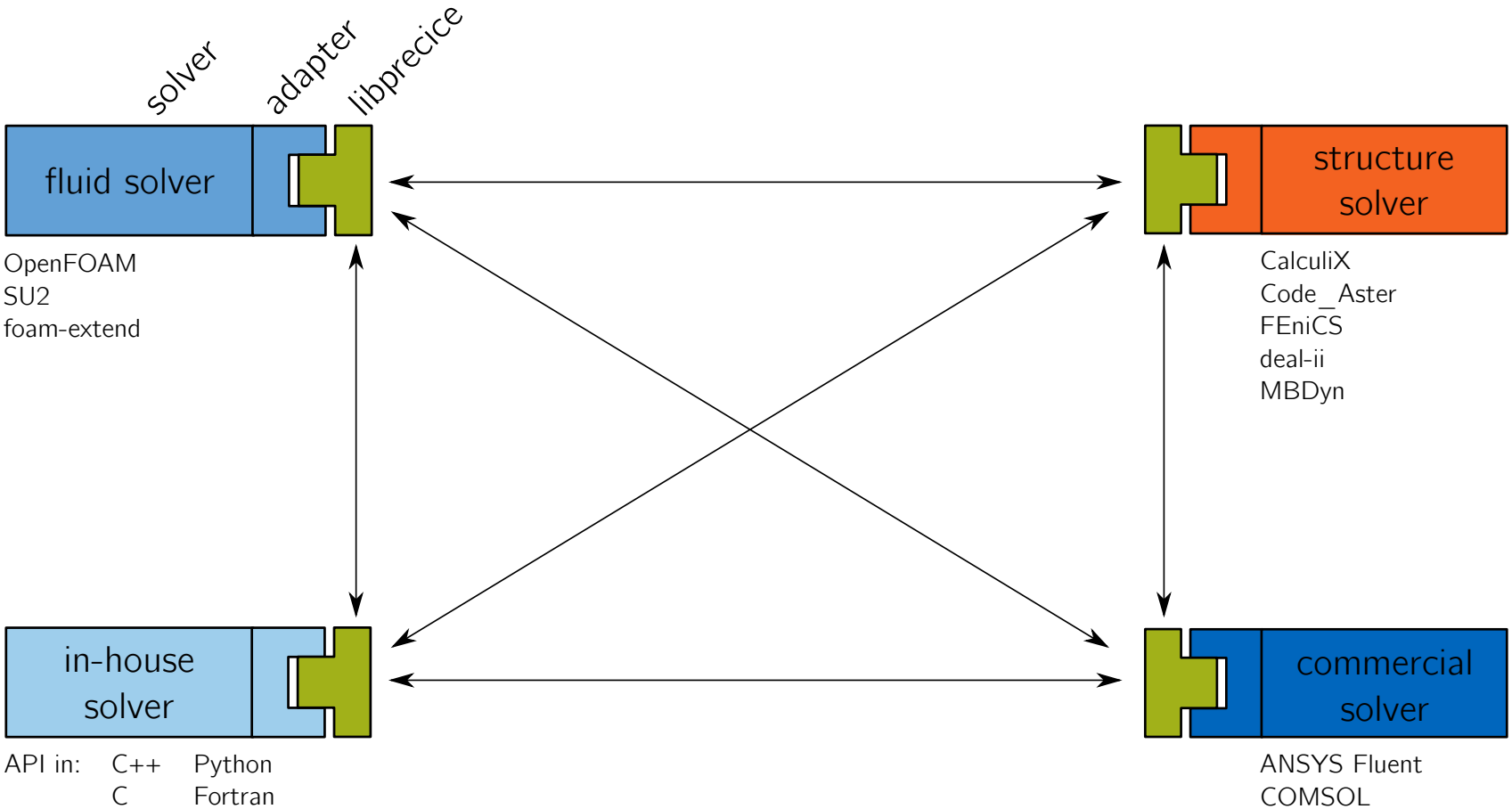
OpenFOAM
SU2
foam-extend

preCICE – A Plug-and-Play Coupling Library

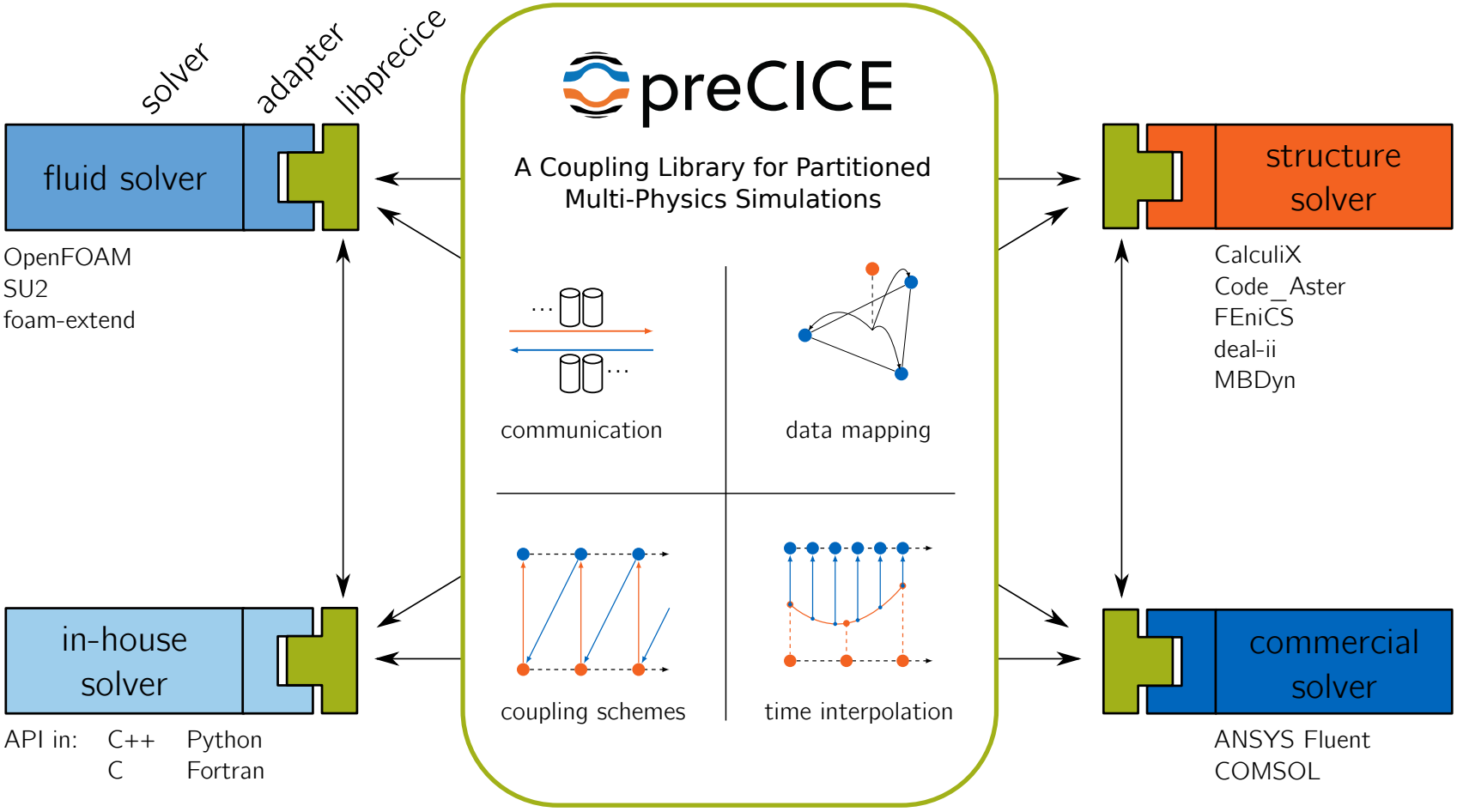
OpenFOAM
SU2
foam-extend

CalculiX
Code_Aster
FEniCS
deal-ii
MBDyn

preCICE – A Plug-and-Play Coupling Library



preCICE – A Plug-and-Play Coupling Library

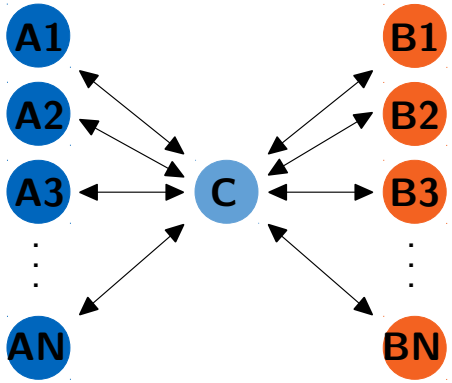


Unique Selling Points (USPs)

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

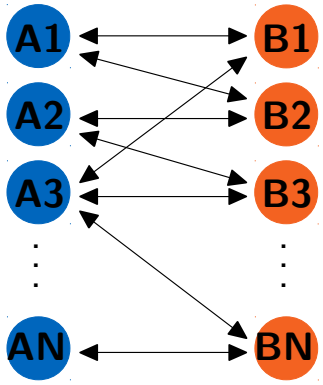
USP 1: Scalability

Server-Based Concept



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

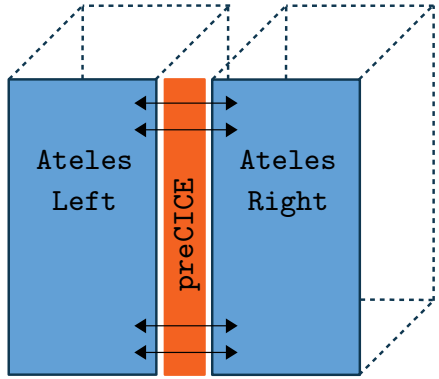
Our Peer-To-Peer Concept

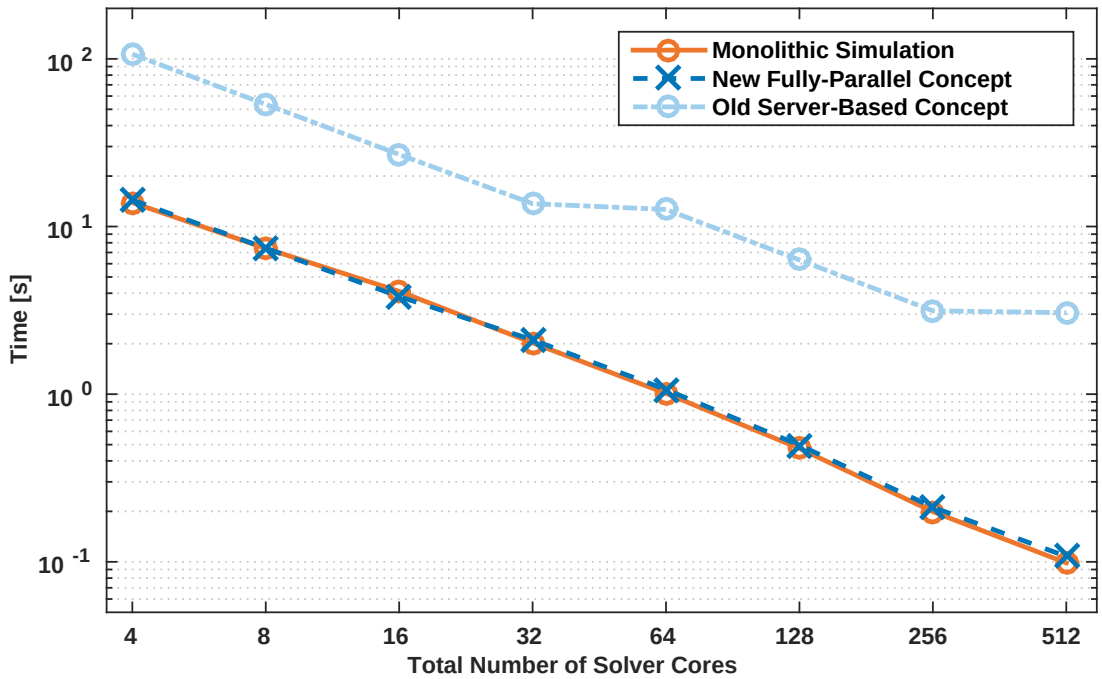


- No central entity
- $\Rightarrow$ Easier to handle (user does not need to care about server)
- $\Rightarrow$ No scaling issues

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

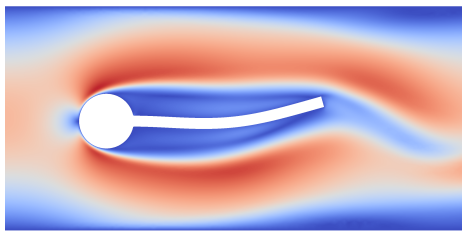




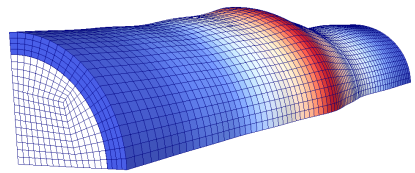
USP 2: Quasi-Newton Coupling

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

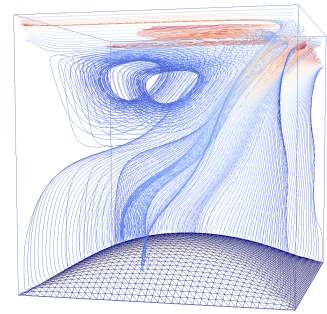
FSI3



3D-Tube



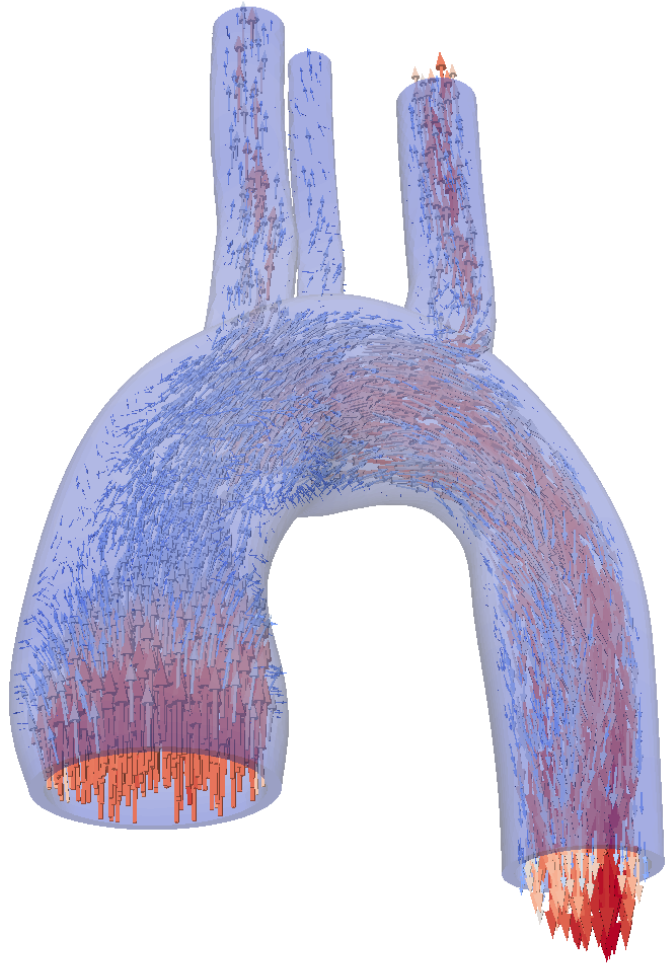
Driven Cavity



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

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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
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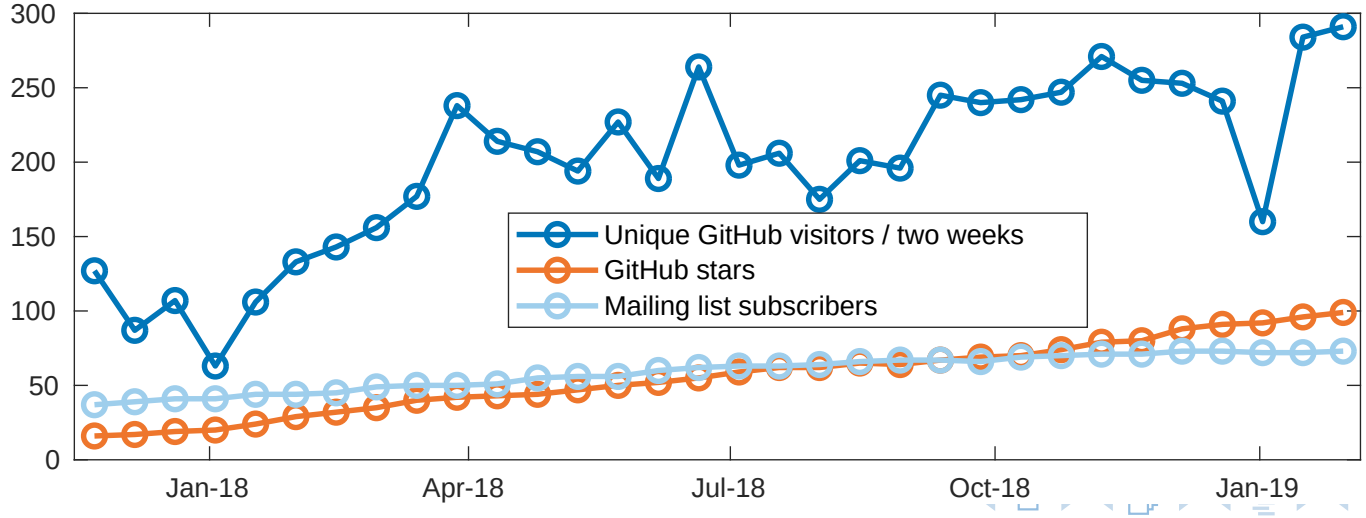
- CTTC UPC, Barcelona, Spain
- Amirkabir U. of Technology, Iran

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`

- LGPL3 license
- User documentation in the wiki

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

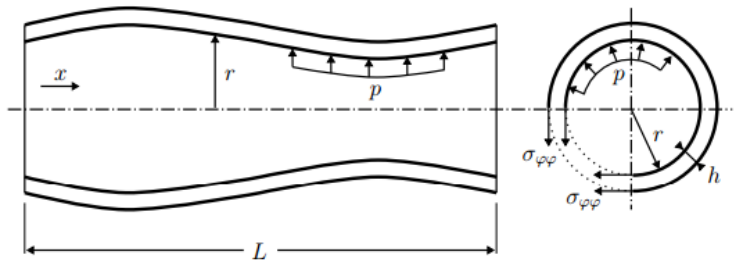
Experimental

- Conda, Docker, Debian package, Spack
- Windows

Tutorials

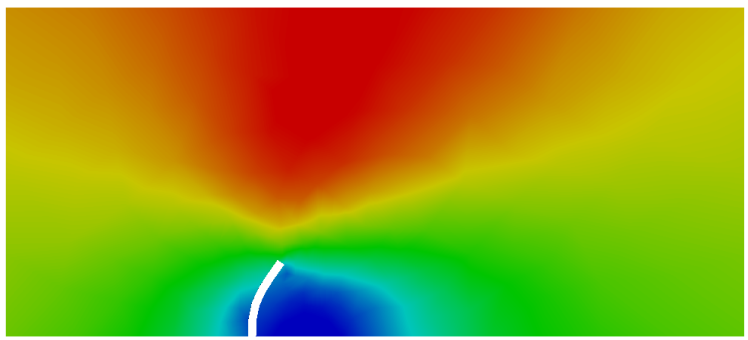
1D Elastic Tube

- Simple provided solvers
- Learn about API and configuration



Flexible beam

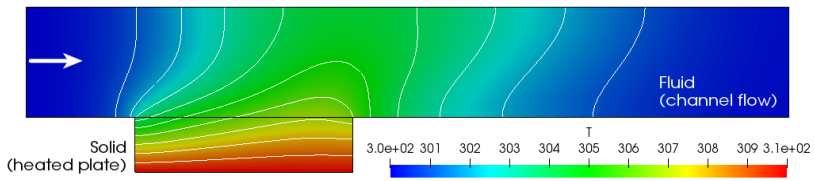
- Fluid-structure interaction
- Couple SU2 or OpenFOAM to CalculiX
- Learn about coupling schemes
- Also interactive version available in browser `http://run.coplon.de/`



Tutorials

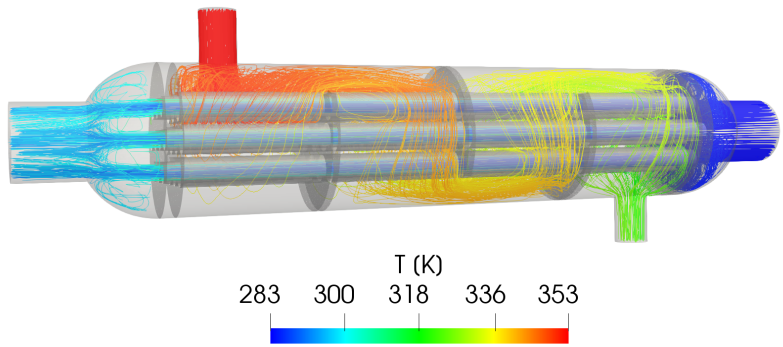
Flow over a Heated Plate

- Conjuagte-heat transfer
- Couple two OpenFOAM solvers
- Learn about OpenFOAM adapter



Heat exchanger

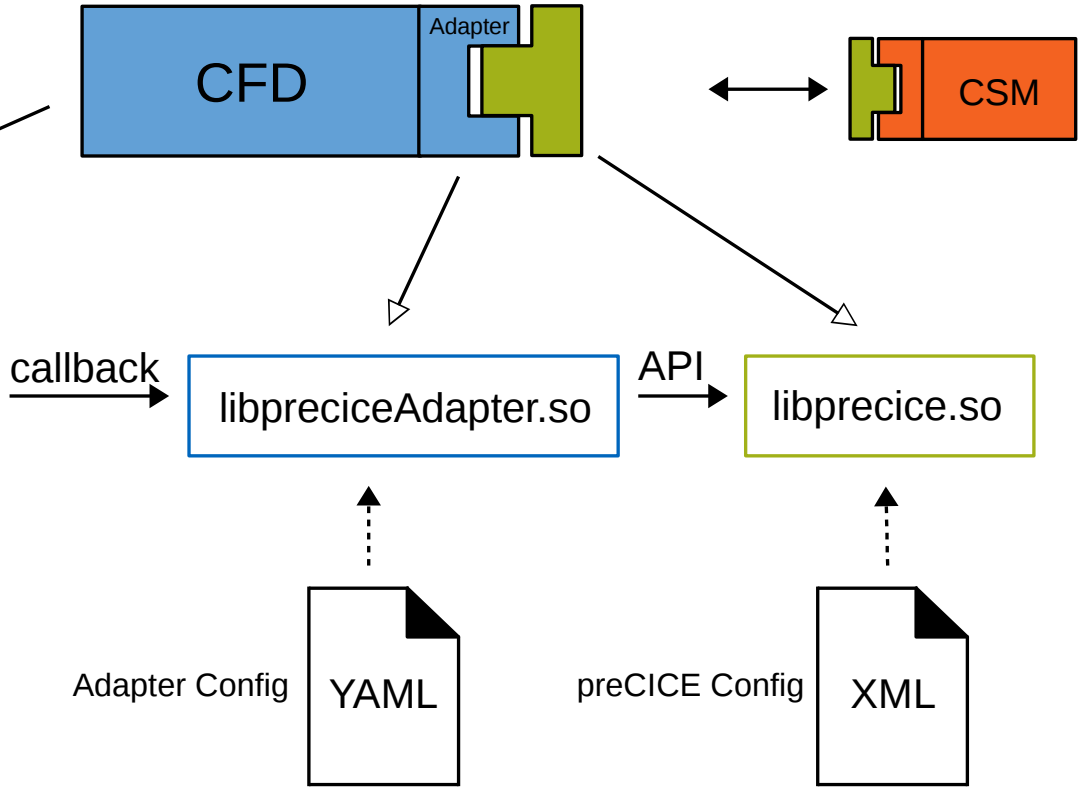
- Conjugate-heat transfer
- Couple two OpenFOAM instances with CalculiX
- Learn about multi coupling



The OpenFOAM Adapter

```
int main(int argc, char *argv[])
{
    #include "setRootCase.H"
    #include "createTime.H"
    #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)
        );

        if (piso.momentumPredictor())
        {
            solve(
                  UEqn
                  ==
                  -fvc::grad(p)
                 );
        }

        // --- PISO loop
        while (piso.correct())
        {
            ...
        }

        runTime.write();
    }

    Info<< "End\n" << endl;
    return 0;
}
```

myFoam



Flow over a Heated Plate

Load adapter at runtime in `system/controlDict`:

```
functions
{
    preCICE_Adapter
    {
        type preciceAdapterFunctionObject;
        libs ("libpreciceAdapterFunctionObject.so");
    }
}
```

Define coupling boundary in `system/blockMeshDict`:

```
interface
{
    type wall;
    faces
    (
        (4 0 1 5)
    );
}
```

Flow over a Heated Plate

Configure adapter in `precice-adapter-config.yml`:

```yaml
participant: Fluid

precice-config-file: /path/to/precice-config.xml

interfaces:
- mesh: Fluid-Mesh
  patches: [interface]
  write-data: Temperature
  read-data: Heat-Flux
```

Flow over a Heated Plate

3. How can I couple my own code?

How to couple my own code?

```
precice::SolverInterface precice("FluidSolver",rank,size);
precice.configure("precice-config.xml");
precice.setMeshVertices();
precice.initialize();

while (precice.isCouplingOngoing()) { // main time loop
    solve();

    precice.writeBlockVectorData();
    precice.advance();
    precice.readBlockVectorData();

    endTimeStep(); // e.g. write results, increase time
}

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

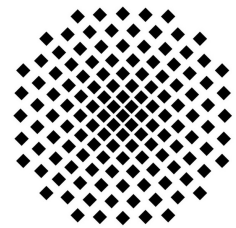
Current Developments Adapters

- 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 $\rightarrow$ support of very large cases
- Support of re-meshing and dynamically changing coupling interfaces
- Consistent time interpolation

Funding



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Summary

preCICE

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`
`github.com/precice`
`@preCICE_org`
Mailing-list, Gitter
Literature Guide on wiki