Partitioned strongly coupled Fluid-Structure Interaction

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Topics

DHCAE Tools

- Motivation
- Common problems with FSI
- Objective
- General FSI procedure
- Idea for the new solver structure
- Modeling
- Requirements for the solvers
- Updated lagrangian finite volume solver
- Aitken relaxation
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Motivation

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Why Fluid-Structure Interaction?

- In flow problems the deformation of solids is not always negligible (e.g. wing deflection)
- The deformation might be used in an application (e.g. membrane pump)
- The maximal solid deformation is a design property that needs to be statisfied (solid cracking)

General FSI procedure

In general FSI solver have the following steps:

- Solve the fluid domain
- Set the pressure at the interface as BC for the solid
- Solve the solid
- Move the mesh
- (strong coupling:) repeat until convergence

Common Problems with FSI

Working with FSI one usually deals with those problems:

- Interpolation errors on the Interface
- Stability problems
- (incompressible flows:) artificial added mass effect

⇨ These are coupling problems and can be handled independent of the fluid / solid solvers

Idea for the new solver structure

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When looking at the FSI solver by Robert Campbell who used a separate class for the solid solver and one for the coupling this idea came up:

Create a general FSI solver which

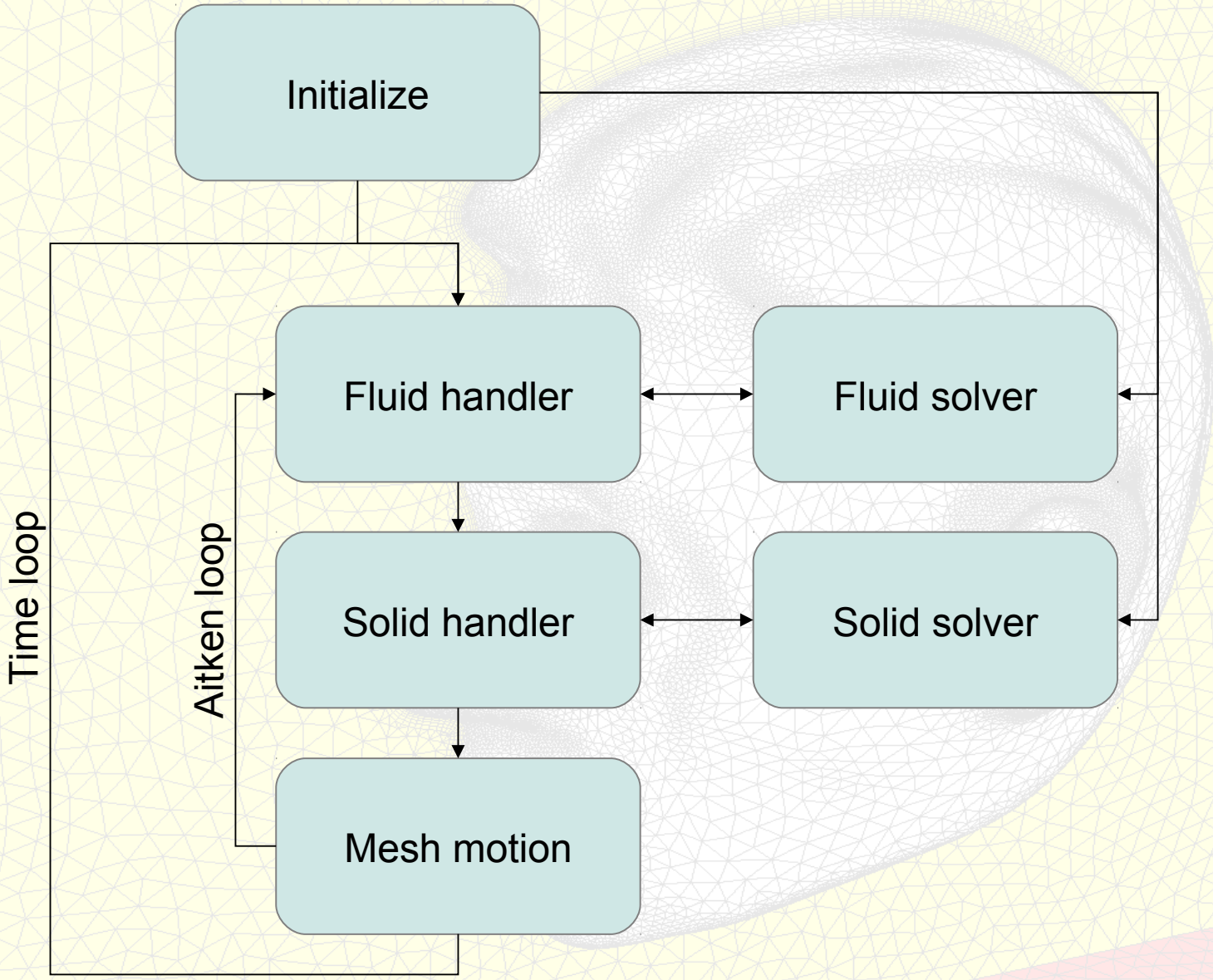
- Calls dynamically loaded solvers which are userdefined (e.g. SIMPLE / PISO)
- Handles general FSI common problems (Interpolation / Stability)
- Moves the mesh

Objective

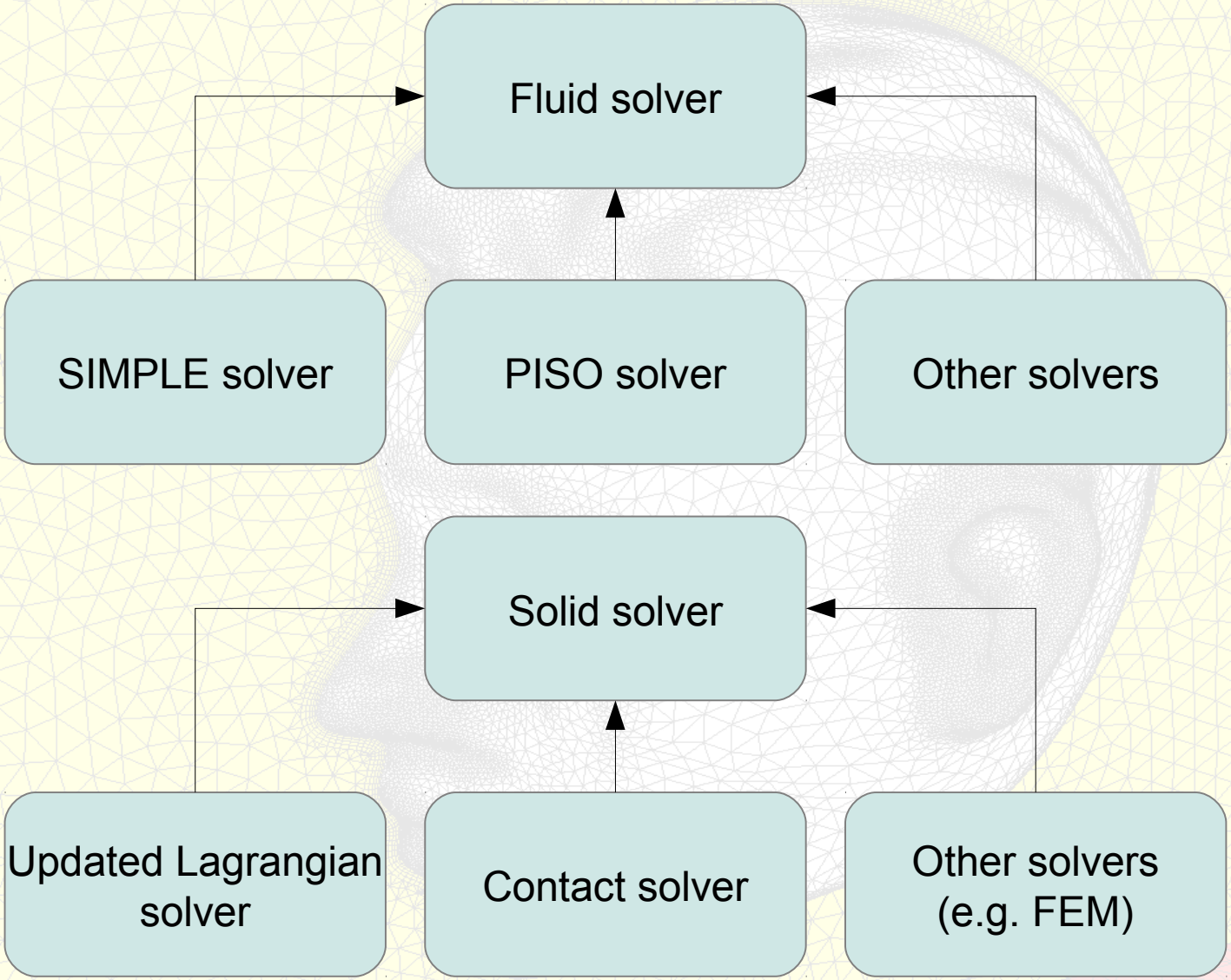
The aim is to provide a coupling solution for Fluid-Structure Interaction problems with these properties:

- Strong coupling
- Aitken relaxation
- Solver independent, i.e. the coupling itself is modeled but different solvers can be used (even non-OpenFOAM solvers); they only need to fulfill the requirements.
  ⇨ They are loaded on runtime – like turbulence models

Modeling


Initialize
Fluid handler
Fluid solver
Solid handler
Solid solver
Mesh motion
Time loop
Aitken loop

Modeling


Fluid solver
SIMPLE solver
PISO solver
Other solvers
Solid solver
Updated Lagrangian solver
Contact solver
Other solvers (e.g. FEM)

Requirements for the solvers

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Fluid solver:

- No problems with moving mesh
- Output of the pressure at the boundary

Solid solver:

- Uses traction BC
- Output of the displacement

Updated lagrangian finite volume solver

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- The solid solvers in OpenFOAM(-extend) do not support large deformations.
- Testcase for strong coupling needs large deformations
- Need new OpenFOAM solver for solids. In this case the *updated lagrangian finite volume solver* by **Tukovic** and **Jasak** [1] has been used

Test & Validation

The solver has been tested with the benchmark by **Turek** [2]:

- Laminar incompressible flow around a cylinder with
- A flexible bar attached to it
- $\frac{\rho_{solid}}{\rho_{fluid}} = 1$ ⇨ strong coupling is neccessary

Test & Validation

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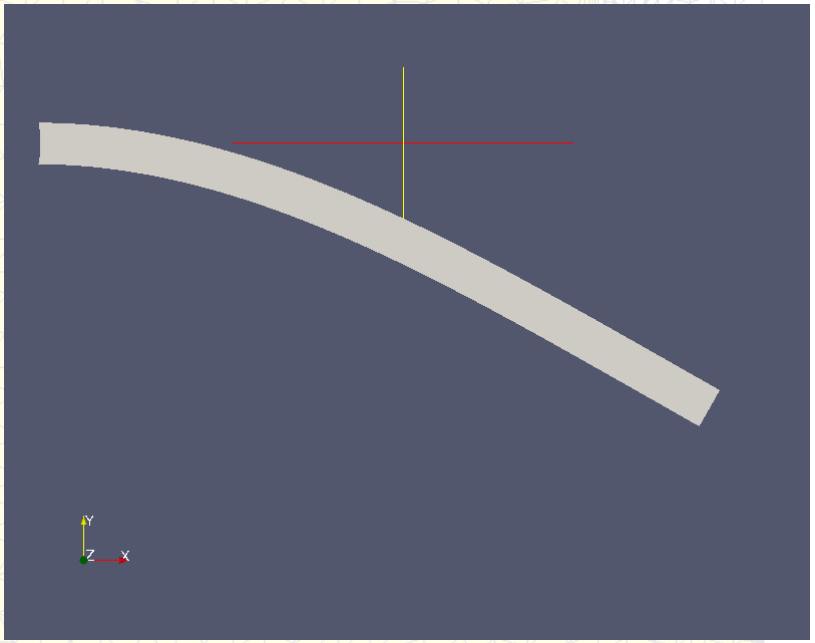
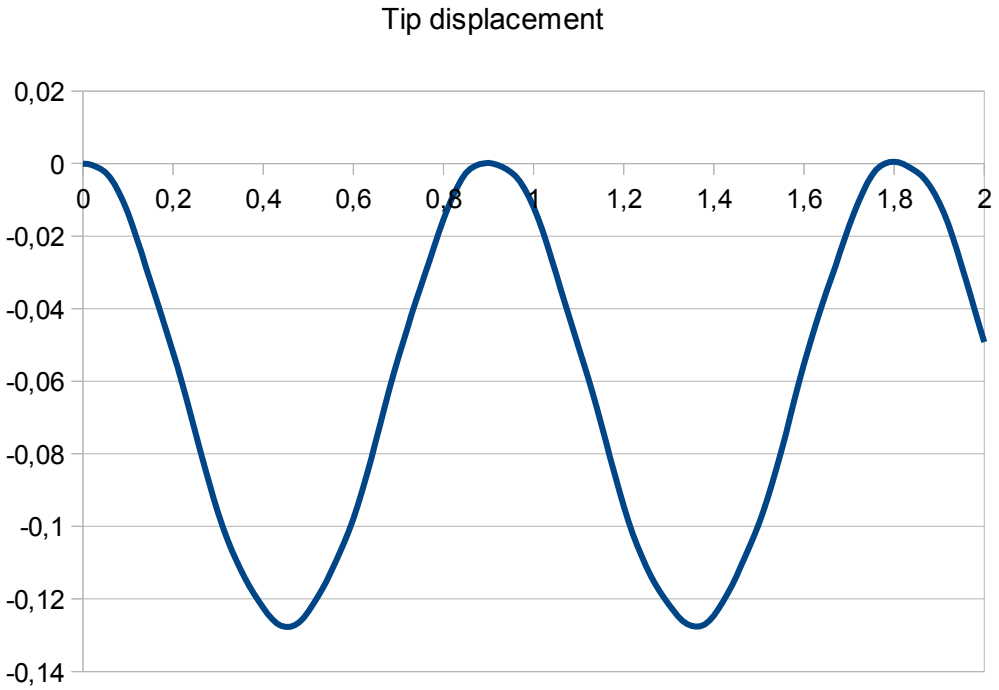
CSM Test:

ρ	[kg/m³]	1000
ν	[-]	0.4
E	[10^6 kg/ms²]	1.4
g	[m/s²]	2

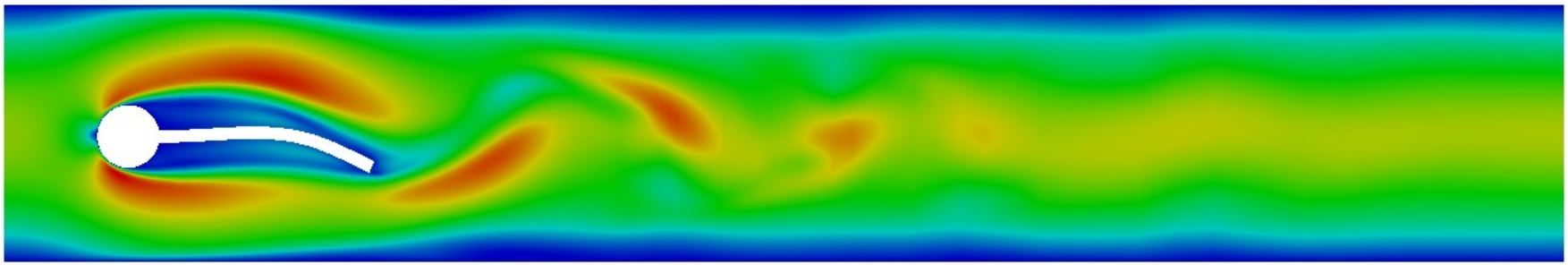




Test & Validation

FSI Test:

		Solid	Fluid
ρ	[kg/m³]	1000	1000
ν	[-] | [10^{-3} m²/s]	0.4	1
E	[10^{6} kg/ms²]	5.6	-
U	[m/s]	-	2



Conclusion

- FSI coupling can be simplified by using existing solvers and just adding a specialized solver for the actual fluid / solid problem, e.g. contact solver for the membrane pump
- External solvers can be used by making an interface for the fluid-/solid-handler
- Development can be faster and more efficient by reusing one piece of code
- **This solver is still in development! News and the final solver will be available at www.dhcae-tools.de**

Questions?

Special thanks to Philip Cardiff, UCD Dublin, who helped me with problems.

[1]: Tukovic, Zeljko; Jasak, Hrvoje, UPDATED LAGRANGIAN FINITE VOLUME SOLVER FOR LARGE DEFORMATION DYNAMIC RESPONSE OF ELASTIC BODY, ISSN 1333–1124

[2]: Bungartz, Hans-Joachim; Schäfer, Michael, eds. (2006). Fluid-structure Interaction: Modelling, Simulation, Optimization. Springer-Verlag. ISBN 3-540-34595-7.