Universität Stuttgart

ExaFSA

ExaFSA – Exascale Simulation of Fluid-Structure-Acoustics Interactions

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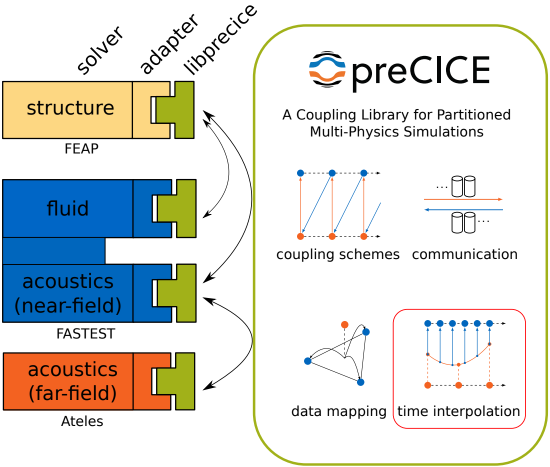
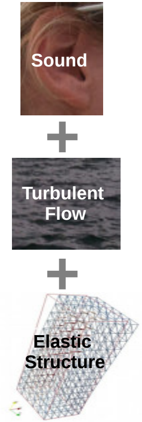
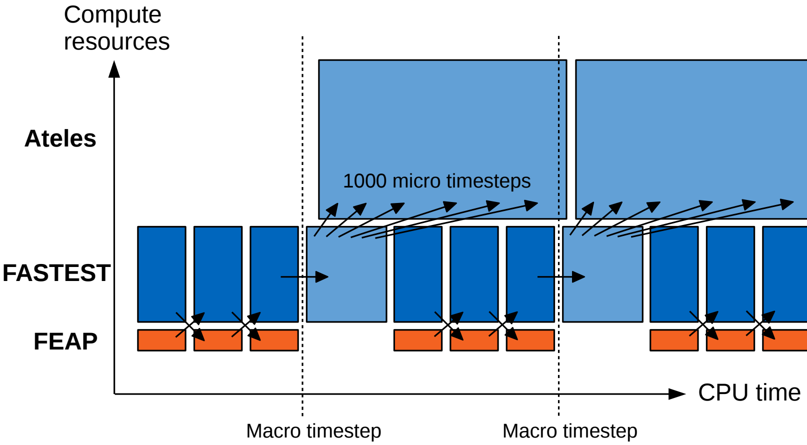


solver
adapter
libprecice
structure
FEAP
fluid
acoustics
(near-field)
FASTEST
acoustics
(far-field)
Ateles
preCICE
A Coupling Library for Partitioned
Multi-Physics Simulations
coupling schemes
communication
data mapping
time interpolation



Sound
Turbulent
Flow
Elastic
Structure

ExaFSA

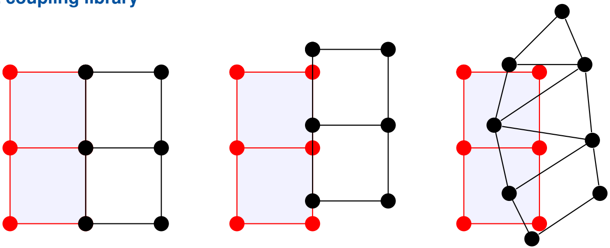

Compute
resources
Ateles
FASTEST
FEAP
1000 micro timesteps
CPU time
Macro timestep
Macro timestep

ExaFSA

1. Coupling – Data Mapping
2. Coupling – Communication Connections
3. Coupling – Consistent Time Stepping
4. Moving Geometries
5. Performance Portability
6. Coupling Acoustics near - Acoustics far
7. A simple method to sonify quasi-2D field data

Coupling – Data Mapping

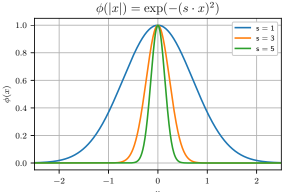
inside the preCICE coupling library



Radial Basis Function Mapping:

$$S(x) = \sum_{i=1}^{N_A} \gamma_i \cdot \phi(\|x - x_i\|)$$

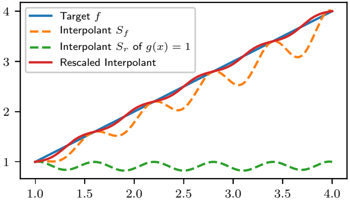
$$v_j^B = S(y_j) = \sum_{i=1}^{N_A} \gamma_i \cdot \phi(\|y_j - x_i\|) \quad \forall j = 1 \dots N_B$$



Black-box! Accuracy & Efficiency?

Coupling – Data Mapping

inside the preCICE coupling library



Compute interpolant S_1 of $g = 1$

Rescale S_f:

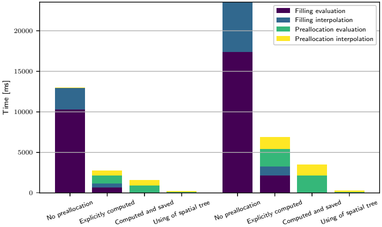
$$S_r(x) = \frac{S_f(x)}{S_1(x)}$$

eliminates oscillations

Deparis, S., Forti, D. & Quarteroni, A. *A Rescaled Localized Radial Basis Function Interpolation on Non-Cartesian and Nonconforming Grids*, SIAM J. Sci. Comput. 36, 2014

Pre-allocation:

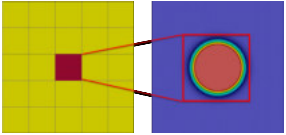
- sparsity structure of interpolation system,
- solved in parallel with Petsc

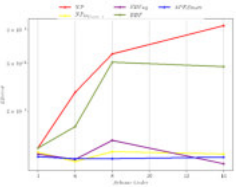


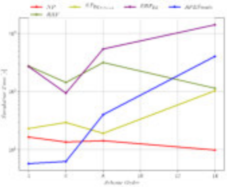
Coupling – Data Mapping

inside Ateles

Pressure pulse:

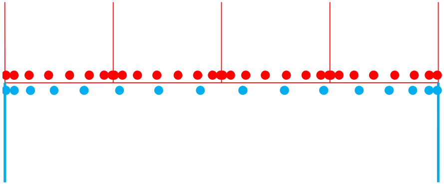






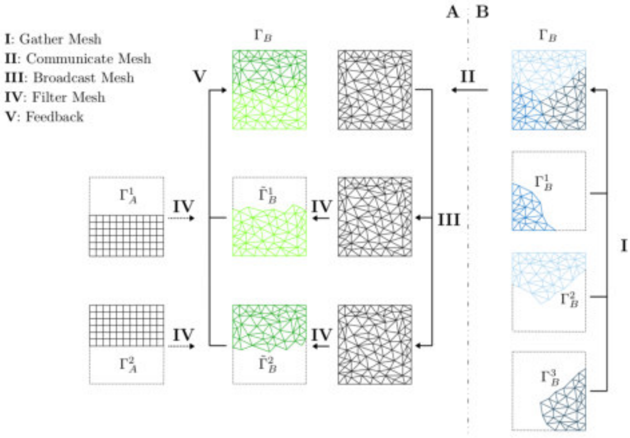
Nearest projection, **Nearest projection equidistant**, **RBF**, **RBF equidistant**

APESmate



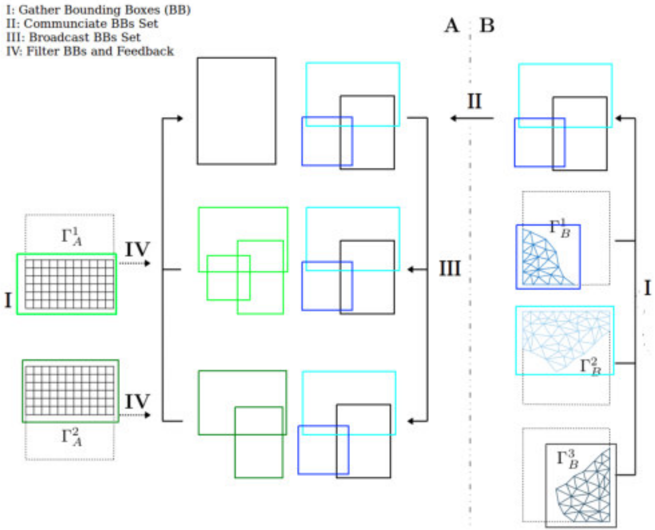
Coupling – Communication Connections

inside the preCICE coupling library



Coupling – Communication Connections

inside the preCICE coupling library

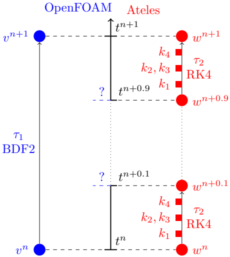


Coupling – Consistent Time Stepping

inside the preCICE coupling library

preCICE

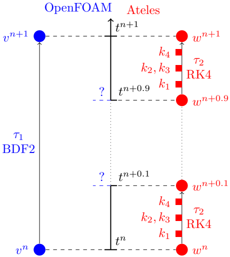
Black-box solvers, different time-stepping:



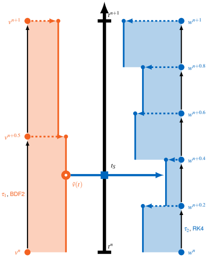
Coupling – Consistent Time Stepping

inside the preCICE coupling library

Black-box solvers, different time-stepping:



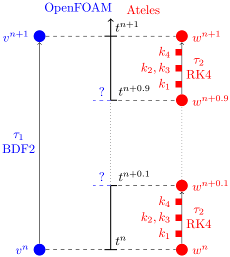
Standard Implicit Coupling:



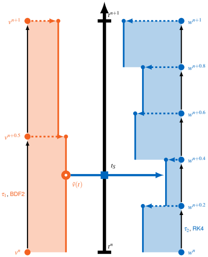
Coupling – Consistent Time Stepping

inside the preCICE coupling library

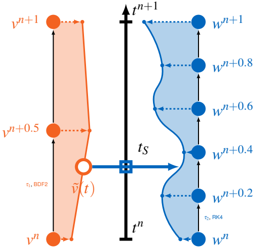
Black-box solvers, different time-stepping:



Standard Implicit Coupling:

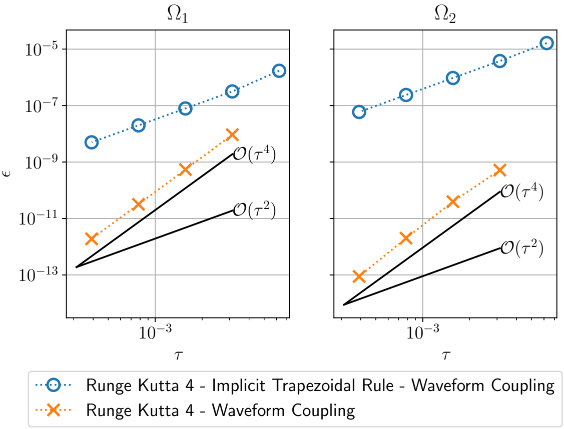


Waveform Relaxation:



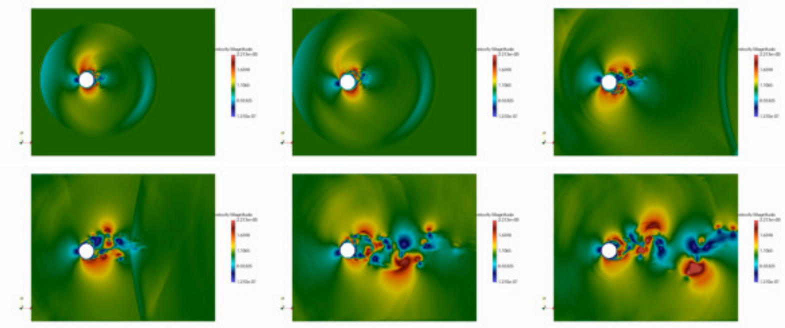
Coupling – Consistent Time Stepping
inside the preCICE coupling library

Partitioned Heat Transport:



Moving Geometries

inside Ateles



Performance Portability

with Xevolver

Xevolver

vector length 256 | **vector length 4**

```
!$xev directive                Original
do iVar = 1,nScalars               +
  do iElem=1,nElems          custom directive
    do facepos = 1,mpd1_square
      ...
    end do
  end do
end do
```

Transformation

```
do iVar = 1,nScalars
  m=nElems
  n=mpd1_square
  mn=m*n
!cdir nodep
  do ij= 0, mn - 1
    iElem=ij / n + 1
    facepos=mod(ij, n) + 1
    ...
  end do
end do
```

Code Transformation:

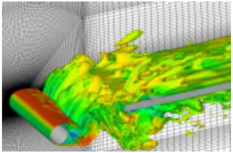
- inserting only directives into the original code,
- transformation triggered by the directives

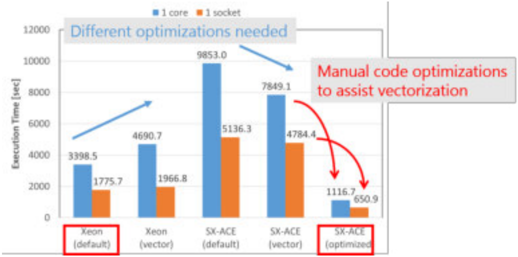
Performance Portability – FASTEST

with Xevolver

Xevolver

FASTEST:
finite volume flow solver





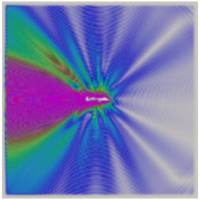
- differences between default and vector versions expressed as user-defined code transformations
- non-vectorizable loops manually modified to be vectorizable only if the modifications do not degrade the scalar performance

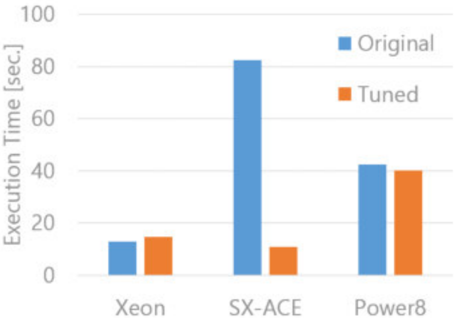
Performance Portability – Ateles

with Xevolver

Xevolver

Ateles:
discontinuous Galerkin flow/
acoustic solver

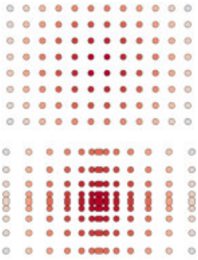




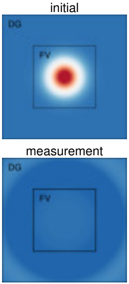
- separate the optimization from source code
- easily enable or disable the optimizations
- preserves maintainability of the source code

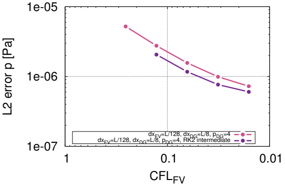
Coupling Acoustics near - Acoustics far

with FASTEST



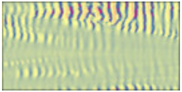
coupling faces

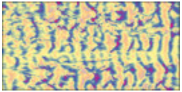


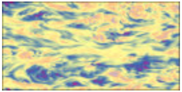


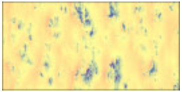
- coupling of same equation set with different numerical schemes (FV - DG)
- task: find optimal setup in terms of numerical errors and efficiency
- Gauss pulse, grid/time step refinement
- $\rightarrow$ recovers 1st order, error reduction by RK2 intermediate coupling

A simple method to sonify quasi-2D field data


2nd order instabilities

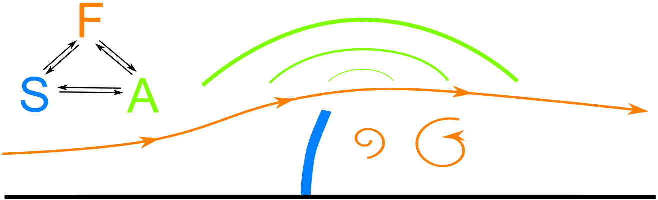

shear layer breakup

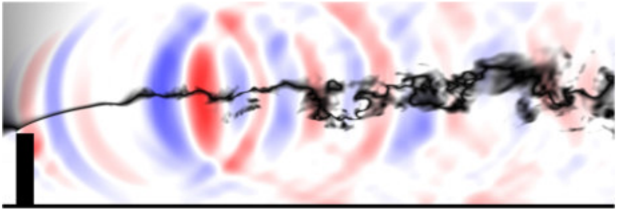

recirculation zone


outer region

- exploration of massive time-dependent flow data
- retain characteristics of flow region (see t-z contour plots)
- take advantage of periocidity $\rightarrow$ concatenate transient lines along periodic dimension
- sonic characteristics resemble flow: low/high frequencies, complexity of sound, ...

Fluid-Structure-Acoustic Scenario – Bending Fence





Largest run: three-field flow coupling with Ateles, 16K cores on SuperMUC

Thank you for your attention!