ExaFSA – Exascale Simulation of Fluid-Structure-Acoustics Interactions

M. Mehl, S. Roller, D. Sternel, H. Takizawa, S. van Zuijlen
SPPExa Annual Plenary Meeting 2018, Garching
March 21-22

1 Simulation of Large Systems, Institute for Parallel and Distributed Systems, University of Stuttgart
Neda Ebrahimi Pour, U Siegen
Ryusuke Egawa, Tohoku U
Florian Linder, U Stuttgart
Thorsten Reimann, TU Darmstadt
Benjamin Rüth, TU Munich
Amin Totounferoush, U Stuttgart
Benjamin Uekermann, TU Munich
ExaFSA – Exascale Simulation of Fluid-Structure-Acoustics Interactions

**A Coupling Library for Partitioned Multi-Physics Simulations**

preCICE

- **solver**
  - structure: FEAP
- **adapter**
  - fluid: FASTEST
  - acoustics (near-field): FASTEST
  - acoustics (far-field): Ateles
- **libprecice**

**coupling schemes**

**data mapping**

**time interpolation**

**communication**

**Sound**

**Turbulent Flow**

**Elastic Structure**
Compute resources

Ateles

FASTEST

FEAP

Macro timestep

1000 micro timesteps

Macro timestep

CPU time
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
Radial Basis Function Mapping:

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

\[ \nu_j^B = S(y_j) = \sum_{i=1}^{N_A} \gamma_i \cdot \phi(\|y_j - x_i\|) \quad \forall j = 1 \ldots N_B \]

Black-box! Accuracy & Efficiency?
Compute interpolant $S_1$ of $g = 1$

Rescale $S_f$:

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

eliminates oscillations


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

Black-box solvers,
different time-stepping:

\[ v^n, v^{n+1} \]
\[ w^n, w^{n+0.9}, w^{n+1} \]
\[ \tau_1 \text{ BDF2} \]
\[ \tau_2 \text{ RK4} \]

OpenFOAM  Ateles
Coupling – Consistent Time Stepping
inside the preCICE coupling library

Black-box solvers, different time-stepping:

Standard Implicit Coupling:

\[ t^n \rightarrow t^{n+1} \]
\[ v^n \rightarrow v^{n+1} \]
\[ w^n \rightarrow w^{n+0.9} \]
\[ \tau_1 \text{ BDF2} \]

\[ k_1, k_2, k_3 \]

\[ \tau_2 \text{ RK4} \]

\[ \hat{v}(t) \]

OpenFOAM Ateles

\[ t^n \rightarrow t^{n+0.1} \]
\[ v^n \rightarrow v^{n+0.1} \]
\[ w^n \rightarrow w^{n+0.9} \]
\[ \tau_1 \text{ BDF2} \]

\[ k_1, k_2, k_3 \]

\[ \tau_2 \text{ RK4} \]
Coupling – Consistent Time Stepping
inside the preCICE coupling library

Black-box solvers, different time-stepping:

- OpenFOAM
- Ateles

Standard Implicit Coupling:

- $v^{n+1}$
- $v^n$
- $w^{n+1}$
- $w^n$
- $k_2$, $k_3$
- $k_1$
- $\tau_1$, BDF2
- $\tau_2$, RK4

Waveform Relaxation:

- $v^{n+1}$
- $v^n$
- $w^{n+1}$
- $w^n$
- $\tilde{v}(t)$
- $t^n$
- $t^n+1$
- $t^n+0.5$
- $t^n+1$
- $t^n+0.5$
- $t^n+0.5$
- $t^n+1$
- $t^n+0.5$
- $t^n+1$
- $t^n+0.5$
- $t^n+1$
- $t^n+0.5$
- $t^n+1$
- $t^n+0.5$
**Coupling – Consistent Time Stepping**

inside the preCICE coupling library

**Partitioned Heat Transport:**

- $\Omega_1$
  - $\mathcal{O}(\tau^2)$
  - $\mathcal{O}(\tau^4)$

- $\Omega_2$
  - $\mathcal{O}(\tau^2)$
  - $\mathcal{O}(\tau^4)$

- Runge Kutta 4 - Implicit Trapezoidal Rule - Waveform Coupling
- Runge Kutta 4 - Waveform Coupling
Moving Geometries
inside Ateles
Performance Portability
with Xevolver

Code Transformation:
- inserting only directives into the original code,
- transformation triggered by the directives
Performance Portability – FASTEST
with 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

Ateles:
discontinuous Galerkin flow/
aoustic 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 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
- → recovers 1st order, error reduction by RK2 intermediate coupling
A simple method to sonify quasi-2D field data

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

2nd order instabilities  shear layer breakup  recirculation zone  outer region
Fluid-Structure-Acoustic Scenario – Bending Fence

Largest run: three-field flow coupling with Ateles, 16K cores on SuperMUC
Thank you for your attention!