EXAFSA:
Exascale Simulation of Fluid-Structure-Acoustics Interactions

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Fluid-structure-acoustics interaction

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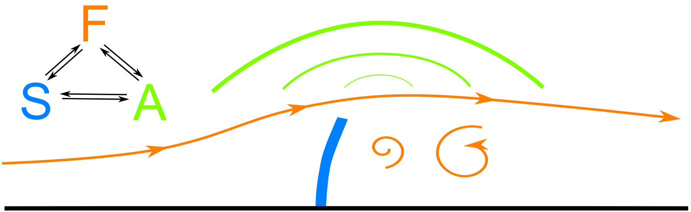
- Continuum mechanics, sets of PDE's for subproblems
- OpenFOAM: flow/acoustics (compressible, near-field), structure
- FASTEST: flow/acoustics (split, near-field)
- Ateles: flow/acoustics (compressible, far-field)
- preCICE: coupling (segregated)
- APESmate: coupling (integrated)
- FEAP: structure



EXAFSA: Tasks and topics

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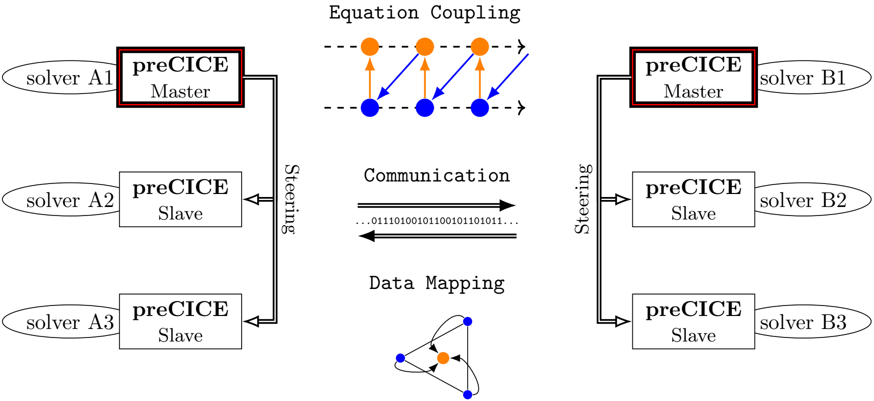
- TN1.P2P Optimize point-to-point communication between solvers
- TN2.LOAD Dynamic load balancing
- TN3.INT Efficient parallel algorithms
- TN4.VAL Validation and testing
- TN5.VIS Large-scale visualization
- TN6.TIME Methods and schemes for coupling in time
- TN7.PERF Performance portability for HPC platforms

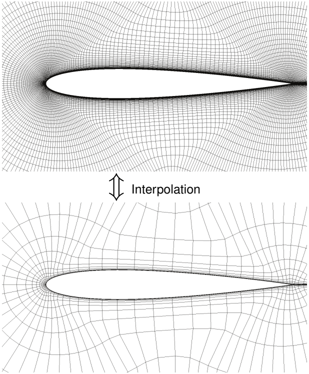
- Solvers: capability, flexibility, performance
- Coupling: algorithms, mapping, communication
- Application: validation, data analysis

preCICE: point-to-point communication



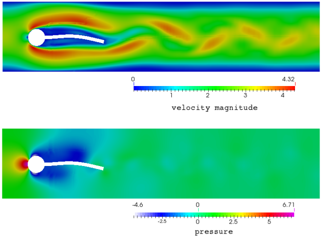
Manifold mapping: technique

- IQN-ILS: approximate inverse Jacobian
- Manifold Mapping (MM): combine high-fidelity model with less expensive coarse model to reduce high-fidelity model cost
- Capture low wave number modes, accelerate convergence
- Algorithm (loop): Evaluate fine model $\rightarrow$ solve coarse model optimization problem $\rightarrow$ update mapping matrix



Manifold mapping: performance

- Cylinder flap benchmark
- 100 000 / 1 500 CV
- Manifold mapping outperforms standard IQN-ILS
- Provable convergence to correct solution



	IQN-ILS (0)	IQN-ILS (4)	MM (0)	MM (4)
iterations fine/coarse	9.3/0.0	3.3/0.0	4.1/27.5	2.1/9.5
duration	4.0	1.4	2.0	1.0

Radial basis functions: State of the art

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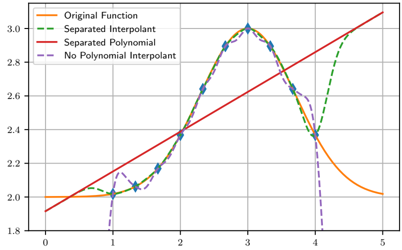
- RBFs are augmented by a global polynomial *q*, i.e. baseline for all values
- Separate treatment of this polynomial improves condition...
- ... and accuracy near the boundary



$$S(x_j) = \sum_{i=1}^{N} \gamma_i \cdot \varphi(\|x_j - x_i\|) + q(x_j)$$

Radial basis functions: Challenges

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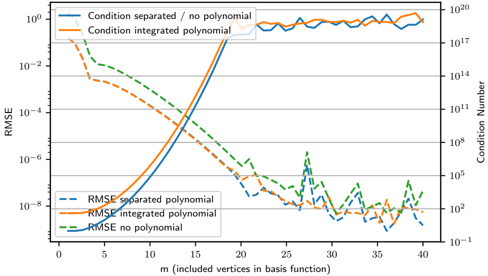
- Trade-off between accuracy and numerical condition
- Unstable solution for wide support of basis functions ($m > 20$)
- Problematic on non-uniform meshes
- RBFs still need user experience for choosing the support radius



APESmate: Overview

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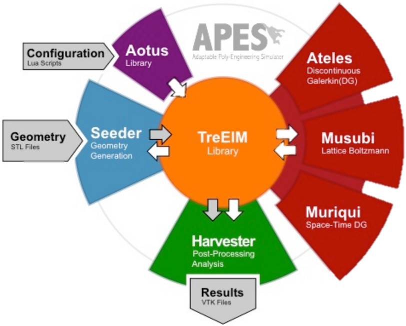
- Integrated approach in APES:
- One executable with access to TreElM libraries
- Fluid-acoustic coupling
- Solver-specific data mapping
- DG: Evaluation of polynomials at sampling points
- $\rightarrow$ Accuracy and computing time increase with scheme order



APESmate: Example

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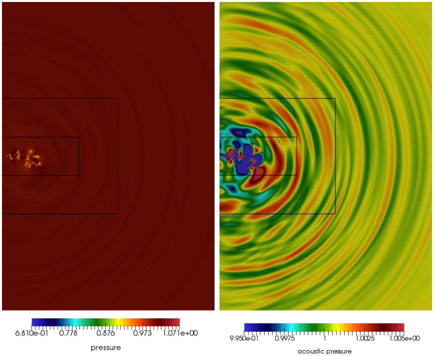
- 2d jet
- bidirectional coupling within Ateles
- three coupling domains: Navier-Stokes ↔ Euler ↔ linearized Euler
- Re=400, Ma=0.4, 72 mio. DOF



APESmate: Performance

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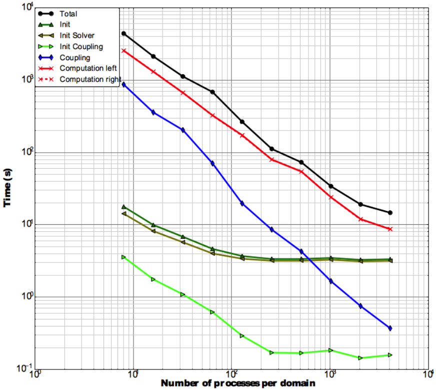
- Strong scaling of integrated approach APESmate
- breakdown the overall time into initialization, computation and coupling
- test case: density pulse advection between domains (Euler/Euler)
- 4096 elements/domain, 164 mio. DOF/domain



Xevolver: Performance portability

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- Separate system-awareness from code
- Minimize modifications and keep maintainability
- Insert `xev` directives into existing code
- User-defined code transformation
- Application to Ateles for NEC SX-ACE: inline expansion, loop collapse
- Current speedup (linear Euler): 5

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

→

```
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
```

	FREQ.	EXCL. TIME[sec]	%	AVER.TIME [msec]
BEFORE	4584	69.650	83.8	15.194
AFTER	4584	2.117	13.7	0.462

Validation: Swept bending fence

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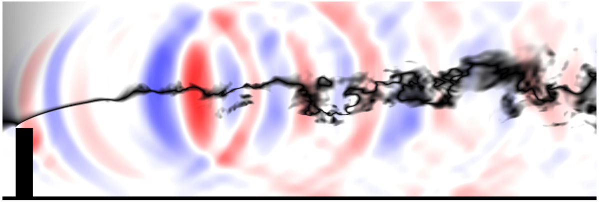
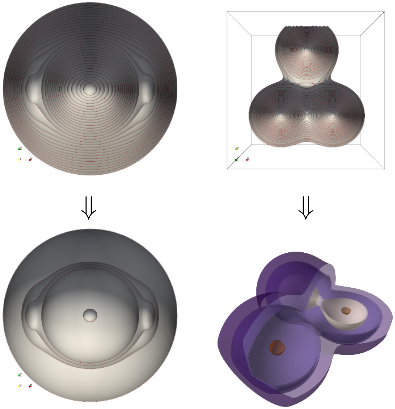
- Sound generation in turbulent shear layer, Re=3000
- $\rightarrow$ multiscale problem
- split: FEAP/FASTEST/FASTEST/Ateles/preCICE
- compressible: OpenFOAM/OpenFOAM/OpenFOAM/Ateles/preCICE



Visualization: Data reduction by surface selection

- Select representative surfaces from a set of related surfaces
- Fully automated selection based on geometric similarity
- Discard surfaces already sufficiently well represented by selection



Sonification: Dynamic wavetable synthesis

- Representation of data by means of sound
- Conventional technique: parameter mapping
- Represent complex data from multidimensional fields to single audio stream
- Add character: sound modification by arbitrarily complex synthesis