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# ExaFSA

## Exascale Simulation of Fluid-Structure-Acoustics Interactions


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Code transformation separates performance concerns from application codes, which can be maintained without considering a particular system configuration.


[1] Kazuhiko Komatsu, Ryusuke Egawa, Shoichi Hirasawa, Hiroyuki Takizawa, Ken'Ichi Itakura and Hiroaki Kobayashi, "Translation of Large-Scale Simulation Codes for an OpenACC Platform Using the Xevolver Framework," International Journal of Networking and Computing, Volume 6, Number 2, pages 167-180, 2016.


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

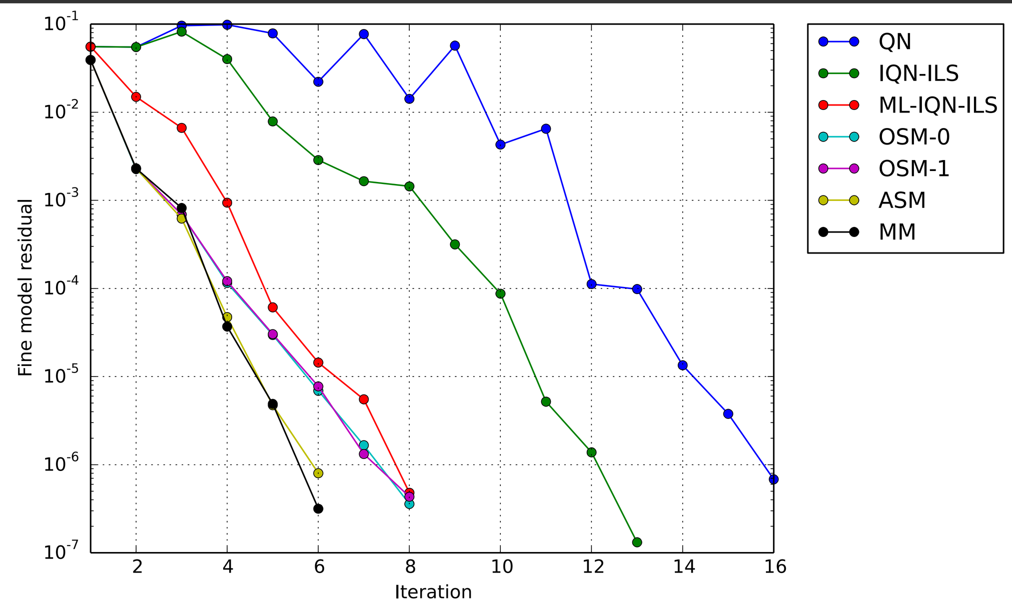
→

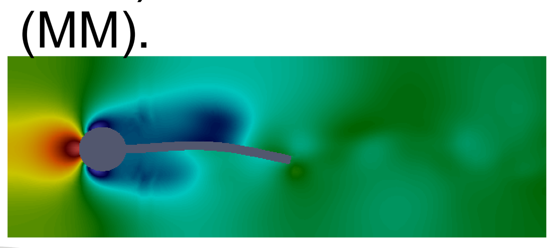
```
do iVar = 1,nScalars
  m=nElems
  n=mpd1_square
  mn=m*n
!cdir nodep
  do ij= 0, mn - 1
    iElem=ij / n + 1
    facepos=mod(ij, n) + 1
    ...
  end do
end do
```

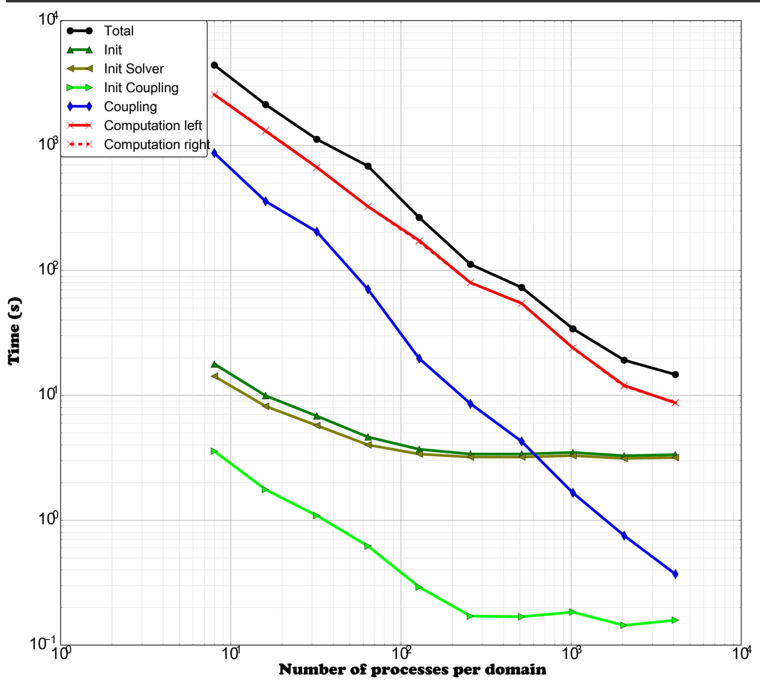
Code transformation can be done with keeping the original code clean

| | FREQ. | EXE. TIME[sec] | EXE. [%] | AVER.TIME [msec] | MFLOPS | V.OP RATIO | AVER. V.LEN | ADB HIT ELEM.% |
|---|---|---|---|---|---|---|---|---|
| BEFORE | 4584 | 69.650 | 83.8 | 15.194 | 25.9 | 53.85 | 151.1 | 99.99 |
| AFTER | 4584 | 2.117 | 13.7 | 0.462 | 1135.1 | 99.83 | 256 | 73.51 |

Convergence history of fluid-structure coupling iterations using Quasi Newton approaches (QN, IQN_ILS), multi-level accelerated approaches based on coarse level Jacobian approximation (ML-IQN-ILS), and aggressive, output space mapping (ASM, OSM) and manifold mapping (MM).

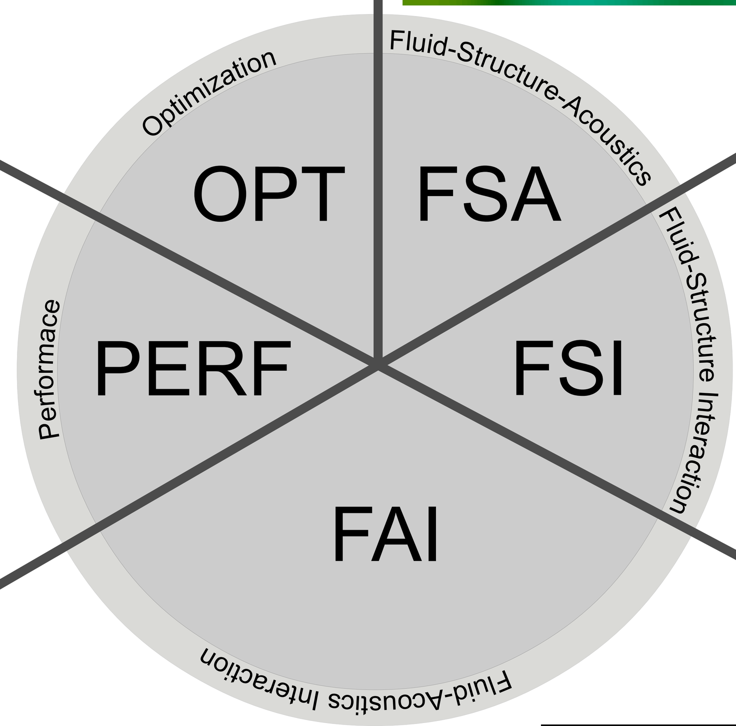


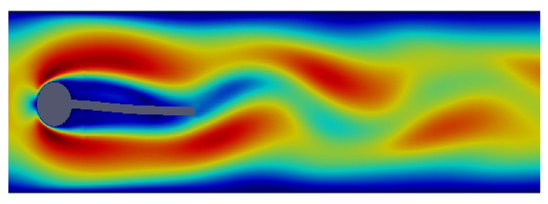



Strong scaling of integrated approach APESmate, breakdown the overall time into initialization, computation and coupling. Two coupling domains: left and right.

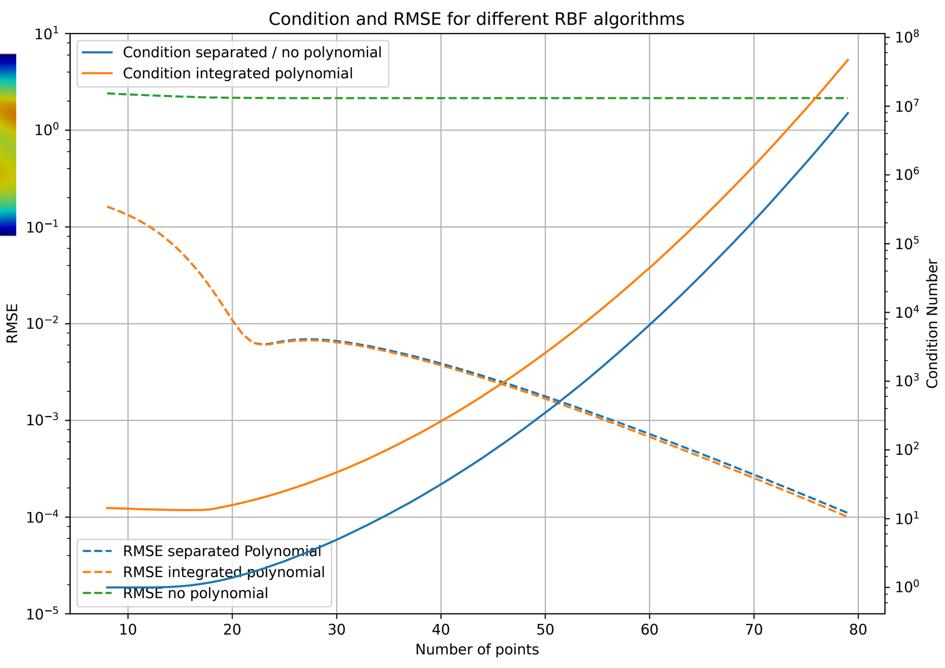

[1]Verena Krupp et al. "Efficient coupling of fluid and acoustic interaction on massive parallel systems". In:Sustained Simulation Performance 2016. Ed. by Michael Resch et al. Springer, 2016.

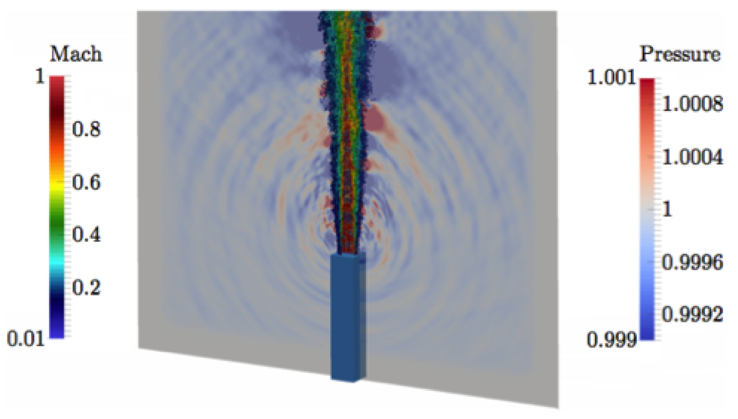




Coupling iterations accelerated via manifold-mapping. The communication is based on peer-to - peer approach. An Efficient and stable data mapping via RBF: Employ ACBF based preconditioners.

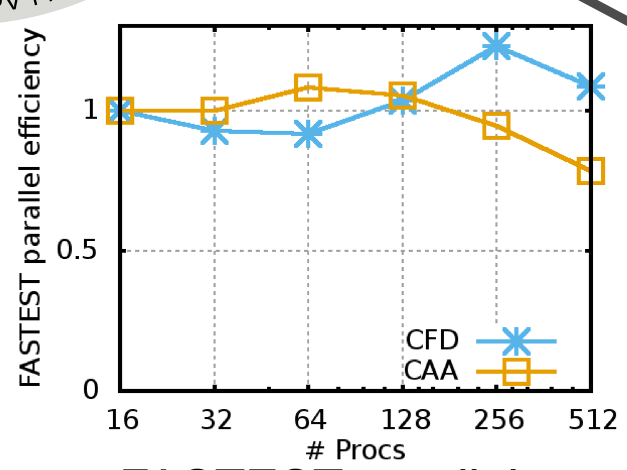



[1] Bungartz et al. preCICE - A Fully Parallel Library for Multi-Physics Surface Coupling. Comput. Fluids 1–9 (2016).

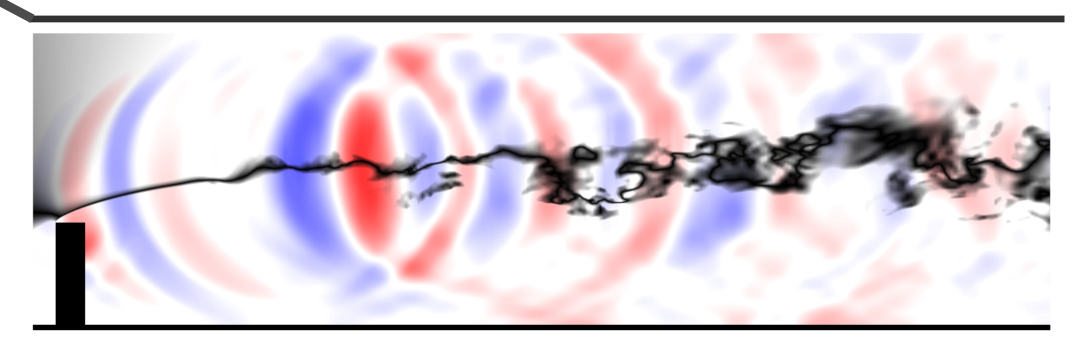




A flow field of a supersonic jet with more than 2.85 billion degrees of freedom that resolves the smallest scales in the flow. Iso-surface of vorticity magnitude colored by Mach number and acoustic pressure on a slice around the core of the free-stream jet. Solved with **Discontinuous Galerkin solver Ateles**




FASTEST parallel efficiency.



Acoustic splitting: Turbulent shear layer flow with acoustical waves. Solved with **Finite Volume solver FASTEST.**

**Second Project Period:**

- point-to-point communication at all stages
- dynamical load balancing
- parallel advanced interface numerics
- testing and validation
- enhanced visualization
- multiple time step coupling
- performance portability

- **performance portability** for Ateles (Siegen) & all other project software
→ code transformation, autotuning (Takizawa)

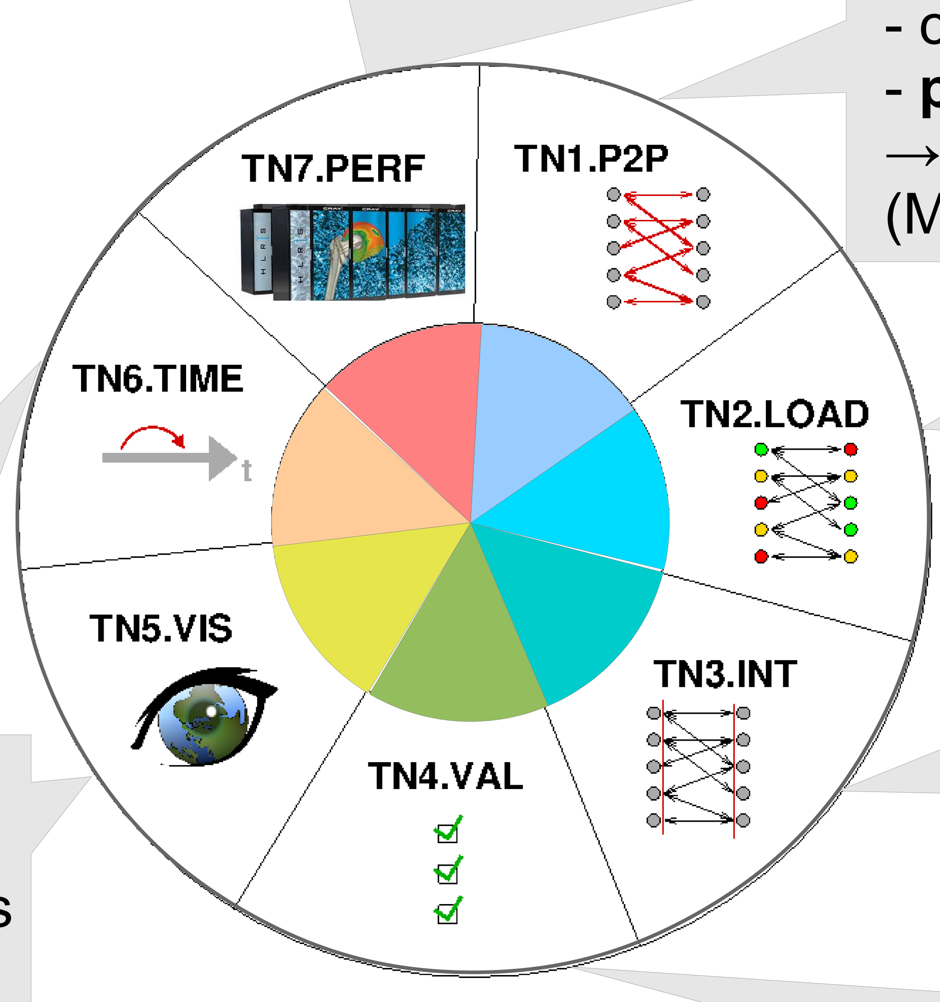
FASTEST APES preCICE

- coupling surface and data partitioning
- **point-to-point** communication initialization
→ hierarchical approaches
(Mehl, Sternel, van Zuijlen)

preCICE

- consistent coupling
- **multiple time step sizes**
→ Lax-Wendroff, Chauchy-Kowalesky, CERK,...
(Mehl, Roller, Sternel, van Zuijlen)

preCICE




- **dynamical balancing**
- locally adaptive
→ optimal task size, work stealing
(Mehl, Roller, Sternel, van Zuijlen)

OpenFOAM preCICE FASTEST APES

- highly scalable **in-situ visualization**
- **multi-field** visualization
→ view-dependency, hierarchical representations
→ frequency based wave analysis (Ertl)

- **parallel interface numerics** (coupling, mapping)
- scalability versus numerical properties
→ scalar products, tall and skinny QR
(Mehl, Roller, Sternel)

preCICE

- functional **correctness, performance, scalability** & physical correctness
→ functional tests (unit & integration tests), comparison with experimental measurement data
(Ertl, Roller, Sternel, van Zuijlen)

OpenFOAM APES FASTEST preCICE

| I/2016 | II/2016 | I/2017 | II/2017 | I/2018 | II/2018 |
|---|---|---|---|---|---|
| hierarchical initialization | | point-to-point at all stages | | scalable quasi-Newton | |
| load weights | mesh adaptivity | local time-stepping | adaptive mesh with preCICE | hp-adaptivity, monitoring | implementation in preCICE |
| | parallel data mapping | | parallel coupling strategies | | |
| | strategy | validation of new features | prototype visual validation | | validation of full FSA |
| | concise FSA-visualization | | | reduced in-situ representation | |
| time interpolation | multi-scale in flow solver | asynchronous coupling | | new coupling & stabilization | implementation in preCICE |
| provide Ateles | | APES ported to NEC SX-ACE | code pattern catalogue | tools usable for other codes | |