Università della Svizzera italiana

Models, Math, Data, and Computing - Computational Science at USI

R. Krause

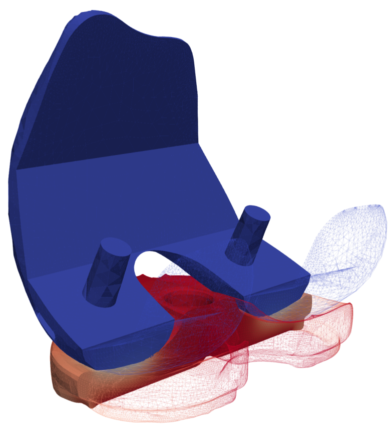
A. Auricchio, S. Bader, P. Benedusi, V. Braglia, L. Gaedke-Merzhäuser, A. Gharaviri, A. Kopaničáková, C. Tomasi, M. Nestola, S. Pezzuto, C. von Planta, P. Zulian, L. Belluzzi, S. Riva

Euler Institute
USI
Università della Svizzera italiana, Lugano

Lugano, 3.9.2022

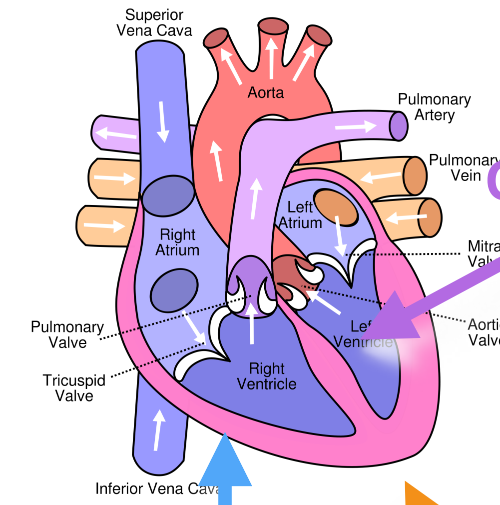
Models, Methods, Applications

Computational Mechanics



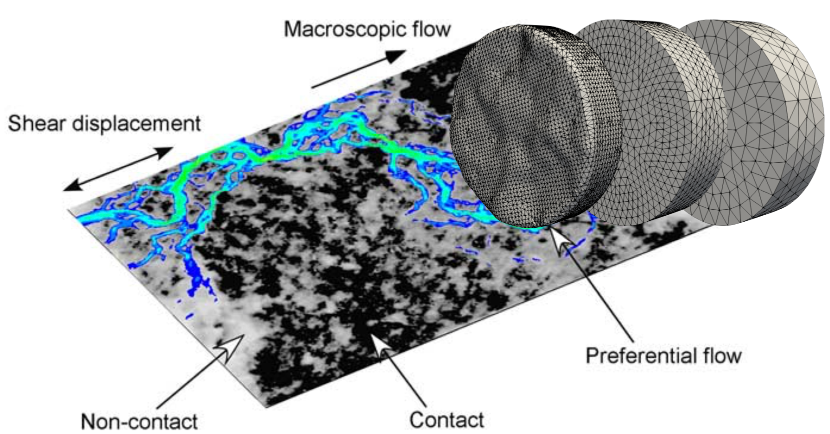
High-performance computing

Computational Medicine



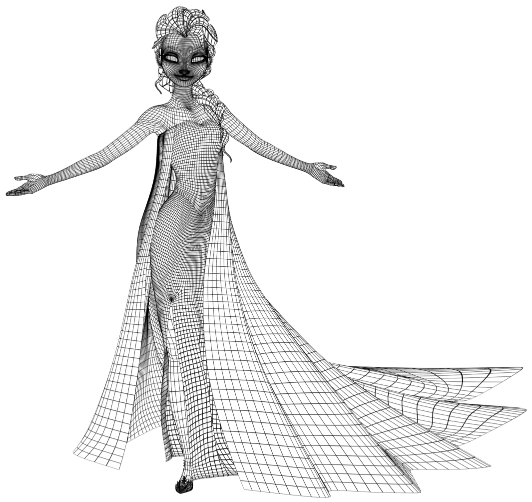
Abstraction Provides Flexibility

SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY



Computational Geophysics

Machine Learning



Cloth simulations for animation

Università della Svizzera italiana Institute of Computational Science ICS

Computational Research at USI

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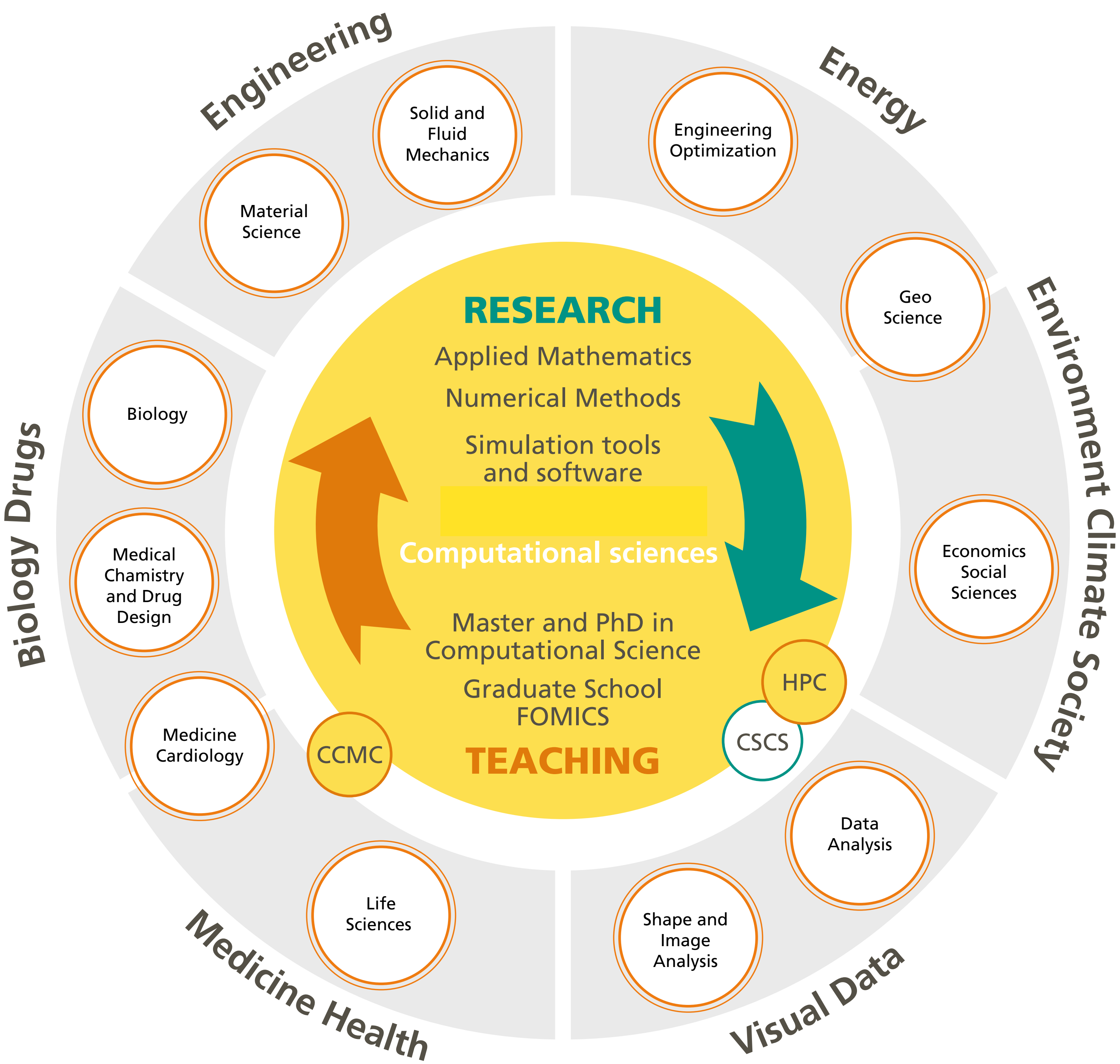
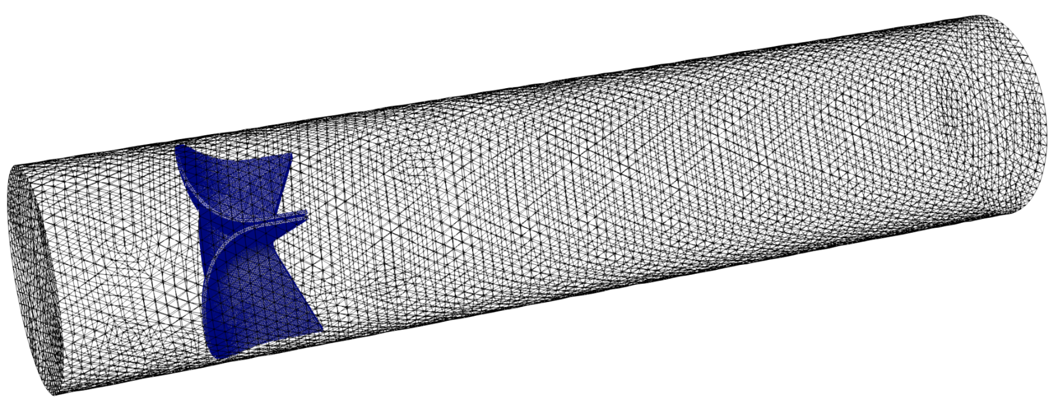
Science
ICS



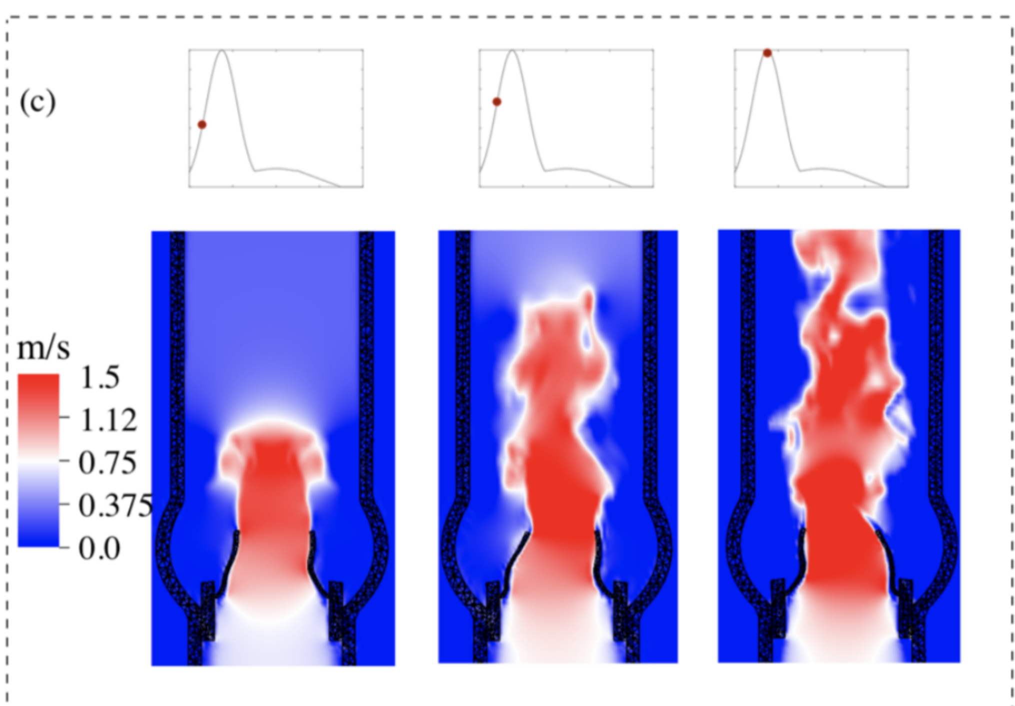
Multiphysics - Bioprosthetic Heart Valve

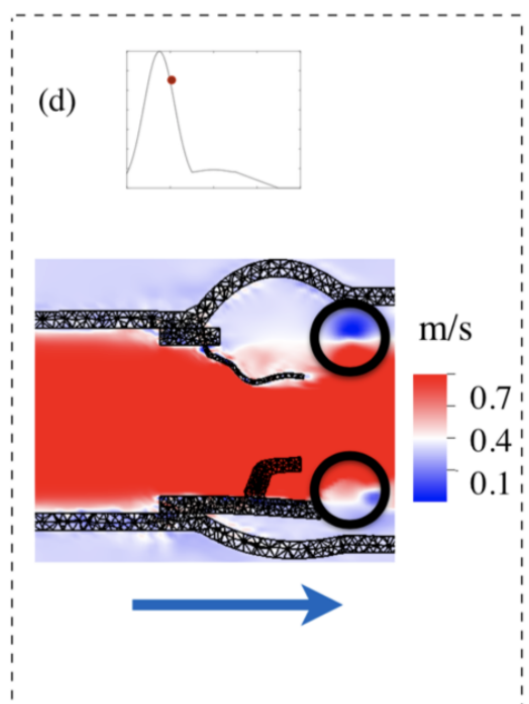
Immersed domain → fluid and solid are coupled in the entire intersection volume

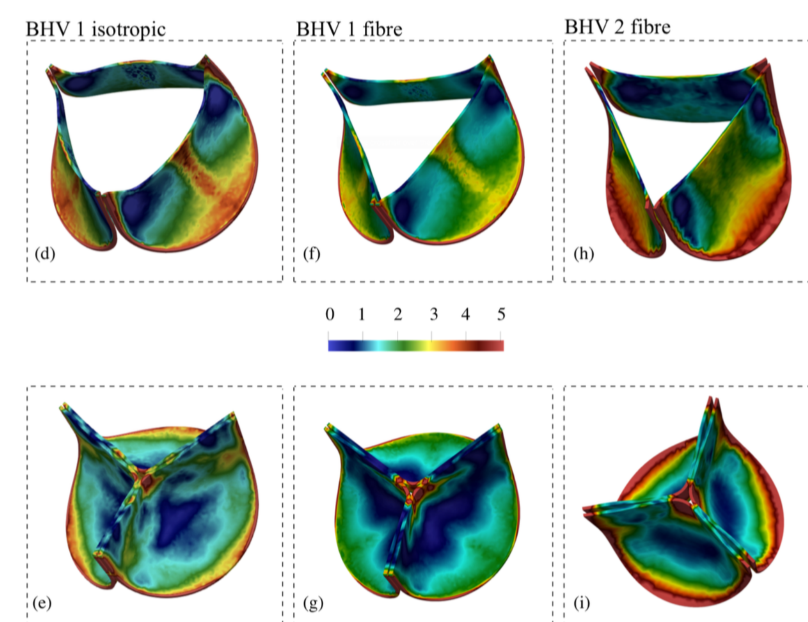


FSI-contact simulation

- Mechanical and haemodynamic performance
- (a) Velocity. Inflow boundary condition.
- (b) Windkessel model for pressure gradient between 80 and 120 mmHg
- (c) Systole
- (d) Diastole





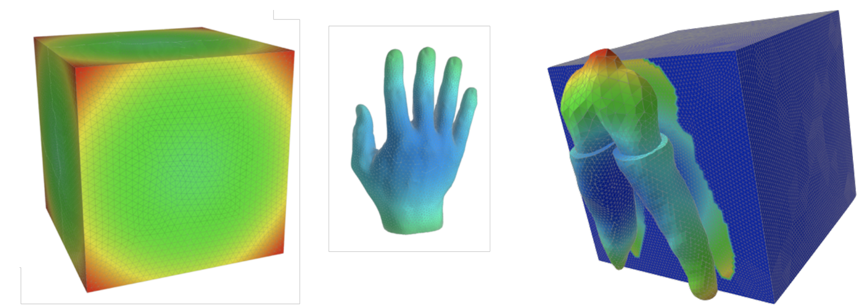


Lagrange multipliers

Method of Lagrange multipliers

- **FSI** terms (**Volumetric** coupling)
- **Contact** conditions (**Surface** coupling)
- Transfer of information between **solid** and **fluid** discretizations

→ In this presentation both use **FEM** or **CVFEM**



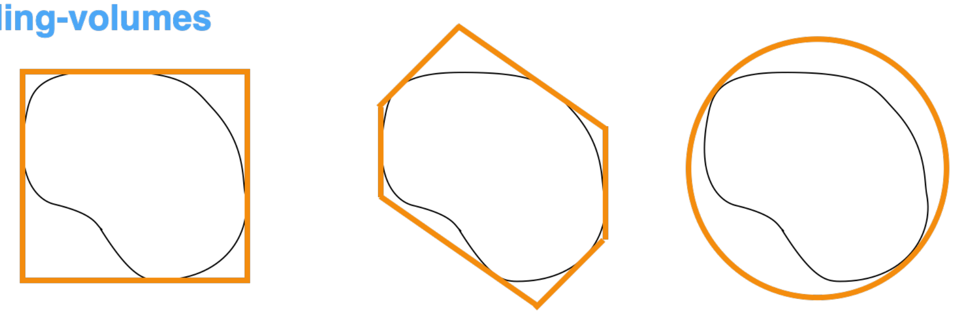
Geometric operations

- **Solid** is considered in the **deformed**/physical **configuration**
- Mesh **entity relationships** have to be determined

→ Geometric search using space partitioning techniques (MPI based bounding volume hierarchies)

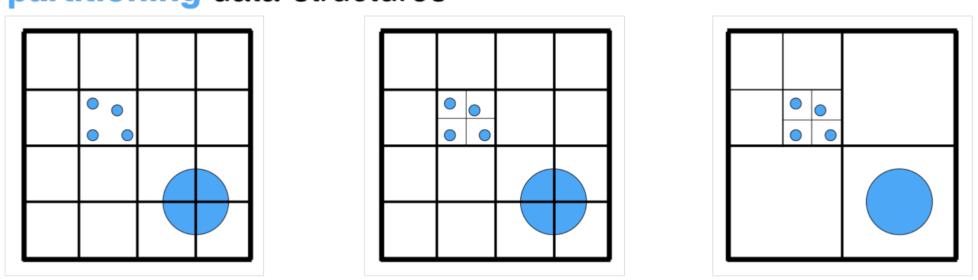
Variational transfer: parallel algorithm

Bounding-volumes



AABB k-DOP Sphere

Space partitioning data-structures



Uniform grid Hierarchical grid **Quad-tree**

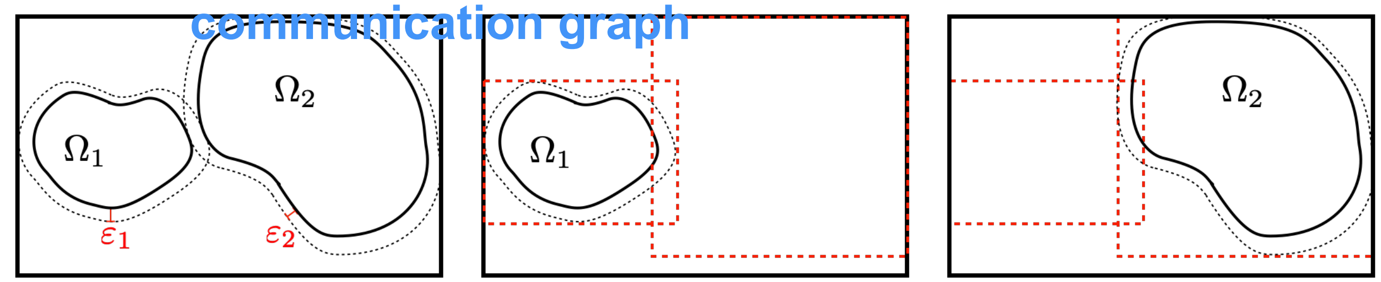
Parallel tree-search

Broad-phase detection

•Computation of local bounding volumes

•**All-to-all** communication

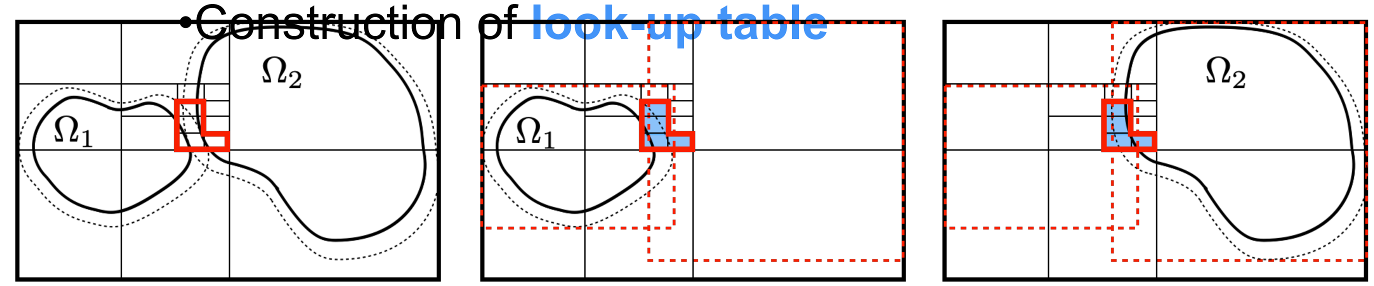
•Construction of **sparse** point-to-point **communication graph**



Middle-phase detection

•Tree-construction and *asynchronous* point-to-point **tree comparison**

•Construction of **look-up table**



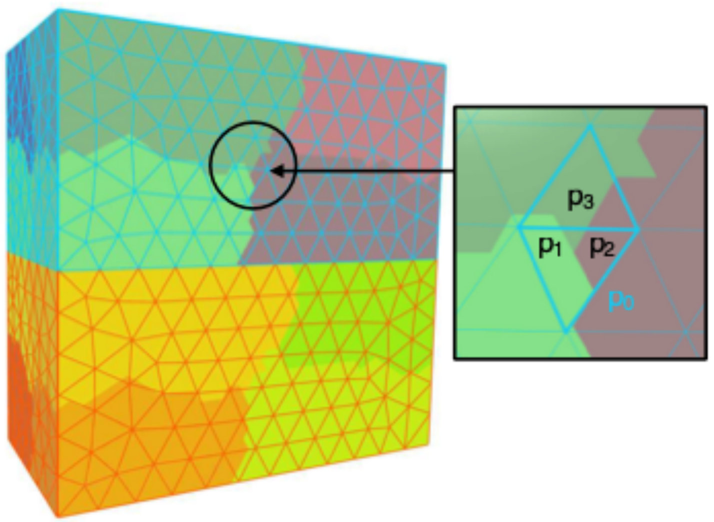
Article: A parallel approach to the variational transfer of discrete fields between arbitrarily distributed unstructured finite element meshes, R. Krause and P. Zulian, SIAM Journal of Scientific Computing 2016

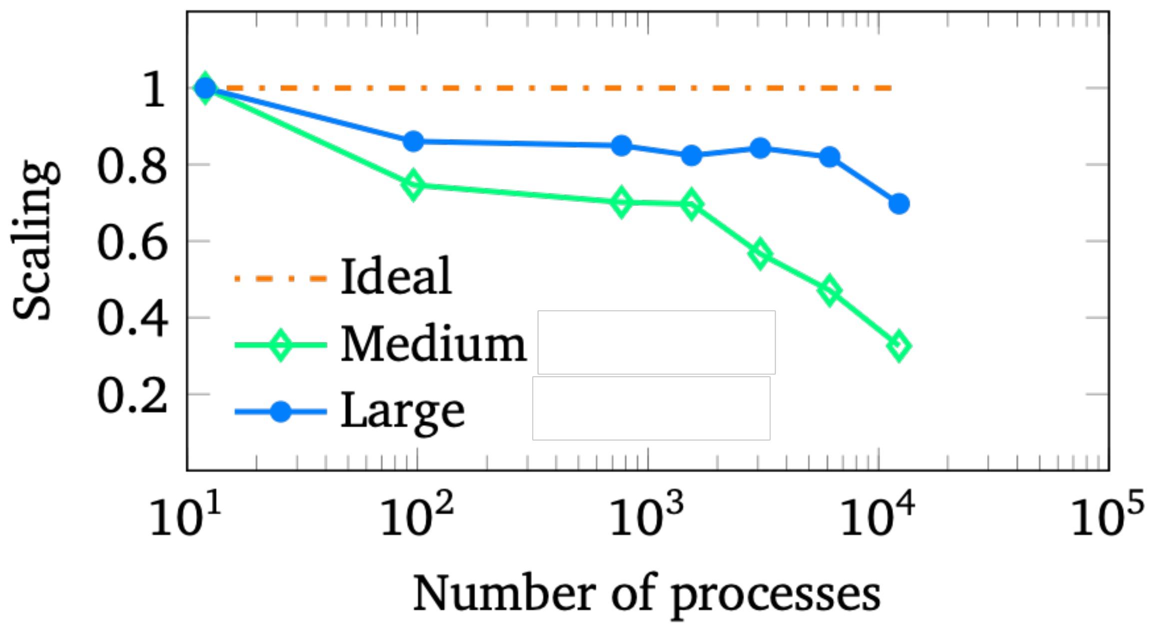
Variational transfer: weak scaling

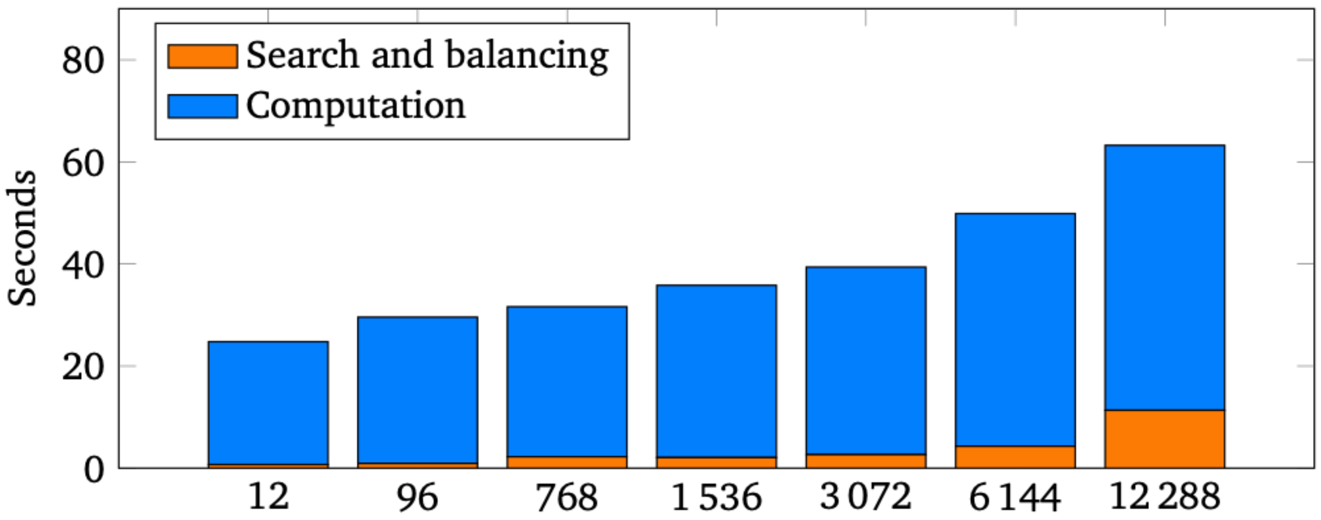
Experiments:

- **Small** **10 000** elements per process
- **Large** **150 000** elements per process
- Output is **x4** (max 8e9 intersections)

Weak scaling is measured as
(time base experiment)/(time experiment)





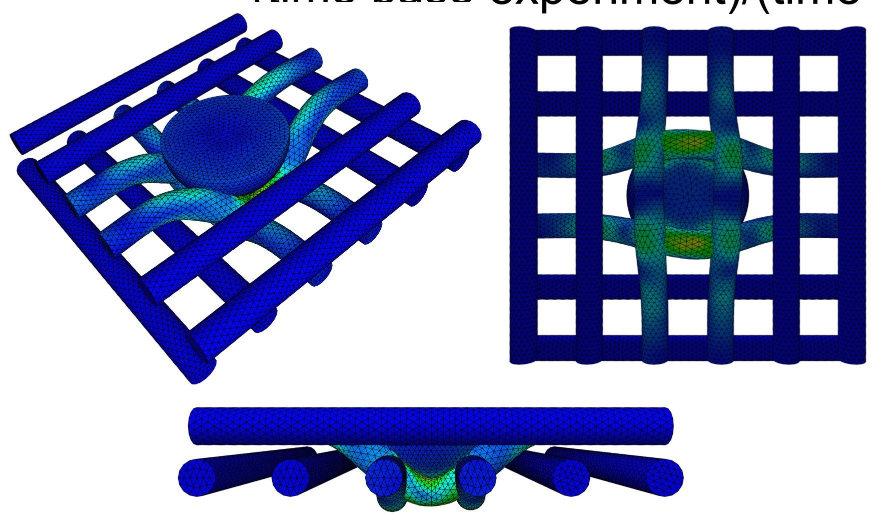


Variational transfer: strong scaling

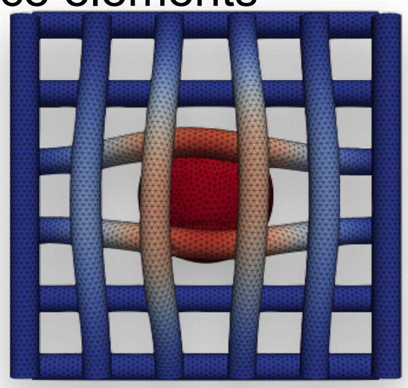
Experiments:

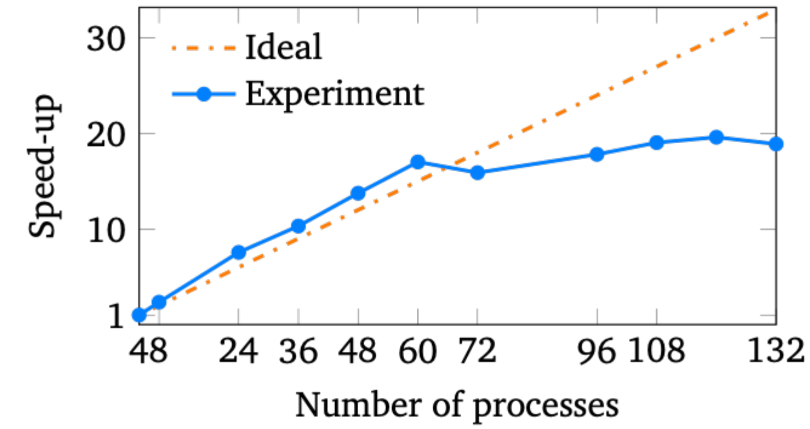
- **Small** **11M** elements, **500K** surface elements
- **Medium** **700M** elements, **8M** surface elements
- **Large** **5G** elements, **30M** surface elements
- Output is **x 0.1**

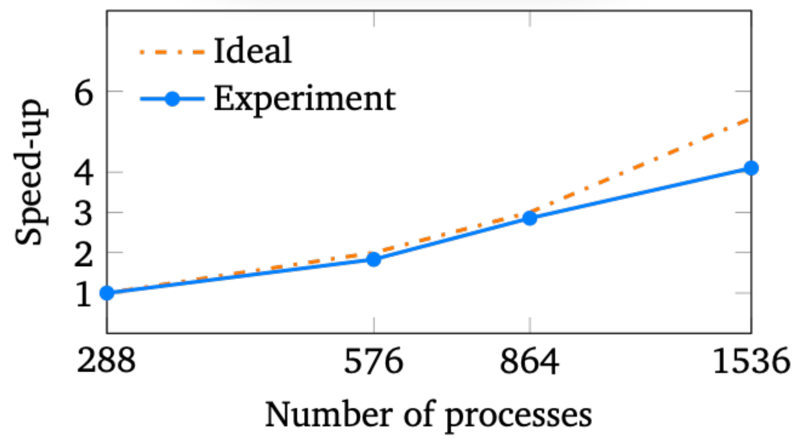
Strong scaling is measured as
(time base experiment)/(time experiment)

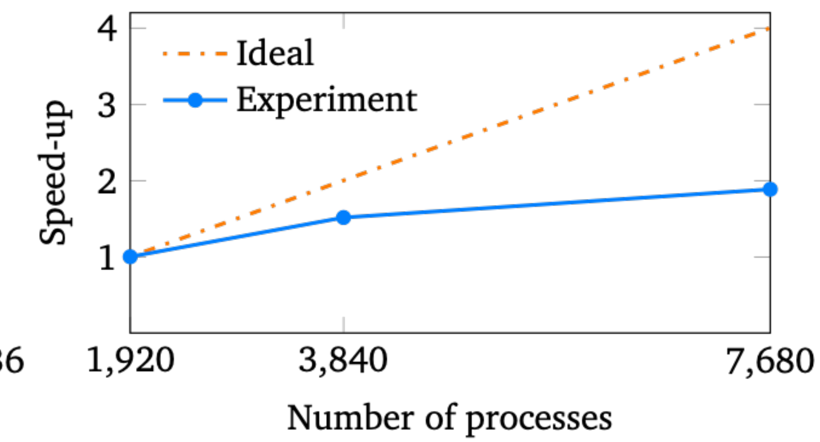


Example simulation









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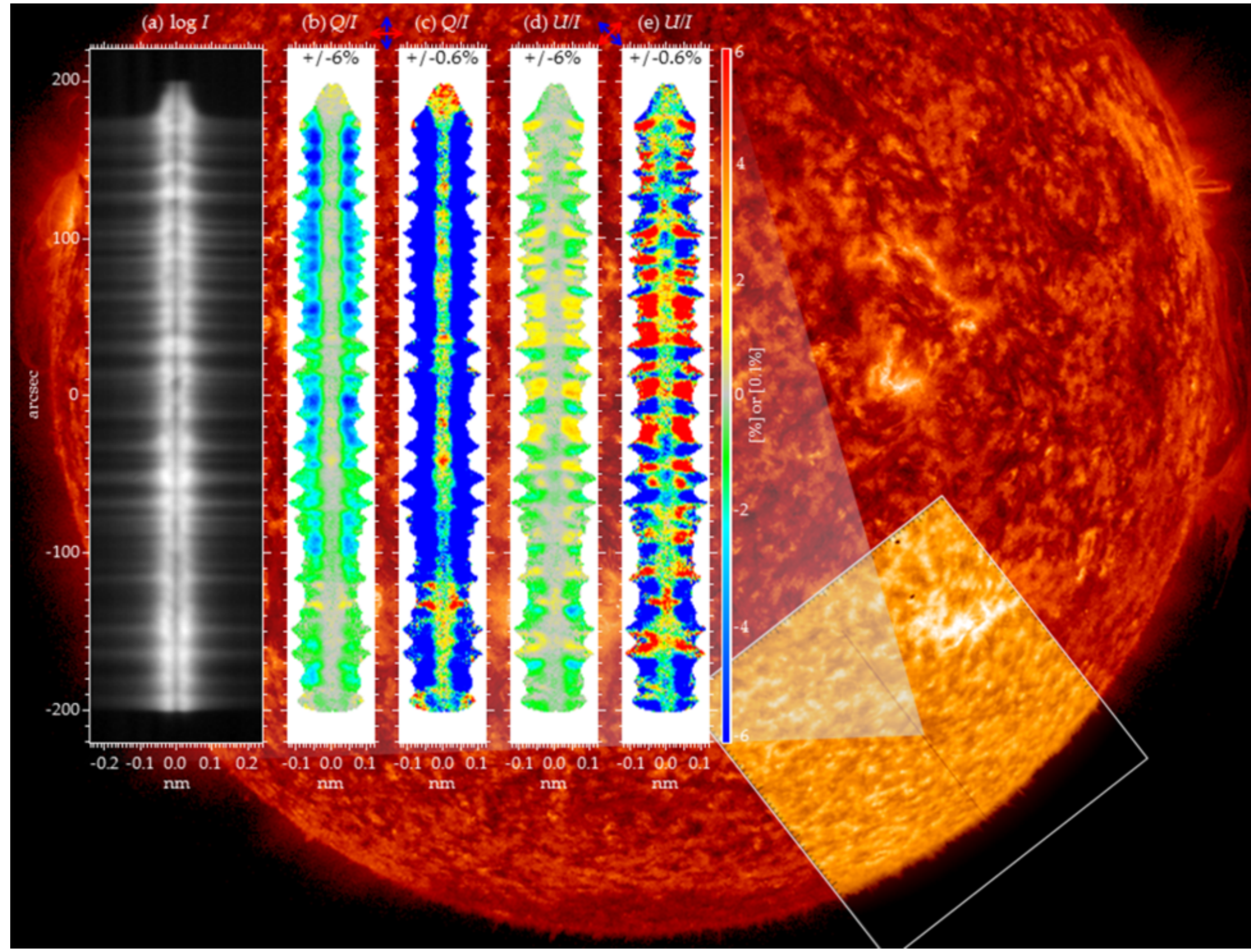
Polarized radiative transfer to understand Sun magnetism

Key problem in solar physics: investigate the magnetism of the outer layers of the solar atmosphere (chromosphere and transition region)

How to do that: by deciphering the information that the magnetic fields on the sun encode in the polarization of solar light



Task: to model the polarization of the solar radiation by *numerically solving the radiative transfer problem for 3D models of the solar atmosphere*

Computational challenge: to solve this problem particular physical processes (partial frequency redistribution (PRD) effects), which strongly affect the polarization of chromospheric spectral lines.

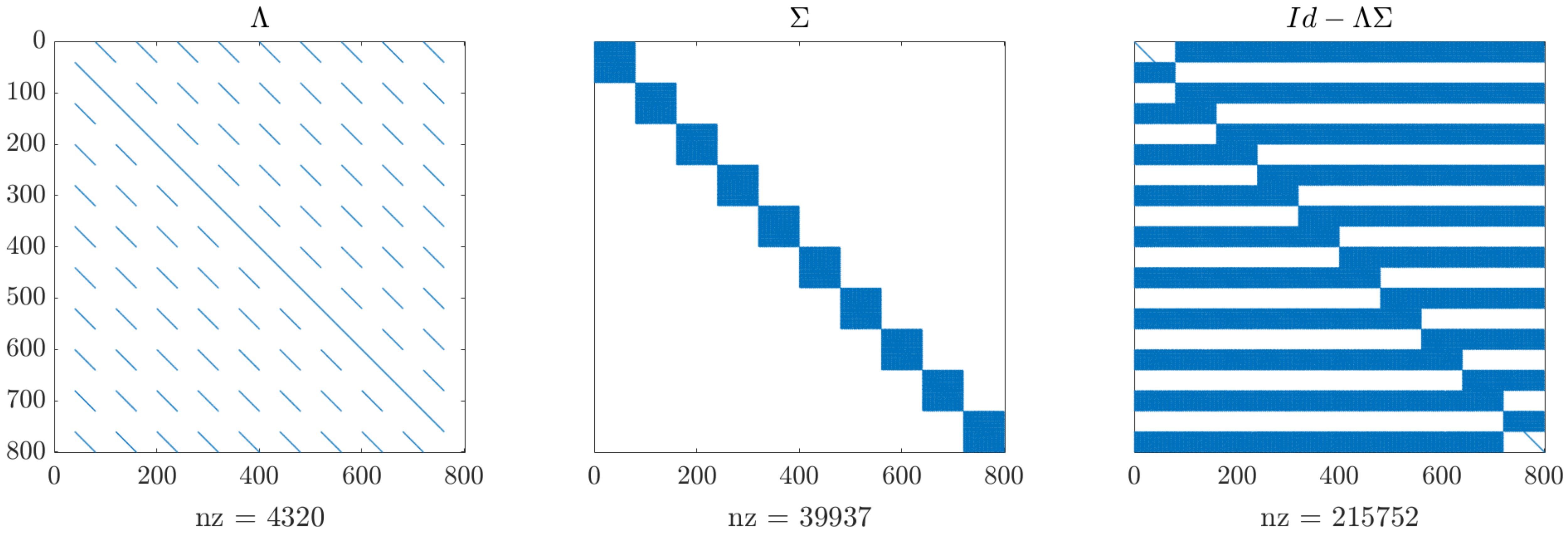
State of the art: for polarized radiation never solved in 3D taking PRD effects into account

RT algebraic formulation

Combining $\mathbf{I} = \Lambda\varepsilon + \mathbf{t}$ and $\epsilon = \Sigma\mathbf{I} + \epsilon^{\text{th}}$:

$$(Id - \Lambda\Sigma)\mathbf{I} = \mathbf{t} + \Lambda\epsilon^{\text{th}},$$

with RT operator $Id - \Lambda\Sigma$.



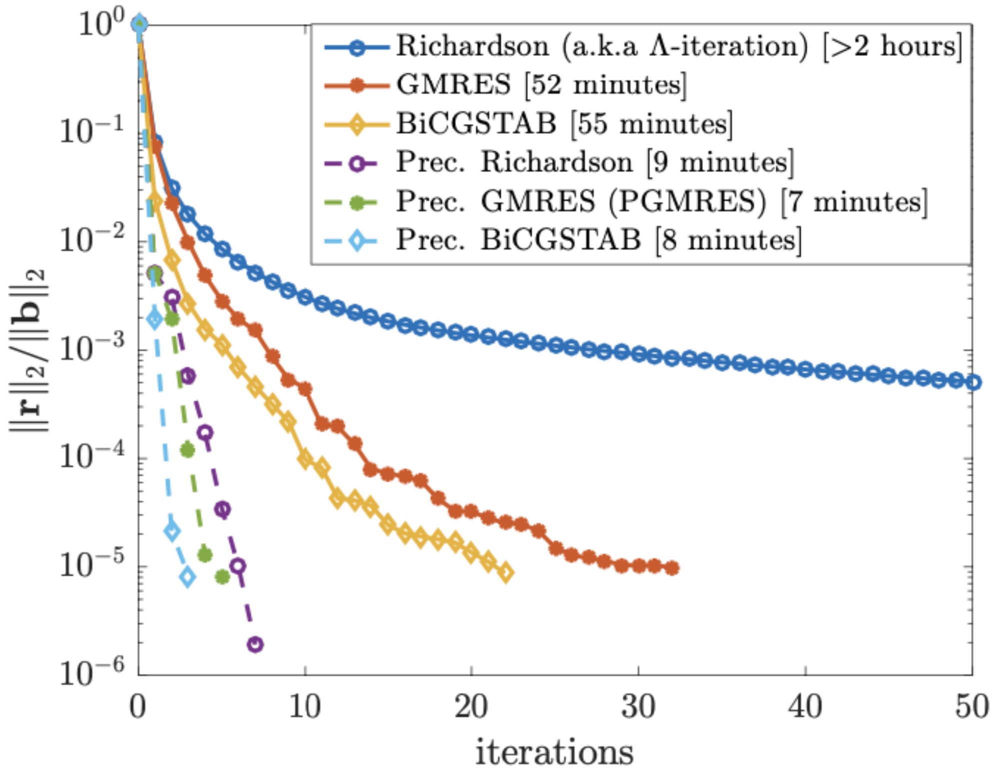
Remarks

1. Operators are **matrix-free**
2. The cost of applying Λ is negligible w.r.t. the Σ one

Multi-fidelity preconditioner

$$P = Id - \Lambda\widetilde{\Sigma}$$

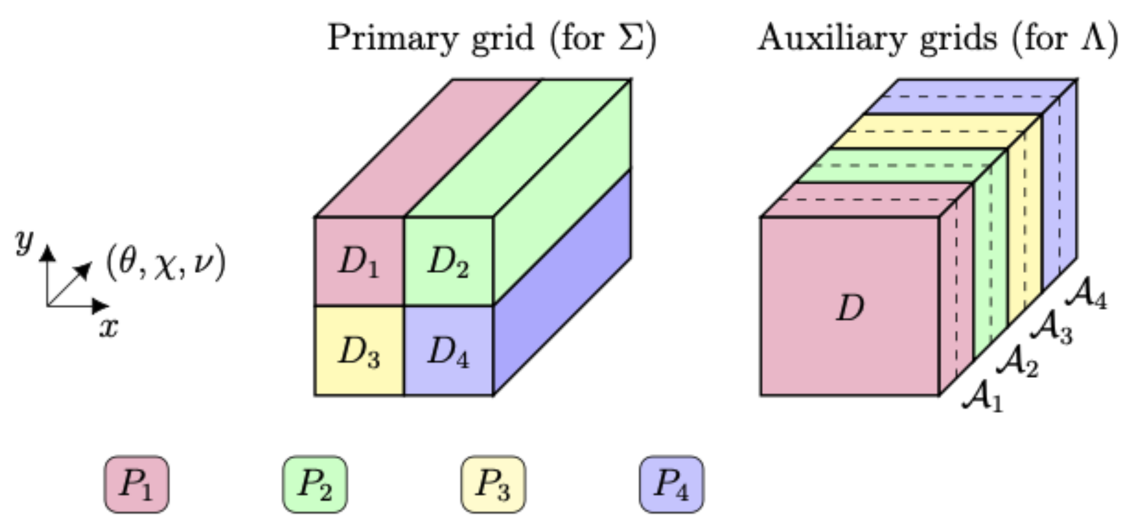
- With $\widetilde{\Sigma}$ cheap approximation of Σ (CRD)
- Computing P^{-1} action using GMRES



Remarks

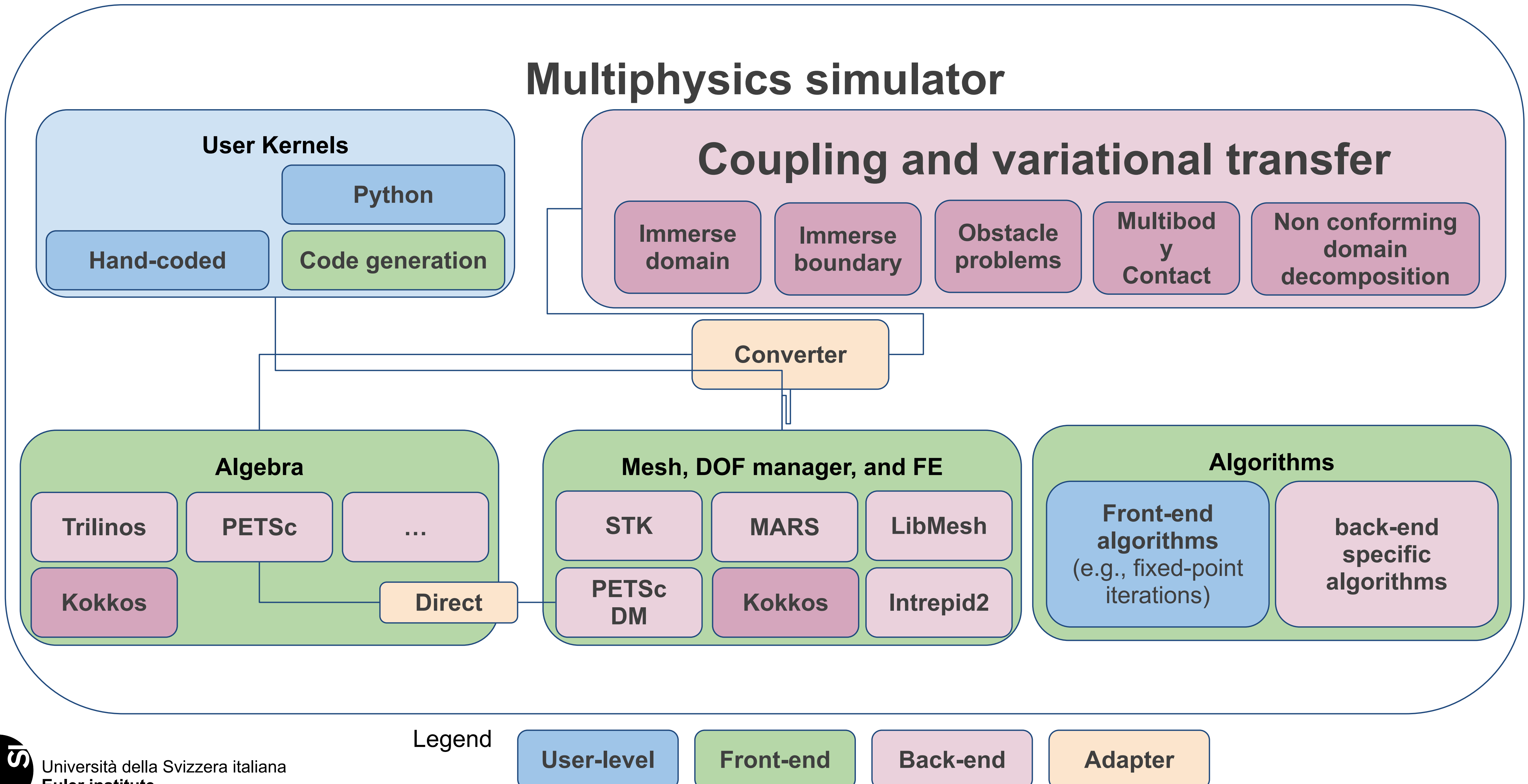
- Robust strategy w.r.t. all disc. parameters

- Σ and $\widetilde{\Sigma}$ evaluation embarrassingly parallel over N_s
- Λ evaluation embarrassingly parallel over $N_\Omega N_\nu$



Single call to `MPI_All_to_all()` to exchange data (no ghost layers)

Flexible Software



Thank you