



Efficient Tools and Coupling Strategies for the Partitioned Simulation of Fluid- Structure Interactions

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Outline

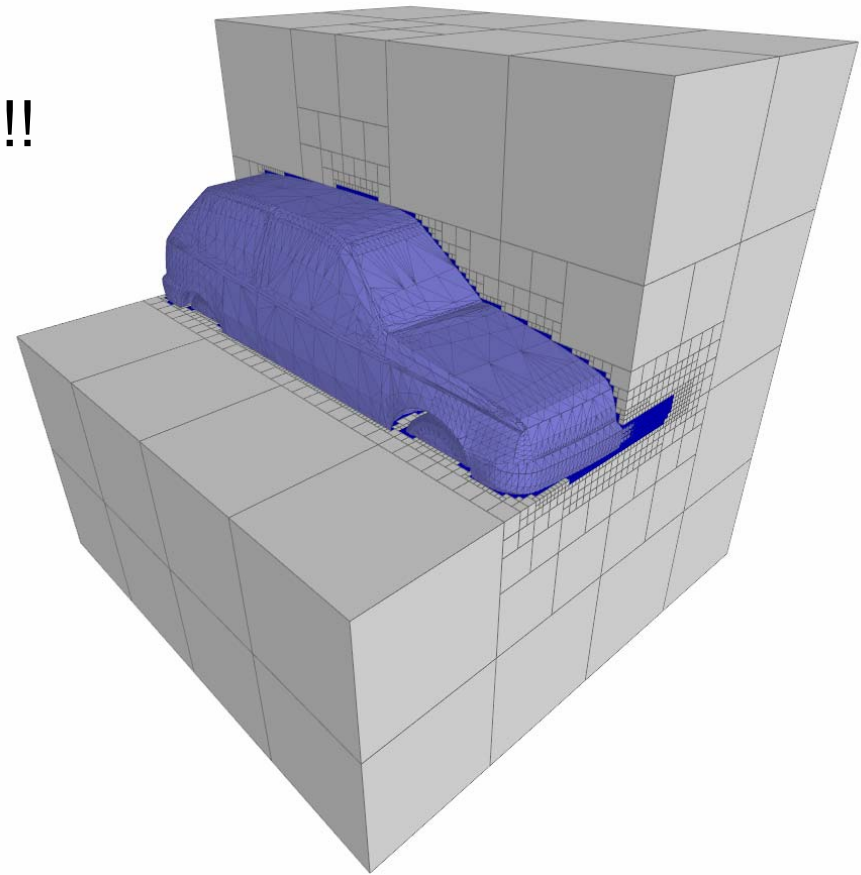
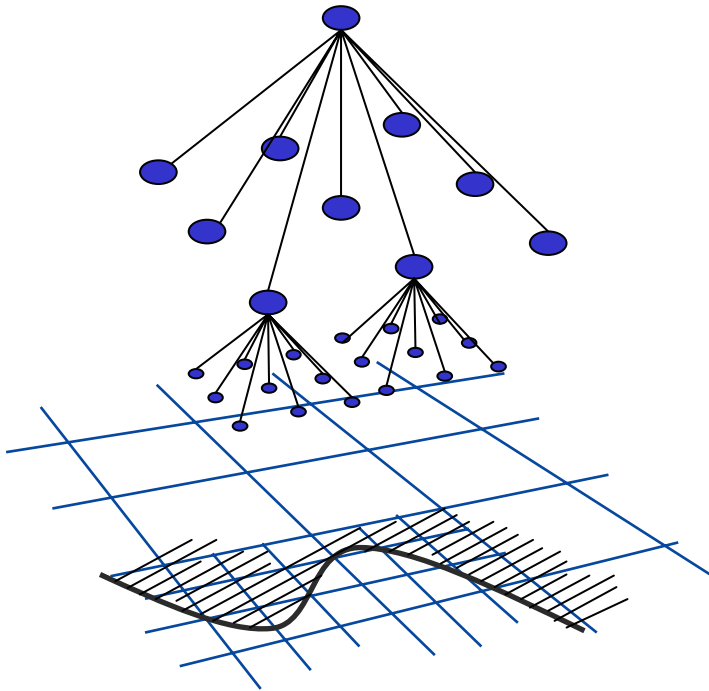
- spacetrees
- preCICE (FSI*ce)
- flow solver Peano
- first coupling results

Outline

- spacetrees
- preCICE
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- first coupling results

Spacetrees

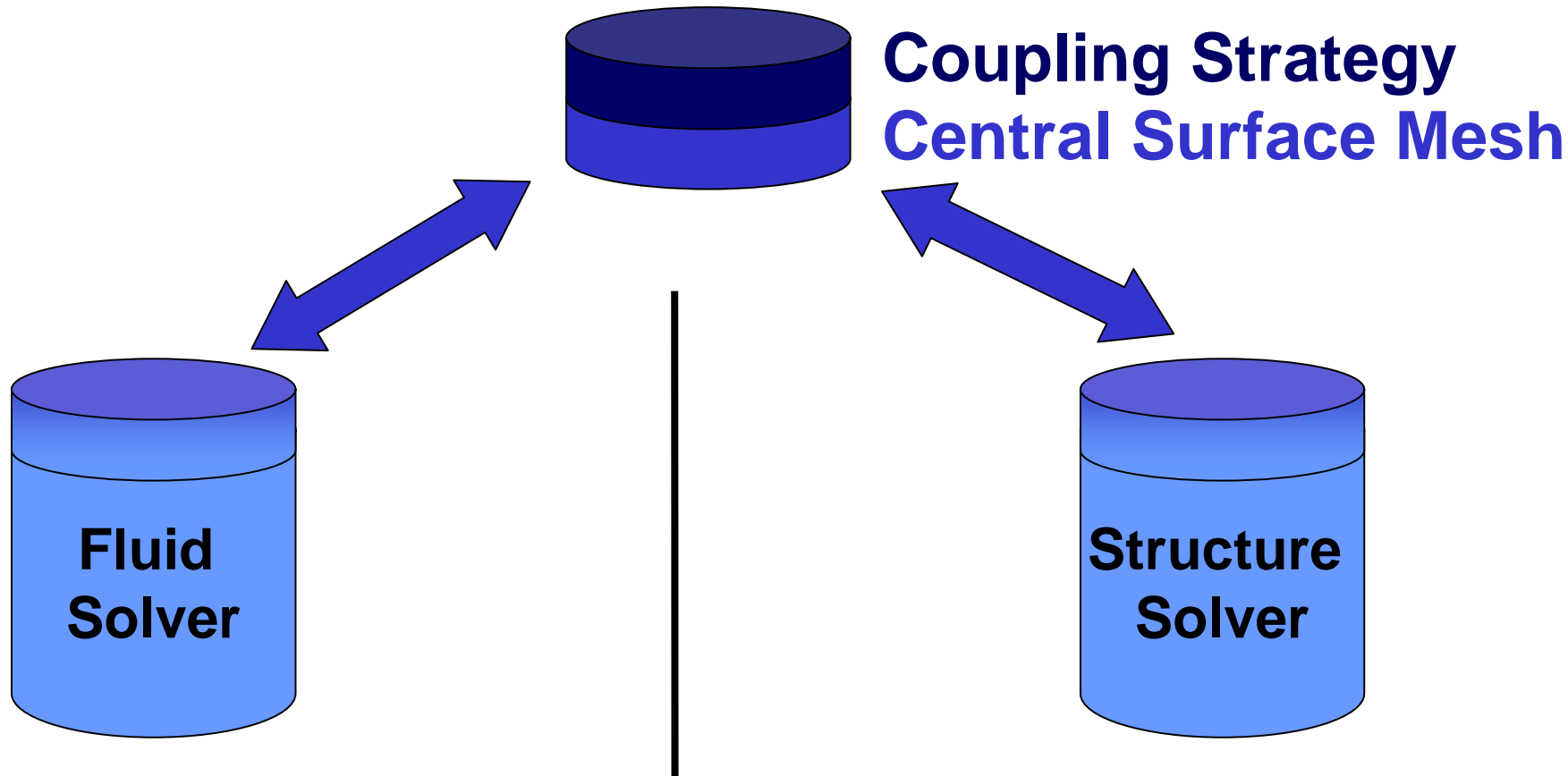
- recursive refinement
- do not store empty information!!!



Outline

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Client-Server Concept of FSI*ce

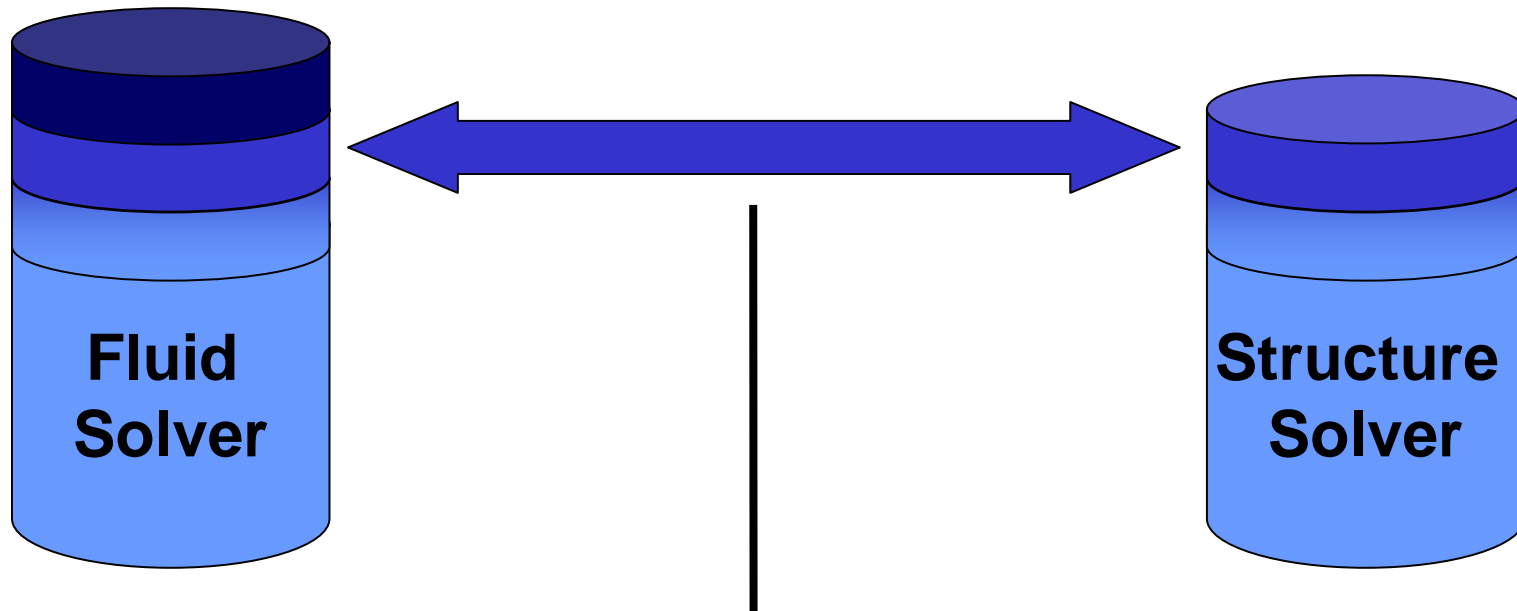


Library Concept of preCICE

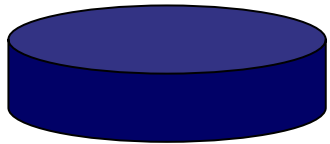
Coupling Strategy

Central Surface Mesh

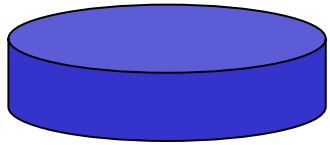
Central Surface Mesh



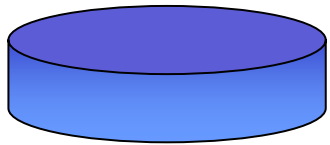
preCICE – Overview



Coupling Strategy

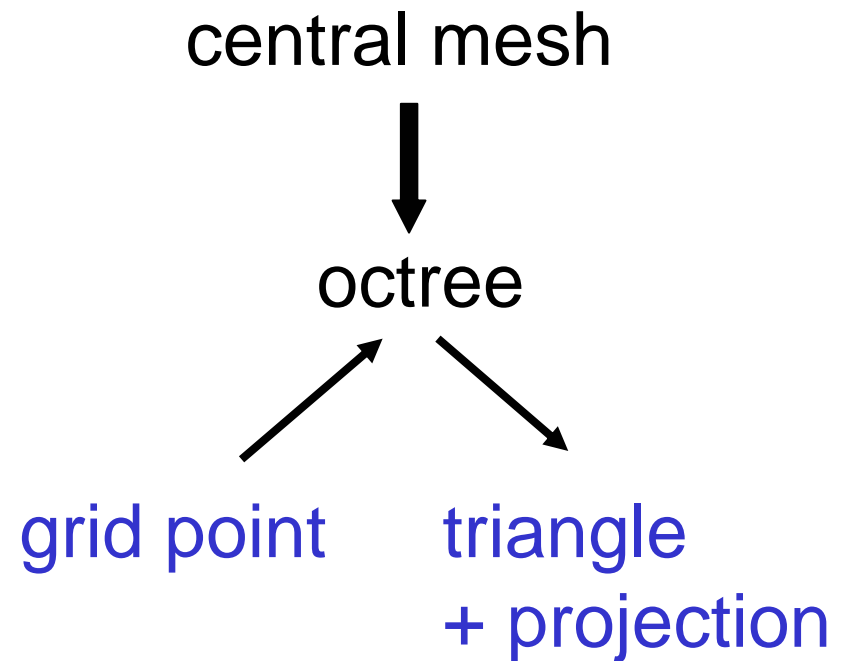
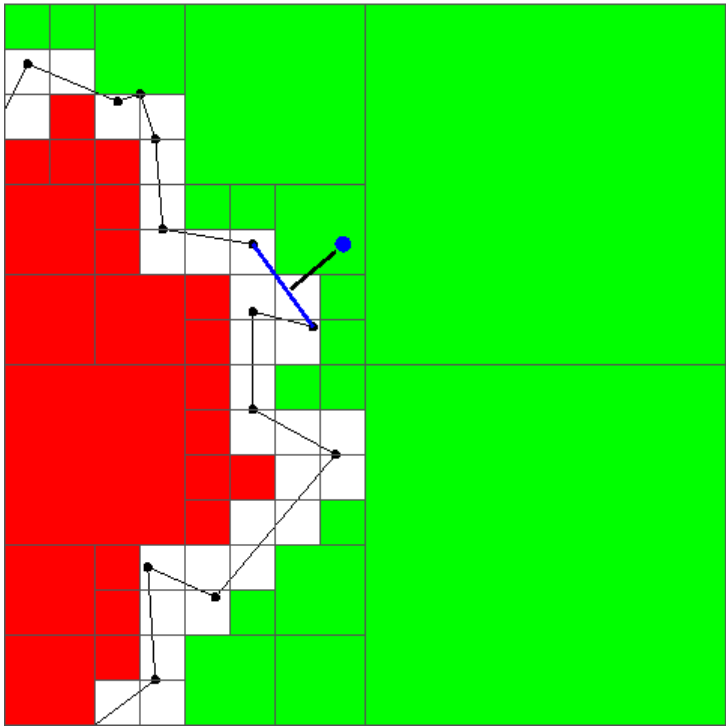
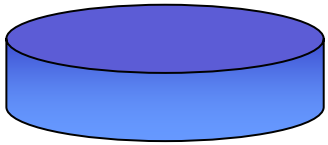


Central Mesh

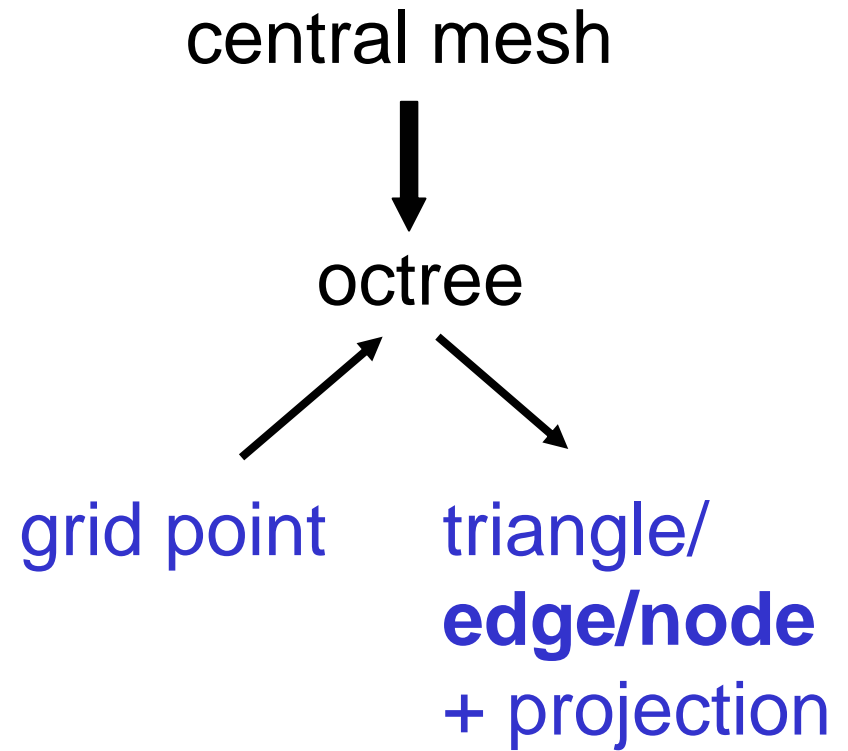
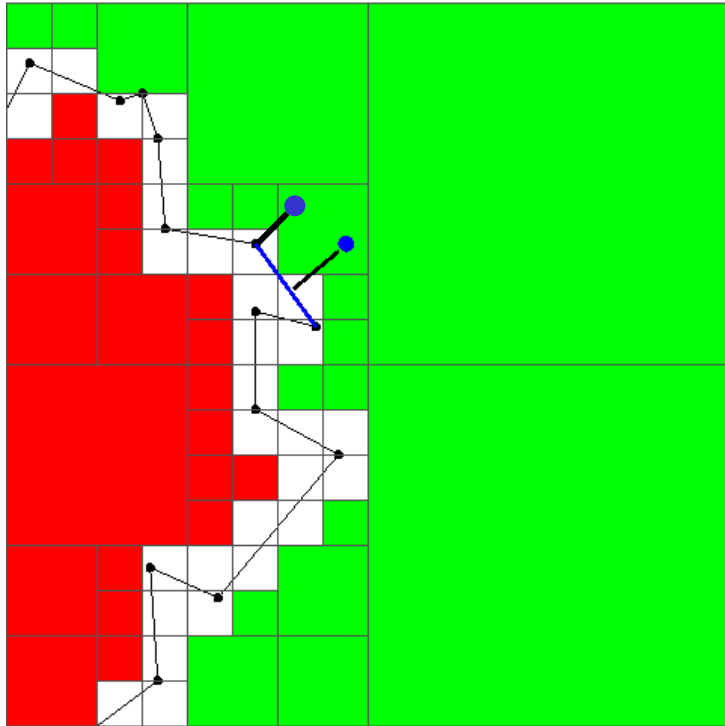
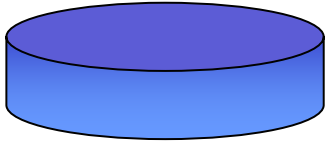


Data Mapping

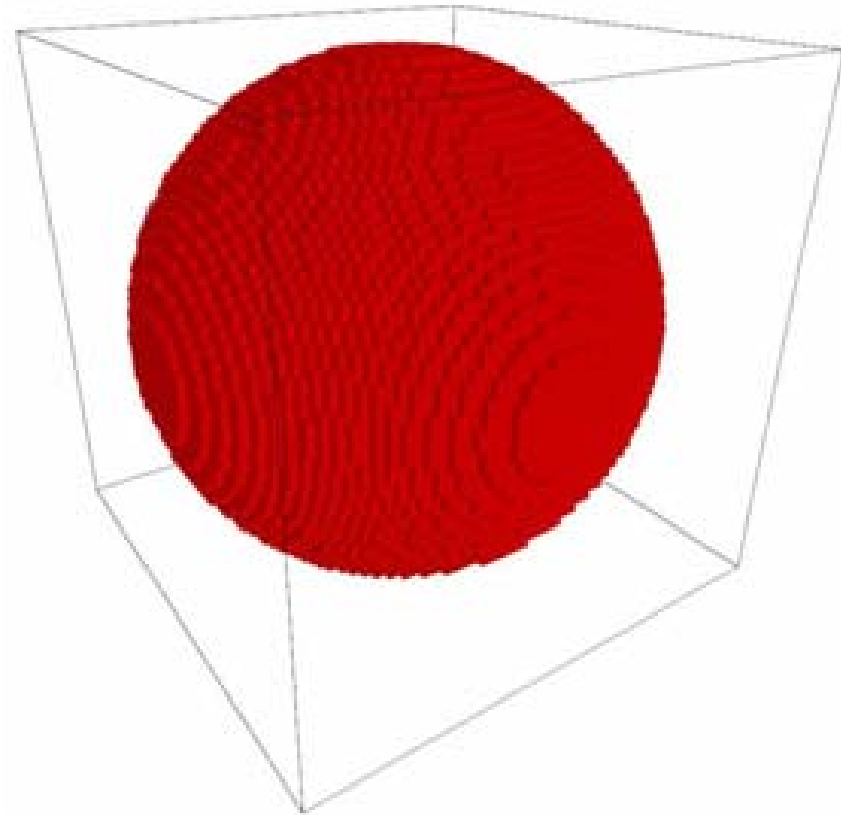
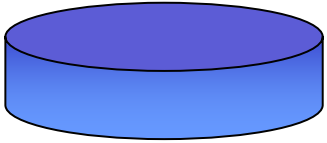
preCICE – Data Mapping



preCICE – Data Mapping



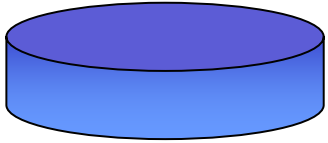
preCICE – Data Mapping



Cart.res.	# triang.	runtime
256^3	8,000	2.6 sec
512^3	8,000	10.1 sec
512^3	32,000	14.3 sec
512^3	128,000	17.4 sec

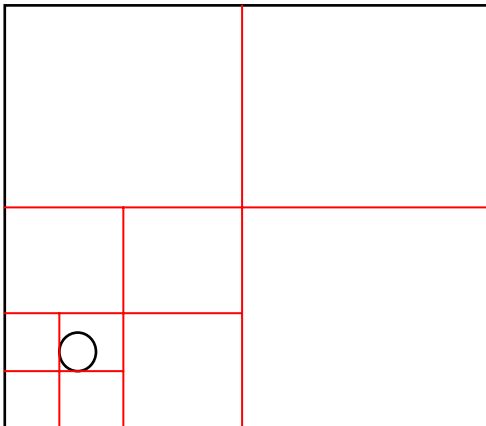
neighbourhood search measured on a Pentium M 1.6 GHz processor with 2048 kB cache

preCICE – Data Mapping

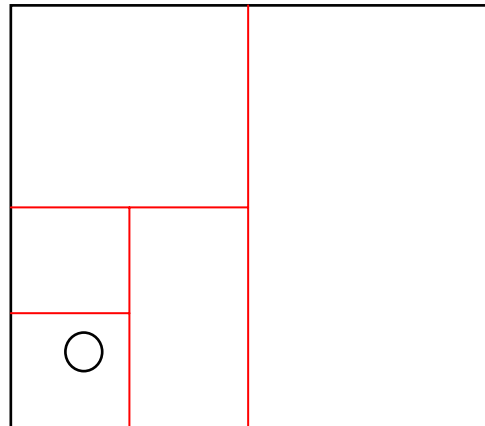


- alternatives: kd-trees
 - not substantially superior

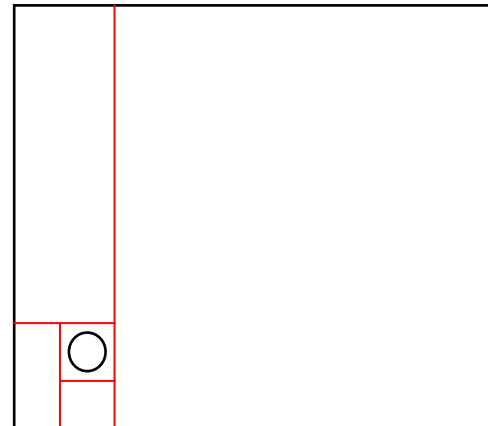
classical quadtree



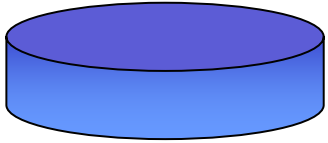
midpoint partitioning



adapted midpoint partitioning



preCICE – Data Mapping

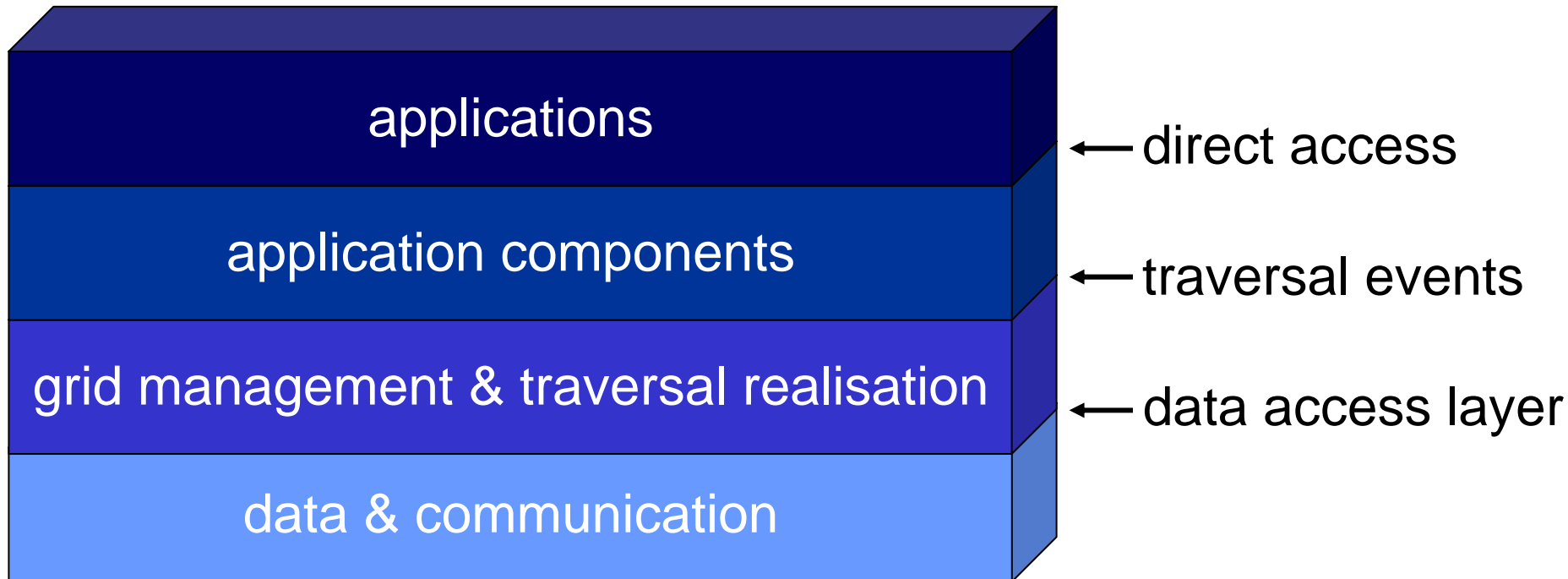


- dynamical spacetree
 - builds up according to queries
 - modification after geometry change
 - one spacetree per geometric element
- avoid storage of unnecessary information
- apt for moving geometries

Outline

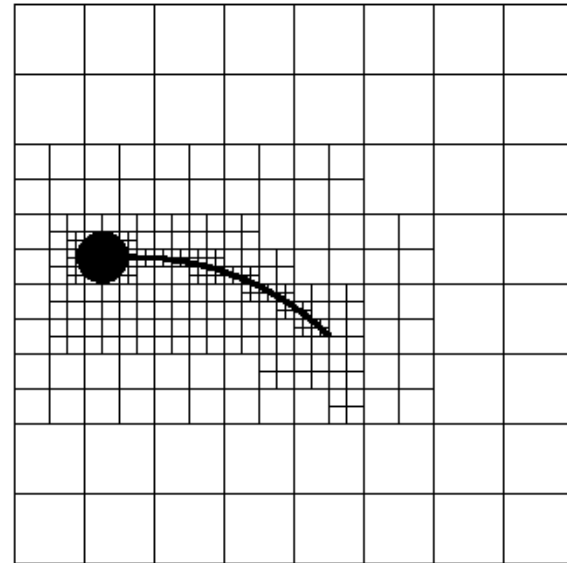
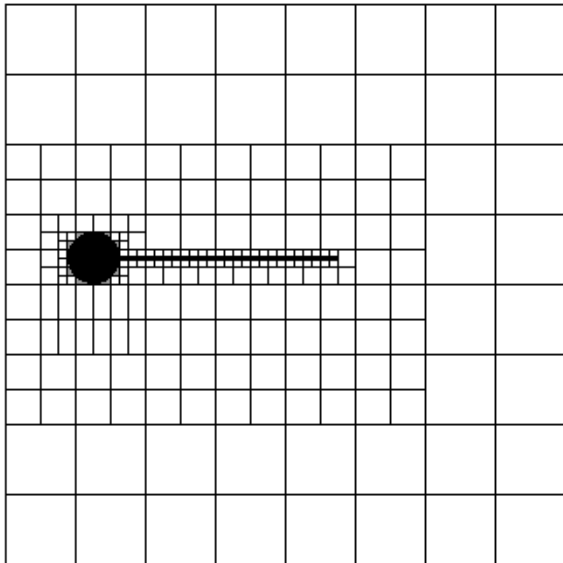
- spacetrees
- preCICE
- flow solver Peano
- first coupling results

PDE Framework Peano



Fluid Solver Peano – Grids

- Eulerian approach (fixed grids)
 - cheap
 - large geometrie changes



Fluid Solver Peano – Data

- Peano traversal order
 - time locality
- data stacks
 - spatial locality

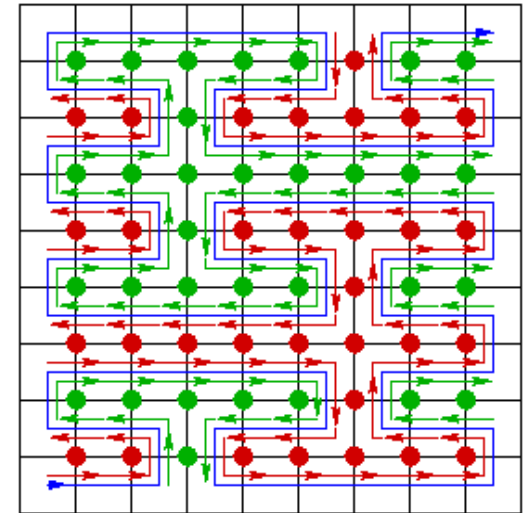


2D input
stack

red line
stack

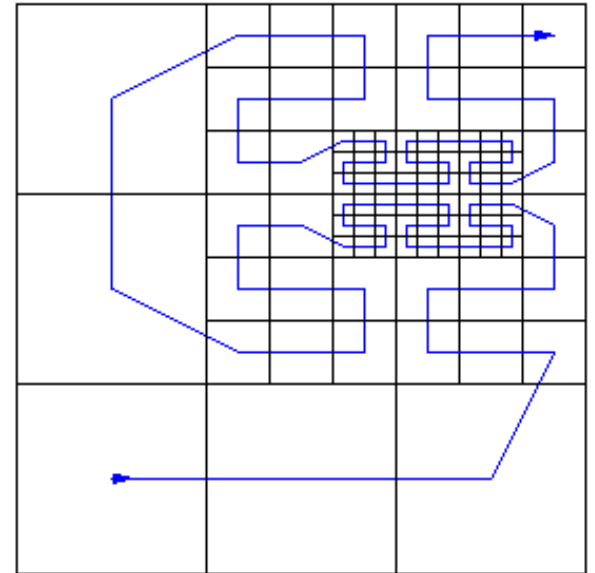
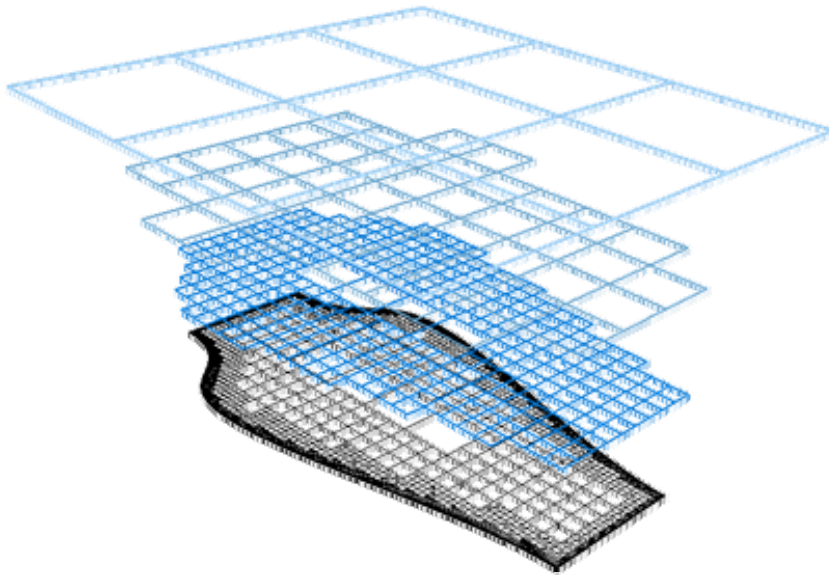
green line
stack

2D output
stack



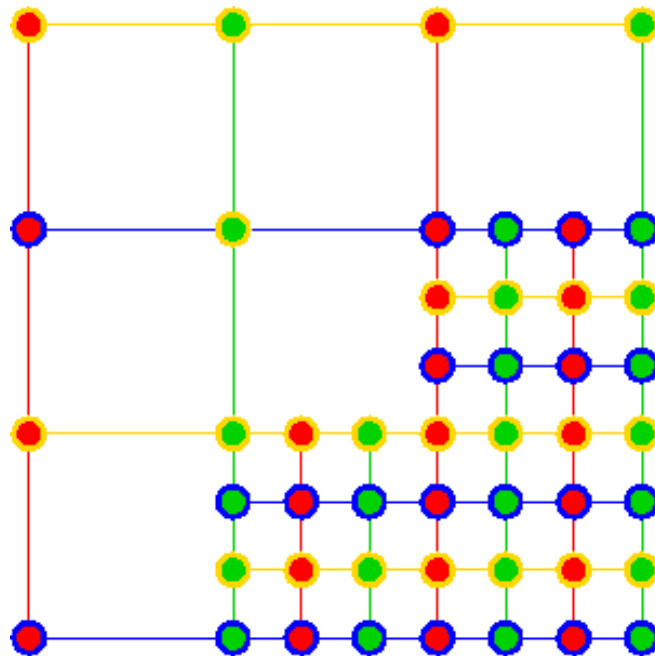
Fluid Solver Peano – Data

- multilevel (hierarchical) data
 - more sophisticated stack concept



Fluid Solver Peano – Data

- multilevel (hierarchical) data
 - more sophisticated stack concept
 - 2007 (Weinzierl): $3^d - 1$ stacks \rightarrow $2d + 2$ stacks



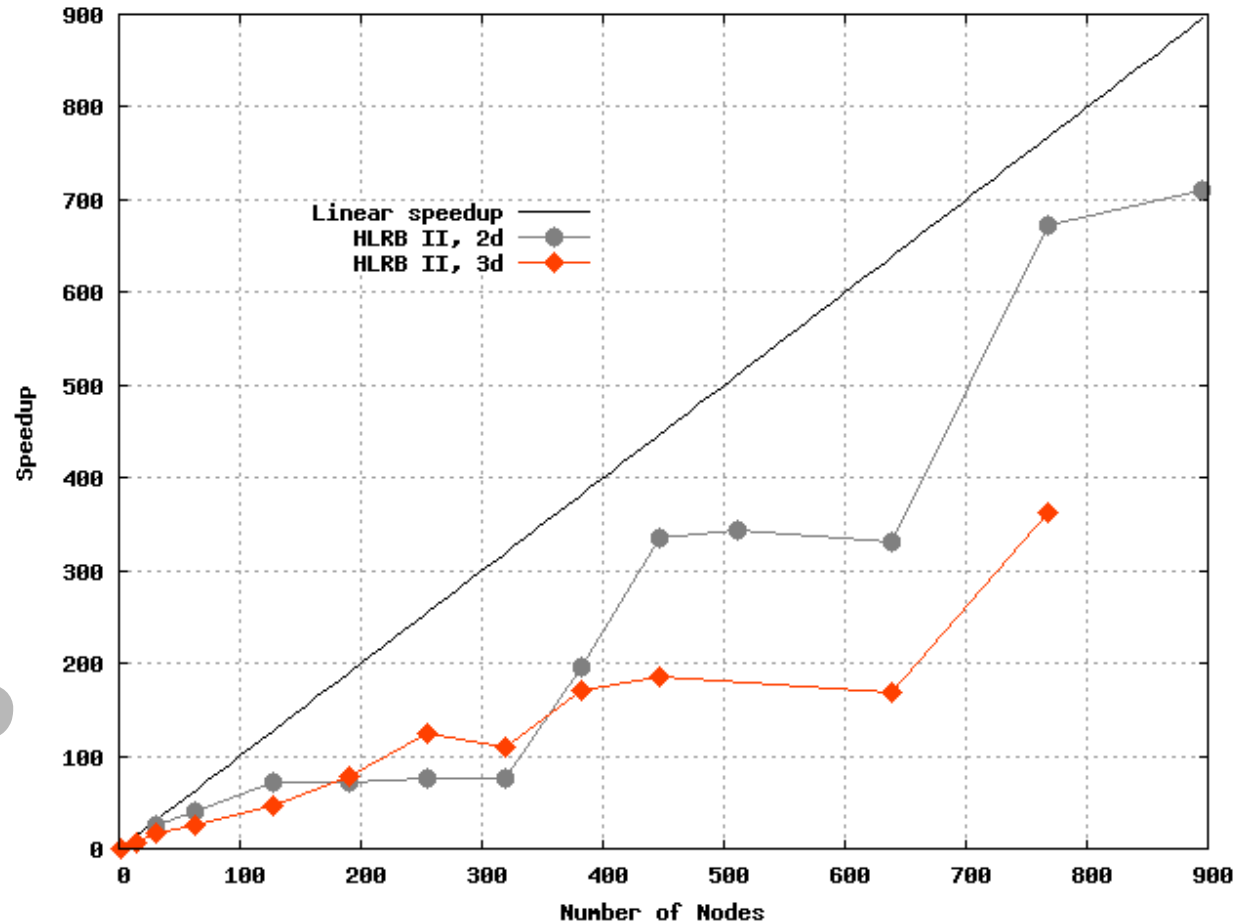
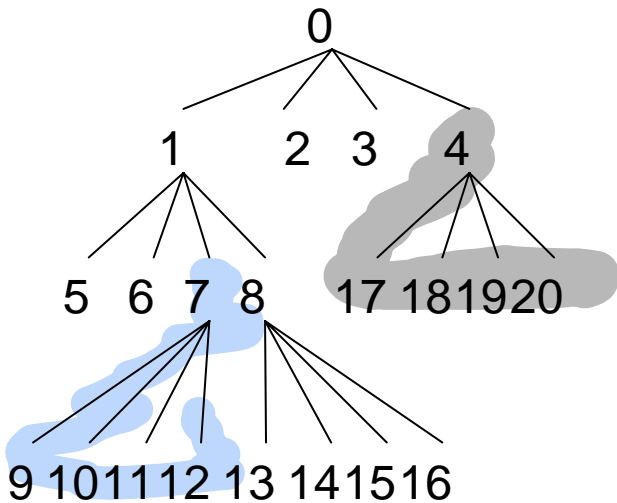
Fluid Solver Peano – Memory

- cache hitrates (L2) > 99%
- low memory requirements (DaStGen)
- file stacks → no memory restriction

	bytes/cell	bytes/vertex	
2D	6	2	only grid
	14	20	flow solver
3D	10	2	only grid
	18	28	flow solver

Fluid Solver Peano – Parallelisation

- Poisson ✓
- Navier-Stokes
 - regular ✓
 - adaptive **todo**



Source: Tobias Weinzierl

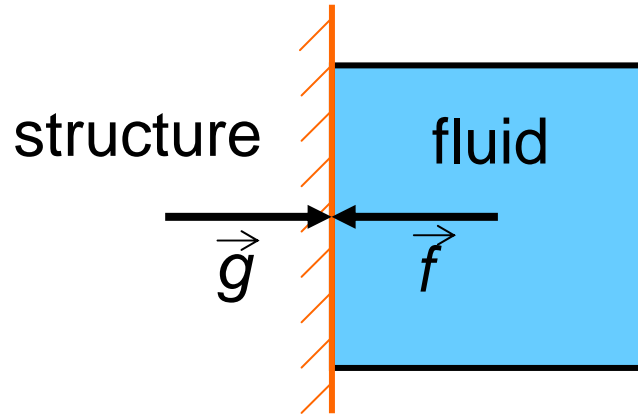
Fluid Solver Peano – Adaptivity

- adaptivity
 - dynamical adaptivity
 - moving geometries → one (partial) grid traversal



Fluid Solver Peano – Forces

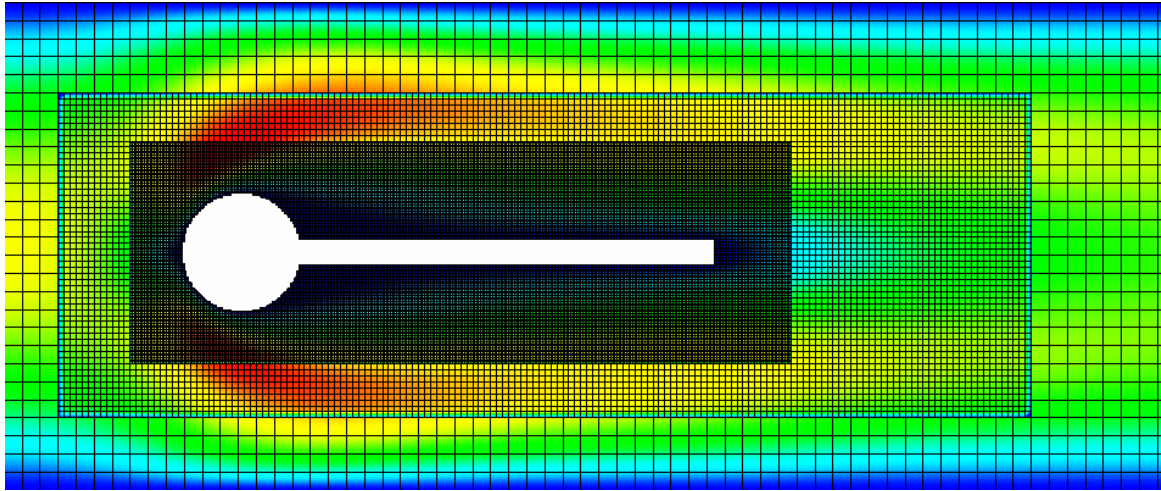
- consistent forces
 - no overhead



$$\vec{g} = -\frac{1}{R} \Delta_h \vec{u}_h + \frac{\partial \vec{u}_h}{\partial t} + (\vec{u}_h \cdot \nabla_h) \vec{u}_h + \nabla_h \rho_h$$

$$\vec{f} = -\vec{g}$$

Fluid Solver Peano – Navier-Stokes

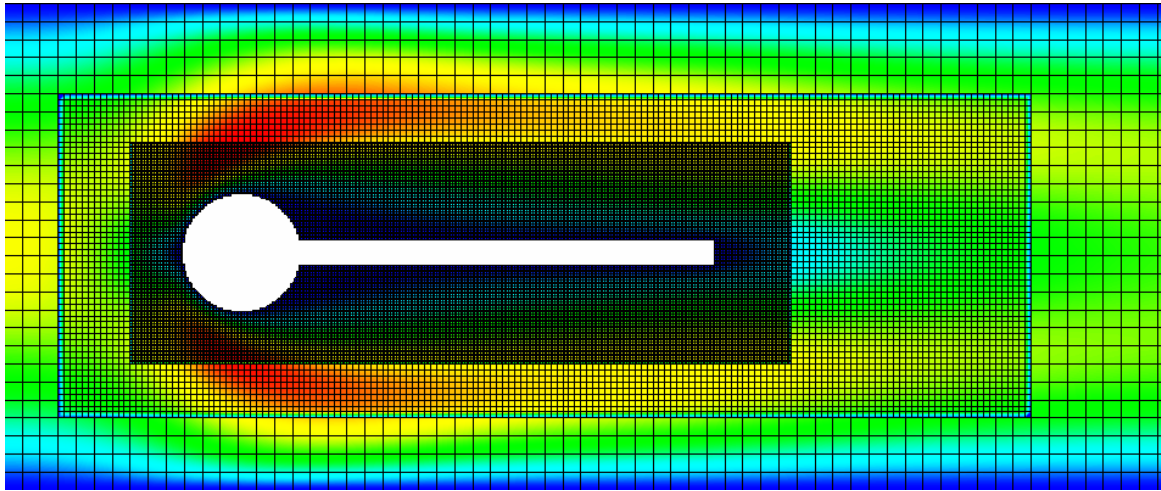


max. level	min. level	no dof	drag	lift
6	6	12,486	15.346	1.854
7	6	14,570	15.579	1.243
8	6	21,302	14.48	1.137
reference	--	--	14.29	1.119

FSI-CFD 1
Re = 20
(Turek, Hron 2006)

Source: Tobias Neckel, Bernhard Gatzhammer

Fluid Solver Peano – Navier-Stokes



max. level	min. level	no dof	drag	lift
6	6	12,486	141.70	15.60
7	6	14,570	149.30	11.44
8	6	21,302	137.07	10.46
reference	--	--	136.70	10.53

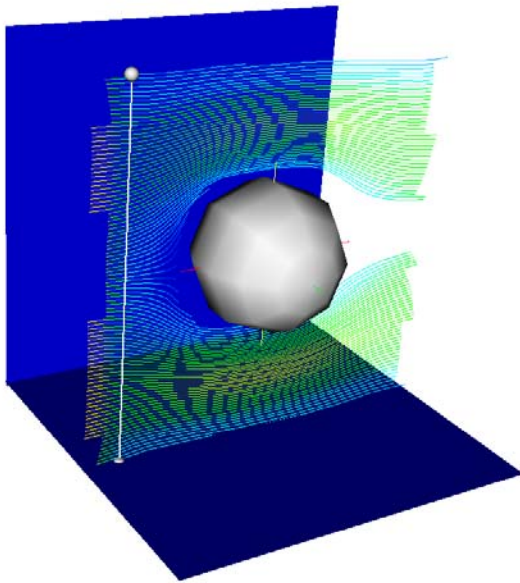
FSI-CFD 2
Re = 100
(Turek, Hron 2006)

Source: Tobias Neckel, Bernhard Gatzhammer

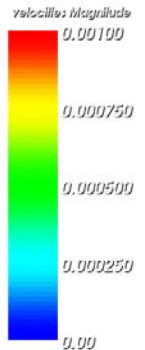
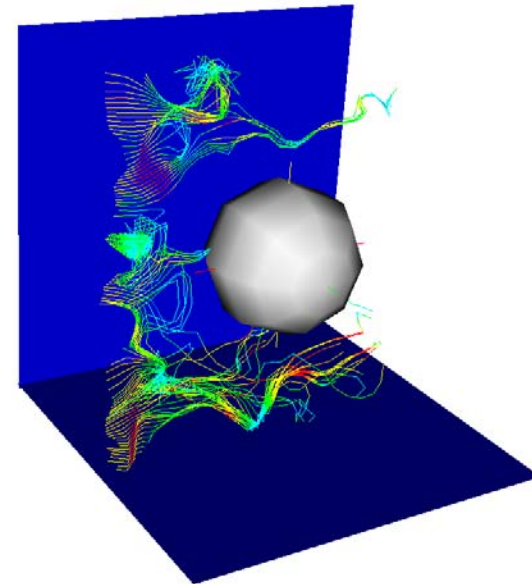
Fluid Solver Peano – Lattice Boltzmann

- regular grids ✓
- adaptive grids **todo**

without fluctuations



with fluctuations



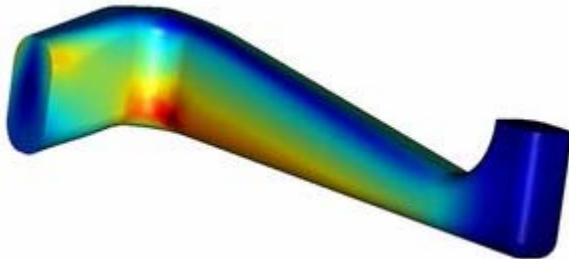
Source: Philipp Neumann

Outline

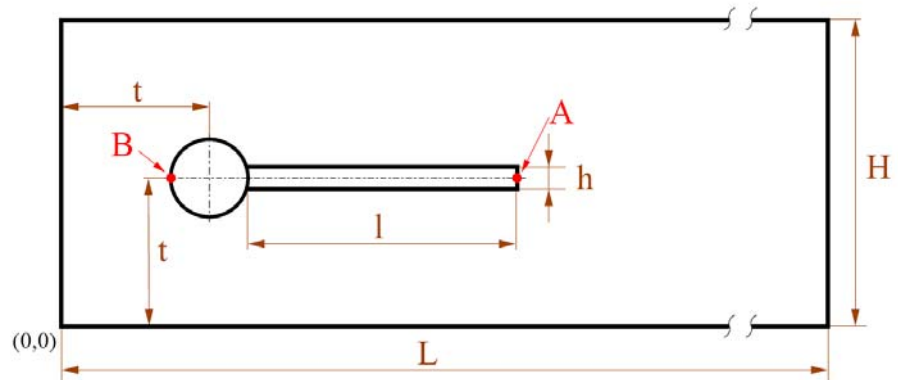
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First Coupling Results – COMSOL

- structure solver → COMSOL



Source: <http://www.comsol.com>

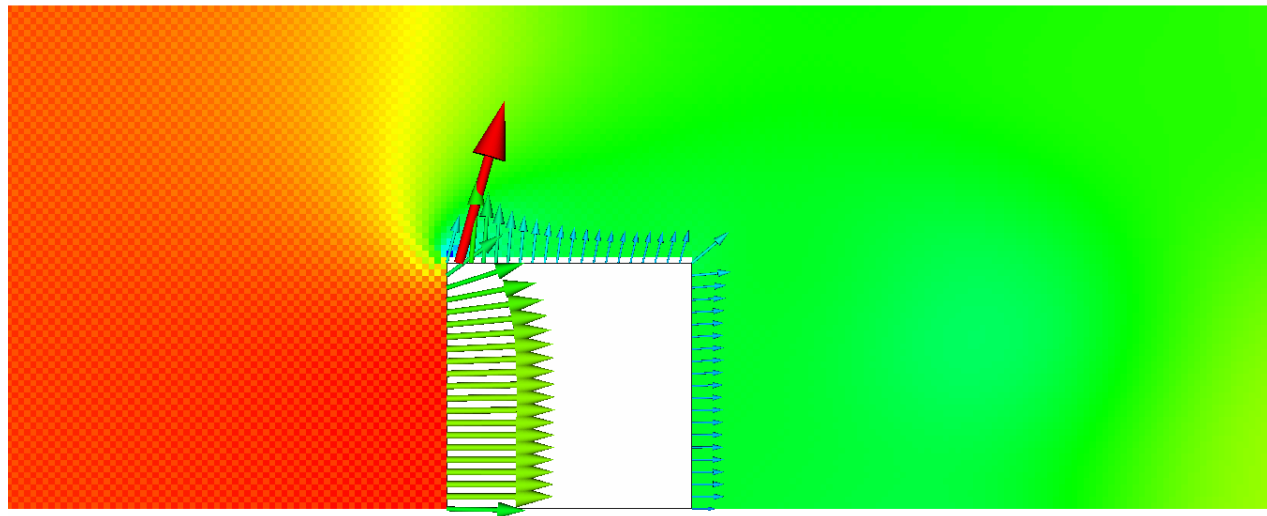
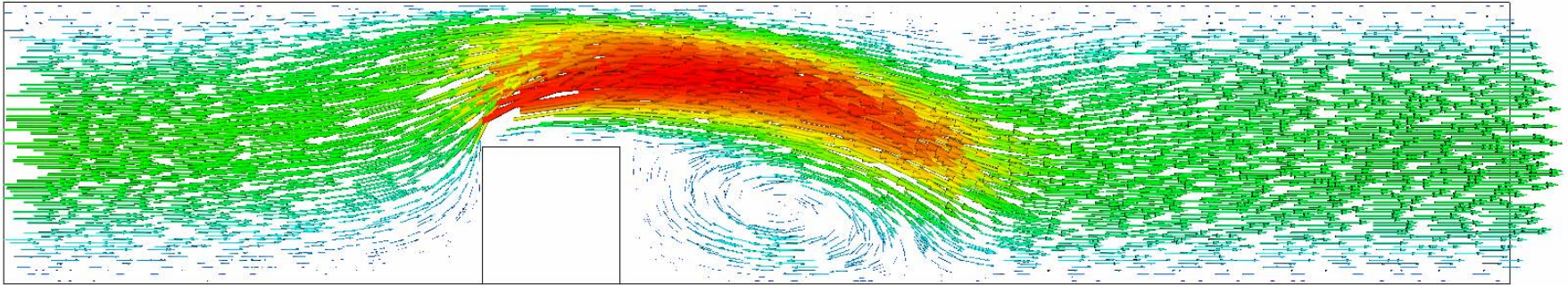


	X-Deform.	Referenz	Y-Deform.	Referenz
CSM 1	-7.198e-3	-7.187e-3	-66.09e-3	-66.10e-3
CSM 2	-0.4707e-3	-0.4690e-3	-16.97e-3	-16.97e-3
CSM 3	- 14.454e-3 +/- 14.454e-3	- 14.305e-3 +/- 14.305e-3	- 64.508e-3 +/- 64.522e-3	- 63.607e-3 +/- 65.160e-3

FSI-CSM
Turek/Hron 2006

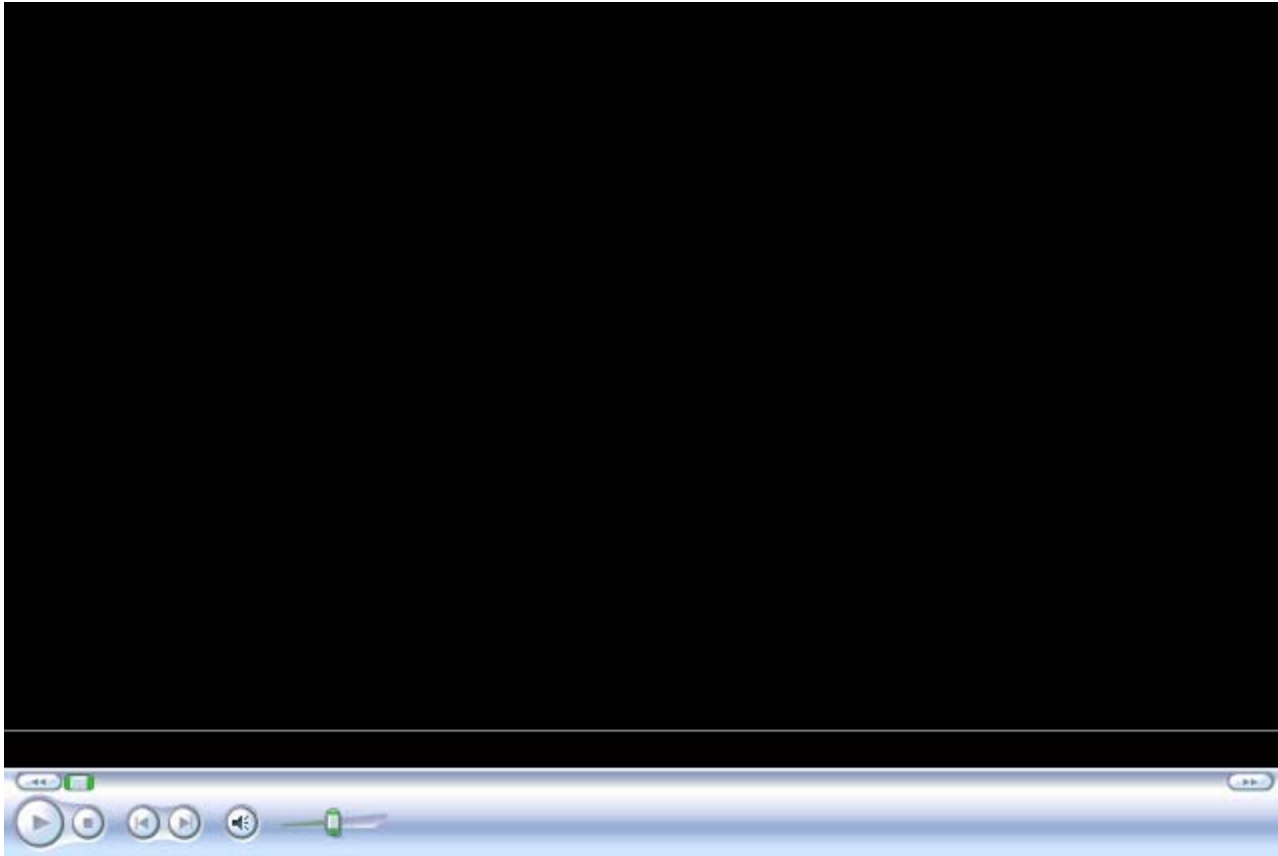
Source: Janos Benk, Bernhard Gatzhammer

First Coupling Results – Peano



Source: Bernhard Gatzhammer

First Coupling Results – Peano+Dummy



Source: Bernhard Gatzhammer

Summary and Outlook

- preCICE
 - full partitioned flexibility ✓
 - fast data mapping with spacetrees ✓
 - more sophisticated coupling strategies **todo**
- Peano
 - high memory-efficiency ✓
 - fully adaptive fixed grids ✓
 - consistent forces ✓
 - space-time adaptivity (4D grids) **todo**
 - volume-coupled problems **todo**

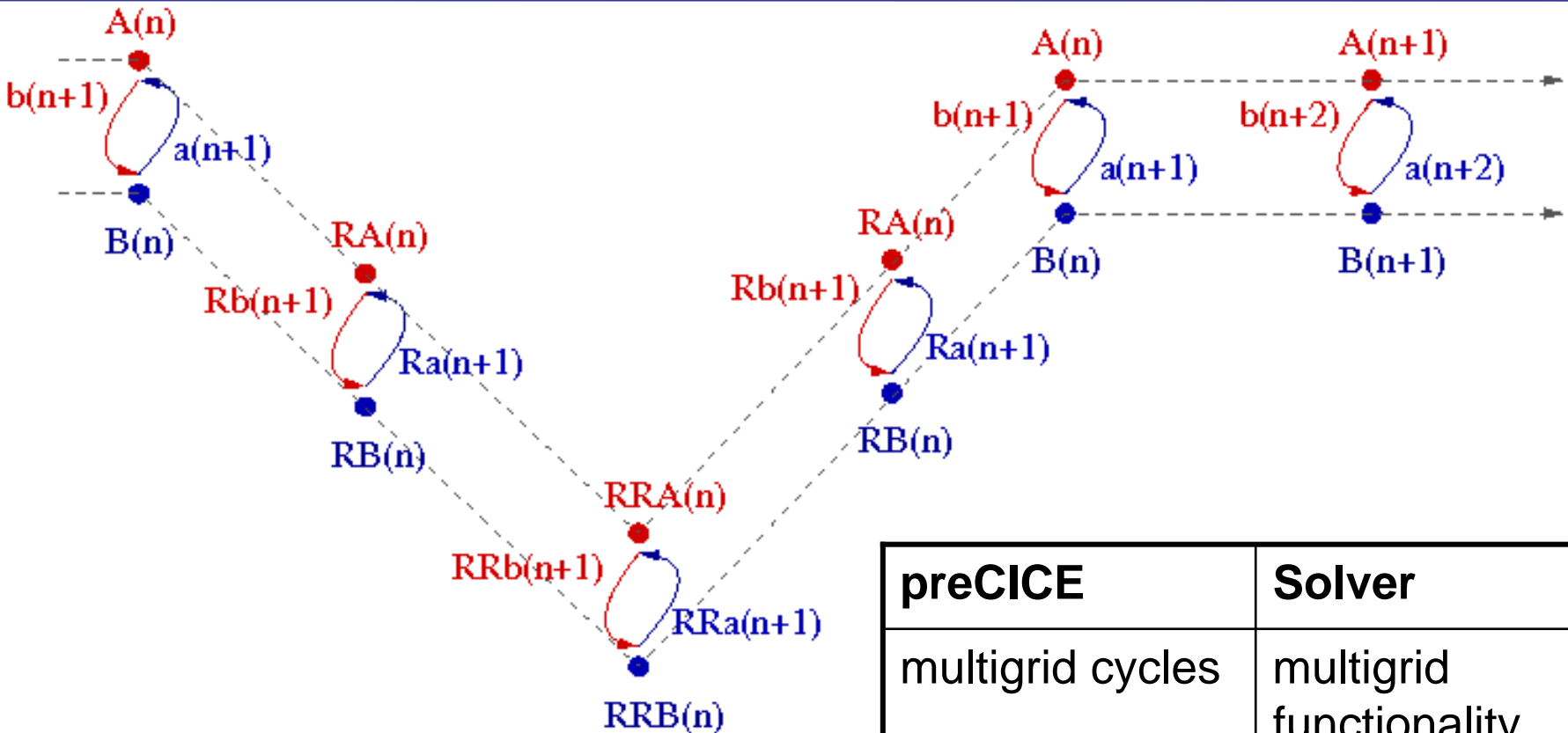
Acknowledgements

- Bernhard Gatzhammer
- Tobias Neckel
- Tobias Weinzierl
- Philipp Neumann
- Janos Benk

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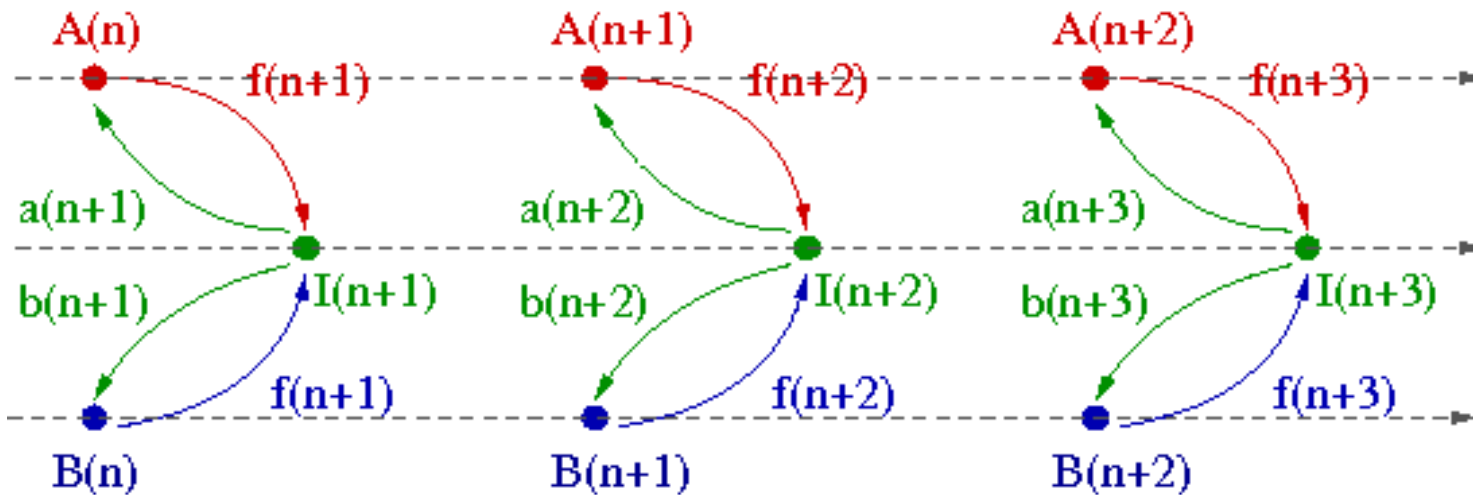
preCICE – Coupling Potential



multigrid

preCICE	Solver
multigrid cycles	multigrid functionality
restrict central mesh	extended data mapping

preCICE – Coupling Potential



interface equation

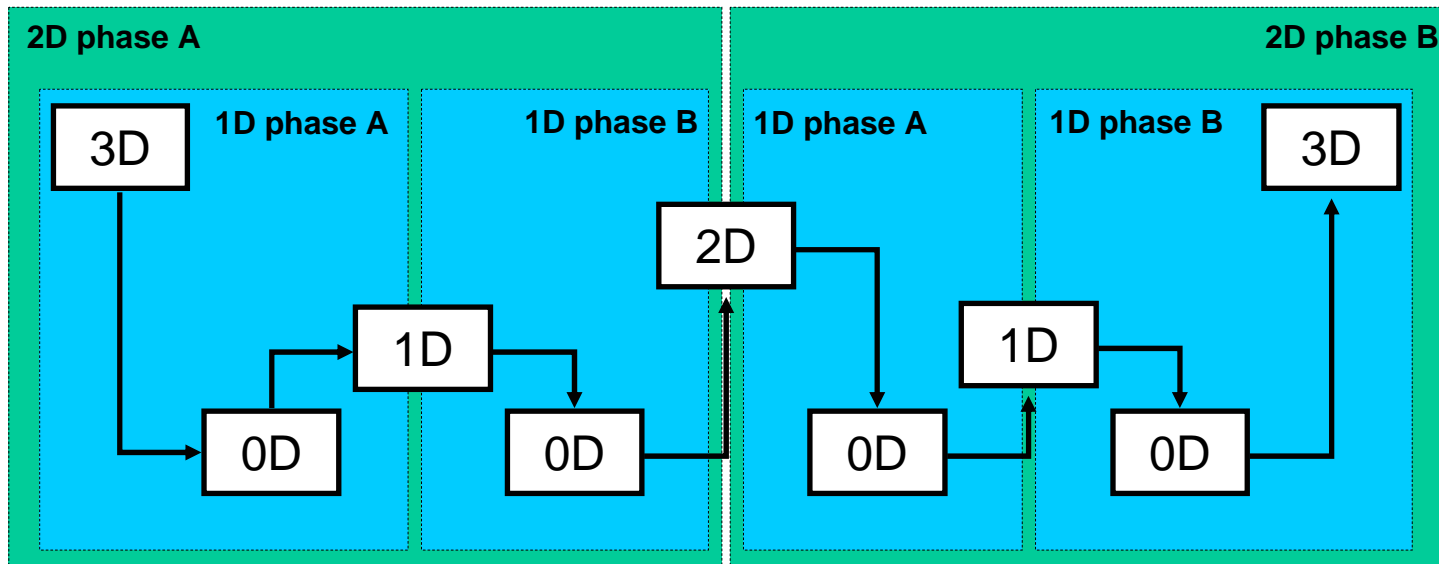
➤ LLM (Park, Felippa, Ross)

➤ Newton-like (reduced order, Vierendeels)

preCICE	Solver
interface equation	modified data mapping

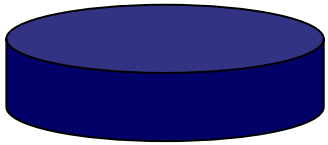
Fluid Solver Peano – Data

- multilevel (hierarchical) data
 - more sophisticated stack concept
 - 2004 (Günther, Pögl): dimension recursive $\rightarrow 3^d - 1$ stacks

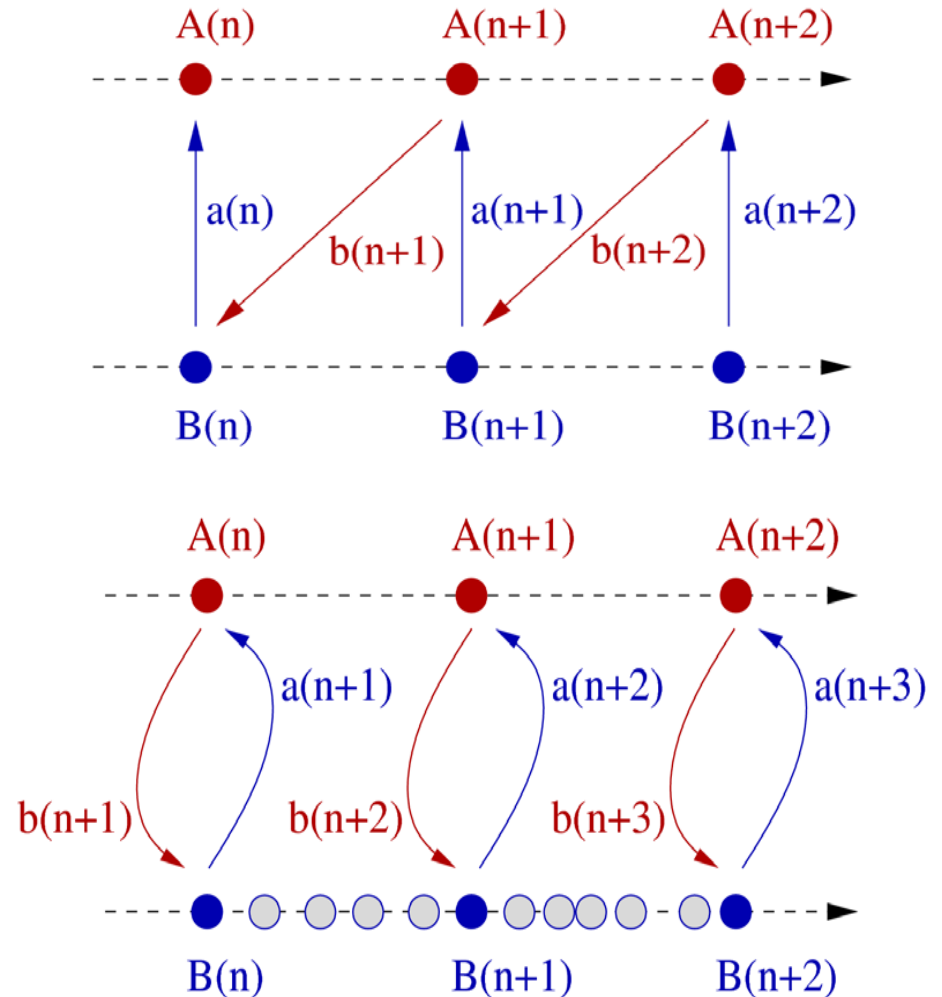


Quelle: Andreas Krahnke

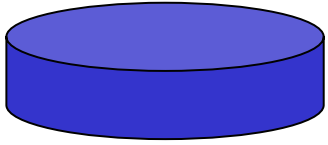
preCICE – Coupling Strategy



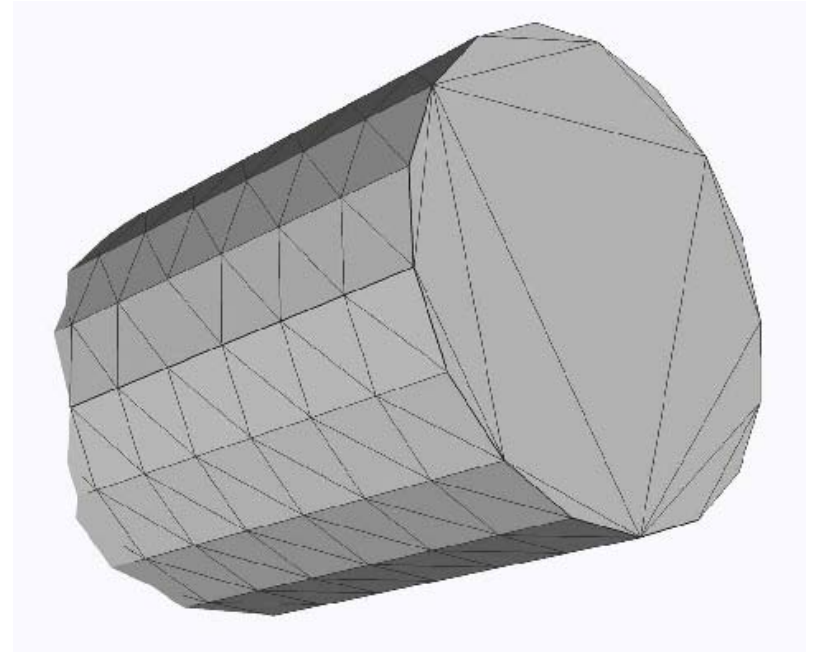
- Explicit (weak)
- Implicit (strong)
- Subcycling
- Pre-computations
- Many others possible:
just extend supervisor



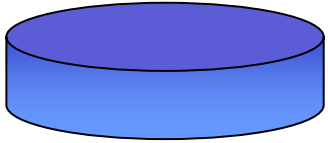
preCICE – Central Mesh



- surface triangulation
- CAD interface **todo**
- Peano geometry interface ✓



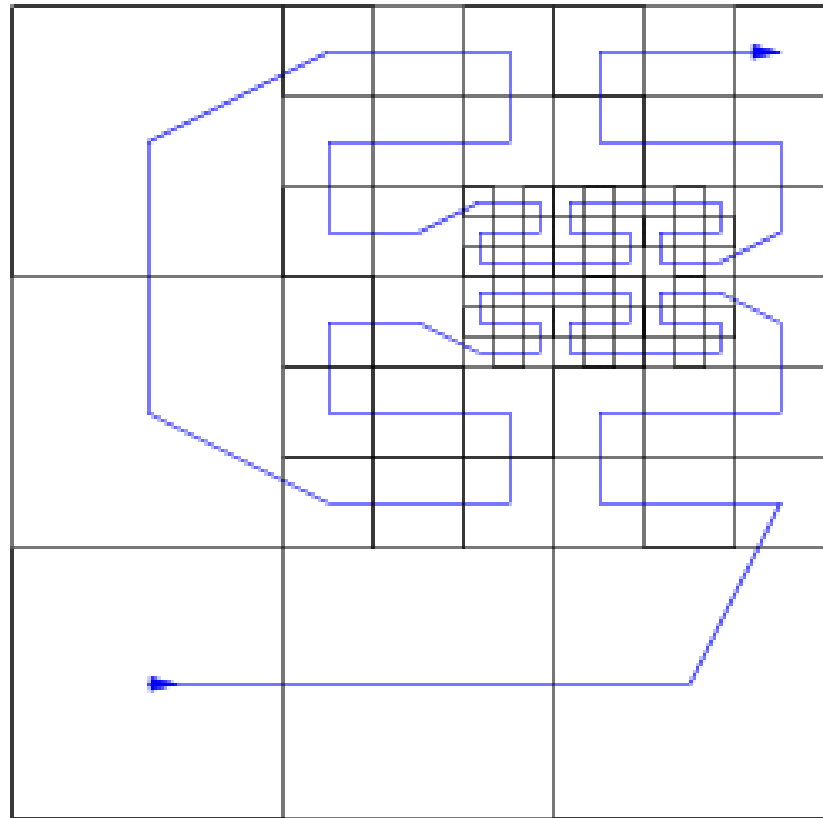
preCICE – Data Mapping



- octree for efficient neighbour search
 - some projection / interpolation included
 - custom interpolations possible

Fluid Solver Peano – Algorithm

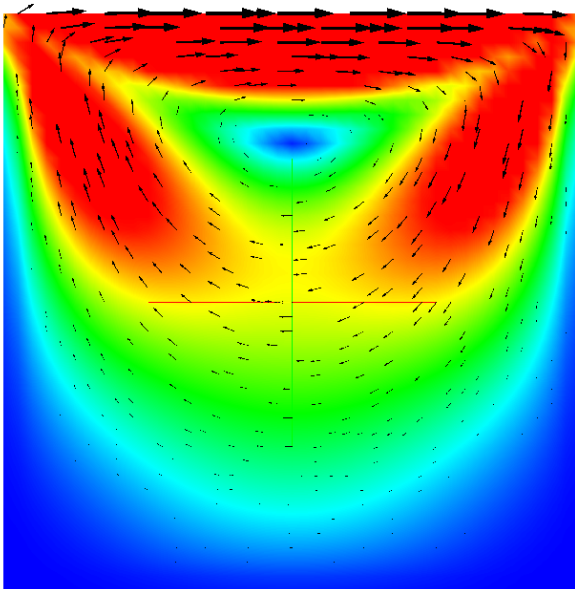
- Peano traversal order
 - time locality



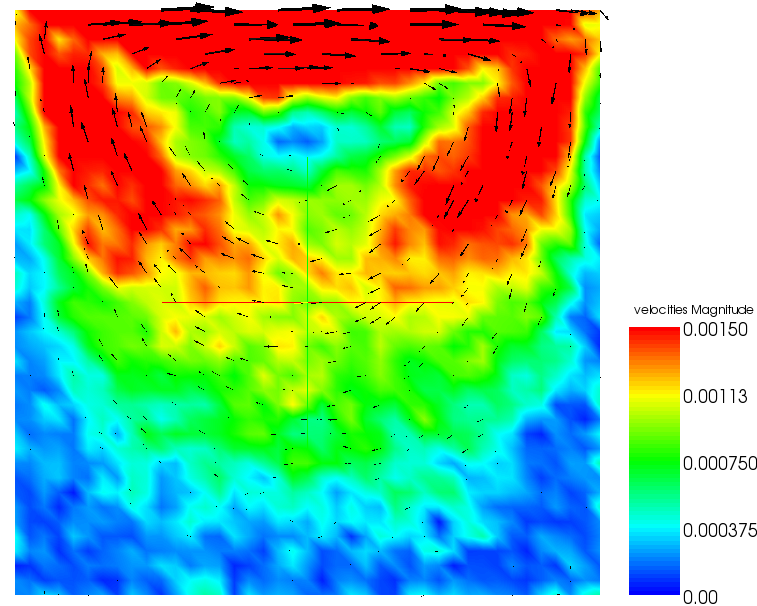
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with fluctuations



Source: Philipp Neumann