CFD simulations using an AMR-like approach in the PDE Framework Peano

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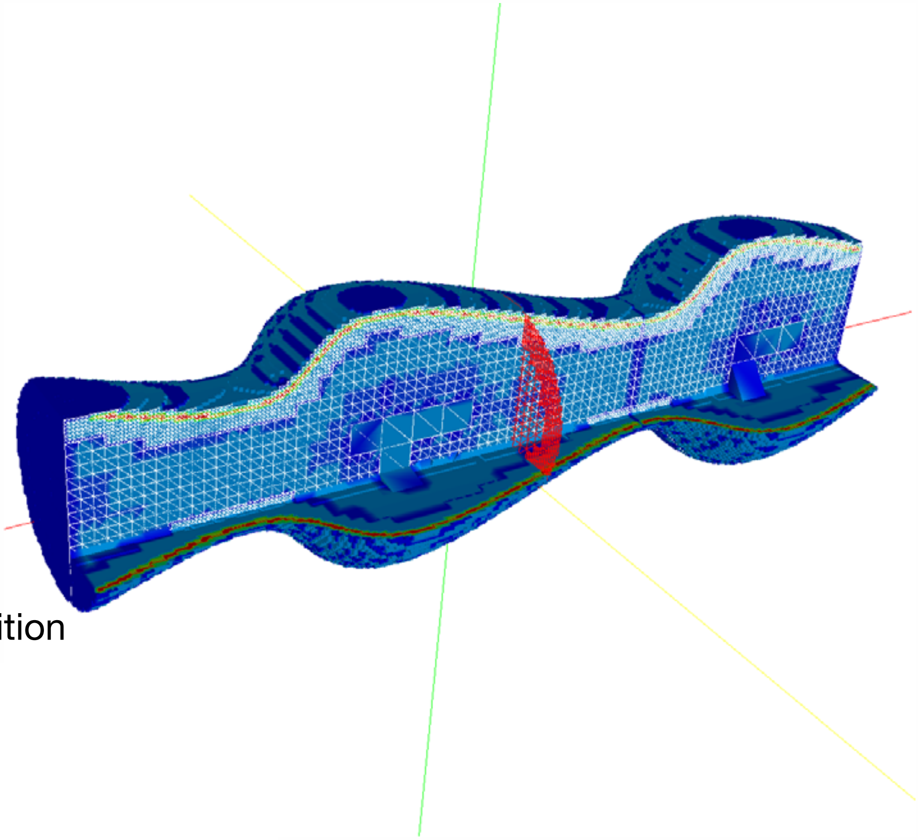
Outline

- PDE Framework Peano
  - Vision & Motivation
  - Features
- Adaptive Simulation Results
- Integration of higher-order IDO into Peano

Peano - Vision

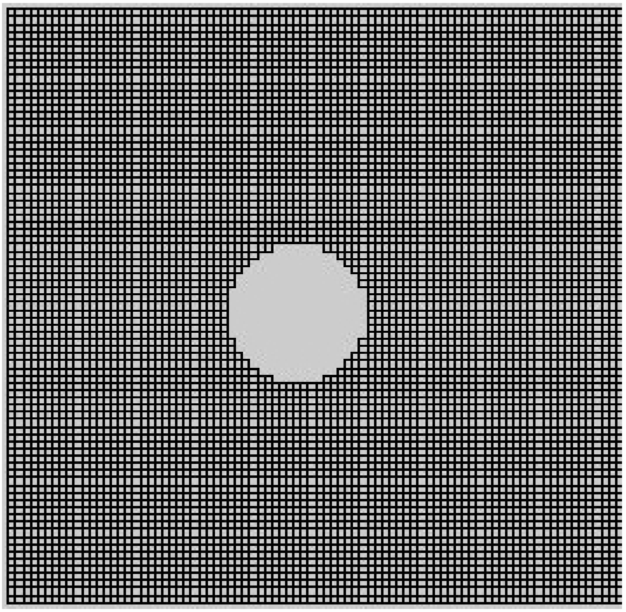
- Computational challenges
  - Multi-scale in time
  - Multi-scale in space
  - Multi-physics
- Techniques
  - Complex/changing geometries & solution behaviour: dynamic (local) adaptivity
  - Geometric multigrid solver
  - Computational demands: parallelisation via domain decomposition
- Approach
  - Cartesian grids
  - Space-filling curves
  - Stack data structures



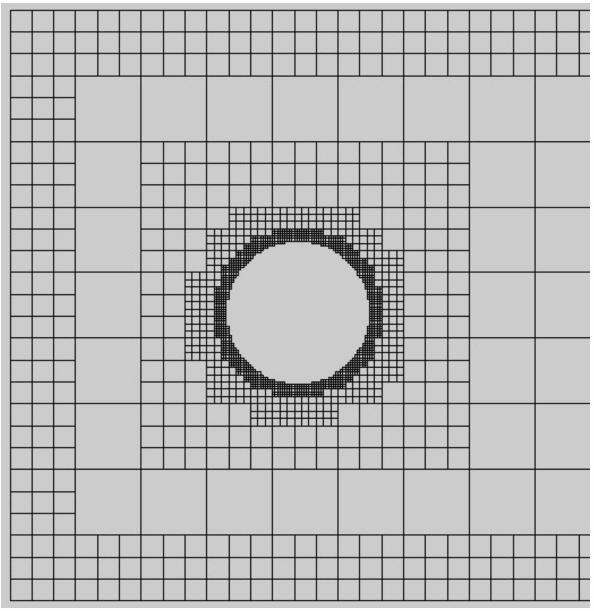
Peano - Features

- Framework for different applications (Poisson, NSE, etc.): “plug-in concept”
- Cartesian grids

Regular (lexicographic)

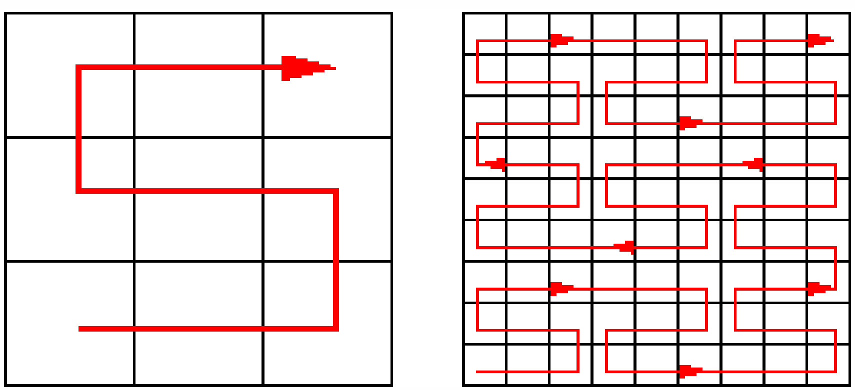


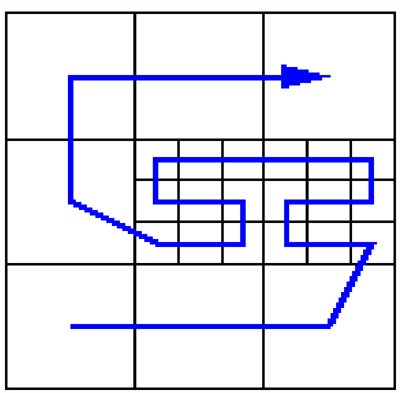
Adaptive (spacetree)



Peano - Features

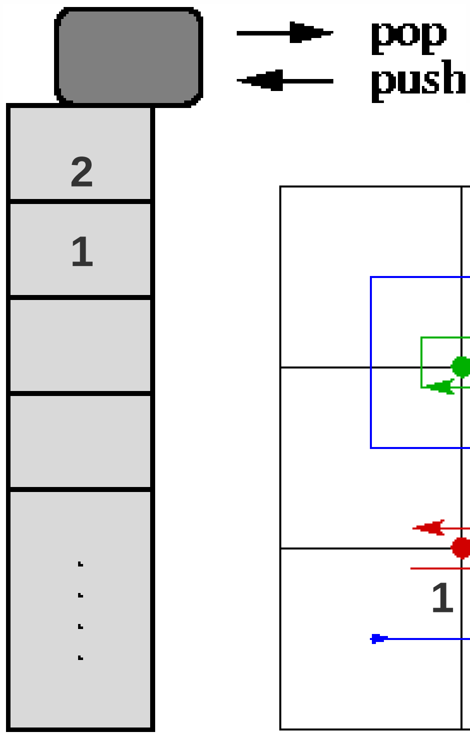
- **Space-filling curves** (Peano):
  - Seralisation of the adaptive grid (parallelisation + load balancing)
  - Recursive construction fits to spacetree grid construction
  - Allow for high cache-hit rates (>98%):
    - Temporal locality
    - Spatial locality (with stacks)



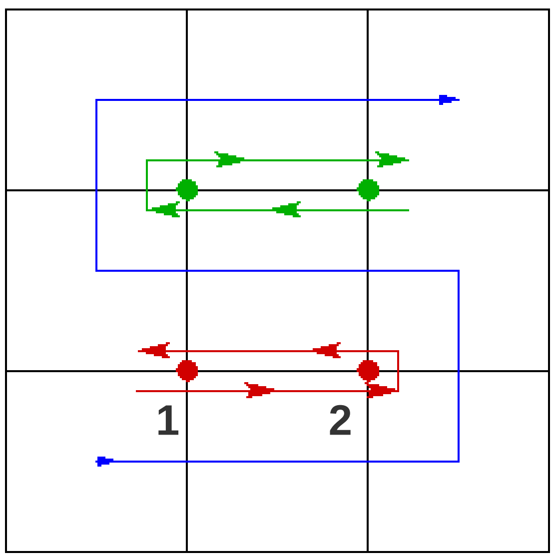


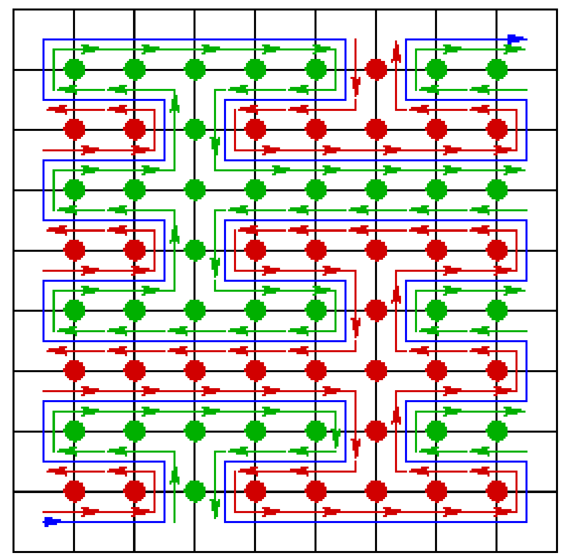
Peano - Features

- Stack data structures



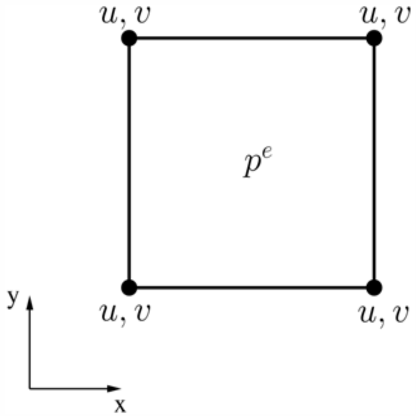
- **Spatial locality!**





Adaptive Simulation Results

- CFD in Peano:
  - incompressible Navier-Stokes equations
  - Semi-implict approach
  - Low-order FEM (Q1P0)
  - Pressure Poisson Equation (PETSc)
  - Time-integration: Explicit Euler



- Benchmark scenario: Laminar channel flow around a cylinder
  - A lot of reference data available 1)
  - Lift and drag forces for comparison
  - Re = 20

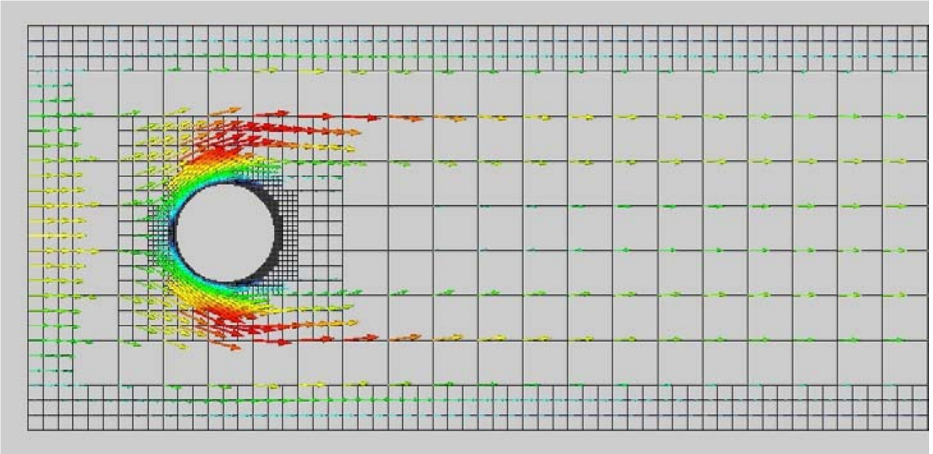
1) S. Turek and M. Schaefer, "Benchmark Computations of Laminar Flow around a Cylinder" Vieweg, Notes on Numerical Fluid Mechanics 52, 1996

Adaptive Simulation Results

l_{max}	l_{min}	cells	vertices	c_d	c_l	time
6	5	1622	1309	5.656	0.0324	0.060
7	5	1953	1578	5.521	0.0220	0.075
8	5	3017	2466	5.569	0.0158	0.100
9	5	5469	4438	5.540	0.0156	0.180
ref.	-	-	-	5.580	0.0107	-

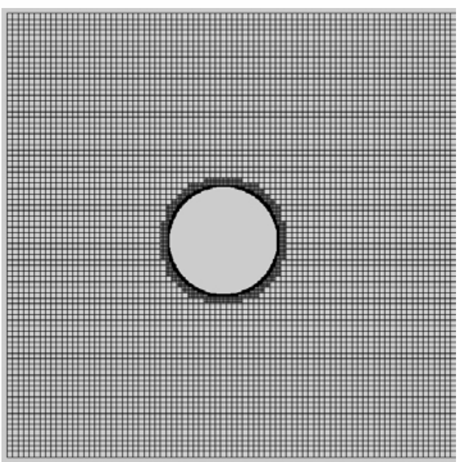
lmax = 8

lmin = 5



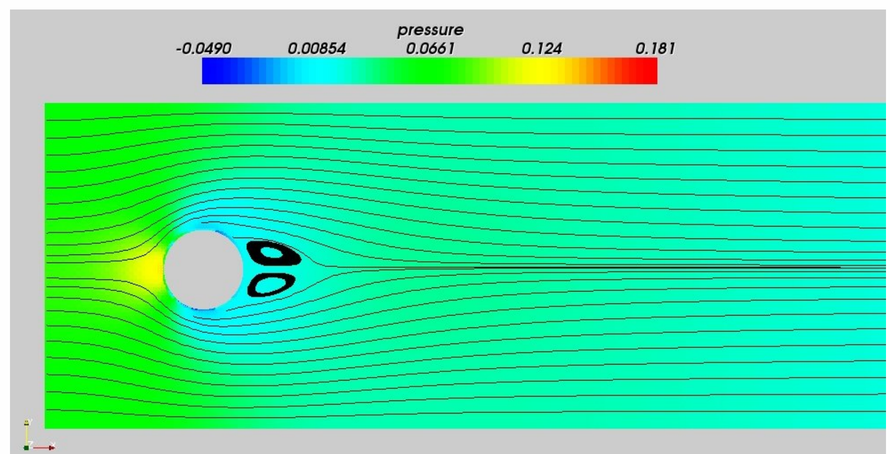
Adaptive Simulation Results

l_{max}	l_{min}	cells	vertices	c_d	c_l	time
6	6	4342	4167	5.678	0.0443	0.08
7	7	39073	38494	5.558	0.0135	0.69
8	7	39973	39222	5.684	0.0147	0.71
9	7	42501	41270	5.591	0.0113	0.78
ref.	-	-	-	5.580	0.0107	-



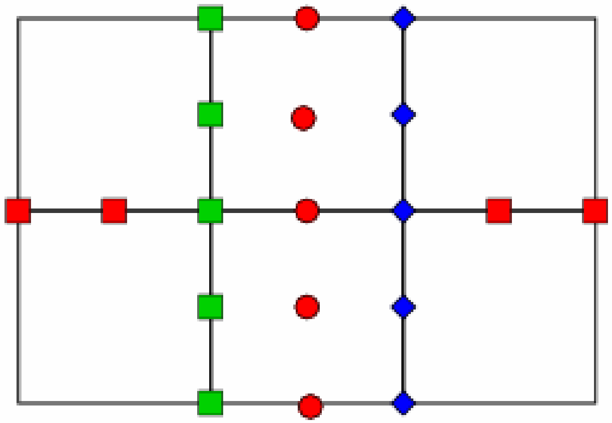
lmax = 9

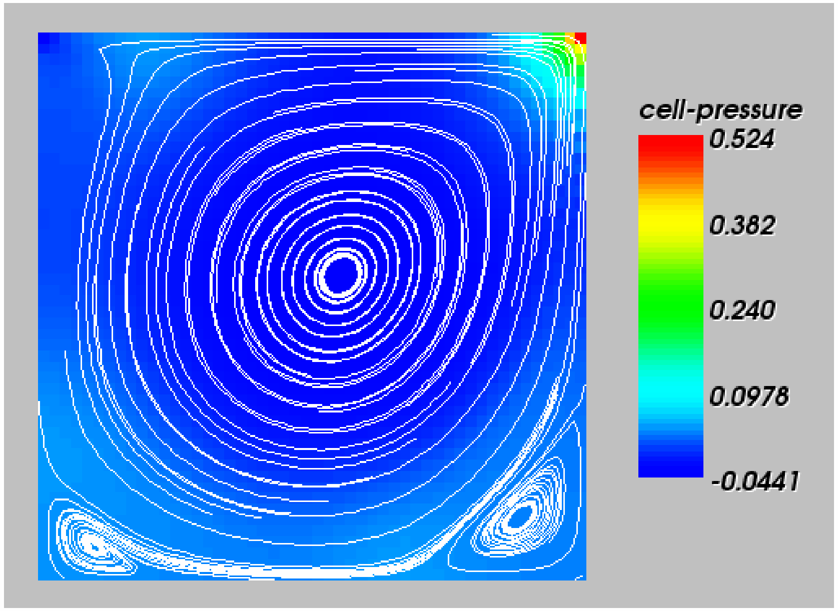
lmin = 7



Integration of IDO into Peano

- Lid-driven cavity (NSE), IDO-CF
  - Regular grid
  - Runge-Kutta
  - Operators cell-wise!
  - Temporary data:
    - 2 Vectors per node
    - 1 Vector per face





Re=1000, 50x50 cells

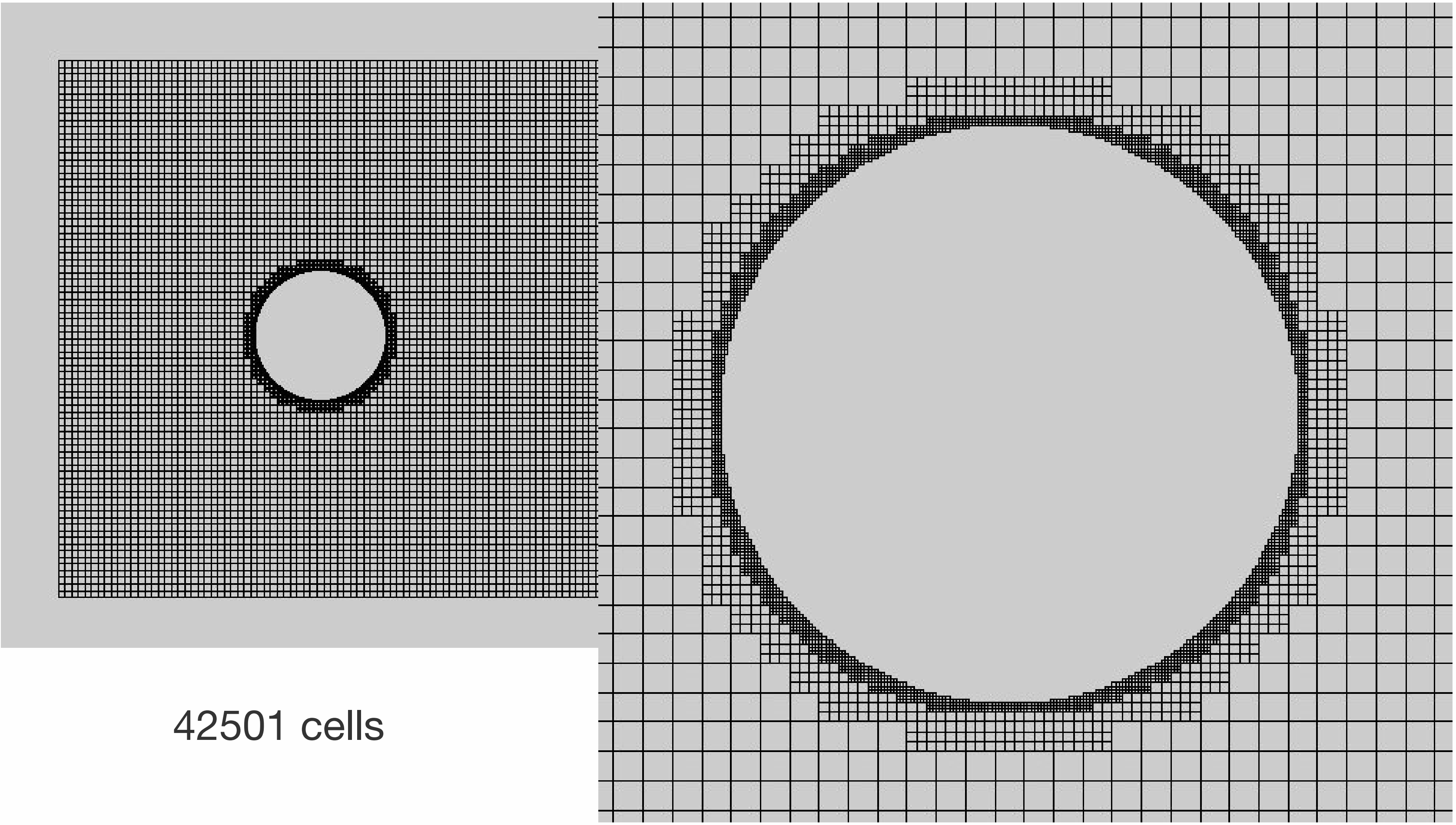
Summary & Outlook

- Peano:
  - Suitable framework for PDE simulations on adaptive Cartesian grids
  - Stacks + SFC: performance + changing geometries
  - Integration of higher order schemes directly feasible

- Ongoing work:
  - Dynamic adaptivity criteria
  - 3D simulations with moving geometries (such as FSI)
  - Performance tuning
  - Parallelisation
  - Geometric multigrid

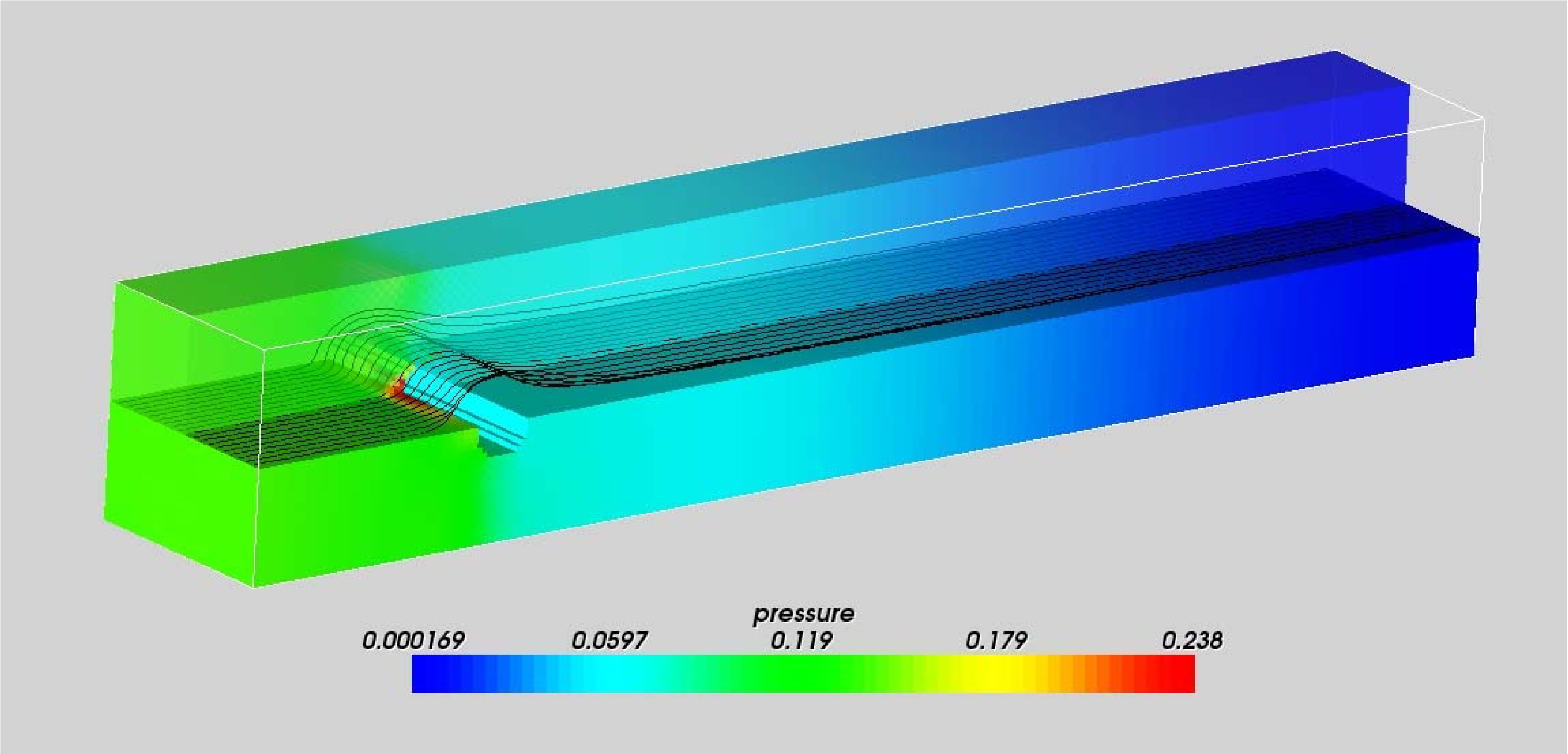
Thanks for your attention!

Backup – Adaptive Grid



42501 cells

Backup II – Cylinder Benchmark 3D



416642 cells

Peano – Motivation - raus???

- **Problem for PDE solver:**

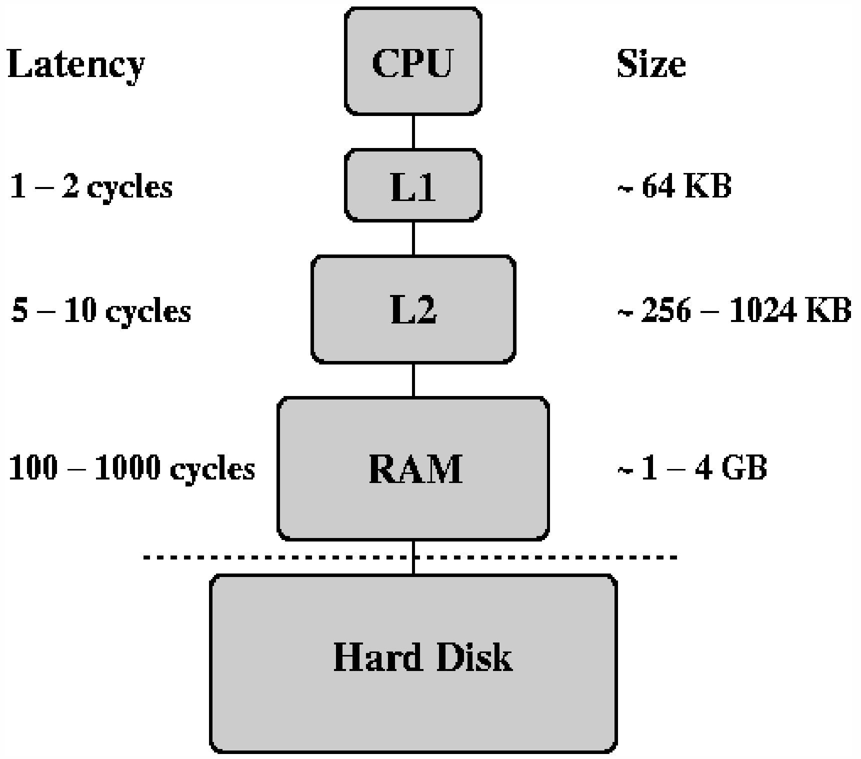
  storage usage => loss of efficiency

- **Solution:**

  cache hierarchy on modern computer architectures

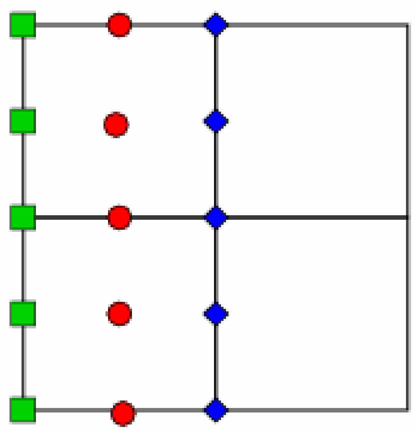
<u>Our approach:</u>

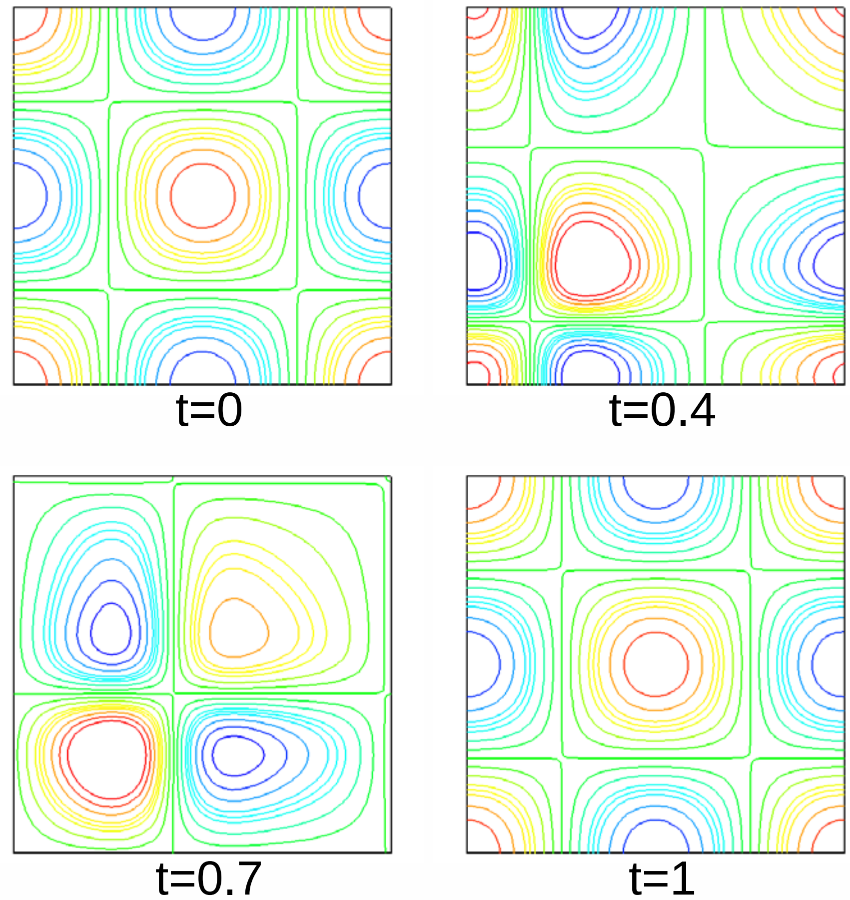
Cartesian grids
(spacetree)
+
space-filling curves
+
stacks



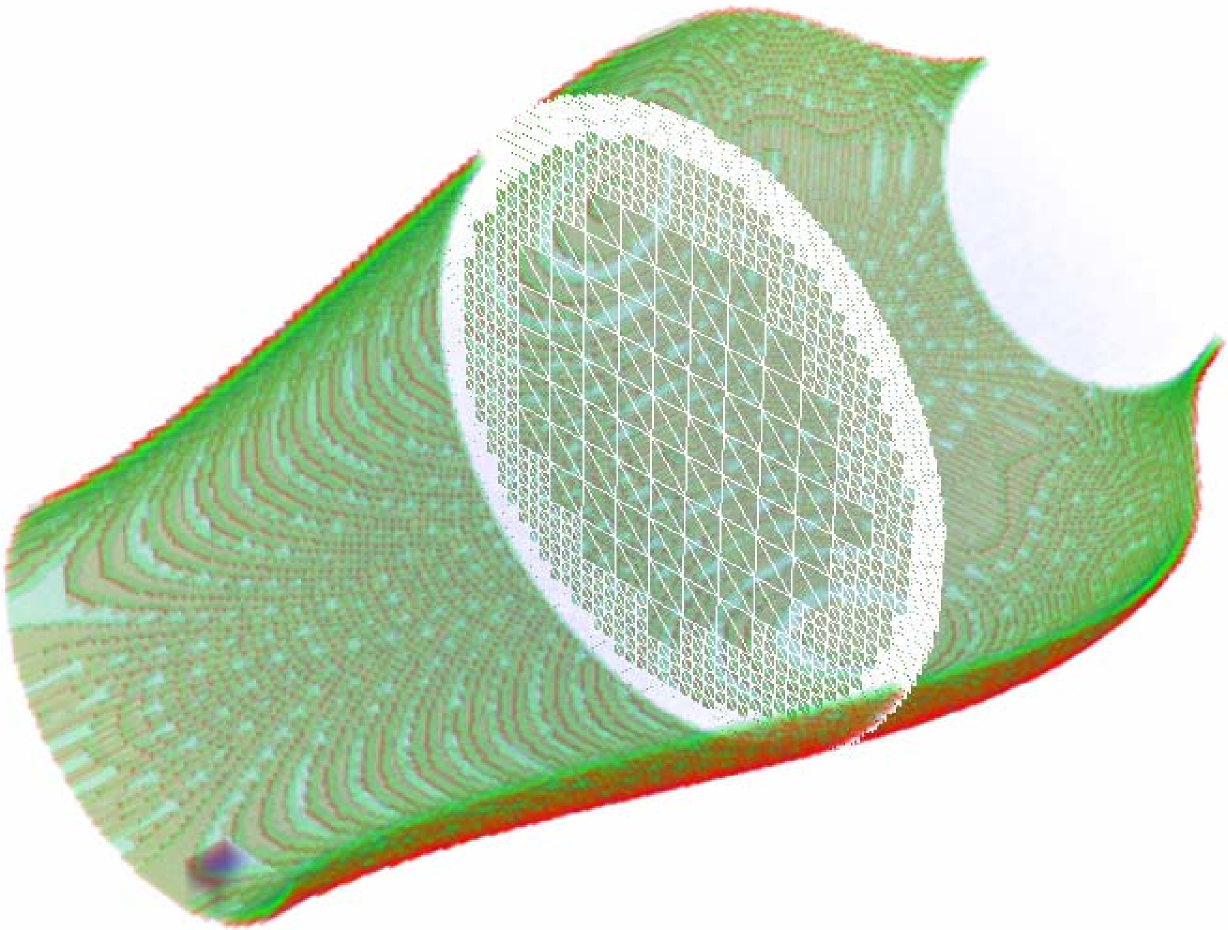
Integration of IDO into Peano

- Continuity equation
  - Unit square $[0,1]^2$
  - Periodic boundary conditions
  - Regular grid
  - Runge-Kutta time integration
  - Operators: cell-wise!





Backup III – 3D adaptive Drift-Ratchet



Backup IV – Peano Architecture