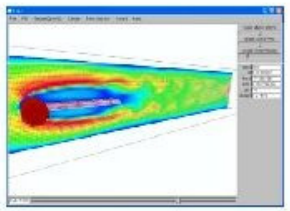
Tackling the Multi-Challenge Multiphysics

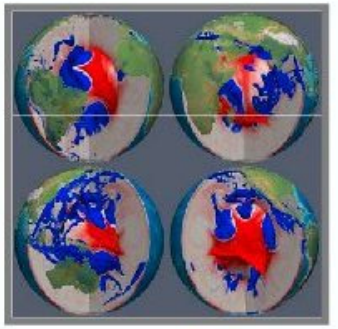
Miriam Mehl

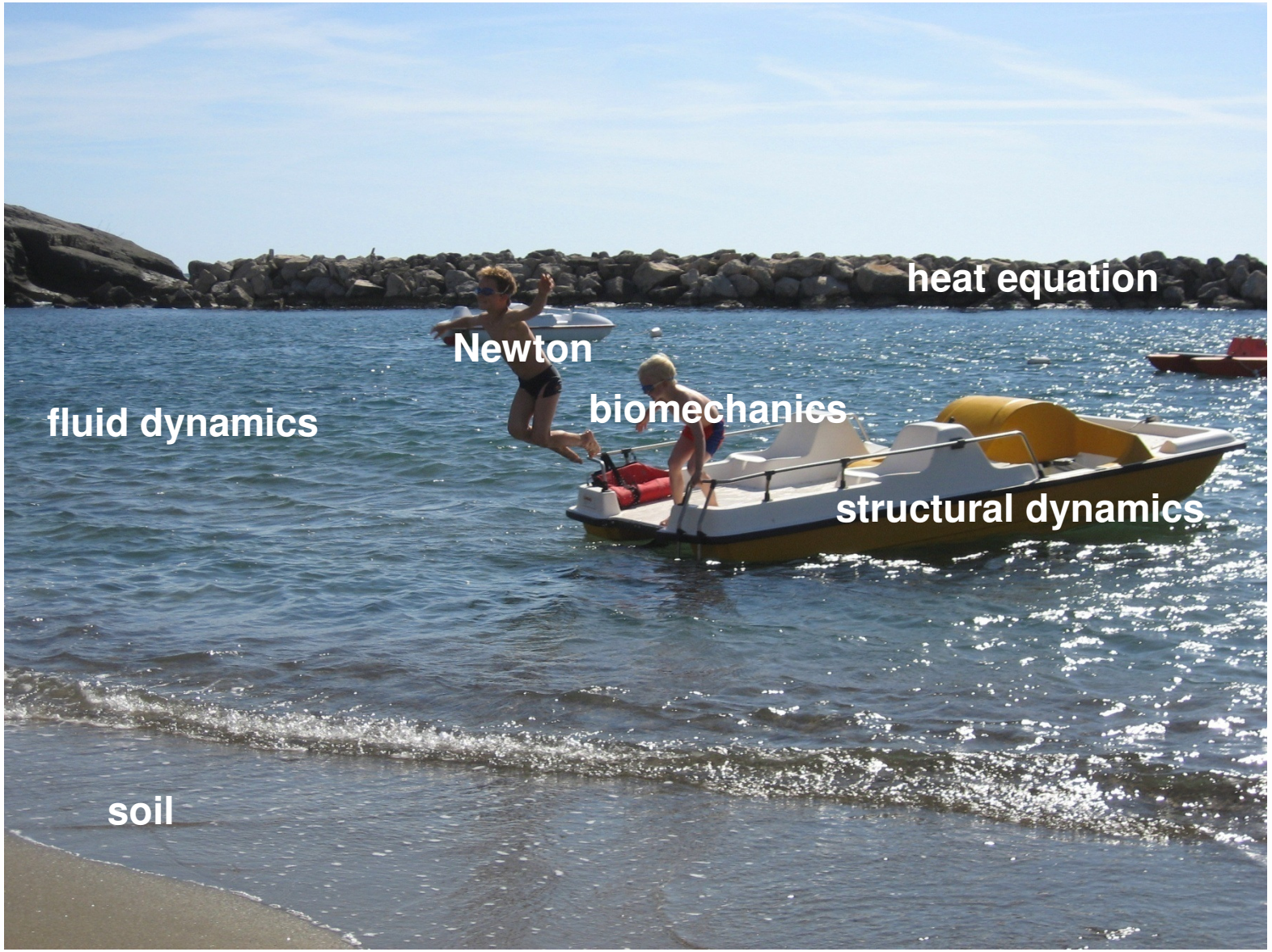
MAC Summer Workshop 2010

IAS Inaugural Lecture

IAS Focus Group
HPC: Tackling the Multi-Challenge – Multiphysics






heat equation
Newton
biomechanics
fluid dynamics
structural dynamics
soil

Outline

- general challenges
- partitioned approaches
- our vision
- conclusion

Outline

- **general challenges**
- partitioned approaches
- our vision
- conclusion

General Challenges – Model Flexibility

fluid dynamics

+

structural dynamics

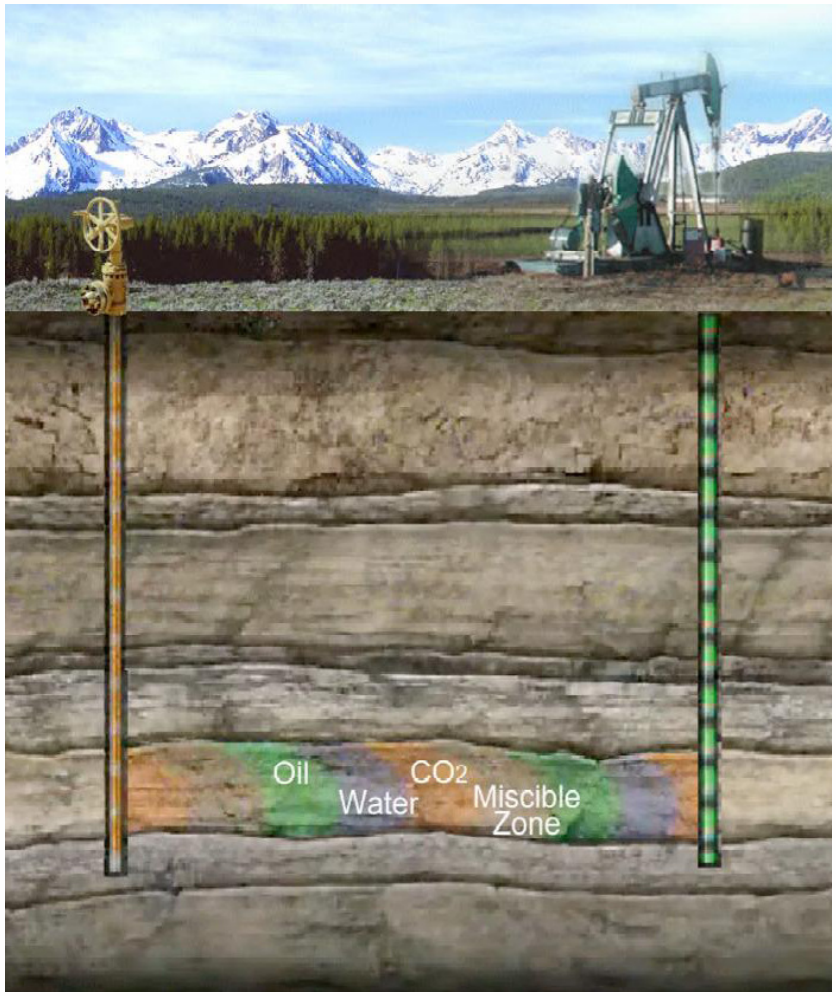
+

acoustics

+

thermodynamics

General Challenges – Model Flexibility



free flow

+

porous media flow

+

mixing and diffusion

+

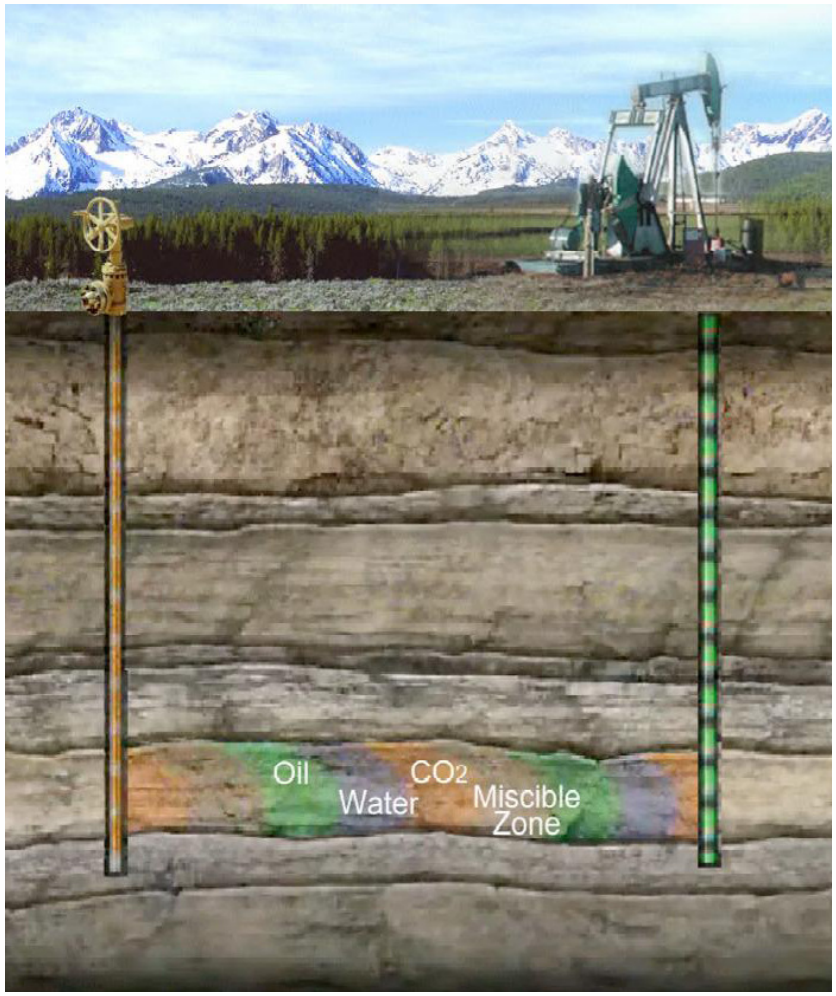
structural dynamics

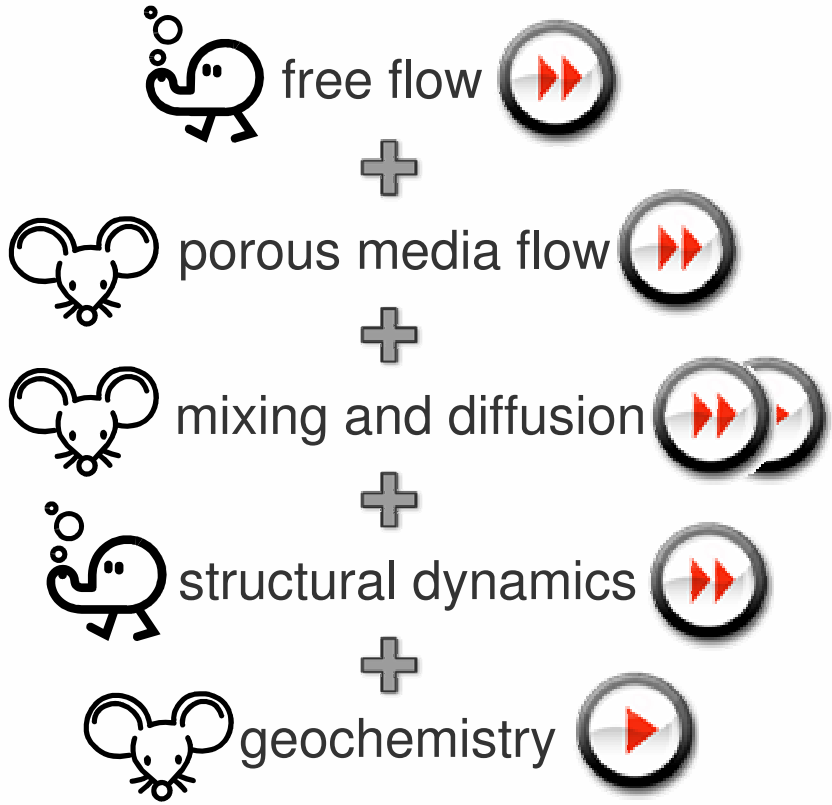
+

geochemistry

source: US Department of Energy

General Challenges – Multiscale





source: US Department of Energy

General Challenges – Coupling Types

fluid dynamics

+

structural dynamics

surface coupled

General Challenges – Coupling Types

fluid dynamics

+

acoustics

volume coupled

Outline

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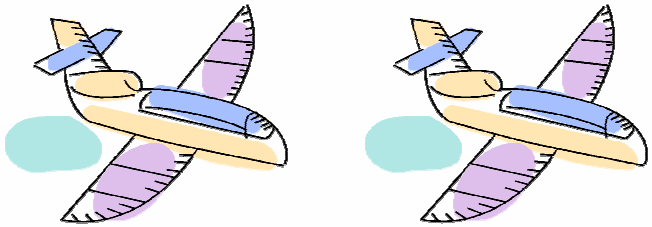
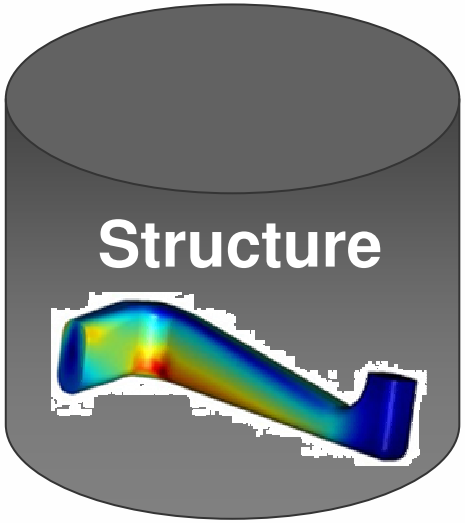
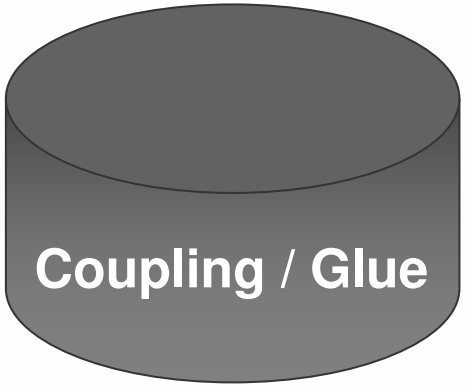
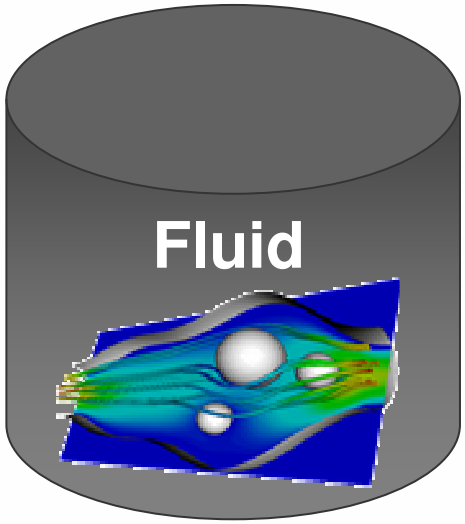
- **partitioned approaches**
- our vision
- conclusion

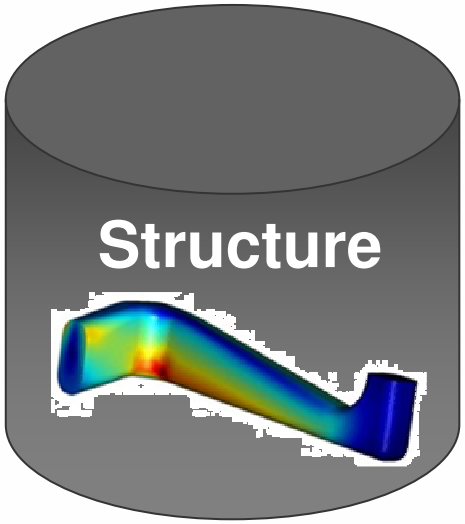
Partitioned Approaches



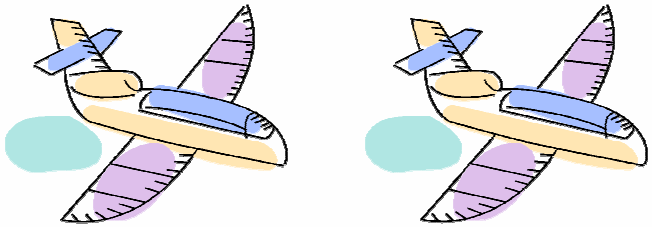


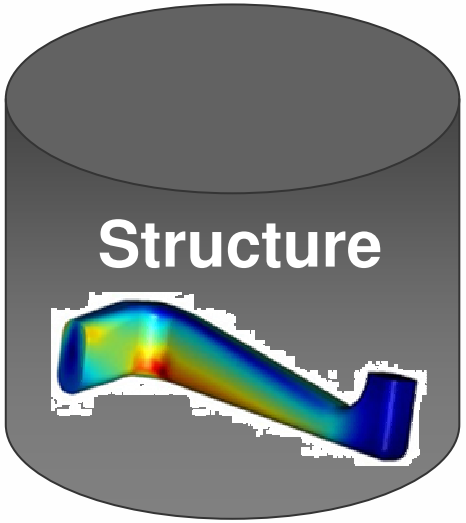


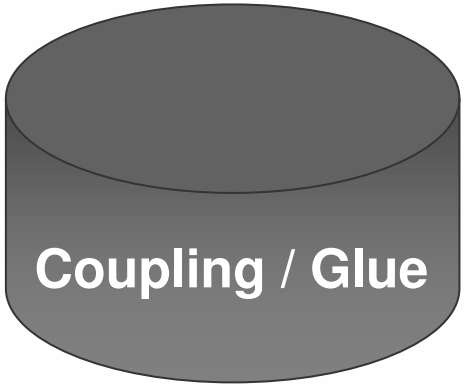


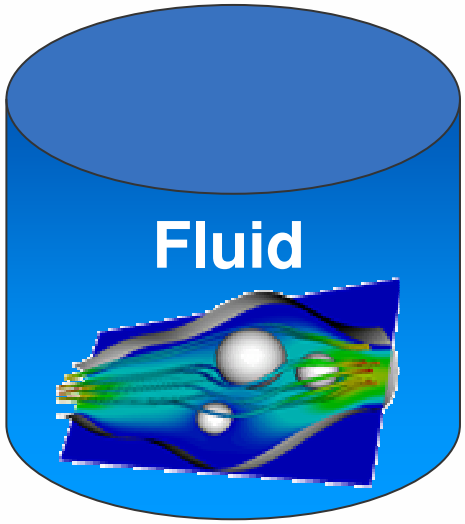


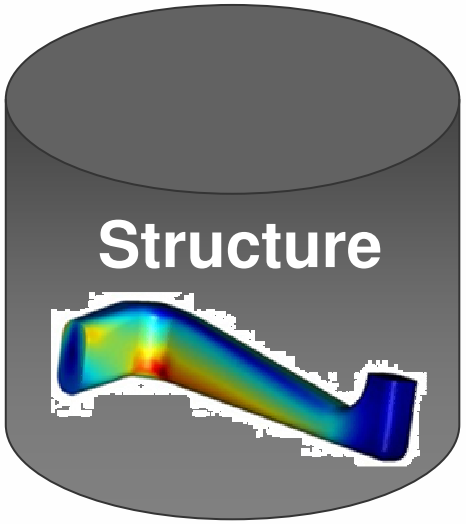
Partitioned Approaches











Flexibility

Accuracy?

Stability?

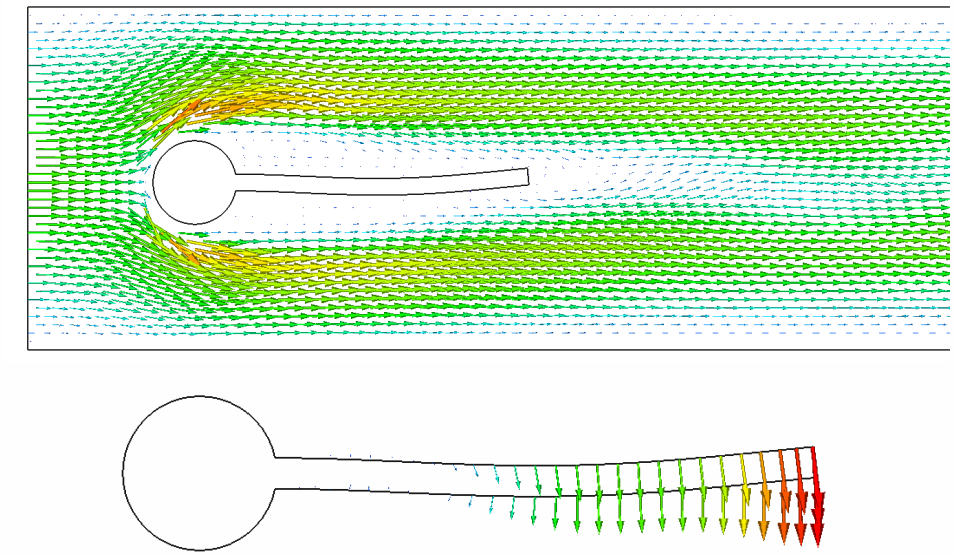
Patitioned Approaches – Unidirectional Coupling

Koyan dam, India
Mike R. Ross, PhD thesis, 2006

Morrow Point dam, Colorado

fluid ⟹ structure

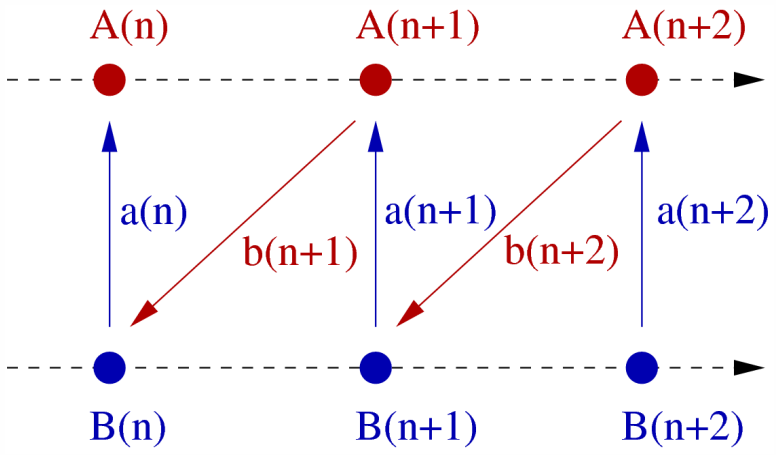
Patitioned Approaches – Bidirectional Coupling



Source:
Bernhard Gatzhammer,
Janos Benk

fluid ⟺ structure

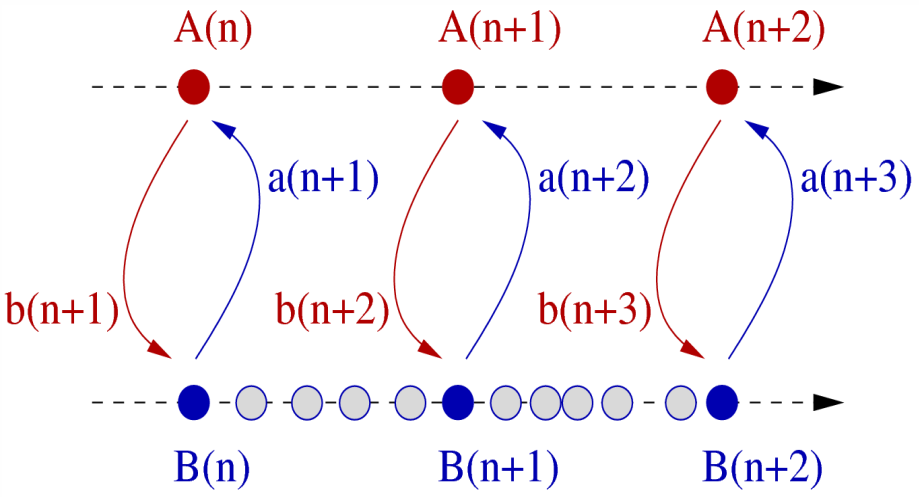
Patitioned Approaches – Bidirectional Coupling



staggered time stepping

- simple,
- cheap, but
- often unstable

Patitioned Approaches – Bidirectional Coupling



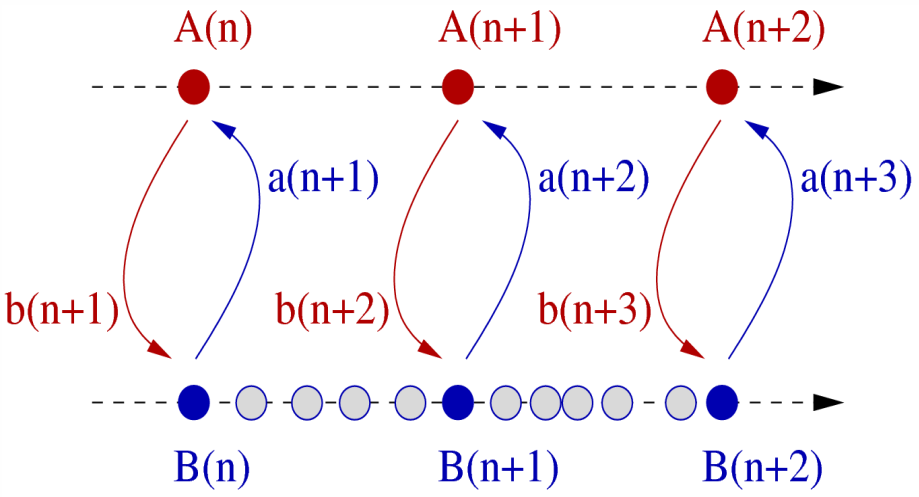
Gauss-Seidel iterations

- simple, but still
- often unstable

+ (Aitken) underrelaxation

- stable, but
- slow convergence

Patitioned Approaches – Bidirectional Coupling

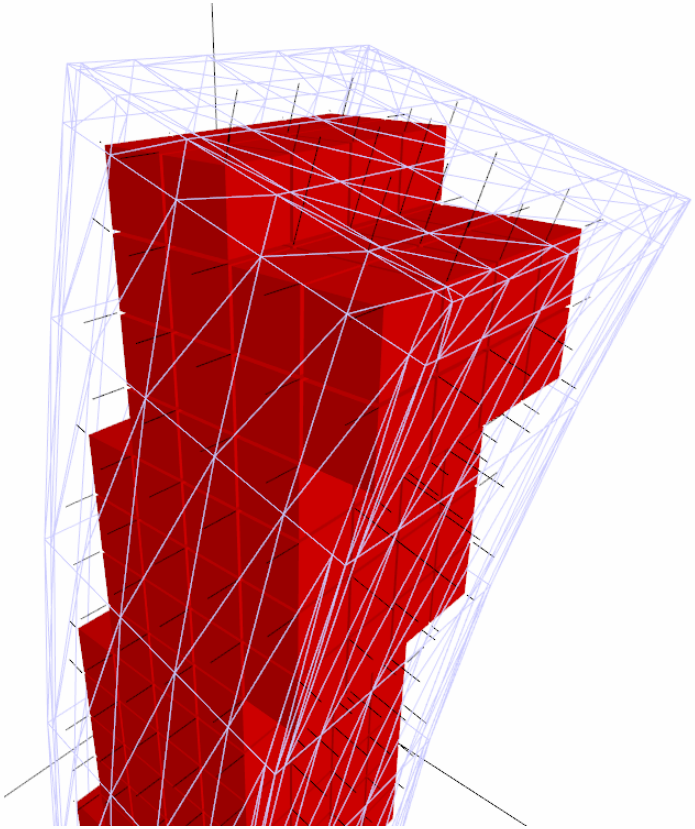


(quasi-)Newton

- stable,
- good convergence, but
- costly

Partitioned Approaches – Data Mapping

- projection
- polynomial interpolation
- radial basis functions
- Mortar elements
- localized Lagrangian multipliers

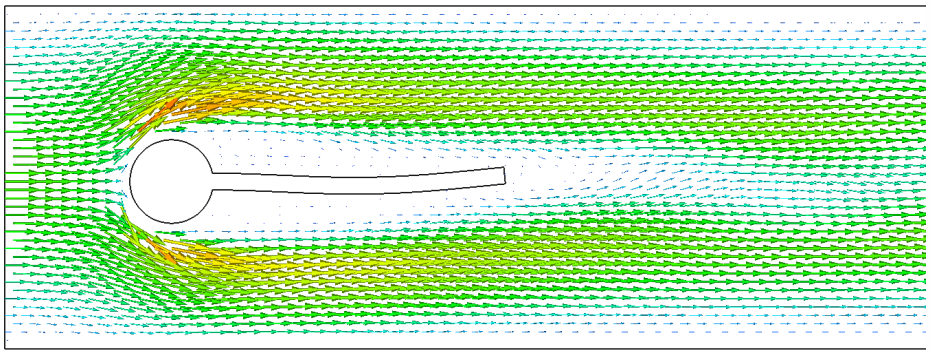


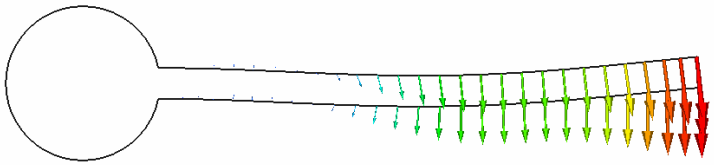
Outline

- general challenges
- partitioned solution approaches
- **our vision**
- conclusion

Our Vision – Example Application

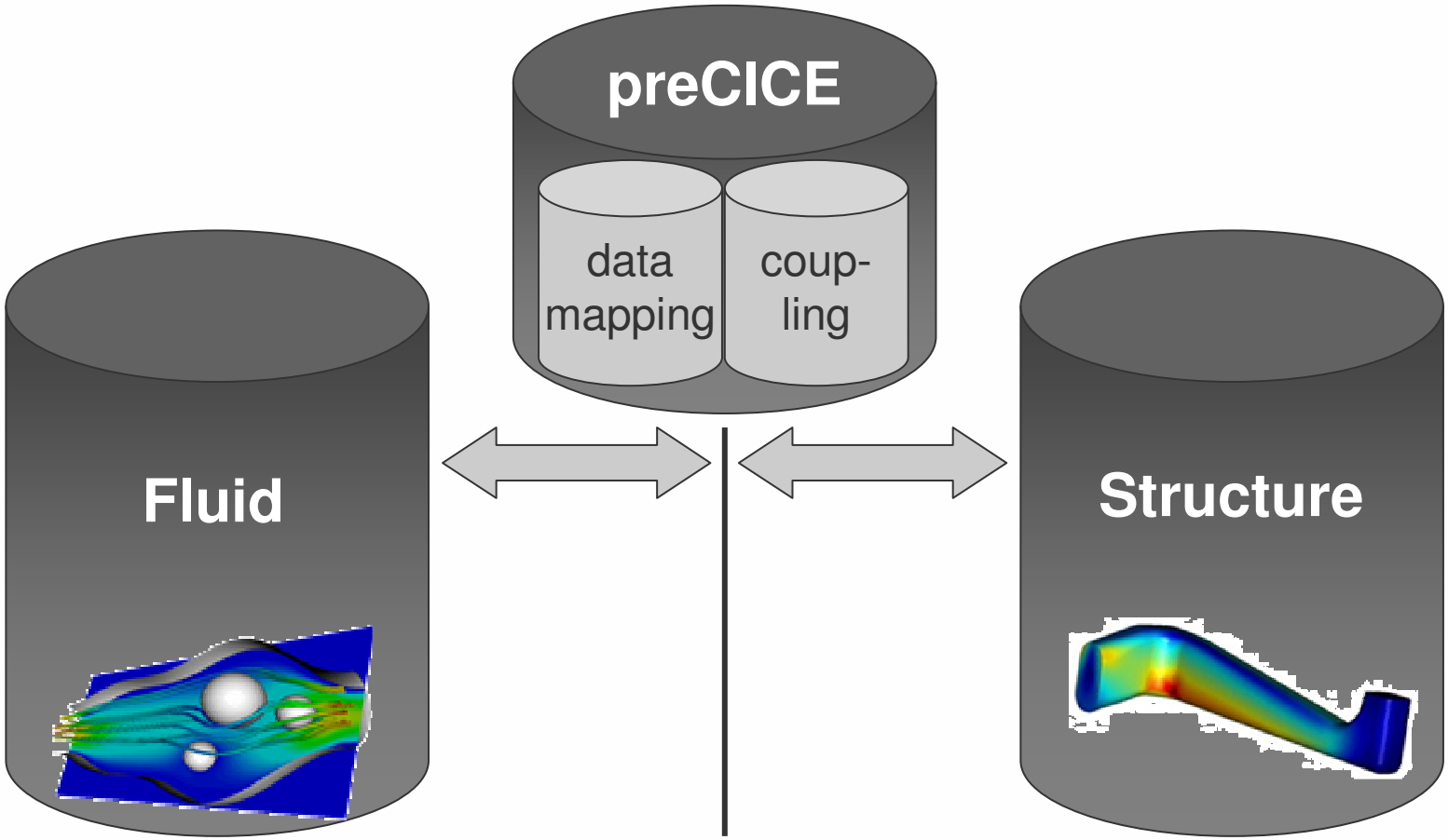
- **fluid-structure interaction**
- stability issues
- surface coupling → interface condition?
- (different discretisation orders)



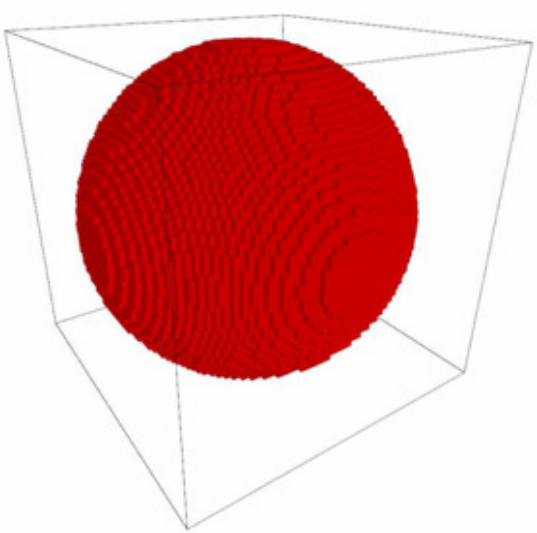


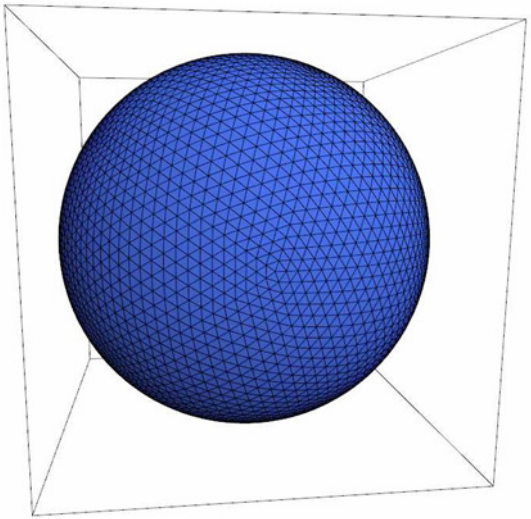
Source: Bernhard Gatzhammer, Janos Benk

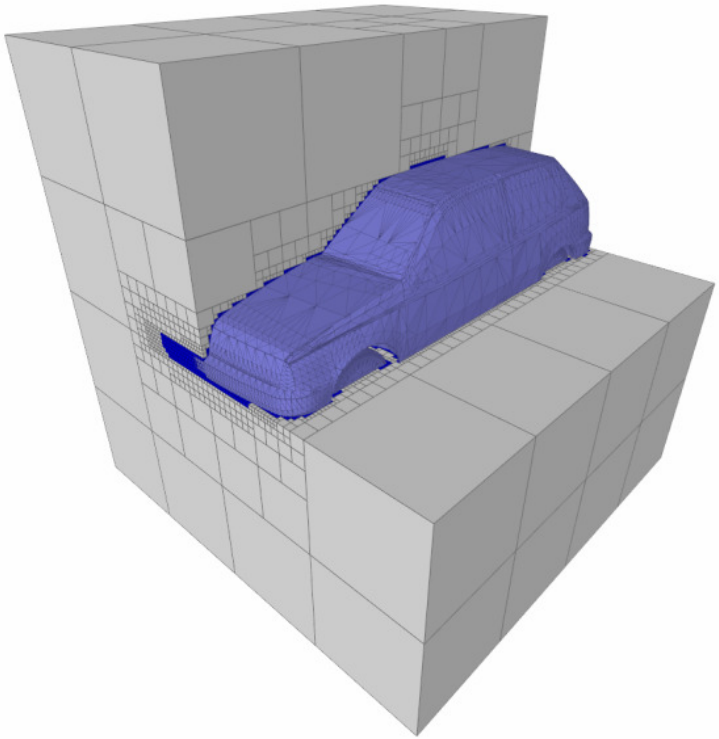
Our Vision – preCICE



Our Vision – preCICE Data Mapping



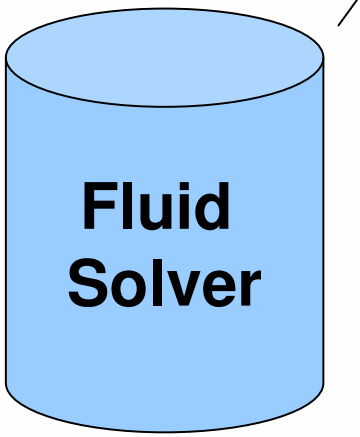




Cart.res.	# triang.	runtime
256	8,000	2.6 sec
512	8,000	10.1 sec
512	32,000	14.3 sec
512	128,000	17.4 sec

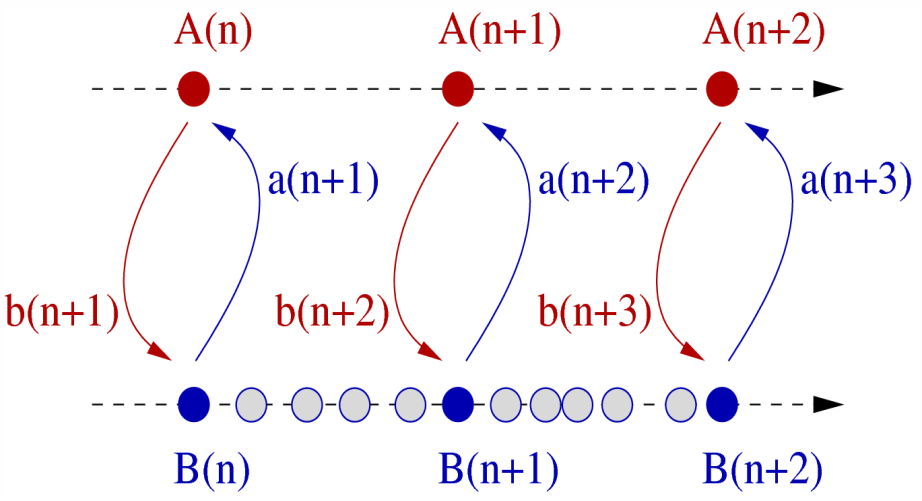
neighbourhood search measured on a Pentium M 1.6 GHz processor with 2048 kB cache

Our Vision – preCICE Interface




```
FSI_Init()
while (FSI_Is_running())
        if (FSI_Is_new_interface_values())
                Read coupling data from com.mesh
        Set time step length
        Compute values of next time step
        Write coupling data to com.mesh
        FSI_Data_exchange()
        if (FSI_Is_implicit_converged())
                Store values of next time step
end while
FSI_Finalize()
```

Our Vision – Peano

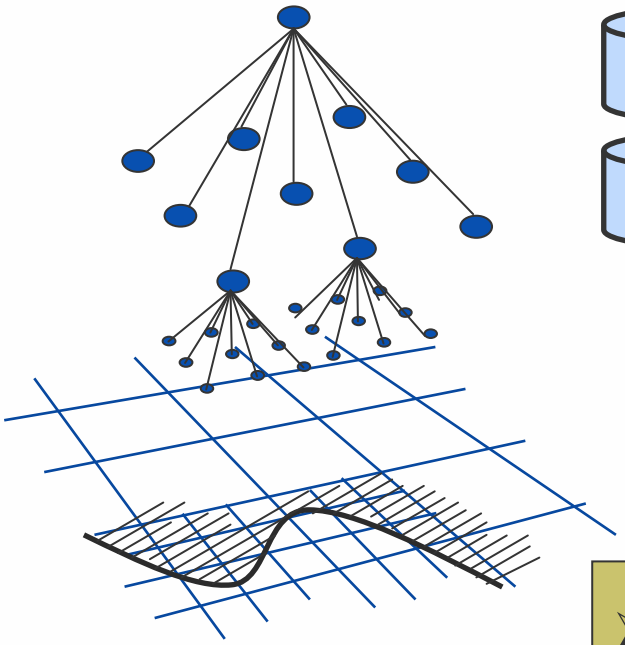


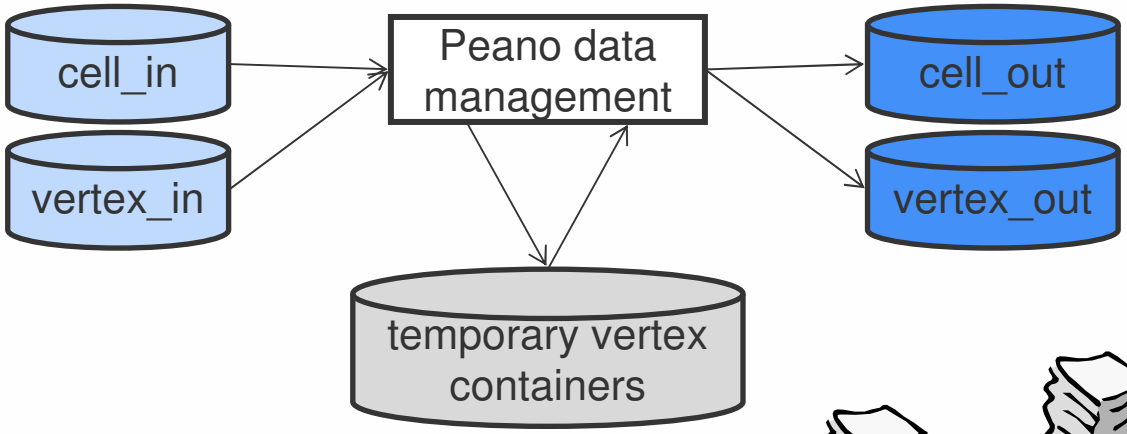
add outer iterations

➢ computational costs!!!

fast fluid solver

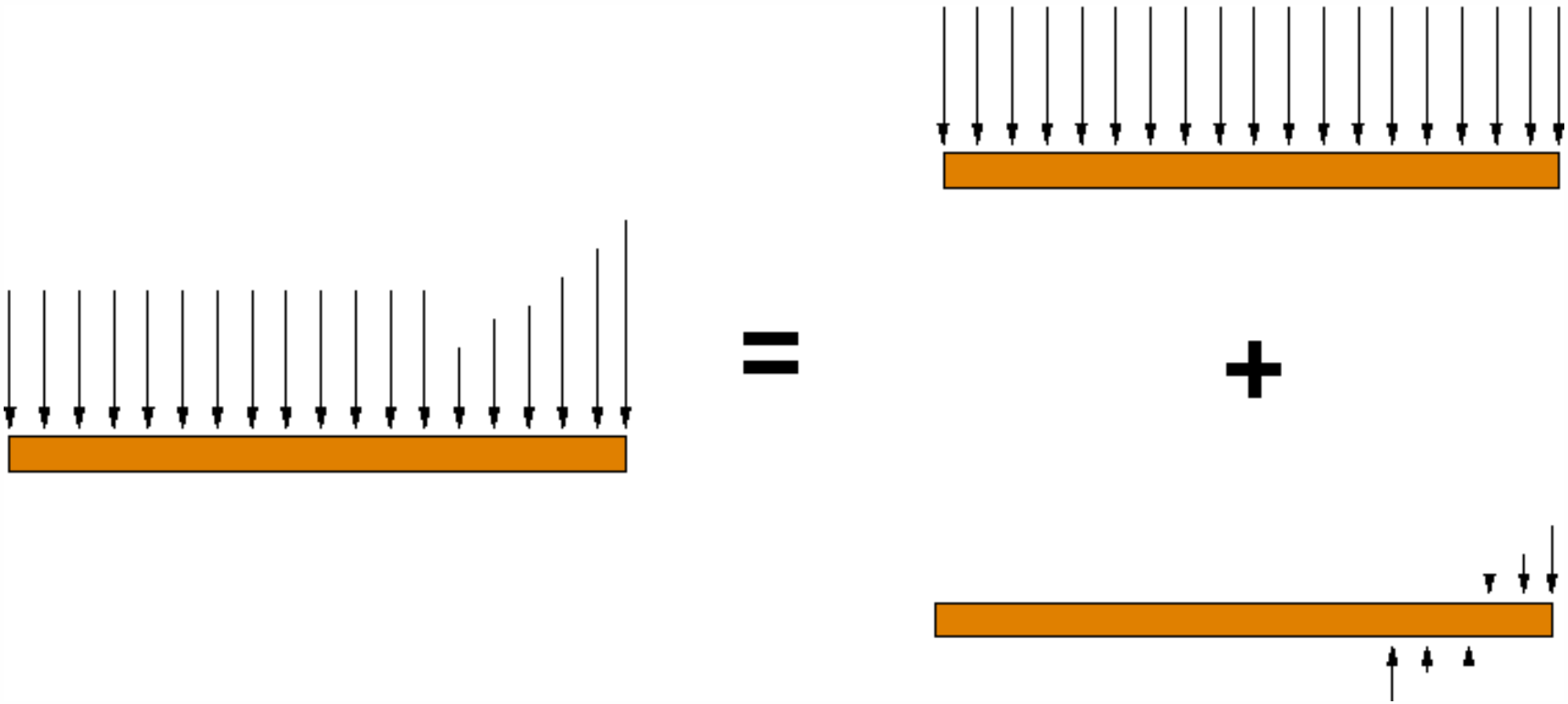
Our Vision – Peano





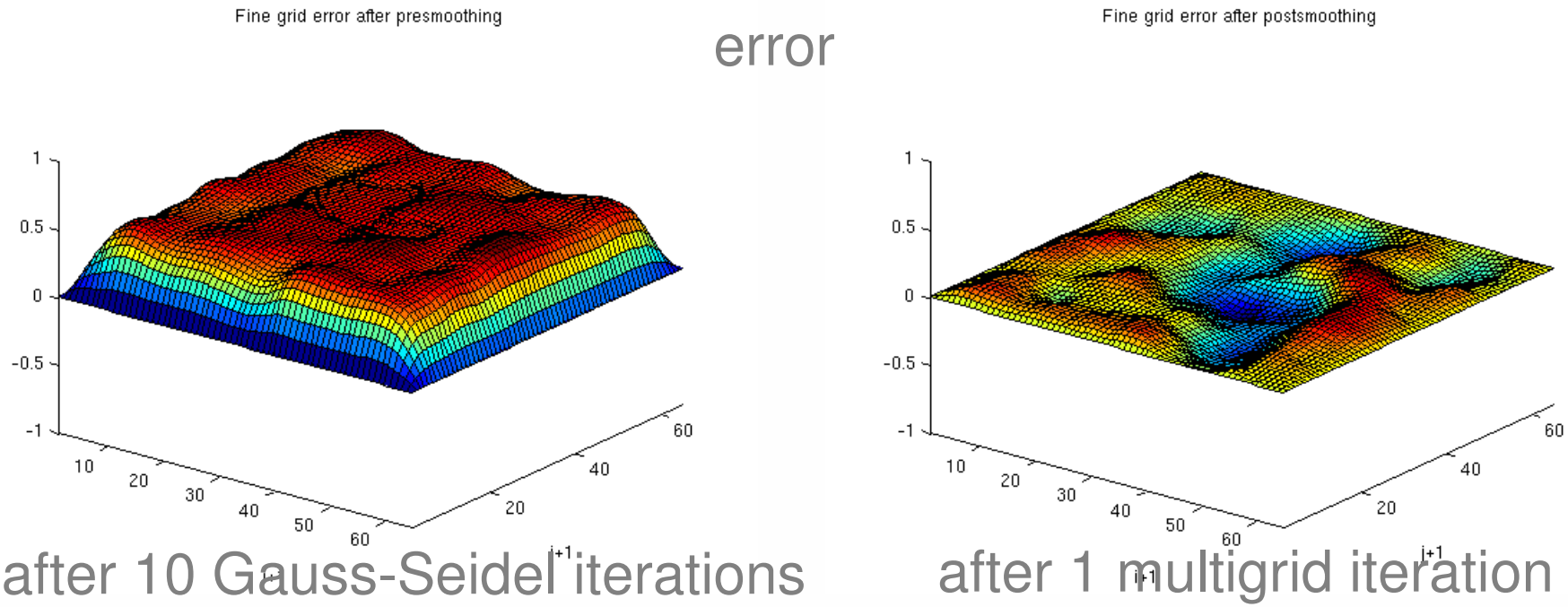
- memory efficient
- hierarchical
- dynamically adaptive

Our Vision – Multigrid / Hierarchical Coupling



Our Vision – Multigrid / Hierarchical Coupling

standard case for multigrid solvers

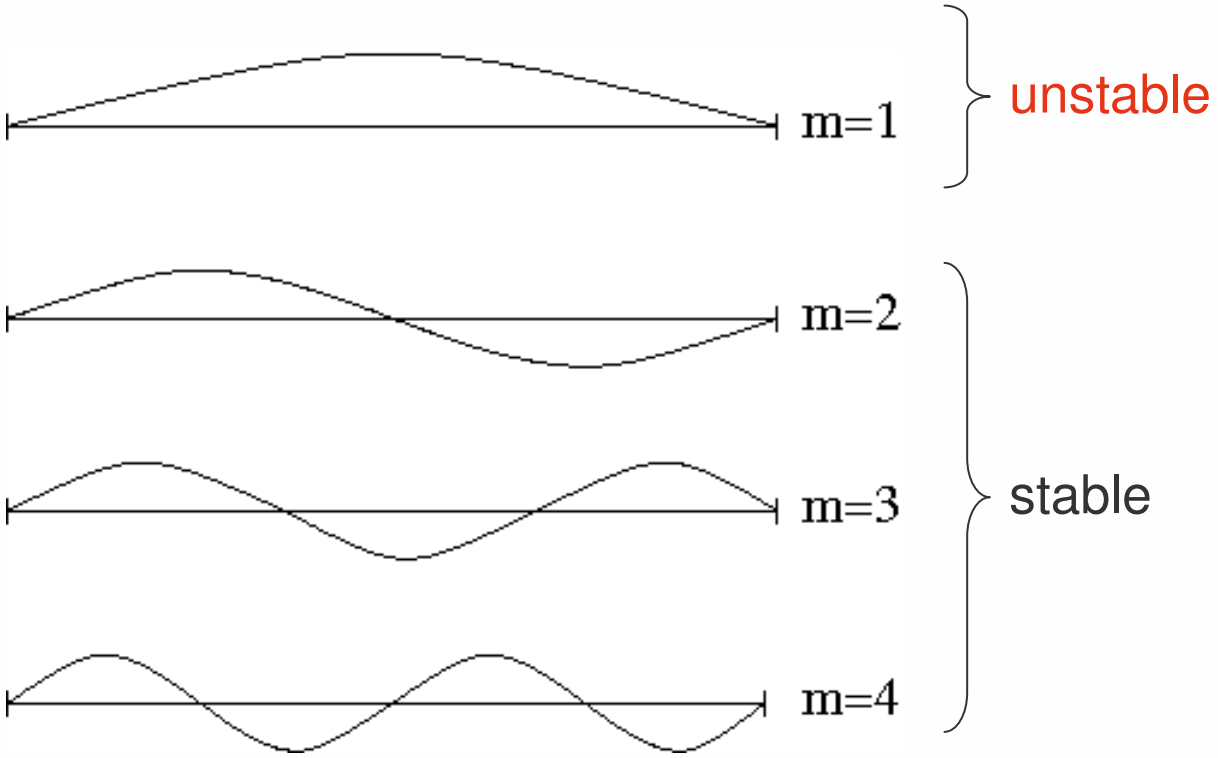


after 10 Gauss-Seidel iterations

after 1 multigrid iteration

Our Vision – Multigrid / Hierarchical Coupling

partitioned fluid-structure interaction



$$\rho \propto frq^{-1}$$

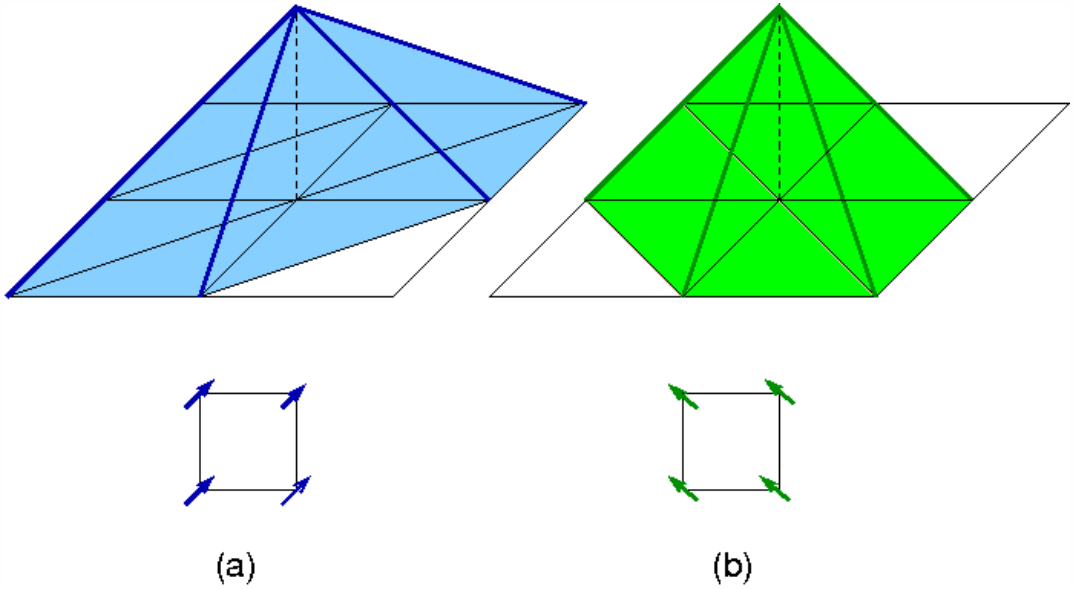
$$\rho \propto h^{-q}$$

New methods?

Our Vision – Variational Interface Treatment

- variational interface conditions?
- energy-conserving space-time finite elements?

➢ stable partitioned simualtion



Outline

- general challenges
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- our vision
- **conclusion**

Conclusion

- multiphysics requires flexibility
- partitioned approaches
  - stability, accuracy, costs?
- example aplication: fluid-structure interaction

➢ fast (fluid) solvers

➢ stable coupling → variational interface condition?

➢ fast convergence → multigrid / hierarchical solvers?