Tackling the Multi-Challenge
Multiphysics

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MAC Summer Workshop 2010
IAS Inaugural Lecture
IAS Focus Group
HPC: Tackling the Multi-Challenge – Multiphysics

“Mult-this and multi-that”

Domains & Education
....disciplinary

Models
....physics

Models
....scale

Numerics
....dimensional

Multi...

Systems
....core

Numerics
....level
Outline

• general challenges
• partitioned approaches
• our vision
• conclusion
Outline

• general challenges
  • partitioned approaches
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• 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

free flow + porous media flow + mixing and diffusion + structural dynamics + geochemistry

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

- general challenges
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Partitioned Approaches
Partitioned Approaches

Fluid

Structure

Coupling / Glue

Flexibility

Accuracy?

Stability?
Partitioned Approaches – Unidirectional Coupling

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

Morrow Point dam, Colorado

fluid  →  structure
Partitioned Approaches – Bidirectional Coupling

Source: Bernhard Gatzhammer, Janos Benk

fluid ↔ structure
Partitioned Approaches – Bidirectional Coupling

- staggered time stepping
  ➢ simple,
  ➢ cheap, but
  ➢ often unstable
Partitioned Approaches – Bidirectional Coupling

Gauss-Seidel iterations
- simple, but still
- often unstable

+ (Aitken) underrelaxation
- stable, but
- slow convergence
Partitioned 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

preCICE

Fluid

Structure

data mapping

coupling

MAC Summer Workshop 2010, IAS Inaugural Lecture, Garching, July 2010
Miriam Mehl
Our Vision – preCICE Data Mapping

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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

\[ \rho \propto \text{frq}^{-1} \]

\[ \rho \propto h^{-q} \]

New methods?
Our Vision – Variational Interface Treatment

- variational interface conditions?
- energy-conserving space-time finite elements?
  - stable partitioned simulation
Outline

• general challenges
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• our vision
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Conclusion

• multiphysics requires flexibility
• partitioned approaches
  – stability, accuracy, costs?
• example application: fluid-structure interaction
  ➢ fast (fluid) solvers
  ➢ stable coupling → variational interface condition?
  ➢ fast convergence → multigrid / hierarchical solvers?