Fast Simulation of Highly Heterogeneous and Fractured Porous Media

Knut–Andreas Lie

SINTEF ICT, Dept. Applied Mathematics

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The GeoScale Project Portfolio

Vision:

Direct simulation of fluid flow on high-resolution geomodels of highly heterogeneous and fractured porous media in 3D.

Research keywords:

- multiscale methods, upscaling/downscaling
- robust discretisations of pressure equations
- fast simulation of fluid transport

Contact:

http://www.math.sintef.no/geoscale/

Knut-Andreas.Lie@sintef.no

+47 22 06 77 10 / +47 930 58 721

GeoScale Portifolio – A Collaborative Effort

Partners:

- SINTEF
- Universities of Bergen, Oslo, and Trondheim
- Schlumberger, Shell, Statoil

Education:

4-5 PhD grants (RCN, UoB, NTNU, Shell)

4 postdoc grants (RCN, EU, Schlumberger)

2 master students

Collaboration:

Stanford, Texas A&M, Umeå

Schlumberger Moscow Research, Statoil Research Centre

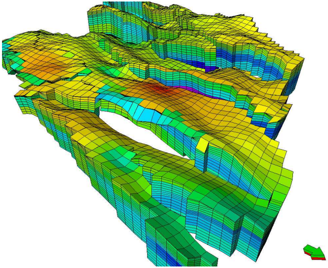
Simulation on Geological Models

For various reasons, there is a need for direct simulation on high-resolution geomodels. This is difficult:

- $\mathbf{K}$ spans many length scales and has multiscale structure

$$\max \mathbf{K} / \min \mathbf{K} \sim 10^3\text{–}10^{10}$$

- Details on all scales impact flow



Gap between simulation models and geomodels:

- High-resolution geomodels may have $10^7 - 10^9$ cells
- Conventional simulators are capable of about $10^5 - 10^6$ cells

Motivation

Applications for fast (and lightweight) simulators for :

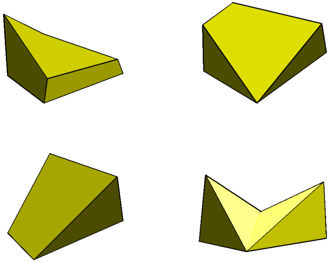
- direct simulation of large geomodels
- multiple realisations
- history-matching
- ...

Long-term collaboration with Schlumberger:

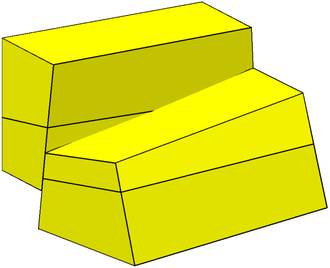
- Petrel workflow tools
- FrontSim streamline simulator

Accurate simulation on industry-standard grid models is challenging!

Skew and deformed grid blocks:



Non-matching cells:



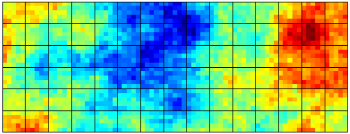
Our approach: finite elements and/or mimetic methods

Developing an Alternative to Upscaling

We seek a methodology that:

- gives a detailed image of the flow pattern on the fine scale, without having to solve the full fine-scale system
- is robust and flexible with respect to the coarse grid
- is robust and flexible with respect to the fine grid and the fine-grid solver
- is accurate and conservative
- is fast and easy to parallelise

Standard upscaling:



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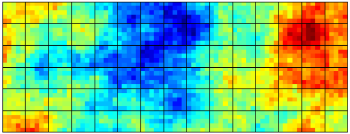

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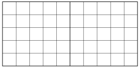
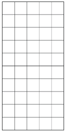
Coarse grid blocks:





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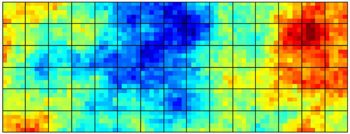

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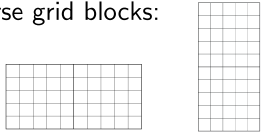

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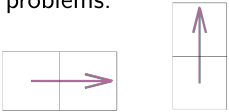
Flow problems:



From Upscaling to Multiscale Methods

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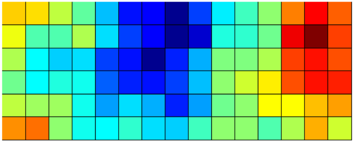

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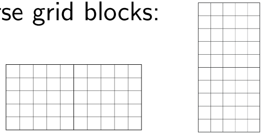

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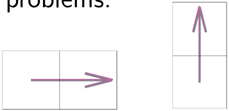

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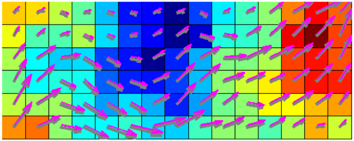

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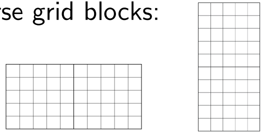

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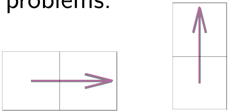

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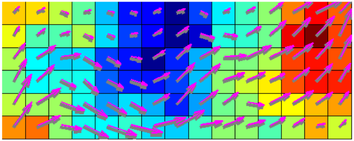

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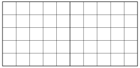

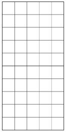

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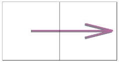
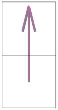
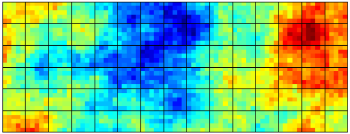




Multiscale method:



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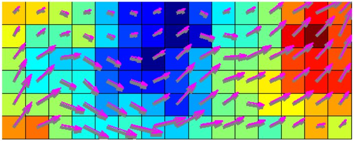

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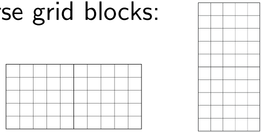

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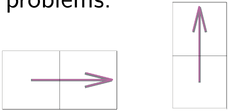

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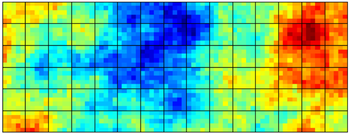

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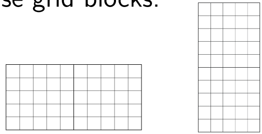

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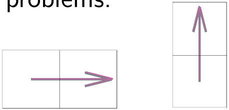

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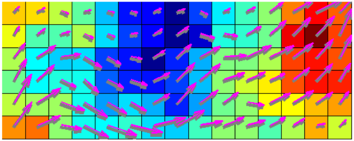

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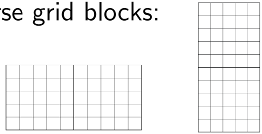

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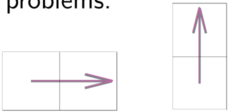

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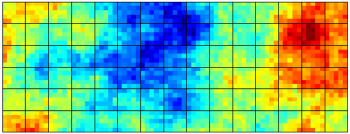

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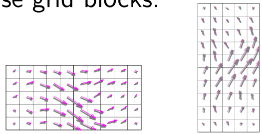

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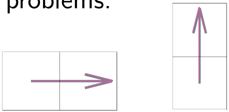

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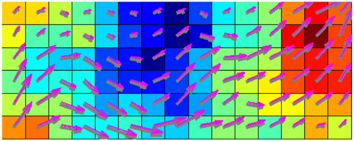

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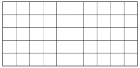

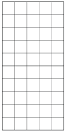

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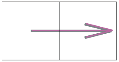
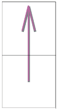
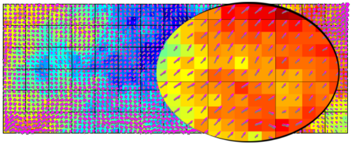




Multiscale method:



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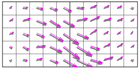

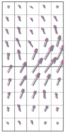

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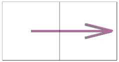
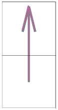
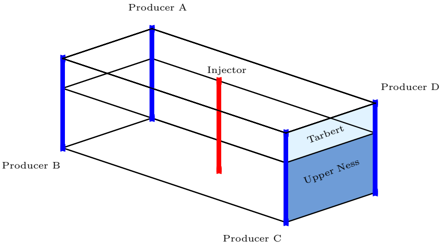
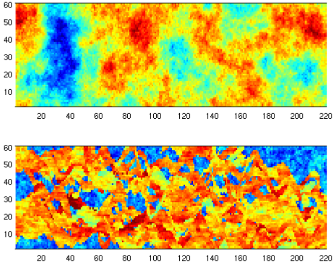




Advantage: Accuracy
10th SPE Comparative Solution Project

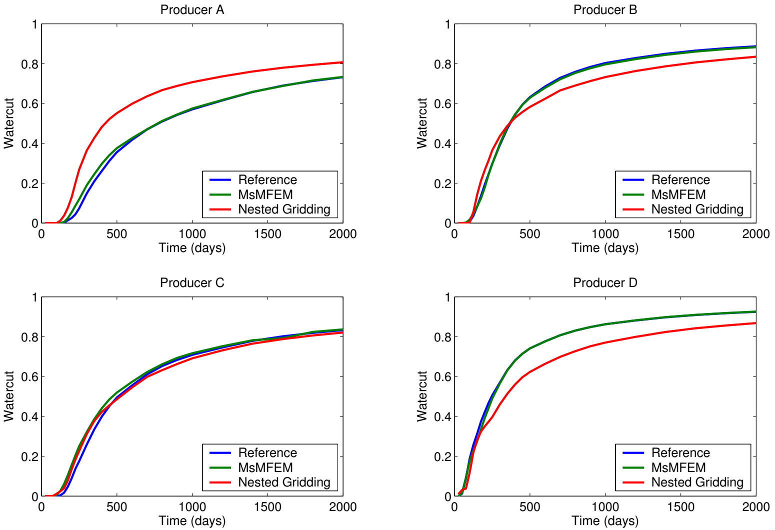




- Geomodel: $60 \times 220 \times 85 \approx 1,1$ million grid cells
- Simulation: 2000 days of production

Advantage: Accuracy

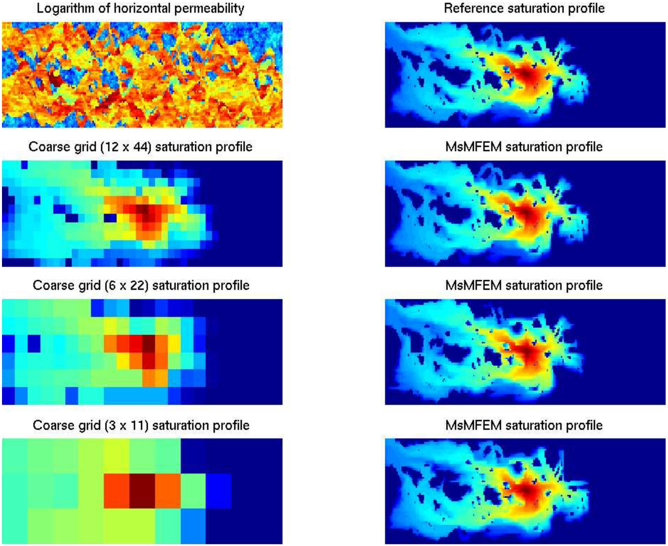
SPE10 Benchmark ($5 \times 11 \times 17$ Coarse Grid)



Nested gridding: upscaling + downscaling

Advantage: Robustness

SPE10, Layer 85 (60×220 Grid)



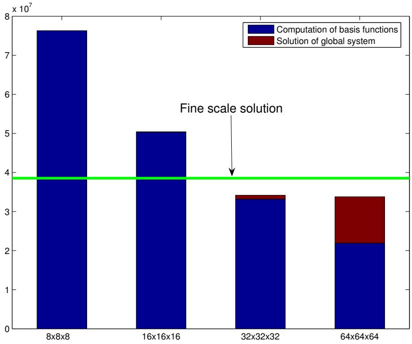
Computational Complexity

Direct solution may be more efficient, so why bother with multiscale?

- Full simulation: $\mathcal{O}(10^2)$ time steps.
- Basis functions need not be recomputed

Also:

- Possible to solve very large problems
- Easy parallelization

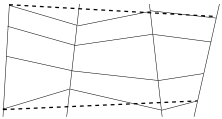


Flexibility

Multiscale mixed formulation:

coarse grid = union of cells in fine grid

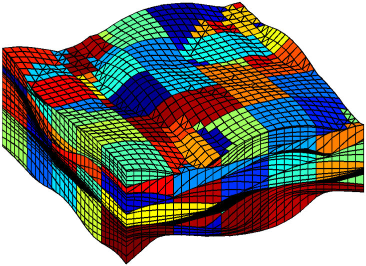
- Given a numerical method that works on the fine grid, the implementation is straightforward.
- One avoids resampling when going from fine to coarse grid, and vice versa

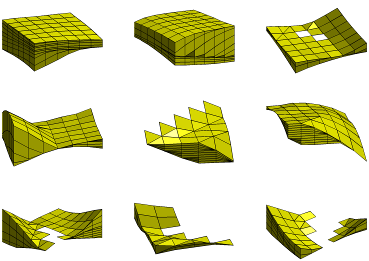


Other formulations:

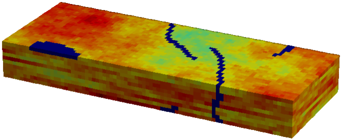
Finite-volume methods: based upon *dual grid* $\longrightarrow$ special cases that complicate the implementation in the presence of faults, local refinements, etc.

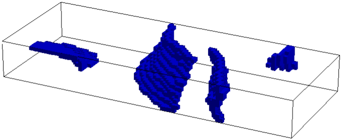
Flexibility wrt. Grids



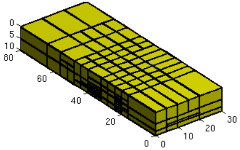


Flexibility wrt. Grids
Around Flow Barriers, Fractures, etc

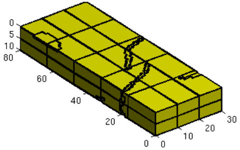




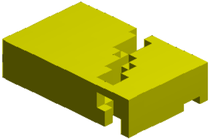
Non-uniform grid, hexahedral cells

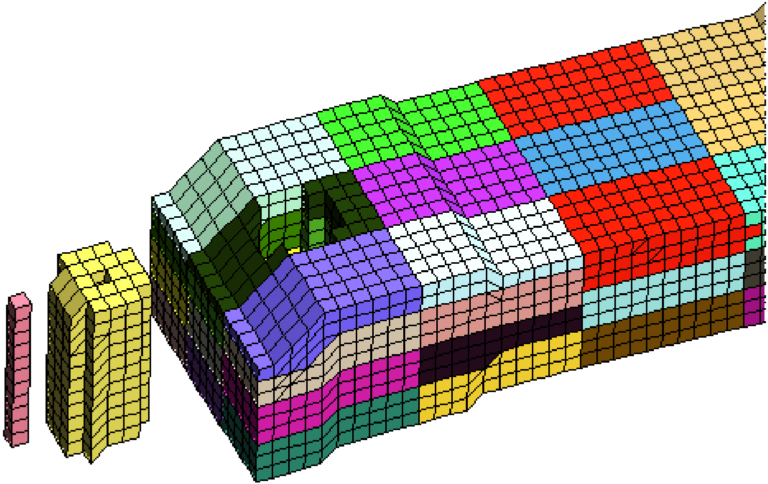


Non-uniform grid, general cells



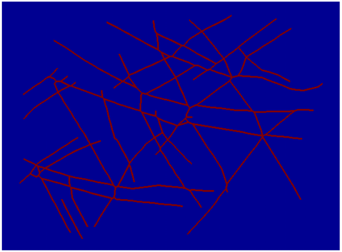
General grid-cell

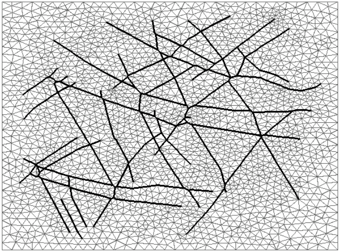




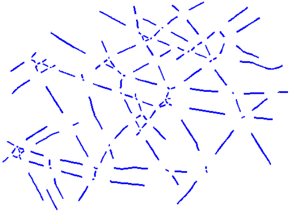
Flexibility wrt. Grids

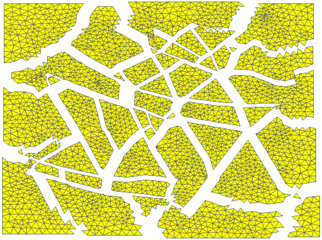
Fracture Networks





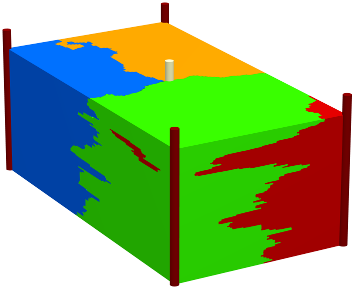
[1]

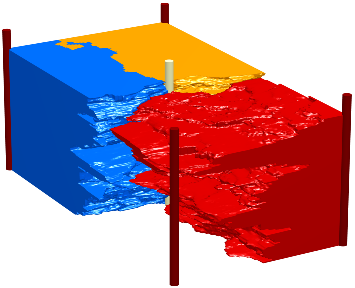




[1] Grid model courtesy of M. Karimi-Fard, Stanford

Fast Simulation of Fluid Transport

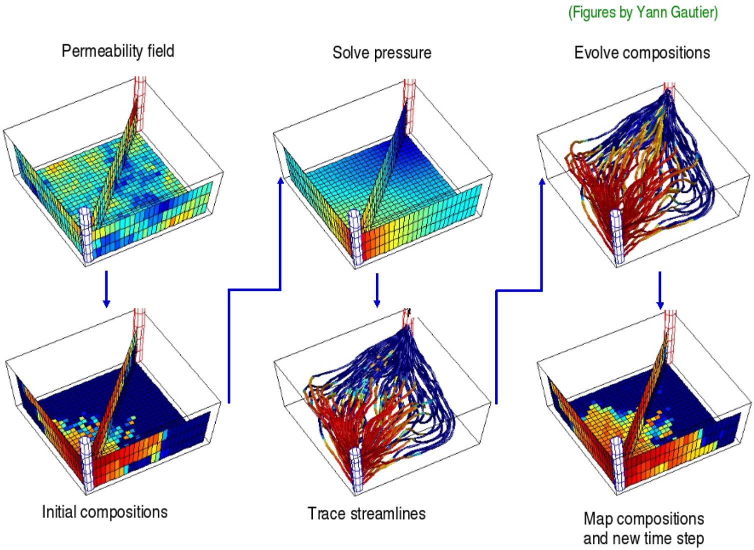




- discontinuous Galerkin
- reordering
- large time-steps

- multiphase transport
- tracer flow
- delineation of volumes

3D Streamline Simulation



Future Work

Multiscale methods

- Well models (adaptive gridding, multilaterals)
- More general grids (block-structured, PEBI, ..)
- Compressibility, multiphase and multicomponent
- Adaptivity
- Fractures and faults

Applications:

- Multiscale history matching
- Carbonate reservoirs..?
- CO_2..?