The GeoScale Project Portfolio: Multiscale Methods to Bypass Upscaling

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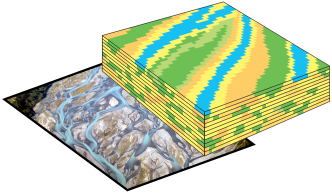
The GeoScale Project Portfolio

SINTEF ICT, Department of Applied Mathematics, Oslo

Research group

- 7 researchers (6 with PhDs)
- 1 postdoc
- 2–3 PhD students
- 1 programmers



Collaboration with national and international partners in industry and academia

Research vision:

Direct simulation of complex grid models of highly heterogeneous and fractured porous media - a technology that bypasses the need for upscaling.

`http://www.sintef.no/GeoScale/`

Customers and Collaborators

Recent and ongoing projects

Customers

- Research Council of Norway
    - Petromaks program
    - CLIMIT program
- StatoilHydro
- Shell E&P
- Schlumberger (SIS)
- + confidential clients
- . . .

Collaborators

- University of Bergen
- NTNU
- University of Oslo
- Texas A&M
- Stanford University
- University of Stuttgart
- MIT
- . . .

Our Way of Thinking..

Three principles used to develop fast simulators

Simplified flow physics

“Full physics” is not always required. Reduced models may suffice and/or geology may be more important than flow physics.

Operator splitting

- fully coupled solution is slow..
- subequations often have different time scales
- splitting opens up for tailor-made methods

Sparsity / (multiscale) structure

- effects resolved on different scales
- small changes from one step to next
- small changes from one simulation to next

Key Technology #1:

Multiscale methods — simulation without upscaling

Sequential solution:

- Pressure/velocity and transport separated
- Use *sufficient* flow physics ⟶ 80% of the result in 20% of the time
- Splitting allows for sequentially implicit formulation

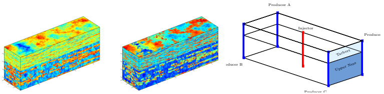
Multiscale pressure solvers:

- Pressure on coarse grid, velocity on fine grid
- Robust and accurate replacement for upscaling
- Minimal grid-orientation effects
- Allows up-gridding process to be automated
- Easy to build on-top of existing solvers
- Highly efficient, scalable, easy to parallelize

Fast simulation of fluid transport:

- Streamline solvers (fine grid)
- Flow-based coarsening
- Reordering techniques (fine grid)

SPE 10:

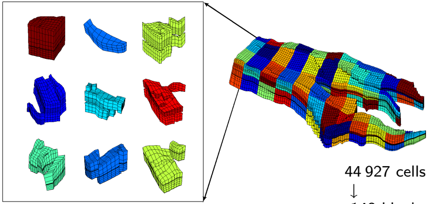


- $60 \times 220 \times 85 = 1.1$ million cells
- 2000 days of production from five-spot

Multiscale-streamline simulation: 2 min 22 sec

Key Technology #1:
Ideas underlying multiscale technology

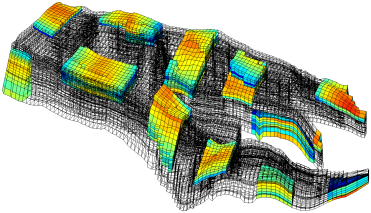
Coarse grid by uniform partitioning in index space for corner-point grids



44 927 cells
↓
148 blocks

9 different coarse blocks

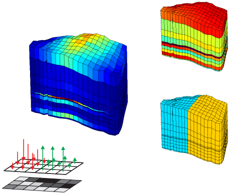
Block in coarse grid: building blocks for global solution



Basis functions: solve pressure eq.

$$\nabla \cdot \psi_{ij} = \begin{cases} w_i(x), & \text{for } x \in T_i, \\ -w_j(x), & \text{for } x \in T_j, \end{cases}$$

for each pair of adjacent blocks forcing one unit of flow across the common interface



Key Technology #1:

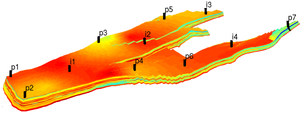
Efficient evaluation of gradients via adjoint multiscale methods

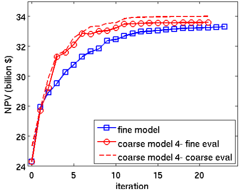
Methodology:

- Multiscale pressure solver + flow-based nonuniform coarsening for transport
- Rapid updates through pre-computed coarse grid mappings
- Adjoint implemented for obtaining gradients

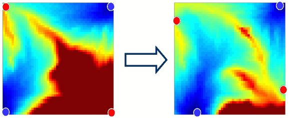
Example: 45 000 grid cell model

Find rates that optimize NPV.
Simulation time for coarse model: 5 sec.





Well-placement optimization:



Activity supported through *IO-Center*

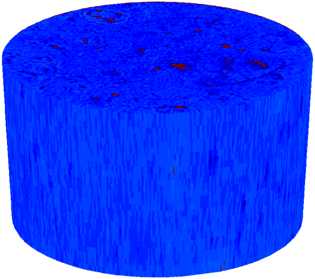
- Partners: NTNU, SINTEF and IFE
- Budget: 40 MNOK annually, five years
- Sponsors: Research Council of Norway and 10 industrial partners

Key Technology #1:
Multiscale multiphysics simulation of flow in naturally fractured and vuggy media

Methodology:

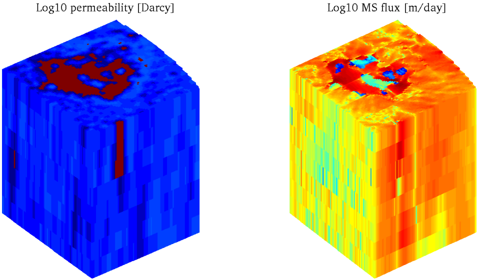
- Basis functions: Stokes–Brinkman equations
- Coarse-scale equations: Darcy equations

Full model:



512 × 512 × 26 cells
3.449.654 active

Subsample:



Log10 permeability [Darcy]

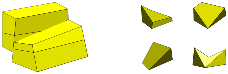
Log10 MS flux [m/day]

85 × 85 × 8 cells, 55.192 active, 75 blocks
pressure boundary conditions

Key Technology # 2:
Accurate discretization on complex grids

Challenge:

- Industry-standard: nonconforming grids with skewed and degenerate cells



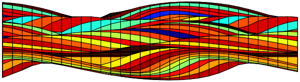
- Trend towards unstructured grids
- Standard methods produce wrong results on skewed and rough cells

Our solution:

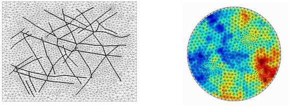
- mimetic methods = multipoint mass-conservative finite-volume scheme for pressure and velocity
- Applicable to general polyhedral cells
- Discretization across LGR and fractures is straightforward

Examples:

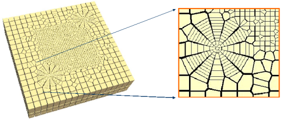
- Corner-point grids:



- Unstructured tetrahedral grids:



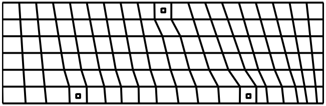
- PEBI grids:

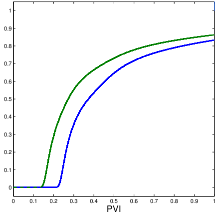


Key Technology #2:

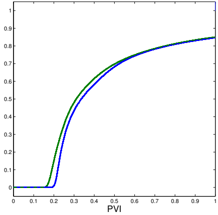
Example: standard method + skew grid = grid-orientation effects

Homogeneous and isotropic medium with a symmetric well pattern ⟶ symmteric flow



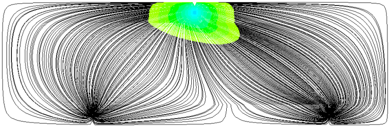


Water cut, two-point

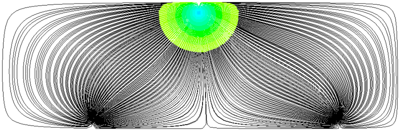


Water-cut, mimetic

Streamlines with two-point method

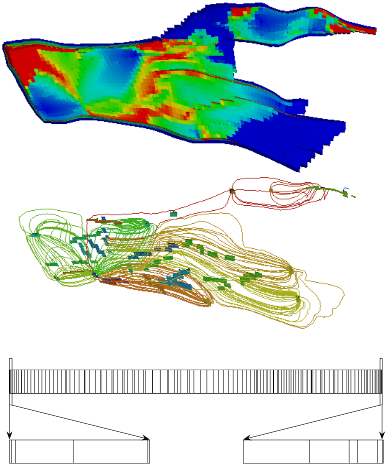


Streamlines with mimetic method



Key Technology #3:

Streamline simulation – order of magnitude faster than conventional methods



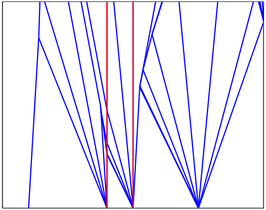
Our contributions:

- tracing on unstructured grids
- front tracking: fast 1-D solvers for streamlines and gravity lines
- analysis of accuracy and efficiency of operator splitting

Front-tracking of (in)compressible flow:

Solution of discontinous Riemann problems

Tracking of dynamic and stationary fronts



Key Technology #3:
Streamline-based history matching

Challenge:

Assimilation of production data to calibrate models

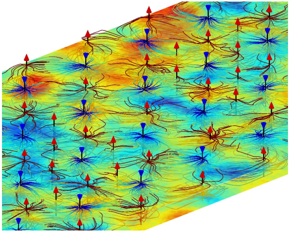
- Highly under-determined problem
- Errors in model, data, and methods
- Nonlinear forward model
- *Nonconvex misfit functions*
- *High computational cost*

Our solution:

- Generalized travel-time inversion (quasi-linearization of misfit functional)
- Analytical sensitivities along streamlines
- Multiscale flow solver, updates based on sensitivities

Example:

- 1 million cells, 32 injectors, and 69 producers
- 2475 days of water-cut data



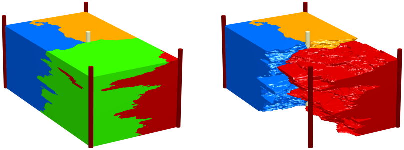
Solver	CPU-time (wall clock) Total	Pres.	Transp.
Multigrid	39 min	30 min	5 min
Multiscale	17 min	7 min	6 min

2.4 GHz Core 2 Duo, 2 GB RAM
7 forward simulations, 6 inversions

Key Technology #4:

Fast methods based on reordering – grid-based alternative to streamlines

Delineation of reservoir volumes:



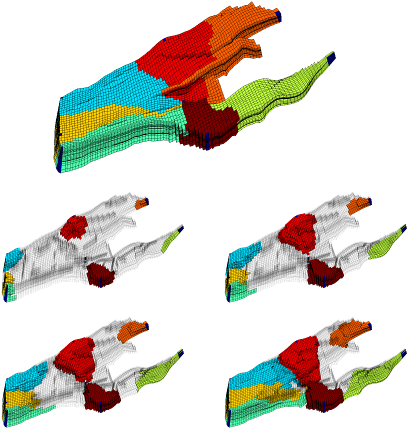
SPE 10, Model 2, 60 × 220 × 85

Simplified flow information can be obtained in a few seconds:

- Stationary tracer
- Time-of-flight, thresholded with real-time

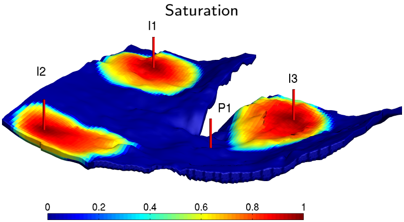
Here: computed using discontinuous Galerkin with optimal ordering of unknowns

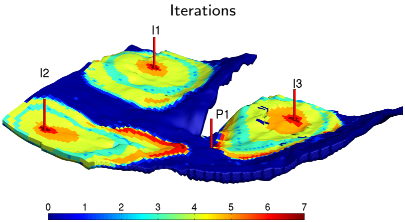
Timelines in the reservoir:



Key Technology #4

Fast methods based on reordering – optimal solver for advective flow


Saturation


Iterations

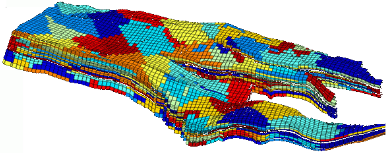
Δt	NR-UMFPACK		NR-PFS		NPFS	
days	time (sec)	iterations	time (sec)	iterations	time (sec)	iterations
125	2.26e+00	12.69	3.28e-01	12.69	4.44e-02	0.93
250	2.35e+00	12.62	3.32e-01	12.62	4.73e-02	1.10
500	2.38e+00	13.25	3.46e-01	13.25	4.16e-02	1.41
1000	2.50e+00	13.50	3.49e-01	13.50	4.21e-02	1.99

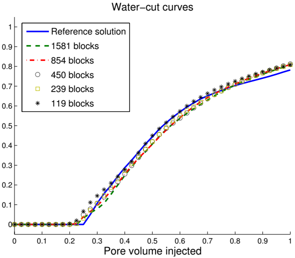
Fast desktop solver:

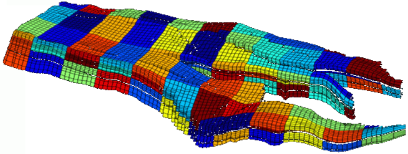
Operator splitting: solve advective flow and gravity separately (as with streamline methods) using highly efficient solver for each operator

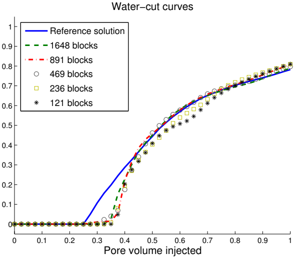
Speedup: 2-3 orders of magnitude of finite-volume methods given same assumptions as in a streamline solver

Key Technology #5:
Flow-based nonuniform coarsening – adaptive model reduction of transport grids




Water–cut curves




Water–cut curves

Key Technology #5:

Flow-based grids combined with logical partitioning for MsMFEM

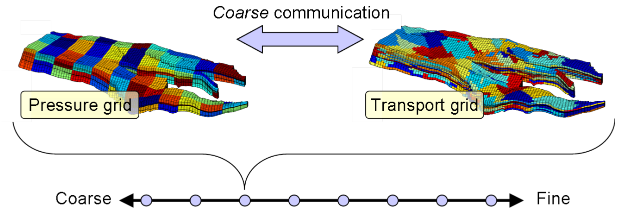
Challenge:

Different grids for flow and transport

- Flow: uniform partition in index space
- Transport: flow-based grids
- Communication via fine-grid is slow
- Need to store the whole model?

Solution:

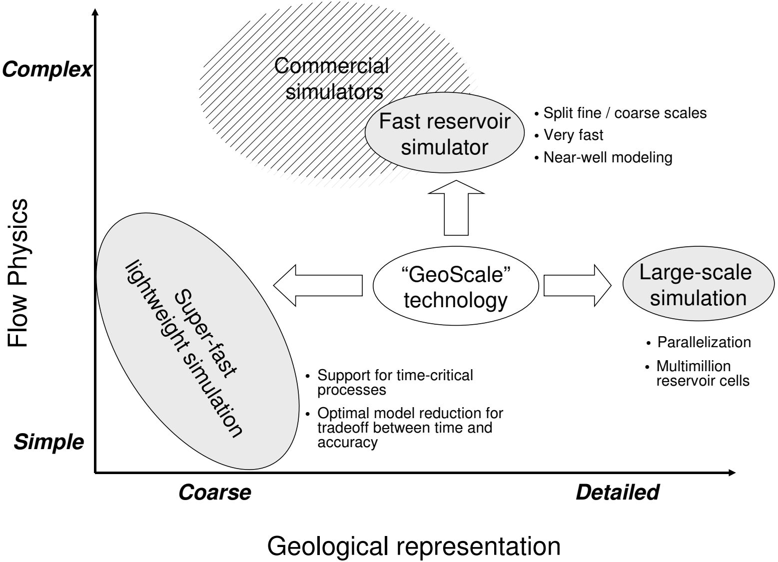
- Coarse mapping computed as part of preprocessing
- Fluxes stored only at interfaces of the two coarse grids
- Assembly of coarse system is partially precomputed



Computational saving: a factor 10–20 for this particular model

Future Research Directions

Activity based on strategic research grants



- Split fine / coarse scales
- Very fast
- Near-well modeling

- Support for time-critical processes
- Optimal model reduction for tradeoff between time and accuracy

- Parallelization
- Multimillion reservoir cells

MATLAB Reservoir Simulation Toolbox

Released under the GNU Public License, April 2009

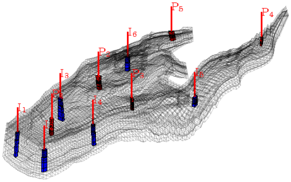
First GPL release:

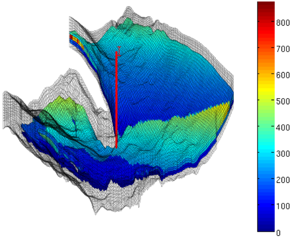
- routines and data structures for reading, representing, processing and visualizing unstructured grids
- corner-point grids / Eclipse input
- standard flow and transport solvers for one and two phases
- multiscale flow solvers

Inhouse version:

- black-oil models
- Stokes–Brinkman models
- adjoint methods, reordering, flow-based grids, etc.

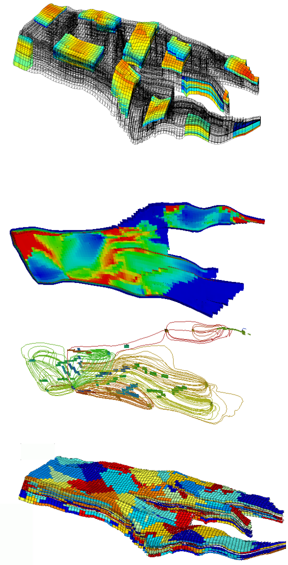
`http://www.sintef.no/MRST`





Inhouse Solvers

Implemented using generic programming concepts (templates in C++)



Based on operator splitting
Emphasis on efficiency

Flow solvers:

- corner-point and unstructured grids
- mimetic, TPFA, multiscale

Fast transport solvers:

- streamlines
- front-tracking
- reordering methods
- flow-based grids

The OPM Initiative

Open-source simulators of Porous Media flow

A long-lasting, efficient, and well-maintained, open-source software for flow and transport in porous media.

The resulting software should:

- be built on modern software principles,
- have functionality supporting multiple application areas,
- be easy to extend with new functionality,
- be built on open-source code principles,
- have a relatively low user threshold.

The software should be used/maintained based on a collaborative effort and involve groups with different research focus

Univ. Bergen, Univ. Heidelberg, Univ. Stuttgart, SINTEF, IRIS, StatoilHydro, ..