Non-uniform grid coarsening applied on explicit fracture modeling

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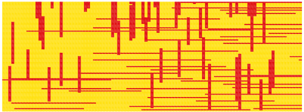
Non-uniform grid coarsening applied on explicit fracture modeling

- We want to determine a coarse grid suitable for saturation simulations that preserves important characteristics of the flow.
- Investigate two coarsening strategies: Non-uniform coarsening and Explicit fracture-matrix separation.

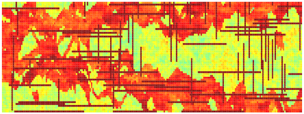
Key ideas:

- Velocity computed on a fine grid which resolves the fractures
- Saturation computed on the coarse grid

Homogeneous model with 100 fractures



Heterogeneous model with 100 fractures



Non-uniform coarsening algorithm

Two parameters:

V_{min}: Minimum volume of a coarse block

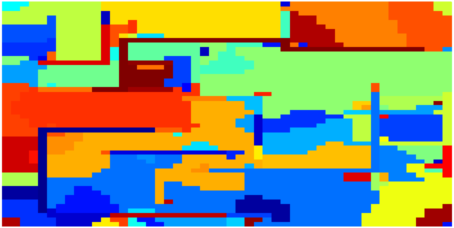
G_{max}: Maximum flow through each coarse block

The most important points from the algorithm:

- Group cells of similar flow magnitude into coarse blocks
- Coarse blocks have to be connected collections of fine cells
- Avoid too small blocks
- Avoid too large blocks

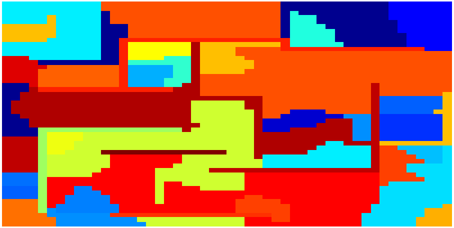
Non-uniform coarsening algorithm

Step 1: Segment $\log|v|$ into N level sets.



Step 1: 118 blocks

Step 2: Combine small blocks ($|B| < c$) with a neighbor.

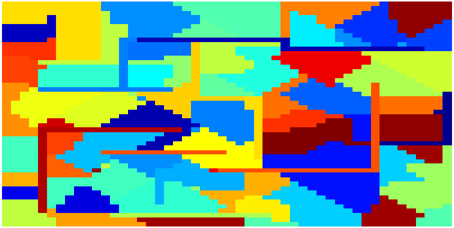


Merge B with less volume than $V_{\min}$ with the neighbor that has velocity magnitude close to B.

Step 2: 44 blocks

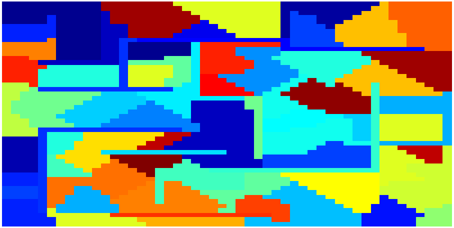
Non-uniform coarsening algorithm

Step 3: Refine blocks with too much flow $|B|g(B) > G_{\max}$.



Step 3: 81 blocks

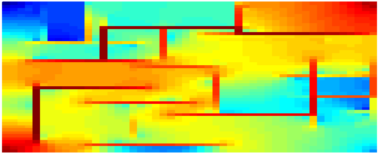
Step 4: Combine small blocks with neighboring blocks.



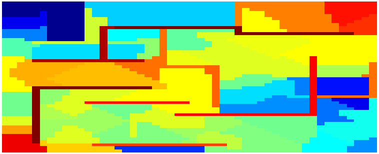
Repeat step 2.
Step 4: 70 blocks

Non-uniform coarsening algorithm

log $|v|$ on fine grid (2500 cells)



log $|v|$ on coarse grid (70 blocks)

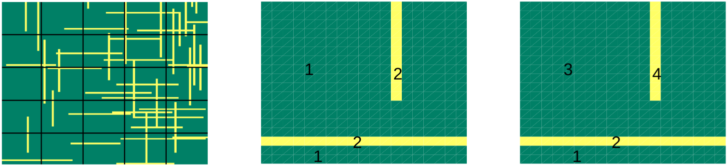


Advantages of the non-uniform coarsening algorithm:

- Applicable to both structured and unstructured grids
- Robust with respect to degree of coarsening
- Robust with respect to well-placement

Aarnes, J.E. et al: 2007, "Coarsening of three-dimensional structured and unstructured grids for subsurface flow". *Adv. Water Resour.* **30**(11), 2177-2193.

Explicit Fracture-Matrix Separation (EFMS)



Step 1 Step 2 Step 3

Initial model: 100 $\times$ 100 grid cells, 50 fracture lines

- Step 1: Introduce an initial coarse grid, here 5 $\times$ 5
- Step 2: Separate fracture and matrix part
- Step 3: Split non-connected blocks

Disadvantage: Upscaling factor difficult to tune.

Saturation equation and numerical discretization

Water saturation equation for a water-oil system:

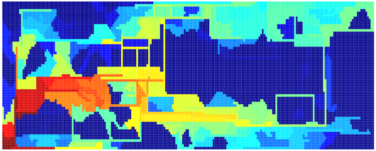
$$\phi \frac{\partial S}{\partial t} + \nabla \cdot (f_w v) = q_w$$

- First-order finite volume method discretization
- Fluxes are computed as upstream fluxes with respect to the *fine* grid fluxes on the coarse interfaces

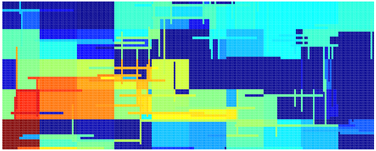
Comparison of coarse grids: NUC, EFMS and Cartesian

Heterogeneous model with 100 fractures.
Saturations solutions at 0.48 PVI.

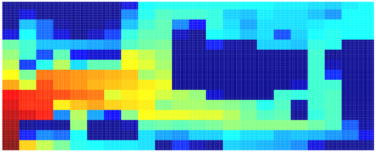
NUC grid with 206 blocks



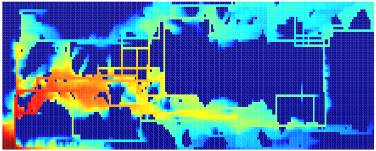
EFMS grid with 236 blocks



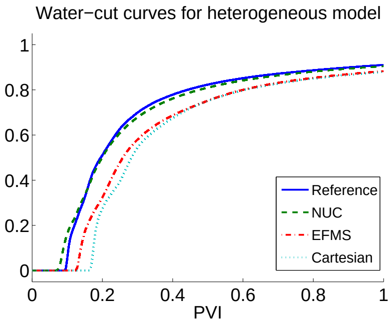
20×20 Cartesian grid



Fine grid



Results of comparison

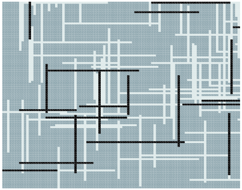


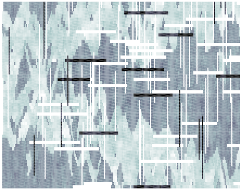
	# of blocks	e(w)
NUC	273	0.0273
EFMS	294	0.1208
Cartesian	330	0.1684

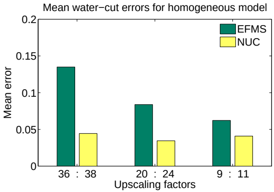
- NUC grid: consistently best accuracy.
- EFMS grid: reasonably accurate solutions for the homogeneous model.
- Coarse Cartesian grid: lower accuracy, smears out saturation profile.

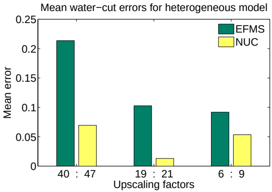
High and low permeable fractures

Stochastically generated fractures: 20 low permeable and 100 high permeable fractures.
$K_{\text{high perm frac}} > K_{\text{matrix}}$ and $K_{\text{low perm frac}} \ll K_{\text{matrix}}$.
25 simulations with different fracture distribution.









Concluding remarks

Accuracy:

- Both coarsening algorithms give more accurate results than conventional coarse grids.
- EFMS: poor accuracy when flow is influenced by underlying heterogeneous structures.

Applicability:

- NUC:
  - Easy to tune upscaling factor.
  - Assumes no prior knowledge of fractures provided they are represented in the geomodel.
- EFMS:
  - Difficult to control upscaling factor.
  - Assumes "fracture cells" are prescribed.

Thank you for your attention!

Questions?

http://www.sintef.no/GeoScale