Constrained Pressure Residual (CPR) preconditioners in OPM Flow

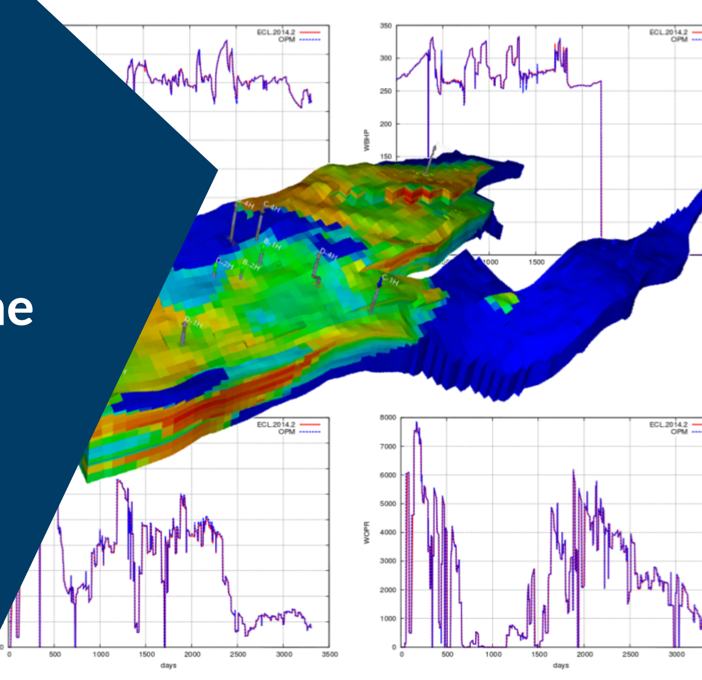
Halvor Møll Nilsen, Atgeirr Flø Rasmussen, Computational Geosciences, SINTEF Digital

OPM Summit, August 28 – 29, Trondheim, Norway

SINTEF

Presentation outline

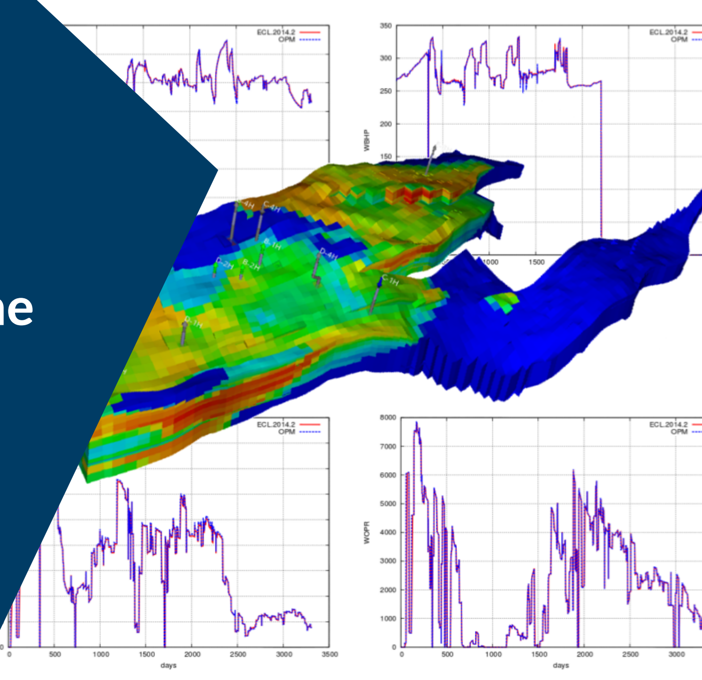
- Motivation
- Constrainded Pressure Residual (CPR) pre-conditioner
- Numerical performance
- Outlook and concluding remarks



SINTEF

Presentation outline

- Motivation
- Constrainded Pressure Residual (CPR) pre-conditioner
- Numerical performance
- Outlook and concluding remarks



Motivation

- Linear solves uses between 50-90 % simulation time
  - NORNE: 50 % ($np = 8$, $tol = 0.01$, ILU0, old assembly)
- Robust linear solves for high accuracy with limmited performanc overhead:
  - reduce Newton iterations
  - avoid time used on difficult linear systems
- CPR is seen as state of the art solver for Black-Oil Multiphase flow

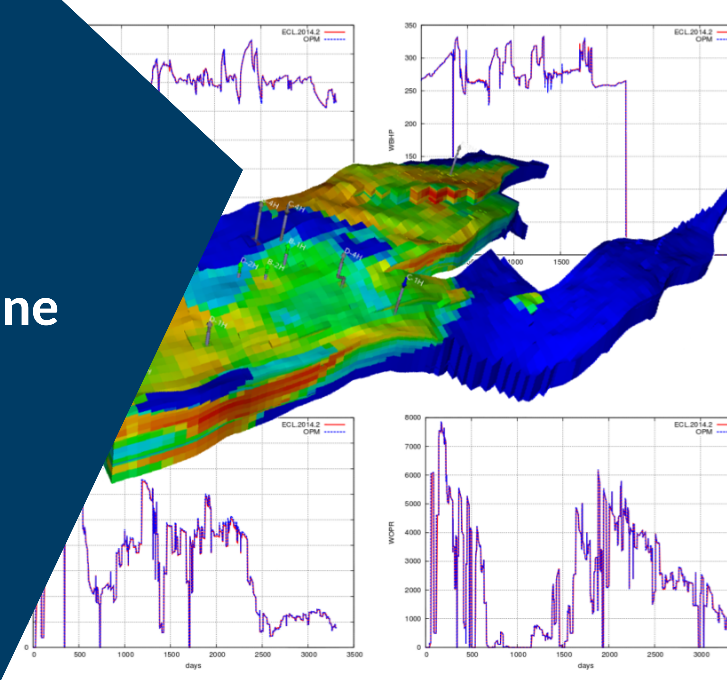
Motivation

- Linear solves uses between 50-90 % simulation time
  - NORNE: 50 % ($np = 8$, $tol = 0.01$, ILU0, old assembly)
- Robust linear solves for high accuracy with limmited performanc overhead:
  - reduce Newton iterations
  - avoid time used on difficult linear systems
- CPR is seen as state of the art solver for Black-Oil Multiphase flow

Aim: Provide robust accurate solver for Reservoir Simulations in OPM

Presentation outline

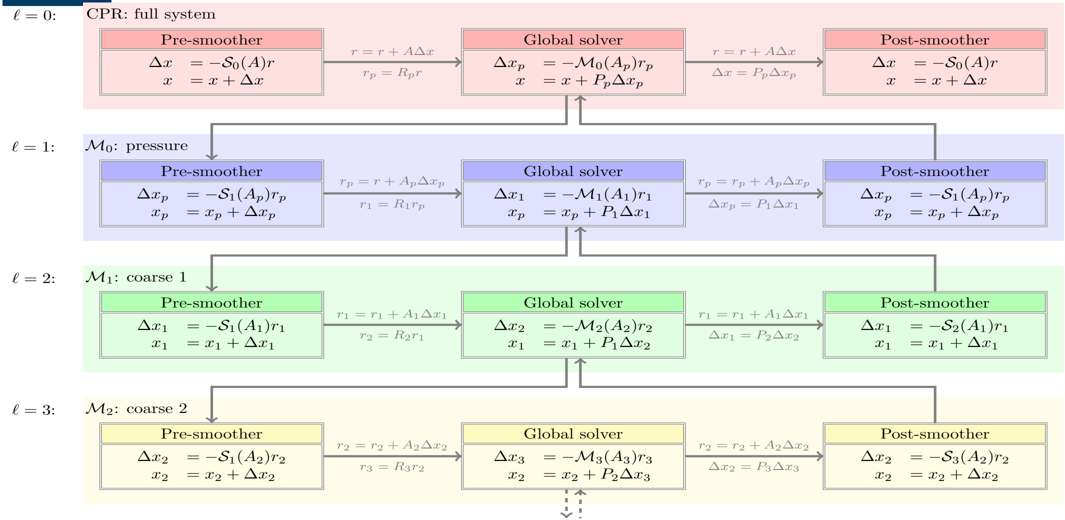
- Motivation
- Constrainded Pressure Residual (CPR) pre-conditioner
- Numerical performance
- Outlook and concluding remarks



Preconditioneing strageties

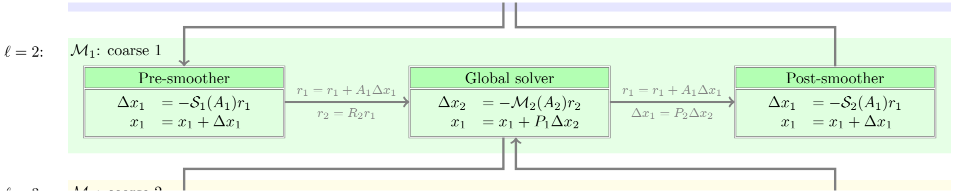
- ”Algebraic Multigrid type”:
  - Hierarchical
  - ”Oscillate” between different type smoothers (small scale) and coarse scale solves (large scale)
- Schwartz type: ”domain decomposition”
  - Domain based
  - Physics based
- Field split
  - Approximate inverse using approximate inverses of subsystems

AMG type: General linear solver framework: OPM Flow



AMG type: Building block

Solves on one level



Global solve is often only applying one approximate solve i.e. (resulting in V-cycle).

OPM Flow: reduced linear solver

- Full system:

$$A = \begin{bmatrix} A_{rr} & A_{rw} \\ A_{wr} & A_{ww} \end{bmatrix} \quad A \begin{bmatrix} x_r \\ x_w \end{bmatrix} = \begin{bmatrix} r_r \\ r_w \end{bmatrix}$$

- Schur-complement system:
$S(A) = A_{rr} - A_{rw}A_{ww}^{-1}A_{wr}$ and $S(r_r) = r_r - A_{rw}A_{ww}^{-1}r_w$.

$$S(A)x_r = S(r_r)$$

- Equivalent Large system:

$$A \begin{bmatrix} x_r \\ \bar{x}_w \end{bmatrix} = \begin{bmatrix} S(r_r) \\ 0 \end{bmatrix}$$

$\bar{x}_w = x_w - A_{ww}^{-1}r_w$.

CPR original approach: OPM Flow

- CPR with fill in:

$$R_{er}S(A)R_{vr}^T x_{rp} = R_{er}S(r_r)$$

- Equivalent extended system

$$\begin{bmatrix} R_{er}A_{rr}R_{vr}^T & R_{er}A_{rw} \\ A_{wr}R_{vr}^T & A_{ww} \end{bmatrix} \begin{bmatrix} x_{rp} \\ \bar{x}_w \end{bmatrix} = \begin{bmatrix} R_{er}S(r_r) \\ 0 \end{bmatrix}$$

- CPR with out fill in (bug found):

$$R_{er}A_{rr}R_{vr}^T = R_e r \mathbf{S}(r_r)$$

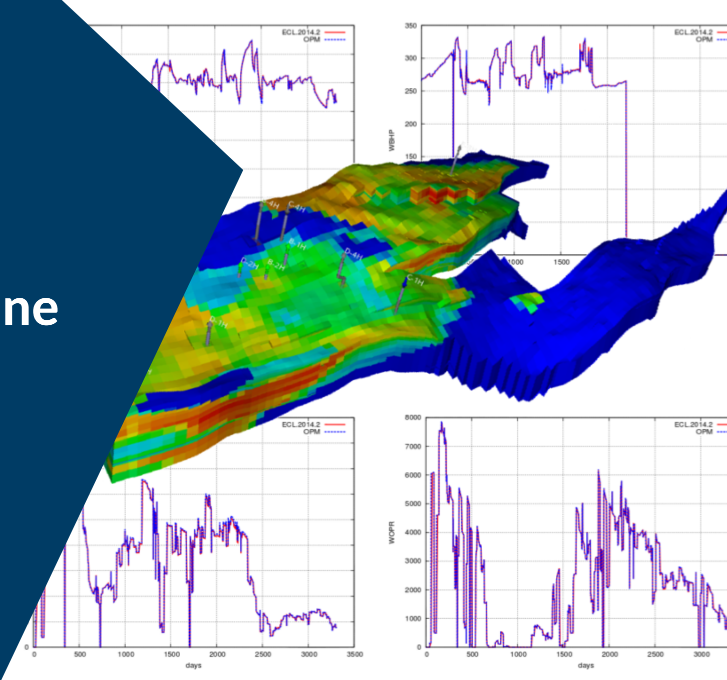
SINTEF

New CPR with wells: OPM Flow

- Problems with traditional:
  - Block structure of wells and reservoir is different
  - Few iterations $\rightarrow$ Schur complement $\sum nperf_i^2$ fill in
  - No fill in $\rightarrow$ more iterations
- Observation: pressure system has no block structure
- Idea extend pressure system to a well pressure system

Presentation outline

- Motivation
- Constrainded Pressure Residual (CPR) pre-conditioner
- Numerical performance
- Outlook and concluding remarks



Small systems

Type	add_w	Newit	LinIt	tol
ParO3	False	408	3156	0.01
ParO3	True	411	3180	0.01
cprw3	False	349	310	0.01
cpr3	True	352	297	0.01
cpr3	False	357	494	0.01

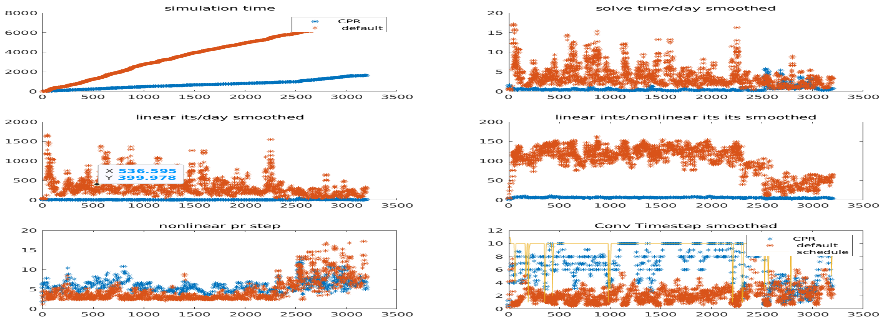
Norne

np	Type	add_w	total	Ass	LTot	LApp	LSet	Newit	LinIt	tol
1	cpr3	True	788	404	232	117	115	1225	1671	0.01
1	cprw3	False	788	400	238	132	106	1218	2057	0.01
1	cpr3	False	871	402	317	209	108	1235	3373	0.01
1	ParO3	True	964	427	357	311	46	1505	21223	0.01
1	ParO3	False	1045	473	386	339	47	1441	21440	0.01

Norne

np	Type	add_w	total	Ass	LTot	LApp	LSet	Newit	LinIt	tol
4	cprw3	False	281	140	97	52	44	1181	2435	0.01
4	cpr3	True	288	142	100	54	46	1223	2205	0.01
4	cpr3	False	303	142	117	74	43	1227	3421	0.01
4	ParO3	False	330	163	115	102	13	1412	21212	0.01
4	ParO3	True	346	168	124	110	14	1464	21081	0.01

Volve



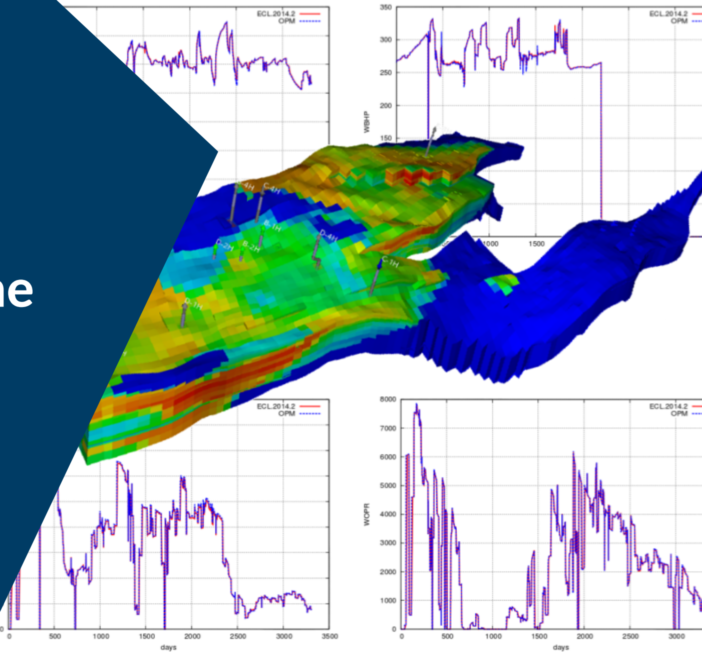
https://discovervolve.com/2021/09/25/how-to-run-the-volve-oilfield-dynamic-model-in-opm-flow/

CPR problems

- Small timesteps were linear solves is easy
- Difficult nonlinear solves, where a lot of linear solves are wasted
- If character of nonlinear solver is
- Any other?

Presentation outline

- Motivation
- Constrainded Pressure Residual (CPR) pre-conditioner
- Numerical performance
- Outlook and concluding remarks



Outlook and challenges

- New investigations
  - Flexible solvers on top level
  - Approaches with flexible on all levels
  - Changing linear solvers to avoid performance penalties of CPR when small time-steps is used.
  - New approaches for new CPR for VFP and multisegement wells
- Challenges:
  - Avoid wasted solves
  - Correct exit strategies (maxiter/tol)
  - Minimizing setup time by reuse

SINTEF

Outlook and challenges

- New investigations
  - Flexible solvers on top level
  - Approaches with flexible on all levels
  - Changing linear solvers to avoid performance penalties of CPR when small time-steps is used.
  - New approaches for new CPR for VFP and multisegement wells
- Challenges:
  - Avoid wasted solves
  - Correct exit strategies (maxiter/tol)
  - Minimizing setup time by reuse

Do OPM flow need working solvers with other cPR/AMG types available AMGCL/PETSC? (flow_blackoil_amgcl, flow_blackoil_petsc)

Conclusion

- CPR is particular good on:
  - cases which require accurate linear solves (for correct newton)
  - cases with long timesteps
  - cases with few steps with problematic timestep cuts
  - tight tolerances
- It is critical:
  - to minimize work on wasted linear solves
  - reuse setup
- New CPR with wells seem to be the best CPR on several of the test cases
- CPR is so far shown to be best preconditioner for NORNE, VOLVE,