ROBUST TUNING TO IMPROVE SPEED AND MAINTAIN ACCURACY OF FLOW SIMULATION
OVERVIEW

› Introduction
› Model tuning as an optimization problem
› Methodology
› Experiments and Results
› Conclusions
› Future Work
INTRODUCTION

- Numerical tuning of a reservoir model can considerably affect simulator performance
- Tuning affects both speed and accuracy
- Models are run multiple times for optimization and model updating workflows
- There are multiple tuning parameters which can be changed
MOTIVATION

› Limitations
  › Tuning affects both speed and accuracy
  › Is carried out by manual trial and error – no formal way
  › Only a single model can be tuned at a time

› Challenges
  › How to automate model tuning ?
  › How to tune an ensemble of models ?
  › How to improve speed while maintaining accuracy ?
MODEL TUNING AS AN OPTIMIZATION PROBLEM

Consider the FLOW simulator as a black box

Carry out robust (ensemble of models) optimization with:

 Controls = FLOW tuning parameters

 Objective = Minimize number of linear iterations

Constraints can be placed on the field production and injection volumes
OPTIMIZATION METHODS

Gradient Free Methods

› Move to the point which has the highest objective function value

› Slow convergence rate towards optimum

Gradient Based Methods

› Calculates a direction in which objective function can be maximized

› Faster convergence rate towards optimum.
1. Choose an initial set of controls
2. Generate an ensemble of control vectors stochastically (red dots)
3. Evaluate each ensemble member of the controls (blue dots)
4. Estimate the gradient from the function evaluations (blue dots)
5. Use an optimization algorithm to find an updated set of controls
6. Repeat from step 2 until convergence is achieved.
STOSAG APPROACH

- Reservoir System
- Single geological model
- Generate Perturbations
- Gradient
- Optimize

1:10

Geological Model 1
Geological Model 2
Geological Model 10

Deterministic Case
Robust Cases

Computationally efficient !!
Theoretical proof; Fonseca (2015)
OPTIMIZATION FORMULATION

- **Objective**
  - Minimize Overall linearization's + Overall linear iterations

- **Controls**
  - Timestepping controls
    - TSINIT, TSMAXZ, TSMINZ, TSMCHP, TSFMAX, TSFMIN, TSFCNV, TFDIFF
  - linear_solver_maxiter (max number of linear iterations)
  - max_strict_iter (max iterations before relaxing max residual condition)
  - max_iter (max number of non-linear iterations)
  - All controls scaled to order 1, Initial guess – defaulted values

![Simulation Log](image)
OPTIMIZATION FORMULATION (CONT)

- Constraints
  - max_strict_iter < max_iter – input constraint
  - TSMAXZ < Report step duration - bound constraint

- Reservoir models
  - REEK (20 ensemble members)
  - NORNE (deterministic)

- Gradient definition
  - Deterministic – 10 perturbation
  - Robust – 1 perturbation per realization
RESULTS – NORNE (DETERMINISTIC)

- Objective function = Overall linearizations + Overall linear iterations (Scaled)
- 31% decrease in objective over 10 optimizer iterations
## RESULTS – NORNE (DETERMINISTIC)

<table>
<thead>
<tr>
<th>Simulation Summary</th>
<th>Base case with FLOW default TUNING (Case 1)</th>
<th>Base Case with ECL default TUNING (Case 2)</th>
<th>Optimized Case (Case 3)</th>
<th>Reduction in iterations (Case 1 v/s Case 3)</th>
<th>Reduction in iterations (Case 2 v/s case 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Well Iterations</td>
<td>914</td>
<td>1137</td>
<td>817</td>
<td>11%</td>
<td>28%</td>
</tr>
<tr>
<td>Overall Linearizations</td>
<td>1928</td>
<td>2276</td>
<td>1528</td>
<td>21%</td>
<td>33%</td>
</tr>
<tr>
<td>Overall Newton Iteration</td>
<td>1590</td>
<td>1794</td>
<td>1235</td>
<td>22%</td>
<td>31%</td>
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<tr>
<td>Overall Linear Iterations</td>
<td>24275</td>
<td>27999</td>
<td>18865</td>
<td>22%</td>
<td>33%</td>
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<tr>
<td>Overall Convergence Problems</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- ~ 22% reduction in overall number of linear iterations (Case 1 v/s Case 3)
- ~ 33% reduction in overall number of linear iterations (Case 2 v/s Case 3)
- Lesser number of convergence problems (Case 1 v/s Case 3)
RESULTS – NORNE (DETERMINISTIC)

Minor differences in field rates and oil saturation between optimized and base case models.
RESULTS – REEK(ROBUST)

- Ensemble Size = 20
- Optimization converges in a single iteration
- REEK model is comparatively simple - need not have lot of scope for optimization
- Majority of realizations have reduced number of linear iterations

- Robust solution - Single set of tuning parameters for all 20 ensemble members which reduces expected overall number of linear iterations
- Robust solution more computationally efficient than having different tuning parameters for each model
RESULTS – REEK(ROBUST)

<table>
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<tr>
<th>Simulation Summary</th>
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<th>Optimized Case</th>
<th>Reduction in iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Overall Well Iterations</td>
<td>323.25</td>
<td>324.3</td>
<td>0%</td>
</tr>
<tr>
<td>Mean Overall Linearizations</td>
<td>1067.85</td>
<td>1048.45</td>
<td>2%</td>
</tr>
<tr>
<td>Mean Overall Newton Iteration</td>
<td>875.15</td>
<td>850.95</td>
<td>3%</td>
</tr>
<tr>
<td>Mean Overall Linear Iterations</td>
<td>14564.75</td>
<td>14112.7</td>
<td>3%</td>
</tr>
</tbody>
</table>

Robust solution - Single set of tuning parameters for all 20 ensemble members which reduces overall number of linear iterations by 3%
APPLICATIONS

- Pre-processing step for model updating and optimization workflows
- Ensemble tuning
- Reduce convergence issues for:
  - Water coning studies
  - Crossflow cases
  - Viscous fingering
  - LGR cases
- Used in conjunction with CO2-EOR optimization, well placement optimization etc.
CONCLUSIONS

- Optimization workflow able to automate model tuning
- Computationally efficient
- Optimization workflow robust solution which reduces overall number of linear iterations for an ensemble of reservoir models
- 33% reduction in number of linear iterations for the Norne deterministic model
- 3% reduction in number of linear iterations for the REEK robust case
- Larger and more complex model have a larger scope for optimization
FUTURE WORK

- Constrained optimization with constraints on field production and injection volumes
- Robust Optimization with the Norne field model
THANK YOU FOR YOUR ATTENTION