UNISIM ON-LINE

YEAR 13, NUMBER 5
123RD EDITION
JUN, 2018

History Matching Combining Iterative Discrete Latin Hypercube with Multi Start Simulated Annealing

Célio Maschio

"The effectiveness of a given optimization or sampling method for history matching is defined by its ability of finding multiples solutions in complex search space."

Introduction

The effectiveness of a given optimization or sampling method for history matching (HM) is defined by its ability of finding multiples solutions in complex search spaces, which is the key challenge of the HM problem. To address this subject, this text presents a compilation of the paper of Maschio and Schiozer (2018) which proposes a new methodology for history matching combining the Iterative Discrete Latin Hypercube (IDLHC) with multi-start Simulated Annealing (SA) methods. The proposed method, named IDLHCSA, combines the potential of the IDLHC (Maschio and Schiozer, 2016) in finding good matched models while preserving the diversity of solutions and the potential of the SA with local control in finding local (refined) solutions.

Methodology

The proposed method is composed of the following steps:

1) Run the IDLHC method.

2) Select N models from IDLHC based on a cutoff value of objective function (Figure 1a). To do this selection, the models generated in all iterations are considered. This is a conservative procedure to avoid choosing model only in a limited portion of the search space. The idea is to choose good candidates scattered in the search space to intensify the search with SA.

3) Compute the Euclidian distance between the best and the N models selected in Step 2, as illustrated in Figure 1b.

4) Sort the N models according to the Euclidian distance and select a subset of models (n1) used as starting points for the simulated annealing (green points in Figure 2). To select these points, the following criteria are used: (a) firstly, select the two most distant points in the Euclidian distance axis (Points 1 and 8 in Figure 2) and (b) select a desired quantity of equally spaced intermediate points in the Euclidian distance axis.

5) Using the n1 points selected in Step 4 as starting points, run n1 SA process in parallel. Each SA process is responsible for intensifying the search around each starting point. In the example shown in Figure 2, the three regions of local minimum are exploited by the SA processes (red points).

6) At the end of the process, select the final models according to the history matching quality.

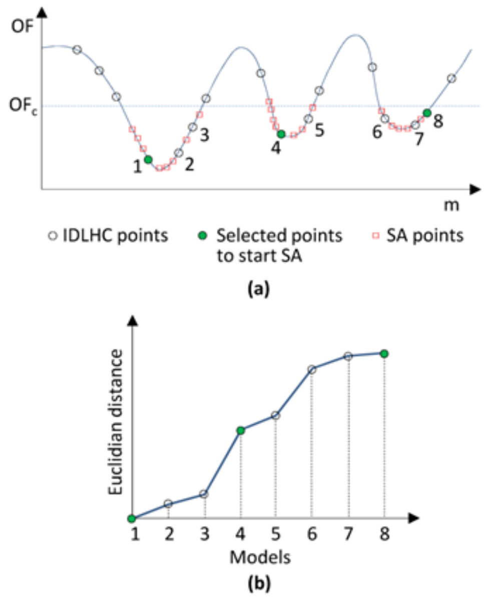

Figure 1: *Representation of the proposed procedure.*

Application and Results

For proof of concept purposes, the methodology was firstly applied to a simple reservoir (Case 1), represented by a cross-section vertical model. It is a two-dimensional problem with 4 local minimum regions very disconnected and far from each other in the search space, representing a challenge for any optimization or sampling method.

To demonstrate the robustness of the proposed method, we carried out exhaustive comparisons (for Case 1) with four consolidated methods: (1) Particle Swarm Optimization (PSO), (2) Designed Exploration and Controlled Evolution (DECE™), (3) genetic algorithm (GA) and (4) Iterative Discrete Latin Hypercube (IDLHC). PSO and DECE™ are available in the commercial tool CMOST. All the details of these comparisons are in Maschio and Schiozer (2018). For Case 1, all methods were run six times (using the same control parameters in each set of runs) to verify the stability of each method. In each run, the number of simulation was 2000.

An example, comparing two executions of IDLHCSA and DECE is given in Figure 2. Note that in all executions, the four local minimum regions were well scanned by the proposed method. The green points in the figure represent matched models with NQD ≤ 1. They represent the 4 local minimum regions. The other visited points are represented in gray. On the other hand, DECE got trapped in one specific local minimum.

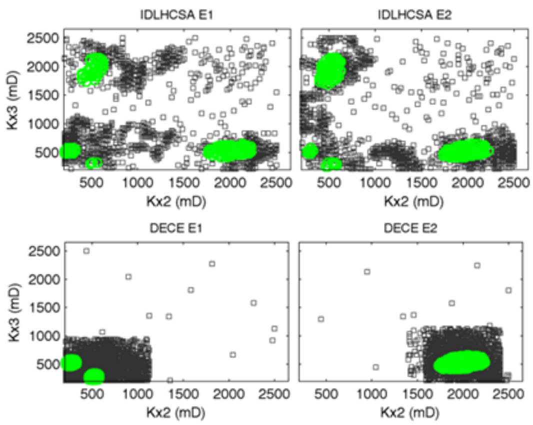

Figure 2: *Comparison between IDLHCSA and DECE (Case 1).*

To show the applicability in realistic reservoir models, the methodology was also applied to the benchmark UNISIM-I-H (Case 2) and compared with the DECE (CMOST) method. A total of 49 uncertain attributes were defined for Case 2, including regional perturbations of porosity and permeability. There are 78 reservoir outputs (data series), including liquid, oil and water rate and bottom-hole pressure for the 14 producer wells and water rate and bottom-hole pressure for the 11 injector wells. The number of simulation was 10350 for DECE and IDLHCSA. It is important to highlight that, in both cases, all methods were run with the same total number of simulations for a fair comparison.

Figure 3 shows a cross plot for a pair of attributes. The top plot shows, in blue, the selected models from Step 1 of the proposed methodology (IDLHC method). These models were selected using an NQD cut-off value of 9 for all functions, resulting in 256 models. The models selected according to Step 4 of the methodology and used as starting points for SA are represented in red (30 models were selected). The middle plot shows all points evaluated (IDLHCSA) and the final 100 filtered models (NQD ≤ 6.4785), represented in green. This plot sows the potential of SA in intensifying the search. The bottom plot shows the same cross-plots for the DECE method. The 100 best models are highlighted in green.

Comparing the results from IDLHCSA and DECE, the first observation is that the IDLHCSA method sampled a larger

Special Interests:

- UNISIM
- UNISIM Publications
- Reservoir Simulation and Management Portal
- Previous Issues

Links:

- UNICAMP
- CEPETRO
- Petroleum Engineering Division
- School of Mechanical Engineering
- Petroleum Sciences and Engineering

Graduate:

Petroleum Sciences and Engineering: interested in Masters and PhD in the Simulation and Oil Reservoir Management area click here.

"It is important to maintain in the final history-matched models the variability of the attributes that do not have strong influence in the history period because they may impact the forecast period."

UNISIM OPPORTUNITIES:

If you are interested in working or developing research in the UNISIM Group (Researchers, PhD ans MSC Students), please contact us.

For further information, [click here](#).

Research in Reservoir Simulation and Management Group

Petroleum Engineering Division - Energy Department

School Of Mechanical Engineering

Center for Petroleum Studies

University of Campinas

Campinas - SP

Phone: 55-19-3521-1220

Fax: 55-19-3289-4916

unisim@cepetro.unicamp.br

portion of the search space. The second observation is that the best models from DECE are concentrated in a limited region of the search space, suggesting that DECE converged to a local minimum, while IDLHCSA found good solutions scattered in the search space. Other manners of comparing the variability of the solutions from all tested methods are in the full version of the paper.

We examined the correlation matrix and realized that the attributes kz/kx12 has a weak correlation with all objective functions during the history period. All correlation factors are smaller than 0.3 (the cut-off value used in the IDLHC) for this attribute, meaning that its variability should be maintained in the final solutions.

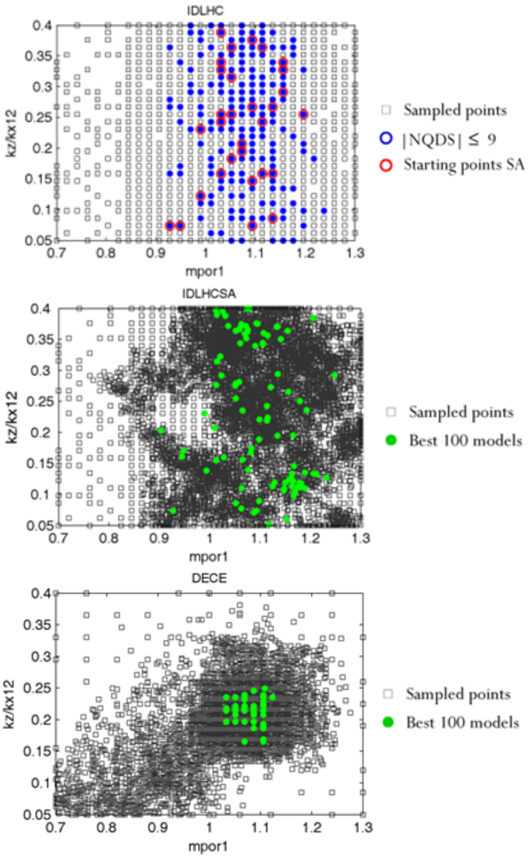

Figure 3: *Comparison between IDLHCSA and DECE - CMOST (Case 2).*

Figure 4 shows water rate curves for the best models for the producer well PROD014 comprising the historical and forecast periods. The well was shut in the reference model and some models from IDLHCSA due to water cut limit (90%) imposed during the forecast. The water rate of the well is relatively well matched for both methods. However, the analysis of the forecast period shows that the variability resulting from IDLHCSA is larger than the variability resulting from DECE. These results suggest that it is important to maintain (in the final solutions) the variability of the attributes that do not have strong influence over the history matching period because these attributes may have influence in the forecast period. Thus, the risk of bias in production forecast can be reduced by preserving the variability of such attributes.

Other details can be found in the complete version of the paper.

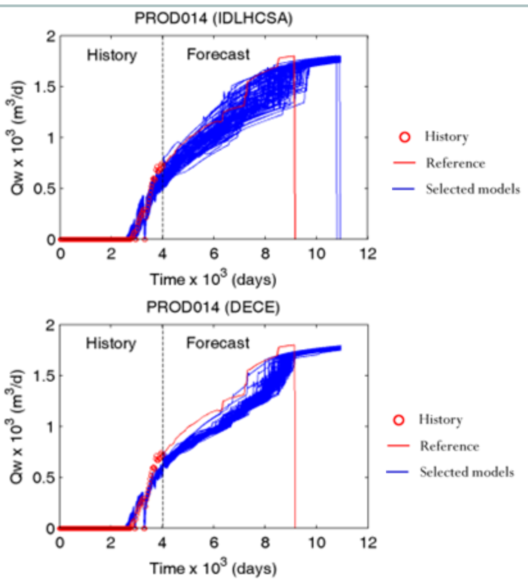

Figure 4: *Water rate in the history and forecast periods resulting from the selected models for IDLHCSA and DECE (CMOST).*

Conclusions

A new method (IDLHCSA) combining IDLHC and simulated annealing methods was proposed. The proposed method combines the ability of the IDLHC method in finding good history matching while maintaining solution diversity and the potential of SA with local control in finding local (refined) solutions. The specific findings are:

- The proposed method is able to find multiple history matching solutions, well-distributed in the search space.
- The simulated annealing with local control was successfully applied as a local search method. It was applied to refine the solutions found by the IDLHC method.
- The variability of the best matched models found by the proposed methodology is higher than the variability of the best models found by the other methods.
- The production forecast results showed that it is important to maintain in the final history-matched models the variability of the attributes that do not have strong influence in the history period because they may impact the forecast period.

References

[1] Maschio, C.; Schiozer, D. J. 2018. A new methodology for history matching combining iterative discrete Latin Hypercube with multi-start simulated annealing. Journal of Petroleum Science and Engineering, 169, 560-577. https://doi.org/10.1016/j.petrol.2018.06.004

[2] Maschio, C.; Schiozer, D. J. 2016. Probabilistic history matching using discrete Latin Hypercube sampling and nonparametric density estimation. Journal of Petroleum Science and Engineering, 147, 98-115. https://doi.org/10.1016/j.petrol.2016.05.011

About the author: Célio Maschio is graduated in Mechanical Engineering from UNESP, holds a MS and a PhD degree in Mechanical Engineering from UNICAMP. He is a researcher at UNISIM/CEPETRO/UNICAMP since 2001 developing research and leading projects focused on history matching.