Year 11, Number 5
101st edition
June, 2016

UNISIM ON-LINE

Production Strategy Optimization Based on Iterative Discrete Latin Hypercube

João Carlos von Hohendorff Filho

"Most problems of production strategy optimization in the oil industry are characterized by a large number of discrete random variables in discontinuous search spaces with non-monotonic behavior yielding objective functions, with many local maximum and minimum."

Most problems of production strategy optimization in the oil industry are characterized by a large number of discrete random variables in discontinuous search spaces with non-monotonic behavior yielding objective functions with many local maximum or minimum. These optimization problems show little linear correlation between the variables and the evaluated objective functions. Population-based optimization, such as genetic algorithms, simulated annealing, particle swarm optimization, and differential evolution, stands out with a high probability of finding an optimal solution for this type of problem.

Goda and Sato (2014) comment that these algorithms have two important capabilities in common: one is to search a better solution and the other is to avoid local minima. The disadvantages of these algorithms, on the other hand, arise in the lack of the theoretical foundations and the slower convergence. These authors formulated the history matching as a global minimization problem and proposed a new population-based global optimization algorithm called Iterative Latin Hypercube Samplings, with a theoretical foundation that proves the capacity of the method to find the optimal solution for any monotonic univariate function.

Maschio and Schiozer (2016) developed a new iterative procedure for probabilistic history matching using discrete Latin Hypercube sampling (DLH) and non-parametric density estimation. Their methodology selects the best samples based on matching quality, together with correlation coefficients between the attributes and the misfit between the results of the simulation and production history of the wells, to reduce uncertainty range and minimize the error between the observed data and the simulated values.

The great advantages of these methods are approaching history matching without prior knowledge and formulating the problem as a global minimization of the misfit between observations and numerical results, as well as the theoretical foundation and good convergence.

DLH is a sampling method that allows the selection of values for discrete random variables within a full region of model parameters, reducing the number of samples needed to preserve probability distributions.

In an iterative procedure, we can choose the best samples generated by the sampling method and gradually reduce the search space of each variable among its lower and upper values. However, in production strategy optimization problems, the posterior frequency distribution of the levels of each variable in the best cases, can present non-continuous distributions. These results can compromise the optimization of the objective function. This paper presents a new approach to reduce the search space.

Methodology

The proposed method comprises an iterative DLH-based process (IDLH) to maximize the objective function in production strategy optimization problems, reducing the search space gradually, with each iteration. The main focus is the proper treatment of the posterior frequency distributions of discrete variable levels, since the search space could be discontinuous with a non-necessarily monotonic objective function with many local optimums within a maximization process.

We could adapt the theoretical foundation proposed by Goda and Sato (2014) to IDLH to find the optimal solution for any monotonic univariate function. This foundation can be extended to a monotonic multivariable function, assuming the function is separable with respect to each variable and might be expressed simply as a sum of one-dimensional functions. The proposed methodology consists of the following steps:

1. Discretize each variable in a number of levels with uniform probability distribution.
2. Generate DLH samples using the sample size N. With many points used as solutions, the method is less likely to stop at a local optimum. It uses values of only one evaluation of the objective function, not two as for derivatives.
3. Obtain objective function values. For numerical reservoir simulation, the simulations can be distributed with parallel computing.
4. Sample the objective function above the threshold cut percentage F to select the best performing samples of F x N objective functions and to update the level frequency histogram of each variable. Variable combinations that result in lower values of the objective function are eliminated, assuming that their variables may generate samples with low objective function value.
5. Fit the level frequency histogram with variables from selected samples, generating posterior frequency distribution for the levels of the variables. More frequent levels are more likely to generate samples with a high objective function value in the next iteration, while less frequent levels maintain the potential to generate good samples with values from variables not yet sampled.
6. Generating a new sample set using the posterior frequency distribution of each variable level.
7. Repeat steps 2 to 6 until convergence criteria is reached, which can be the maximum number of iterations, minimum difference between maximum and minimum values obtained in the iteration, or another criterion.
8. Consider the greatest value of objective function from the samples as the optimum value.
9. Although this is a random-based method, it does not use simple random search techniques. It explores new combinations efficiently with the available knowledge, based on the frequency histogram for each variable, to find new sampling with better values of the objective function.

The choice of parameters N and F has a great impact on performance optimization, which must be evaluated case-by-case so that IDLH is well performed. Selecting too small an N number in relation to the number of variables or the maximum number of variable levels can lead to a poor representation of samples resulting in local optimums, while too large an N number tends to underuse the DLH ability to generate representative samples, increasing the time to optimize an objective function.

The parameter F is related to the updating of level frequency histograms, for which small numbers (<0.1) assists a fast convergence to a local optimum as they discard useful information from good samples that have not yet been sampled, while large numbers (>0.5) tend to slow the search maintaining the levels of variables with low OF values.

Application

We compared the optimizations between the proposed IDLH and the DECE™ method, available in commercial software.

The objective of the proposal was to determine the

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design and control decision variables that would maximize NPV through techniques that account for the combination of operational variables for the benchmark case UNISIM-I-D (Gaspar et al, 2015).

We used both methodologies to maximize the NPV objective function for the same variable set and search space (Table 1) in an intermediate phase of the production development project optimization of the benchmark case UNISIM-I-D in the MR9 representative model. The domain problem had 67 discrete variables, counting 2.5×1040 possible combinations. IDLH was set with 9 iterations, with value N = 100 evaluations of the OF by iteration, counting 900 samples, and F = 0.1. We defined internal parameters for the DECE™ to optimize the 67 variables.

Fig. 1 presents the NPV values from IDLH within 9 iterations, totaling 900 simulations to achieve a maximum value of the OF (US$ 2936 million). As expected for the method, the function values constantly increase with each iteration. All simulations were parallelized, which is possible in population-based search methods, to reduce computational time.

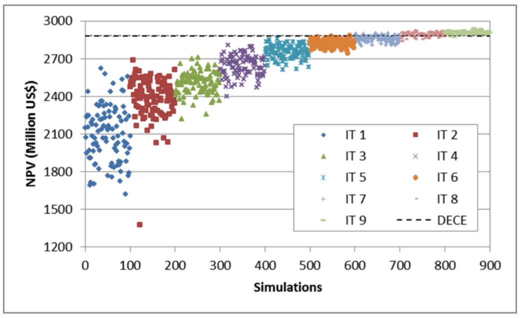

***Figure 1:** Evolution of IDLH in NPV objective function from application case*

Fig. 2 presents the NPV OFs from DECE™, which needed 2936 individuals to reach a maximum value for NPV (US$ 2883 million) and meet the internal stop criteria of the program. The IDLH had an excellent convergence rate to maximize NPV to a close-to-optimum value obtained by DECE ™, requiring a fewer evaluations of the OF.

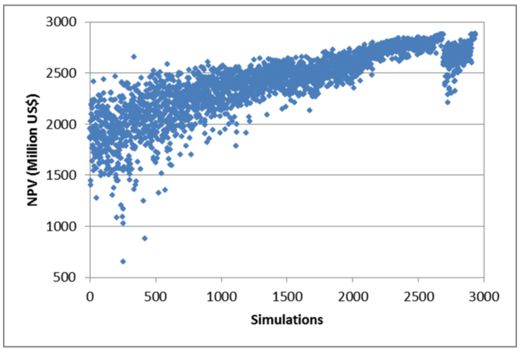

***Figure 2**: Evolution of DECE™ in NPV objective function from application case*

IDLH treated the discontinuities properly to evaluate the maximum of local regions without losing efficiency, by discarding intermediate levels without frequency.

The IDLH method has the advantages of being a simple methodology to maximize OF, reducing the search space gradually with each iteration, while addressing posterior frequency distributions of discrete variable levels.

The robustness of the method could be proven with an exhaustive validation case and a comparable application to a consolidated methodology. The ease of implementing the method is a great incentive for its use.

The IDLH method has the advantages of being a simple methodology to maximize OF, reducing the search space gradually with each iteration, while addressing posterior frequency distributions of discrete variable levels. The robustness of the method could be proven with an exhaustive validation case and a comparable application to a consolidated methodology. The ease of implementing the method is a great incentive for its use.

Conclusions

This paper proposed an iterative DLH-based method to maximize an OF in production strategy optimization problems and, reduce the discrete search space throughout the iterative process. We treated posterior frequency distributions of discrete variable levels and, maximized a non-necessarily monotonic OF within discontinuous search spaces. Many local optimums could be performed successfully in the application case, and compared this to a consolidated optimization methodology.

The proposed IDLH methodology, as a population-based optimization with consistent convergence to optimum, few OF evaluations, and the ability to parallelize multiple simulations, is well suited to address optimization problems in the oil industry.

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About the author:

João Carlos von Hohendorff Filho is graduated in Civil Engineering, specialized in Petroleum Engineering with emphasis on Reservoir Engineering, and master's in Petroleum Sciences and Engineering. Currently, he is a researcher at UNISIM/CEPETRO/UNICAMP, in the area of Simulation and Management of Petroleum Reservoirs.

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