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Assisted history matching using artificial neural network based global optimization method – Applications to Brugge field and a fractured Iranian reservoir

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ABSTRACT

Reservoir simulation is a powerful predictive tool used in reservoir management. Constructing a simulation model involves subsurface uncertainties which can greatly affect prediction results. Quantifying such uncertainties for a field under development necessitates history matching that is a difficult inverse problem with non-unique solutions. History matching is used to minimize the difference between the observed field data and the simulation results and requires numerous simulation runs. In many engineering simulation-based optimization problems, the number of function evaluations is a prohibitive factor limited by time or cost. History matching in hydrocarbon reservoir simulation is one of such computationally expensive problems which pose challenges in the field of global optimization. One way to overcome this difficulty is to use an artificial neural network (ANN) as a surrogate model.

This article presents an ANN-based global optimization method that is used for history matching problem. The method has been applied to an Iranian fractured oil reservoir and the famous Brugge field benchmark. Computational results confirm the success of this method in history matching. We compare history matching results obtained by the proposed method with those of manual history matching and those obtained by simulation based direct optimization algorithm. The results compares favourably with manual history matching in terms of matching quality. The proposed method is superior than the simulation based direct optimization algorithm in finding multiple matched scenarios in less computation time.

1. Introduction

Reservoir simulation is a powerful predictive tool used in reservoir management. One of the difficulties in reservoir simulation is the absence of reliable data on reservoir characteristics.

The reliability of production forecasts obtained by reservoir simulations strongly depend on the proper calibration of the reservoir simulation model. It is generally accepted that any model used for predicting unknown future quantities should be able to reproduce known history data. History Matching is a part of model validation process and is a cumbersome and time consuming task due to the needs for numerous simulation runs.

History matching workflow focuses on calibrating a reservoir model using observed dynamic data (e.g. production data) as well as measured static data (e.g. core or well log data). It requires solving an inverse problem for which the solution would be non-unique since many combinations of parameter settings would yield a similar model response. From an optimization perspective, the history matching problem can be stated as follows:

$$\min_{x \in \Omega} \|O(x) - y\|^2 \tag{1}$$

where $y \in R^m$ is the vector of measured observations and $O(x) \in R^m$ denotes the simulated results. Here x represents reservoir uncertain parameters which belongs to feasible domain Ω. The objective of this inverse problem is to find an x such that the distance between the resulting simulation outputs and the observed data is minimized. It requires excessive costly simulation runs, and in many cases the derivative information is expensive to obtain or may not be available. Various reservoir parameters such

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as aquifer pore volume and connectivity, relative permeability data, faults connectivity, or Kv/Kh data may be considered in the process. Typically, one or two parameters are varied at a time (Vincent et al., 1999). This process is tedious and becomes nearly impossible to investigate the relationships between the model responses and variations of different reservoir parameters for large fields (Schulze-Riegert and Ghedan, 2007).

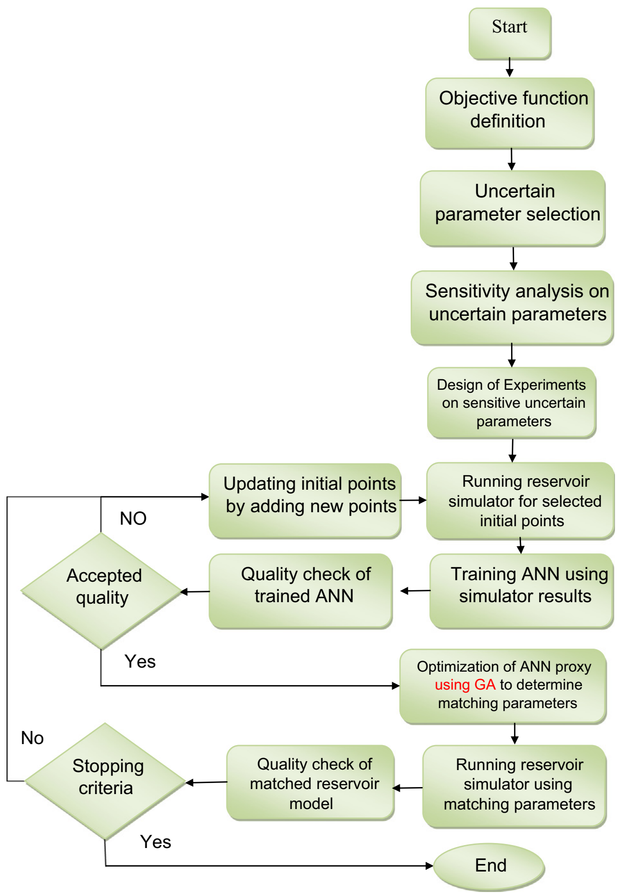

Fig. 1. The proposed assisted history matching workflow.

Recent advances in computational capabilities allow automating the application of optimization algorithms to history matching problem. These developments has led to emerging a new research area within reservoir engineering called ''automated'' or ''assisted'' history matching. The main optimization frameworks and techniques used for assisted history matching can be classified as follows:

- Gradient-based techniques: gradient-based methods have been commonly used to solve many inverse problems (Anterion et al, 1989a, 1989b, Use of Parameter Gradients for Reservoir History Matching; Bissell, 1994; Lepine et al., 1998; Roggero and Hu, 1998). They require either solution of an adjoint system of equations extracted from simulation codes or numerical computation of sensitivity of reservoir performance with respect to reservoir parameters to obtain the gradient search direction (Carter et al., 1974; Chen et al., 1974; Anterion et al, 1989a, 1989b, Use of Parameter Gradients for Reservoir History Matching; Wu et al., 1999; (Vasco et al., 1999; Landa et al., 2000). Computation of gradients using both methods, however, often becomes more expensive than solving flow equations. To overcome this problem, some have used fast streamline-based simulation techniques for the history matching calculations (Emanuel and Milliken, 1998; Vasco et al., 1999; Wang and Kovscek, 2000).
- Meta-heuristic algorithms: meta-heuristic global optimization methods have been used to overcome some of the drawbacks of gradient based methods (Soleng, 1999; Romero et al., 2000; Schulze-Riegert et al., 2002; Williams et al., 2004). Simulated Annealing and Evolutionary Algorithms such as genetic algorithms and Evolution Strategy have been adapted in various reservoir performance optimization frameworks, such as estimation of fracture aperture distribution (Datta-Gupta et al. 1995), well placement optimization (Yeten et al., 2003), flow function parameter estimation (Sun and Mohanty, 2005) and reservoir parameter estimation (Schulze-Riegert et al., 2002; Al-Shamma and Teigland, 2006). They are inspired by the fact that multidimensional, nonlinear optimization problems often

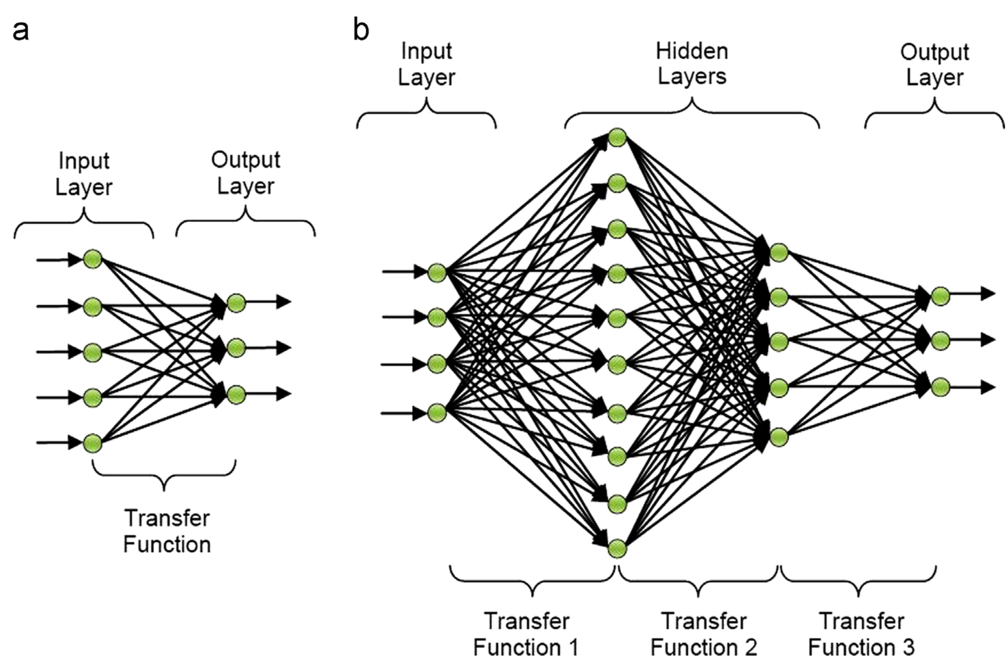

Fig. 2. Classification of network architectures. (a) Singlelayer network and (b) multilayer network.