An Event Based Representation for Oil Reservoir Simulation using Preconceptual Schemas.

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Abstract

Oil reservoir simulation is governed by mass conservation laws. In such laws, flow, accumulation, sources and sinks phenomena in porous media are described. Multiple proposals for frameworks and simulations elaboration have been defined. However, those lack concepts and processes tracing, and event representation for physical phenomena. Preconceptual Schema (PS) is used for including the complete structure of an application domain and representing processes emerging in such. Cohesion, consistency, and tracing between concepts and processes is obtained by using PS. In this article, an executable model for Black oil simulation based on a preconceptual schema is proposed. The executable model is validated by running a study case. The results are in accordance with data reported in the literature. The proposed executable model allows for tracing consistently the concepts, processes, and events, which are present in Oil reservoir simulation.

Keywords: Porous Media, Executable Models, Preconceptual Schemas, Oil Reservoir Simulation, Event based Representation.

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1. Introduction

Oil Reservoir simulation is an application of flow in porous media. Macroscopic fluid displacement through a porous rock is studied in such application. Those displacements are due to pressure, saturation, capillary and gravitational changes. Such phenomena are described by mass and momentum conservation laws, which are expressed as a coupled system of differential equations.

The black oil model (BOM) is vastly used in industrial efforts. Transport of three fluids at standard conditions is considered in this model. In addition, sink and source terms are involved, which are modeled as wells. Analytic solutions of BOM are unfeasible, hence a numerical solution is required. With this purpose, an spatial and temporal discretization is applied to BOM system of differential equations, the resulting algebraic system is solved using Newton-Raphson method.

Preconceptual schemas (PS) are intermediate representations which are useful for establishing a common point of understanding between a stakeholder and a software analyst. Furthermore, PS have elements which allow to represent both structure and dynamics of specific application domains. Moreover, Calle and Noreña **(citar)**, extended PS notation for usage in scientific software contexts, which have a greater complexity.

Mathematical models, such as Black Oil Model (BOM), are representations that appear in every effort for developing a simulator or framework for oil reservoir simulation. In addition, other representations in which, concepts and processes are shown, lack of traceability and event representation. There are proposals in which traceability is considered, but those are implementation-specific. The whole converges in oil reservoir simulators being developed in an empirical manner.

Norena, Calle and Zapata, present PS potential for representing different application domains in scientific software contexts. In their representations, cohesion and traceability between concepts is maintained. Additionally, the whole process is traced in the elaborated PS. In this work, we present the development of an event based representation for oil reservoir simulation using Preconceptual Schemas. The developed representation consists of eight principal concepts, three events which process a simulation, and multiple functions in which reusable portions of representation are used within the PS.

This paper is organized as follows: In Section 2 (ref), we present the Black oil model formulation, its solution method, and PS notation. Section 3 (ref) consists of PS representation and the concepts involved. Section 4 presents a study case for validation of the representation proposed and its translation to C++.

2. Mathematical Model

In this section, we present an extended version of Black Oil Model (BOM). Black Oil Model is a system of partial differential equations for three phases: oil (o), gas (g), and water (w), based on volumetric conservation laws at atmospheric temperature and pressure. Solving BOM equations, for a spatial domain Ω and a time domain Θ, requires finding pressure ($P_f(\vec{x}, t)$) and saturation ($S_f(\vec{x}, t)$) fields, with $f \in \{o, g, w\}$, which satisfy the following:

$$\left.\begin{array}{l} \frac{\partial}{\partial t}\left[\phi\left(\frac{S_o}{B_o} + \frac{R_v S_g}{B_g}\right)\right] - \nabla \cdot \left(\frac{1}{B_o}\vec{u_o} + \frac{R_v}{B_g}\vec{u_g}\right) - \tilde{q}_o = 0 \\ \frac{\partial}{\partial t}\left[\phi\left(\frac{S_g}{B_g} + \frac{R_s S_o}{B_o}\right)\right] - \nabla \cdot \left(\frac{1}{B_g}\vec{u_g} + \frac{R_s}{B_o}\vec{u_o}\right) - \tilde{q}_g = 0 \\ \frac{\partial}{\partial t}\left[\phi\left(\frac{S_w}{B_w}\right)\right] - \nabla \cdot \left(\frac{1}{B_w}\vec{u_w}\right) - \tilde{q}_w = 0 \end{array}\right\} \quad \text{in} \quad \Omega$$

$$\vec{u}_f \cdot \vec{n} = 0, \quad \forall f \in \{o, g, w\} \quad \text{in} \quad \partial\Omega$$

$$\left.\begin{array}{r} P_f(\vec{x}, t) = P_f^0(\vec{x}) \\ S_f(\vec{x}, t) = S_f^0(\vec{x}) \end{array}\right\}, \quad t = 0$$

Where $\vec{u_f}$ corresponds to multiphasic Darcy velocity, which is stated as follows:

$$\vec{u_f} = \frac{\mathbb{K} k_{rf}}{\mu_f} \nabla \Phi_f \tag{1}$$

It is worthnoting that:

$$\begin{gathered} B_f = F(P_f); \quad \mu_f = F(P_f) \quad \forall f \in \{o, g, w\} \\ R_s = F(P_g); \quad R_v = F(P_o); \\ k_{rg} = F(S_g); \quad k_{rw} = F(S_w); \quad k_{ro} = F(S_g, S_w) \\ \phi \approx \phi^0 (1 + C_r (P_o - P_{ref})) \end{gathered} \tag{2}$$

In addition, wells...

2.1. Discretization

An analytic solution for such a model is infeasible, thus a numerical solution is required. Accordingly, a centered finite volume method is used with an implicit scheme for time discretization. Resulting algebraic equations for BOM in a cell i and a time interval $[n; n+1]$ are as follows:

$$\underbrace{\frac{|\Omega_i|}{\Delta t} \left[\phi_i \left(\frac{S_{o,i}}{B_{o,i}} + \frac{R_{v,i} S_{g,i}}{B_{g,i}} \right) \right]_n^{n+1}}_{\text{Accumulation}} + \underbrace{\sum_{c \in S} \left[T_{o,c}^{n+1} \Delta \Phi_{o,c}^{n+1} + R_{v,c} T_{g,c}^{n+1} \Delta \Phi_{g,c}^{n+1} \right]}_{\text{Flujo - Aceite}} - Q_{o,i}^{n+1} = 0 \tag{3}$$

$$\underbrace{\frac{|\Omega_i|}{\Delta t} \left[\phi_i \left(\frac{S_{g,i}}{B_{g,i}} + \frac{R_{s,i} S_{o,i}}{B_{o,i}} \right) \right]_n^{n+1}}_{\text{Acumulación - Gas}} + \underbrace{\sum_{c \in S} \left[T_{g,c}^{n+1} \Delta \Phi_{g,c}^{n+1} + R_{s,c} T_{o,c}^{n+1} \Delta \Phi_{o,c}^{n+1} \right]}_{\text{Flujo - Gas}} - Q_{g,i}^{n+1} = 0 \tag{4}$$

$$\underbrace{\frac{|\Omega_i|}{\Delta t} \left[\phi_i \left(\frac{S_{w,i}}{B_{w,i}} \right) \right]_n^{n+1}}_{\text{Acumulación - Agua}} + \underbrace{\sum_{c \in S} \left[T_{w,c}^{n+1} \Delta \Phi_{w,c}^{n+1} \right]}_{\text{Flujo - Agua}} - Q_{w,i}^{n+1} = 0 \tag{5}$$

where:

$$\left[\phi_i\left(\frac{S_{o,i}}{B_{o,i}}+\frac{R_{v,i}S_{g,i}}{B_{g,i}}\right)\right]_n^{n+1}=\phi_i^{n+1}\left(\frac{S_{o,i}^{n+1}}{B_{o,i}^{n+1}}+\frac{R_{v,i}^{n+1}S_{g,i}^{n+1}}{B_{g,i}^{n+1}}\right)-\phi_i^n\left(\frac{S_{o,i}^n}{B_{o,i}^n}+\frac{R_{v,i}^nS_{g,i}^n}{B_{g,i}^n}\right),$$

$$\left[\phi_i\left(\frac{S_{g,i}}{B_{g,i}}+\frac{R_{s,i}S_{o,i}}{B_{o,i}}\right)\right]_n^{n+1}=\phi_i^{n+1}\left(\frac{S_{g,i}^{n+1}}{B_{g,i}^{n+1}}+\frac{R_{s,i}^{n+1}S_{o,i}^{n+1}}{B_{o,i}^{n+1}}\right)-\phi_i^n\left(\frac{S_{g,i}^n}{B_{g,i}^n}+\frac{R_{s,i}^nS_{o,i}^n}{B_{o,i}^n}\right),$$

$$\left[\phi_i\left(\frac{S_{w,i}}{B_{w,i}}\right)\right]_n^{n+1}=\phi_i^{n+1}\left(\frac{S_{w,i}^{n+1}}{B_{w,i}^{n+1}}\right)-\phi_i^n\left(\frac{S_{w,i}^n}{B_{w,i}^n}\right)$$

$T_{f,c}$ stands for transmissivity in a face c, connecting a cell i, with another cell j.

$$T_{f,c}=\left(\frac{2}{(\Delta l_i/A_cK_{l,i})+(\Delta l_j/A_cK_{l,j})}\right)\frac{k_{rf,c}}{\mu_{f,c}B_{f,c}} \tag{6}$$