Interactive 3D Modeling and Visualization of Well Configurations and Trajectories in Reservoir Simulation Post-Processing

Sowmya Somanath, Department of Computer Science, University of Calgary
ssomanat@ucalgary.ca
Nicole Sultanum, Department of Computer Science, University of Calgary
nbsultan@ucalgary.ca
Jonatas Medeiros, Department of Computer Science, University of Calgary
jdacamar@ucalgary.ca
Emilio Vital Brazil, Department of Computer Science, University of Calgary
evbrazil@ucalgary.ca
Sheelagh Carpendale, Department of Computer Science, University of Calgary
sheelagh@ucalgary.ca
Ehud Sharlin, Department of Computer Science, University of Calgary
ehud@ucalgary.ca
Carla Dal Sasso Freitas, Institute of Informatics, Federal University of Rio Grande do Sul (UFRGS)
carla@inf.ufrgs.br
Eric Mackay, Institute of Petroleum Engineering, Heriot-Watt University
Eric.Mackay@pet.hw.ac.uk
Mario Costa Sousa, Department of Computer Science, University of Calgary
smcosta@ucalgary.ca

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Summary

Reservoir simulation results are typically visualized using a *post-processing* model, where the dataset is first created from numerical simulations, and then used as input to a visualization system for graphical output and interaction. There are no interactions with simulation parameters and/or images generated during the simulation execution. The main advantage of this model is that the data can be examined repeatedly using different mapping techniques. In particular, we are focusing on developing hybrid (interactive-automatic) exploratory methods to assist the reservoir engineer on well manipulation and re-configuration from reservoir post-processing data for subsequent fine-tuning of new simulation runs. These tools allow more intuitive construction and manipulation of new and/or existing wells and visual analysis of uncertainty ranges for both geological and flow simulation properties.

Introduction & Method

The unique challenges of time-varying reservoir visualization are the very dynamic behaviours of the data, the many complex interactions among the reservoir properties, variables, and structures, and the increasing size of observational and simulation datasets. It is often difficult to identify the processes that matter most for a particular reservoir phenomenon. Hybrid tools (i.e. interactive and automatic) must be provided for expert users to identify and visualize correlation fields that represent the relationships between multiple variables, and the correlation represented by the fields themselves. It is difficult for reservoir engineers to perform such investigations rapidly and interactively with existing large multidimensional reservoir datasets. The lack of ability to ensure interactive engagement and exploration, combined with automatic feature extraction and analysis, undermines the effectiveness and relevancy of exploratory visualization of time-varying reservoir data. Novel user interfaces are required to allow effective use of different input and output devices for improving management, navigation, exploration and manipulation of large, complex time-varying reservoir data. Users need the ability to control, manipulate, explore, verify and visualize the evolution of the features interactively, efficiently and robustly. They must be able to see the relationships between features in successive frames, and be able to highlight particular events.

In this project we address the above problems in the context of well planning for reservoir simulations. Well planning is a critical task requiring engineers to perform several tasks such as - filtering the reservoir based on the combination or two or more geological property, identifying fault and trap locations, studying the regions in which an oil well already exists etc. either simultaneously or in a methodological fashion. In order to support such powerful explorations, we need meaningful visualization systems that would allow a seamless integration of several exploratory techniques, which can make these tasks easier, intuitive and focused. To create such a complete system, initially a set of prototype tools are being developed for more intuitive construction and manipulation of flexible well trajectories and configurations, taking into account visual analytics of geological and flow uncertainty ranges. In parallel, we are developing a novel mechanism for more intuitive and interactive cross-sectional "fence diagram" visualizations correlating different sets of flexible wells.

Examples

***(1) Well Trajectories in Reservoir Simulation Post-Processing* –** A critical task in the reservoir engineering workflow consists of creating and/or modifying well placement in reservoir post processing simulation models for fine-tuning subsequent reservoir simulation runs of the same model [2, 3]. Currently, this task involves numerous manual steps, creating a clumsy intensive workflow without proper visualizations to guide the process. The main goal is to develop novel interactive software tools providing more intuitive direct ways for the engineer to create and manipulate 3D flexible well configurations and trajectories in reservoir post processing simulation models. These tools are being integrated with cross-sectional visualizations (Figure 2 of the reservoir correlating the well trajectories with the 3D geology and flow properties. We are also providing tools for Uncertainty Visualization that uses low uncertainty as a parameter for analysing locations for well placements. It consists of tools that help to explore and visualize uncertainty in the reservoir models intuitively and assist in the creation and placement of wells. Figure 1 shows an overview of our current prototype which attempts to support the creation and visualization of well trajectories based on uncertainty information. Let us assume there was a way to measure uncertainty and we could access such uncertainty measures at the post processing stage. Then, we could map these measures to the reservoirs to create a heat map like visualization to encode the regions of uncertainty.

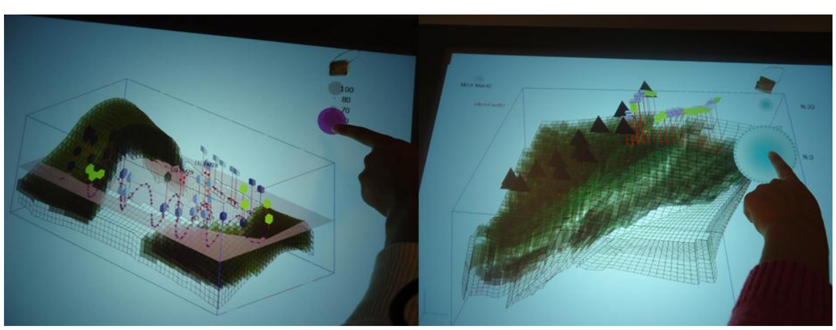
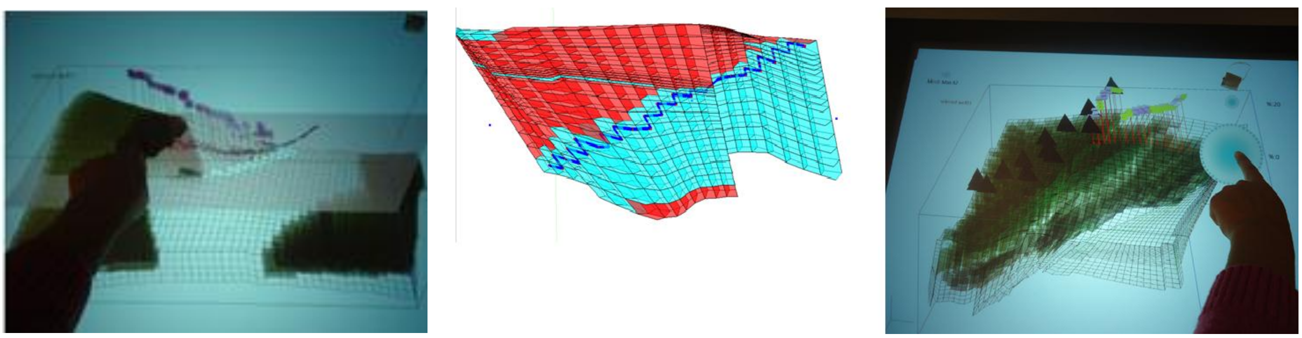


Figure 1: Overview of the Uncertainty Visualization prototype.

However to support creation of well trajectories, we would need tools that can help an engineer reflect upon and explore these uncertainty regions of the reservoir, as well as analyse the uncertainty associated with existing features such as wells, faults etc. Three techniques, namely Candy Visualization, History Circles and Uncertainty indicator have been developed to support such tasks.

Figure 2a represents our current solution for intuitively creating free form well trajectories in 3D space by sketching using direct touch on a Microsoft surface. As the user creates the well, the *uncertainty indicator* tool appearing as a bubble at the tip of his finger, constantly reflects on the accumulation of uncertainty till the current point. The size of the bubble grows warning the user of navigating regions, which may not be appropriate. Figure 2b shows two visualizations that can help an engineer analyse information about existing wells. While the first image represents the cross sectional region that an oil well perforates, in the context of geological property mapping , the second is a combination of two techniques – *Candy visualization and History circles* that visualize the uncertainty associated with existing well trajectories.

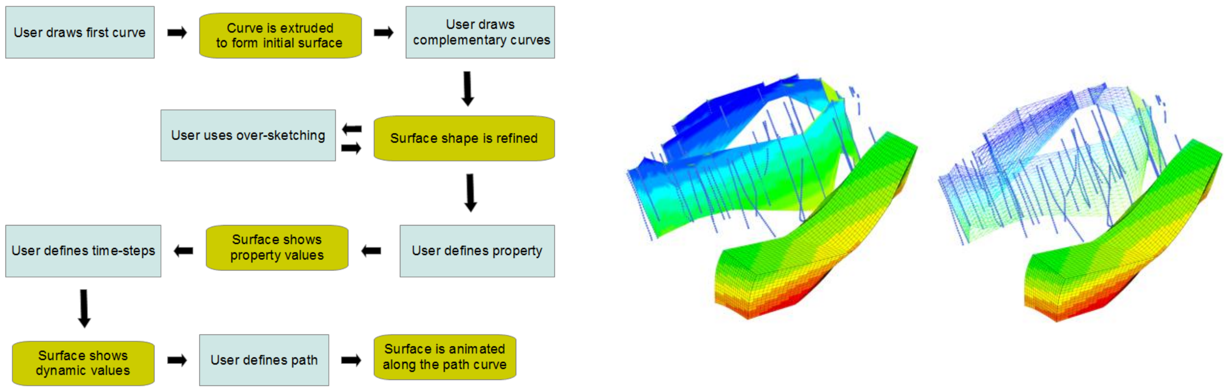


(a) (b)

Figure 2: (a) Constructing well trajectories; (b) Visualizations to assist in exploring existing and new well placements.

The cross sectional visualization is helpful in cases, where we want to understand the nature of the area, an existing well perforates, so that it can be used as a reference for identifying possible locations for drilling new wells. Candy Visualization and History Circles are techniques that represent visual and statistical information about the uncertainty associated with well trajectories, which can be used in cases where we want to compare the placement of two or more wells.

(2) Free-Form Dynamic Fence Diagrams – Fence diagrams are composed of planar cross-sections of the reservoir data set, usually linking vertical wells. They are used to depict continuity of geological, simulation and log data between the wells and for monitoring fluid movement [1, 4, 5]. The traditional fence diagram can give the user a better understanding of the data set but, being limited to planar cross-sections, it is not suitable to link curved well trajectories and it cannot depict well other features like faults. The objective is to give the user the freedom to create cross-sections that are flexible and can be manipulated to reveal more information. Free-form dynamic fence diagrams are created using a sketch-based interface so the user can easily control how the fence is formed. These diagrams can be used to show dynamic information about the flow simulation. Beside the natural animation of dynamic properties, the user will be able to animate fences that create a 5 dimension visual correlation, allowing the user a better interpretation of the data. Each cross-section is defined by a parametric surface created from curves drawn by the user over a visualization of the reservoir model. The shape of the surface and its position relative to the reservoir model can be manipulated by the user (through sketch-based commands) to better fit the feature of interest. The workflow for the creation of the fence diagrams is shown on Figure 3a. The fences can also be created automatically between wells that have curved trajectories as shown on Figure 3b.



(a) (b)

Figure 3: (a) Workflow for creating free-form dynamic fence diagrams; (b) Visualization of a flexible fence diagram linking flexible wells.

Fence diagrams may be used to inspect the interior of reservoir simulation models to identify the distribution of phases or components within a phase at any given time step in the simulation. For example, this can be helpful in identifying the location of unrecovered oil during a water-flood, and whether continued injection of water, say, will help displace this oil, or whether the oil will in fact be bypassed, and infill well drilling in this location is required to maximise recovery. Other applications include, for example, identifying where within the reservoir mineral reactions are taking place as a result of mixing of injected and native brines, leading to precipitation of inorganic scales, and whether this is occurring deep within the reservoir where the effects are relatively benign, or near production wells resulting in loss of productivity. Such processes may occur at locations deep within the reservoir, and may remain hidden unless individual planes can be visualised. Although typically such planes are generated as straight lines, in fact the physical and geochemical processes occurring may be aligned with faults or inter-well streamlines or other features, and may not be straight lines at all.

Conclusions

In this work we present our ongoing efforts for developing interactive applications that can assist the engineers in their decision making process. The two systems are exploratory efforts, designed as a proof of concept to understand the possible benefits and limitations of such system. Our future directions involve performing user evaluations and to obtain feedback from the domain experts to further improve our systems. We also plan to experiment with other interfaces and environments such as tablets; vertical displays etc. to make the systems flexible in terms of their usage as single user systems or collaborative multi user systems.

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