An Introduction to Grid-Free Object-based Facies Modeling

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Object-based modeling is well established and preferred to the conventional variogram-based techniques when there is a good knowledge of representative geo-objects in the geological system. The geomodels generated with object-based modeling can reproduce complex geological features, are often visually attractive and can perform better when used in complex transfer functions such as flow simulation. In most of the object based modeling technique the geo-objects are represented as a template of cells that are coded as a particular facies inside the objects. This can lead to a lack of small scale geological feature reproduction when the features are smaller than the resolution of the grid. The grid-free framework presented in this paper allows for a representation of geological objects as surfaces and parametric shapes that are not linked to any particular Cartesian grid system. Features millimeters thick or kilometers in extent are represented in the same model. Geological sequences are entirely represented by mathematical functions. Examples are provided to highlight the methodology.

1. Introduction

Facies are very important in reservoir modeling because the petrophysical properties of interest are typically dependant on facies type. Geostatistics permits heterogeneity modeling within a stationary domain. The facies model is used to define stationary zones within which the petrophysical property distribution is modeled, typically assuming first and second order stationary.

The reservoir architecture is represented by heterogeneity modeling techniques. There are a number of different techniques for stochastic simulation of facies. Four main approaches are typical: variogram-based modeling, object-based modeling, event-based modeling, and most recently, multiple point geostatistics using training images. Choosing the best approach for facies modeling is highly dependent on the application (Deutsch, 2002).

In variogram-based modeling, the reservoir volume is commonly discretized into a regular Cartesian grid and relies on the two-point variogram statistic to capture structural correlations. Indicator and truncated Gaussian methods are well known examples of this class of techniques; the former indicator approach is more common in practice. Indicator simulation is popular because the sample data are explicitly reproduced in the final model and calculation of the variogram is relatively straightforward; however, complex geological features may not be exactly reproduced as the techniques are limited to two-point summaries of the spatial structure of the variables.

Truncated Gaussian simulation is another variogram-based facies model (Matheron et al., 1987). In this method, spatial distribution of categorical variables is modeled using a continuous multi-Gaussian random function. This method may be suggested when the ordering of facies is important, but is still restricted to two-point summary statistics and cannot reproduce complex features.

Multiple point geostatistics has received much attention recently and relies on extracting multiple point statistics derived from training images. This technique was first proposed by Journel and Alabert (1989) and then used in simulation (Deutsch, 1992; Streblle and Journel, 2000; Lyster, 2009). The method can yield a realistic geology model, but relies heavily on the training image thus representativity of the image is an important issue.

Object-based models are suitable when geo-body geometries are well understood and can easily be specified using simple objects. Examples of geo-objects are channels, levees, crevasses, lobes. It is primarily a Boolean simulation wherein geo-objects are stochastically populated within the model; the presence of many conditioning wells can be problematic and remains a long-standing challenge to these approaches (Deutsch, 2002). The fluvial setting is a common example of reservoirs which are modeled with the object-based techniques (More, 1992; Georgsen and More, 1993; Hatloy, 1995). FLUVSIM is an object-based algorithm for building stochastic fluvial ribbon models (Deutsch and Wang, 1996; Pyrcz, 2004). The method produces visually attractive and realistic facies models and successfully reproduces long range curvilinear connectivity that cannot be captured by cell-based facies methods, but is inefficient at honoring a realistic level of conditioning data.

In all above mentioned modeling techniques, facies are populated on a cell based grid. In the object-based modeling (OBM) a template of cells is utilized to represents the geo-object in the model. The template provides significant CPU advantage; however, the connectivity and preservation of the geological shapes are very sensitive to the choice of an underlying grid size (Deutsch, 2002). A typical geomodeling grid size is 5 m by 5 m by 1 m. This leads to 2 million cells for a model with size of 1 km by 1 km by 50 m. This number of cells is manageable for geostatistical modeling but small scale geological features less than 25 m^3 cannot be represented. An alternative would be to choose smaller grid size but this leads to a large number of grid cells and consequently longer computational times.

The grid free, object-based facies modeling technique introduced in this research addresses this issue by representing the objects with parametric shapes and not a template of cells. This allows preserving the small scale features as well as the large scale features in the same models.

2. Grid Free Modeling

The main idea of the grid free object-based modeling (GFOBM) is to store all the geo-objects and geological sequences in the model without relating them to a Cartesian grid system. This is very similar to the concept of vector graphics in which the visual objects are represented with mathematical functions and not as sets of pixels as in raster graphics (**Figure 1**). When geo-objects are represented with mathematical functions it is possible to introduce both small scale features (such as the centimeter scale shale drapes) and large scale features (kilometer long meandering channels) in the same model.

One of the early steps in any object/event based modeling technique is to reproduce the shape of the geological features by representing them as geometrical shapes. In cases where the geometry of the geo-object is not complex, the object can be represented by mathematical functions. Deutsch and Tran (1999) presented a methodology to parameterize deepwater lobes with simple equations. For more complex geological object such as meandering channels, the discrete smooth interpolation method (DSI), presented by Mallet (1992), can be used. In this method complex objects are represented by sets of discrete points which are connected together with interpolation functions. A cubic spline is an example of interpolator which was used to generate the complex pattern of meandering channels (Pyrcz 2004). Both the mathematical functions and the DSI method can be used in grid free modeling to represent objects.

Implementation of GFOBM involves setting up three main components: 1) a geological object database, 2) the simulation engine, and 3) the rasterization engine. These three components are linked together in different steps of modeling. The general framework of the grid free object-based modeling is shown in **Figure 2**. The general specifications of geo-objects are specifies in the geological object database (GOD). The simulation engine uses the information from the GOD and generates the grid-free models. The rasterization engine takes the grid free model and transforms it to a rasterized model for further geostatistical modeling.

The main reason to setting up these three components is to establish a general framework that can be applied for different applications. Indeed, separating the simulation and rasterization engines allows for fast simulation of geological objects at a very small scale and also high resolution rasterization of larger areas of interest or cross sections.

Geological object database

The geological object database is a general library that contains the specification for all possible geological objects and the associated architectural elements. The architectural elements are defined as components within the depositional system that have distinct facies content. Each depositional environment may have unique architectural elements and geo-objects. For example, fluvial systems contain crevasses and levees that may not appear in turbidite systems.

Having such a library enables the users to generate a different geological object database for different depositional environments. Also, it allows the user to easily include or exclude certain geo-objects in the modeling workflow.

This database is an ASCII file format in which each geo-object is specified with an object ID number, name, number of parameters, and list of the parameters keywords. **Figure 3** shows an example of part of a geological object database. The object ID number makes it possible to easily access the defined object in the other components of the grid free modeling workflow.

Simulation Engine

Simulation engine is the main component of the grid free modeling workflow. Generally, it is a stochastic object-based or event-based algorithm that generates the grid free geological model by following the geological rules and using objects from the geological object database.

In the stochastic object/event based modeling the distribution of geo-objects parameters are predefined by the user. First the simulator should decide which object/event is required for the current step of modeling. Then the specification of the selected object is gathered from the geological object database. The simulation proceeds by randomly choosing the parameters' value from the pre-defined distribution. Then the object is placed in the model randomly or by following geological rules. The object placement in the grid free model is not the same as the conventional object based modeling. In the conventional methods the objects is placed in the model by assigning a code to all grid cells felled inside a specific object. In the grid free mode, an object is placed in the model by noting its coordinate location.

Rasterization Engine

The output of the grid free simulator is a grid free facies model. It contains information about the location, time of appearance and parameters of each object. Since the available geostatistical property simulators such as SGS are not compatible with the grid free model, the grid free model should be gridded before it can be used for the further petrophysical property modeling. The rasterization engine is a tool to transform the grid free geological model to the gridded model for purpose of further petrophysical properties modeling, flow simulation, or visualization.

Rasterization is the process of finding all grid cells inside each object and assigning a code to those cells; however, a single cell can be large enough to contain more than one object. In this case it would be naïve to consider only the centre point of the cell and assign one facies code to that cell. Instead, the cell can be refined by sets of points and proportion of all facies can be calculated within the cell's volume. Discretizing the grid cell with several points gives a better approximation of the distribution of the facies. The level of refinement depends on the level of accuracy and the scale of the objects desired by the user.

The rasterization algorithm involves several steps. First the rasterization engine loops over the geological time steps and begins with the oldest time step or object placed. Then for each time step all the objects are considered. For each object the smallest bounding box, aligned with the desired grid, is defined. The bounding box makes rasterization faster by considering only those cells inside the bounding box. All the grid cells that are inside the bounding box are refined. Then for each grid cell, the number of the refined points falling inside the object is counted and the proportion of facies for that grid cell is calculated. It is possible that a grid cell is pre-occupied by previous object. In this case, the new object should be considered and all facies proportions for that cell are updated. **Figure 4** shows a geo-object, the bounding box and the refined grids.

3. Visualization

Visualization of the grid free model is a challenging task because objects in the grid free model are not stored in the gridded format. As mentioned earlier, the concept of grid free modeling is similar to the vector graphic. There are many software packages available for visualization of vector graphics. To utilize these, the output file of the grid free simulator has to be reformatted. One example of 2D vector image visualization file format is SVG (Scalable Vector Graphic). It is an XML-based file format that has been developed for applications in World Wide Web (Quint, 2003). X3D file format is the extension of SVG for 3D computer graphic visualization (Daly and Brutzman, 2008).

In addition to XML-based visualization packages, the visualization toolkit (VTK) is another widely used visualization package that can be used for visualization of grid free models (Schroeder et al.,1996). It is an open source C++ class library and interface that can be used for 3D visualization.

4. Conclusions

In this paper a framework for the grid free object or event based facies modeling is presented. In this technique the geo-objects are represented with the mathematical functions or parameters. This methodology can be applied for different geological environments. The main advantage of the grid free facies modeling is to include geo-objects with the different scales in the same model. This requires development of geological object database, simulation engine, and the rasterization engine.

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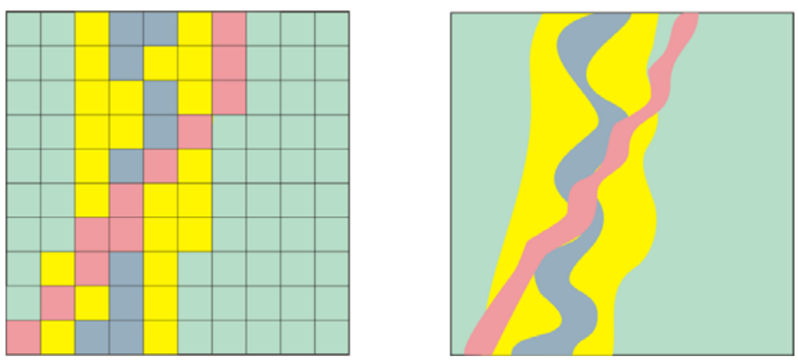

Figure 1: The pixel-based image (left) and its equivalent vector image (right).

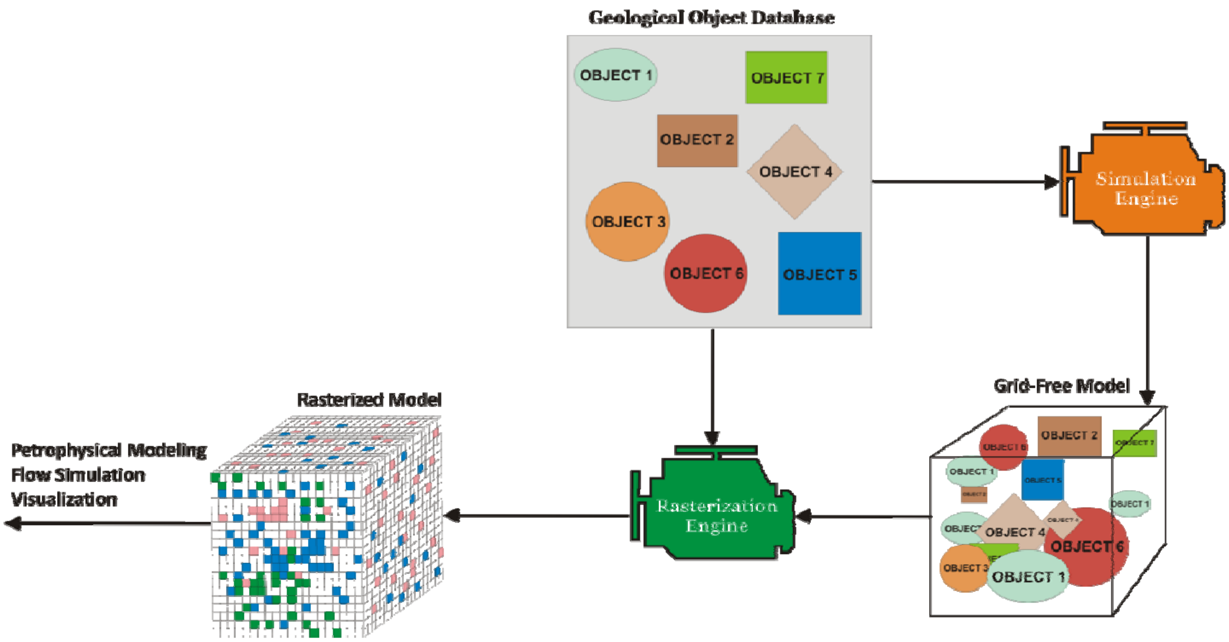

Figure 2: Framework of the grid free object-based modeling.

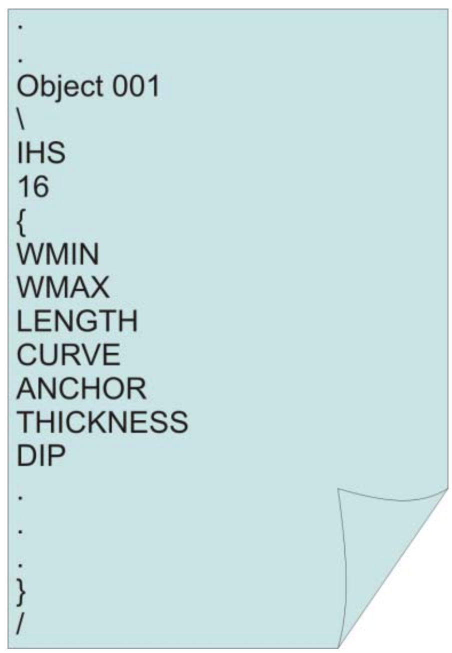

Figure 3: Example of Geological Object Database file.

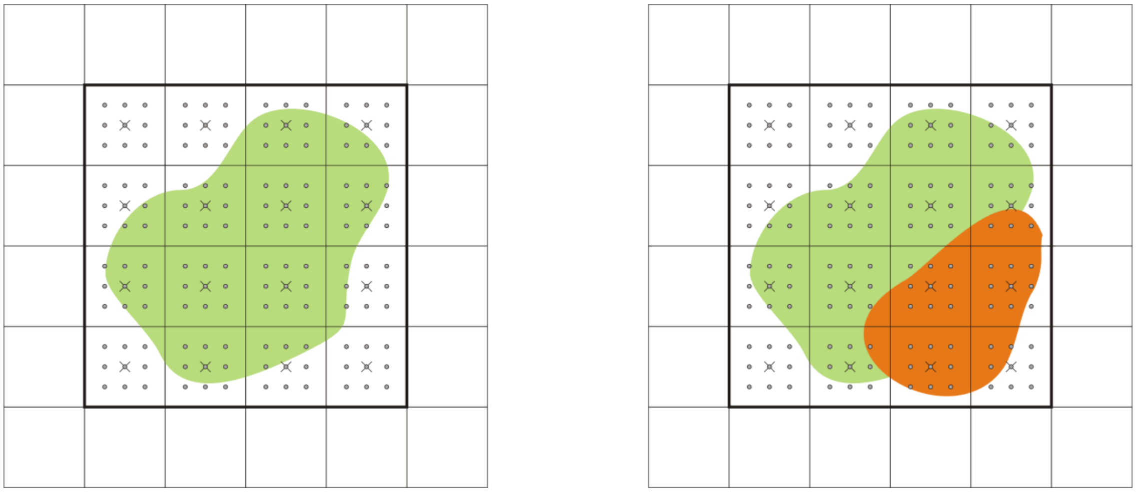

Figure 4 : Grid refinement, geo-object and the bounding box. New object takes over the refined grids that were occupied before with the old object.