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Data Integration, Modeling, and Up-scaling with Adaptive Grid Block Size

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SUMMARY

Current methods of modeling and up-scaling reservoir properties are based on variety of mathematical approximation and uniform grid block data structures. In this project we utilize a variable 'grid' block size and recursive algorithms directly in 3D space. Sizes of the variable grid blocks correspond to homogenous volumes of the model.
Variable size grid blocks support data integration, modeling, and up-scaling reservoir properties that are collected from sources at different resolution (core, log, geochemical, geological, seismic, etc.).
All procedures and algorithms are based on an octree computer data structure that uses variable size blocks (octants). We developed recursive algorithms supporting model creation, manipulation of the model structure, simulation of fluid flow, evaluation of physical properties, and visualization of the models with simulation results.
Finally, we developed three different grid block configurations that we tested in a recursive up-scaling process. These configurations account for possible special connections between grid blocks in specific directions. The effective properties of such configurations were obtained by transformations based on electrical circuit theory. This approach supports large models with millions of grid blocks and fast processing on a desktop hardware.

DATA INTEGRATION and MODEL GENERATION

Adaptive Space Subdivision is applied in this research. It is based on the concept of spatial coherence that the neighboring cubes with specific properties are very likely to have the same properties. By encoding his information into octree structure, considerable savings in space over the complete grid models are possible. The quadtree and the octree are computer data structures implementations in 2D and 3D respectively. The properties of the octrees are similar to the data structure used for exhaustive enumeration where all blocks/cubes have the same size. In simple terms, it may be regarded as a variable size block model, where homogeneous volumes are represented by large blocks and complex sub-volumes are modeled with smaller blocks.

The model generation process is based on deterministic and stochastic procedures. In the first case a data set is converted into a linear octree model. During this process each data source is represented by a model that accounts for a specific parameter at the associated data resolution (grid block size). Linear octrees use grid blocks of the same size at the highest level of resolution corresponding to the data resolution. Thus, homogeneous parts are represented by many voxels. In the next step, these voxels are compressed into higher level nodes and converted into a pointer based models of variable size grid blocks for further data processing. These different data sub-models can be merged into a final model with grid blocks of different sizes as a function of data homogeneity.

The stochastic models are built using the statistical description of reservoir properties. Stochastic pointer based octree models are populated using statistical distributions of properties that are assigned to 3D volumes (grid blocks) associated with the specific parameter. Specifically, histogram bins from the known distributions are associated with the octree levels and corresponding grid block sizes. In cases with sparse field data we can improve geological modeling by applying a mix of the deterministic and stochastic processes.

SIMULATIONS and VISUALIZATIONS

Our simulations are based on laboratory tests performed on rock samples. In simulated processes two fluids are introduced at opposite sample faces in a horizontal direction. Drainage algorithms simulate a non-wetting phase invading the sample at increasing pressure and displacing the wetting phase. This process depends on model connectivity and distribution of properties in the model, the fluid wetting properties, interface connectivity to respective fluid sources, and pressure increases. At a certain pressure the initial break-through for the non-wetting space is recorded and the pressure is increased until the simulation stops when the non-wetting saturation reaches maximum value with the corresponding residual wetting phase saturation. In the next part the imbibitions process is simulated. During this process the pressure applied to the non-wetting phase is lowered by small decrements and the wetting phase invades back the model space.

The fluid movements in both processes are based on pressure at 3D interfaces and properties of grid blocks at these interfaces. The effective properties are measured in three orthogonal cross-sections.

The above algorithms and processes utilize algorithms that traverse the structure to find physical neighbors in 3D space, which are not necessarily neighbors in the octree data structure used to build the models. Our simulation routines use face and edge neighbor finding algorithms for neighbors of greater, equal, and smaller sizes.

Finally, we developed model visualization algorithms that show models with or without fluids in 2D and 3D space. The visualization is used mainly to show the spatial relationships, fluid penetration, connectivity, interfaces, and interaction. Specifically, we developed visualization of the effective network with fluid interfaces at pressure steps.

MODEL PROPERTIES UP-SCALING

In order to test our procedures and algorithms a stochastic model with layered geology was built. It used three sets of distributions. In the presented example simulations were performed on a model with 4.8 million 3D block/voxels of variable size that corresponded to 134 million of voxels of equal size. The simulated interaction of two fluids and estimated model properties at variable pressure were done using three different up-scaling algorithms.

The up-scaling methodology presented here is direct, adaptive, and applied in three dimensions. The effective property of a particular grid block at the leaf level (homogeneous cube/octant) is a single value. However, this is not true for the non-leaf grid blocks that represented a set of cubes with different properties. These non-leaf nodes represent complex areas of the model, or in the case of the root node, the whole model.

The recursive up-scaling process starts from the lowest level where leaf nodes are homogeneous and can be easily estimated. The process continues with up-scaling their properties to the respective parent nodes. The same process is repeated for the parents, thus up-scaling the model properties one level a time in a recursive fashion. This generates a sequence of estimates at higher and higher levels until the root of the octree is reached and the up-scaled properties of the whole model are obtained.

The general processing strategy is a depth-first tree traversal. At every step, an octant property is represented by an element, which is a part of a larger network. Three different configurations have been tested with the octant representation using chain, bundle, and mesh models. The up-scaling process applies a set of rules to a network composed of eight octants which have the same parent. Interconnectivity between octants and the sequential reconstruction of the effective connections between octants account for the assumed flow and connectivity between siblings in the octree in a specific direction. The effective properties of such configurations are obtained by transformations and calculations involving sets of serial and parallel flow elements. Two simple and one advanced network approaches use transformations that represent flow in horizontal and vertical directions.

In the advanced mesh solution each octant is replaced by a 3D cross of six elements, which are connected in the middle of the octant to ensure that each octant still represents the original property in every direction. At the same time, this allows for a better representation of the interaction between nodes having the same parent (cross-flows).

RESULTS

Estimates of resistivity and formation factor indicated that the concept, processes, and algorithms do support simulation of rock properties with two interacting fluids under variable pressure. Specifically, we observed hysteresis effect when estimating electric properties during simulation of drainage and imbibition in the layered model. Furthermore this model had large differences between the vertical and horizontal estimates of effective properties. The hysteresis and directional differences in properties proved our approach, procedures, and algorithms. Finally, the visualization in 3D and 2D emphasized the sample structure, fluid saturations, active network, and fluid interfaces.

CONCLUSIONS

Our software prototype can be used to build sophisticated models using actual data sources and data based on the statistical description of reservoir properties collected at different scales. It supports testing: existing hypothesis, simulate changes due to natural processes, and changes due to oil and gas production in reservoirs. Final flow properties (electric resistivity and permeability) are evaluated with three up-scaling algorithms. The application of adaptive data structure with variable grid blocks allowed to simulate models with millions of grid blocks on a mid range laptop with running times measured in minutes.

APPENDIX 1: LAYERED MODEL IMAGE and ELECTRICAL PROPERTIES HYSTERESIS MEASURED in TWO DIRECTIONS.