

An Interim Format and Tools to Visualize Unstructured Grids

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An important direction of research at CCG is the population of unstructured or irregular non-Cartesian grids. There is no established format to represent such grids. This short note presents an interim format that has been developed to facilitate developments in this area.

Introduction

The use of unstructured grids in modeling geological resources is becoming more common. This is especially true for petroleum reservoir modeling. Grids may be refined near wells to create a more realistic flow simulation regime or grid cell geometry may take on a form to represent geologic features more accurately. One issue with unstructured grids is that there is no industry standard for how they are defined. Several pieces of software do exist for working with unstructured grids; however, each has its own format for how a grid is specified. Research and development of technology to simulate attributes throughout unstructured grids requires a specific grid format.

This paper defines an interim unstructured grid format specifically to be used with a new version of sequential Gaussian simulation (see Paper 103). Combined with simulating on these grids, tools must be made available to visualize results. Some advancement has been made in this area and will be discussed.

Background

Unstructured grids come in many forms. For reservoir modeling, these may include a combination of regular grids (Figure 1), radial nested grids (Figure 2) and voronoi or corner-point grids (Figure 3) for a single reservoir. Regular grids can be defined by corner-point or by on-center geometry. The on-center definition is commonly used with CCG programs such as `sgsim` and `kt3d` (Deutsch and Journel, 1998). All cells of a regular grid are of equal volume and dimension and are fully described by cell dimensions (dx , dy , dz), grid origin (x_0 , y_0 , z_0) and numbers of cells (n_x , n_y , n_z) in the three principal orthogonal directions of interest (x , y and z). Should properties be assigned to these grids, they are printed in order with x cycling fastest, followed by y and then z .

Radial nested grids are commonly found surrounding a vertical well bore. They provide accuracy near the well for characterization and flow simulation. A radial grid can be defined with an origin or center point, an initial angle offset, a top depth, the number of radial, tangential and vertical cells, and radial and vertical cell sizes. The initial cell angle offset defines the location of the start tangential split counterclockwise from the positive x -axis.

Indexing an RNG is based on the definition of cylindrical coordinate systems. Cylindrical coordinates are defined by a radius r , an angle θ and a vertical coordinate z . Tangential cells

cycle fastest and are indexed from the center outwards followed by radial cells and finally vertical cells. The initial radial cell is set as the first encountered when traversing counterclockwise from the positive x-axis.

Corner-point grids offer the most flexible type of geometry. They can be made to conform to geologic entities and surfaces. Unlike regular and radial nested grids, corner-point grids cannot be indexed in a concise manner. Cell geometry is defined by a set of simple geometric entities: vertices, lines, and planes. Vertices are described by their x, y, and z coordinate locations. Lines can be defined in several ways, but for geometric computations an efficient method is using endpoints. Planes can also be described in various ways. Here, a plane is described by a point on its surface and a normal vector to the plane.

A corner-point grid cell is defined by a set of faces forming an enclosure. A face is a plane clipped within a boundary or closed set of lines. Each boundary line is made up of a set of vertices, which are the corner-points of the grid.

Interim Grid Specification

A preliminary unstructured grid specification was created to aid in developing simulation techniques for them. Formulating the definition was done to capture details of the types of grids mentioned in the previous section. Several components of regular, radial and corner-point grids permit them to be combined into a single definition, which is essentially a corner-point grid with lines that can be specified as circular arcs. This method is simple but there is a disadvantage. Specifying a regular grid involves describing all vertex locations, lines, boundaries and cells rather than the set of nine parameters mentioned above.

File structure to define an unstructured grid with this interim format involves a set of keywords for the various geometric structures and number of record indicators for sequential file input. A list of these keywords is given by Table 1. They are ordered the same as they would appear in a specification file. Keywords must be in capital letters.

To clarify this format, a single cell example will be used. We will define a cell with eight vertices and one curved face, see Figure 4. Indices correspond to the order of corner-points and lines in the file structure shown in Figure 5.

In Figure 5, the first line describes the number of nodes, faces and cells. Since there are 10 nodes, 30 records will be read in from the nodes list. The first eight nodes are the corner-points of the cell and the last two are the center points of the circular arcs. The faces list describes the six faces of the cell. For the first face, the boundary line is made up of segments connecting points 1 and 2, 2 and 4, 4 and 3, and 3 and 1. This goes for all face boundaries. The plane definition for each face includes one of the vertices forming the boundary line and a normal vector calculated as the cross-product of two adjacent line segments in the boundary. Notice that corner-point indexing is done so that boundaries do not intersect themselves. Line types for each segment are defined in order that they appear in the faces list. An example of an arc line definition is that for the segment running from node 6 to 2. The line type is 1 and the center-point, node 9, follows. Cells are defined in the same manner as faces with a number and then indices. Any properties to be assigned to a cell are given last; in this case they are labeled PORO and PERM.

Visualization

A tool for visualizing these unstructured grids (usgplot) and any associated properties is under development. The tool is much like pixelplt for gslib in that 2-dimensional views are created; however, cells cannot be represented as pixels since they are no longer regular. Plan views are plotted based on a z-coordinate provided by the user. For a particular z-coordinate, which defined an xy plane, the program determines which cells are intersected by the plane and creates polygons that lie on that plane. Each polygon is plotted and colored based on the cells property value and color scale. Parameters are shown below.

Line	Parameter	Description
1	datafile.dat	-file with sample data
2	2 3 4 5	- columns for x,y,z and value
3	-999 999	- trimming limits
4	usgrid.dat	-file with unstructured grid spec.
5	1 1	- plot data? Plot grid? 1=yes
6	2.0	- plan view z-coordinate
7	usgrid.ps	-file for postscript output
8	1	- plot in color? 1=yes
9	1	- color by which property?
10	-10.0 110.0	-plot limits in x
11	-10.0 110.0	-plot limits in y
12	0.0 10.0	-plot limits in z
13	0.0 15.0 1.0	-plot scale: min, max, increment
14	15 10	-number of x and y axis ticks
15	1	-label every nth axis tick
16	60 0	-rotation angle for x and y axis labels
17	4.0	-bullet size
18	Test Plot	-title

Lines 1 to 3 are parameters for plotting any data as points. This may be the data used in simulating on the unstructured grid for example. Line 9 asks for which property to color cells by. This number coincides with the order in which properties appear in the grid file. Lines 10 to 13 are plot dimension and color/gray scale limits. Remaining lines are just plot attributes. A small grid was setup with 23 cells. Some cells are simply polygons and others were arranged to form a radial nested grid. Simulation results for a realization were plotted with usgplot, see Figure 6.

Conclusions and Future Work

Shifting to the use of unstructured grids for modeling reservoirs and deposits is a complex process. Unstructured grids do offer the ability to more accurately represent what is below the surface. This can be done with complex cell geometry and local grid refinements. The unstructured grid specification provided here was created mainly for petroleum reservoir modeling. It offers enough components to describe many geological features. Radial grids can also be defined with this format.

There are limitations to this format. Curvilinear features can be described, but they must be composed of circular arcs. Use of parabolic and elliptical arcs will provide more flexibility where needed. A way to define and work with faults and stratigraphy is required. Faults can be very important structures in reservoirs.

Future work is also needed for the visualization tools. Ultimately, one would like a 3-dimensional visualization tool; however, this is a very time consuming task. Plotting will be kept to two dimensions for the time being. The ability to plot cross-sections rather than just plan-views is required. Work will also continue as faults and other geological features are incorporated into the grid definition.

Table 1: Unstructured grid specifications keywords and descriptions.

Keyword	Variables	Description
FILEHEAD	nnodes, nfaces, ncells	Always starts a grid specification. Used for variable initialization for number of nodes (nnodes), number of faces (nfaces) and number of cells (ncells).
NODES	x_i, y_i, z_i $i=1, \dots, \text{nnodes}$	Node locations. Nodes are indexed by order of appearance in the file. The number of records is always three times nnodes.
FACES	nn_i, v_j $i=1, \dots, \text{nfaces}$ $j=1, \dots, nn_i$	Each face is defined by the number of vertices in its boundary line (nn_i) and the indices of those vertices in the nodes list (v_j). The number of records must be specified immediately after the FACES keyword separated as space or tab delimited.
LINETYPES	0 OR 1	Indicators defining a straight line (0) or a circular arc (1). If a circular arc is entered, the index of the center point of the arc follows. The center point would have been defined in the nodes list. The number of records must be specified in the same manner as for faces.
CELLS	nf_i, f_j $i=1, \dots, \text{ncells}$ $j=1, \dots, nf_i$	Each cell is defined by the number of faces forming its enclosure (nf_i) and the indices of those faces in the faces list (f_j). Faces are indexed in order of appearance in the faces list. The number of records must be specified in the same manner as for faces.
PROPS	name	Set of cell properties ordered the same as the cells list. The name simply describes the property. There are always ncells values and there can be numerous properties lists.

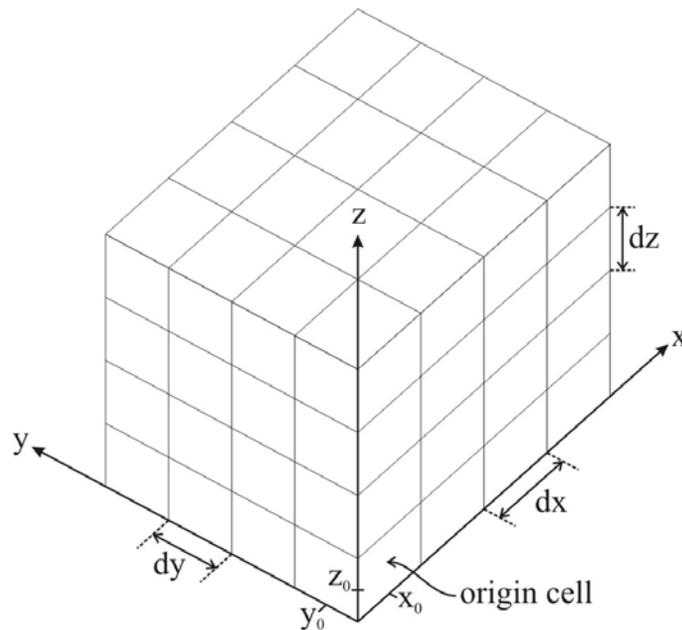


Figure 1: A regular grid and its characteristics.

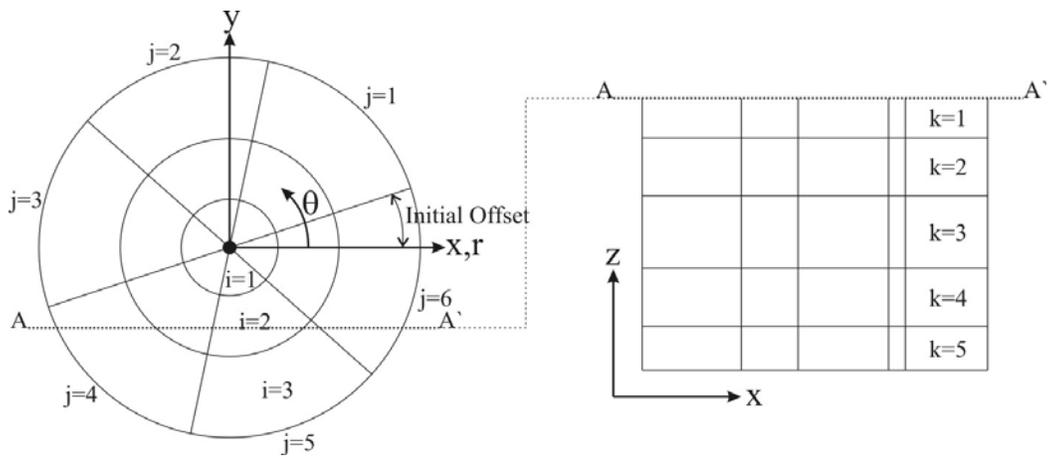


Figure 2: Radial nested grid and its components

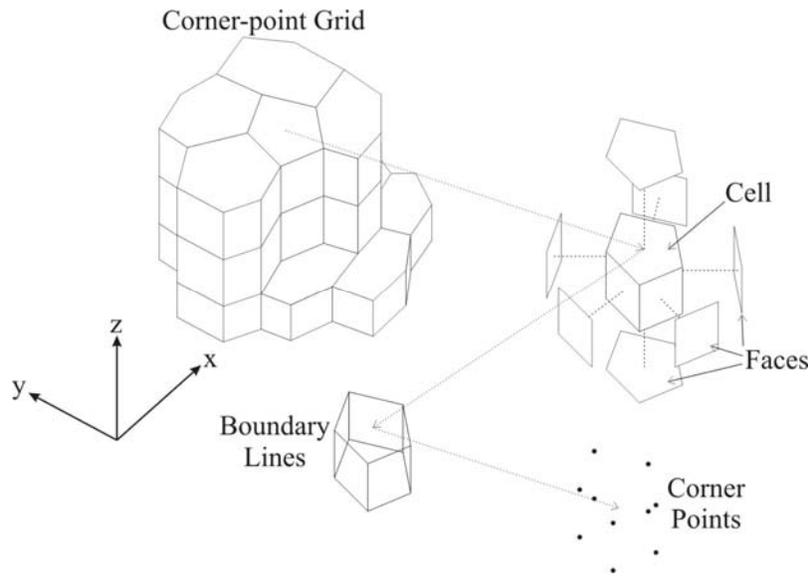


Figure 3: A corner point grid and constructive geometric entities.

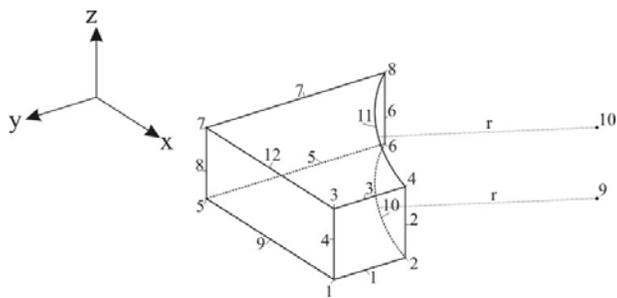


Figure 4: A single cell with corner-point and line indices shown.

```

FILEHEAD 10 6 1

NODES
20.0 0.0 0.0 20.0 10.0 0.0
20.0 0.0 10.0 20.0 10.0 10.0
0.0 0.0 0.0 0.0 20.0 0.0
0.0 0.0 10.0 0.0 20.0 10.0
20.0 35.0 0.0 20.0 35.0 10.0

FACES 30
4 1 2 4 3 4 5 6 8 7
4 5 1 3 7 4 6 2 4 8
4 1 2 6 5 4 3 4 8 7

LINETYPES 28
0 0 0 0 0 0 0 0
0 0 0 0 1 9 0 1 10 0
0 1 9 0 0 0 1 10 0 0

CELLS 7
6 1 2 3 4 5 6

PROPS PORO
0.280

PROPS PERM
0.141

```

Figure 5: Unstructured grid file for single cell example.

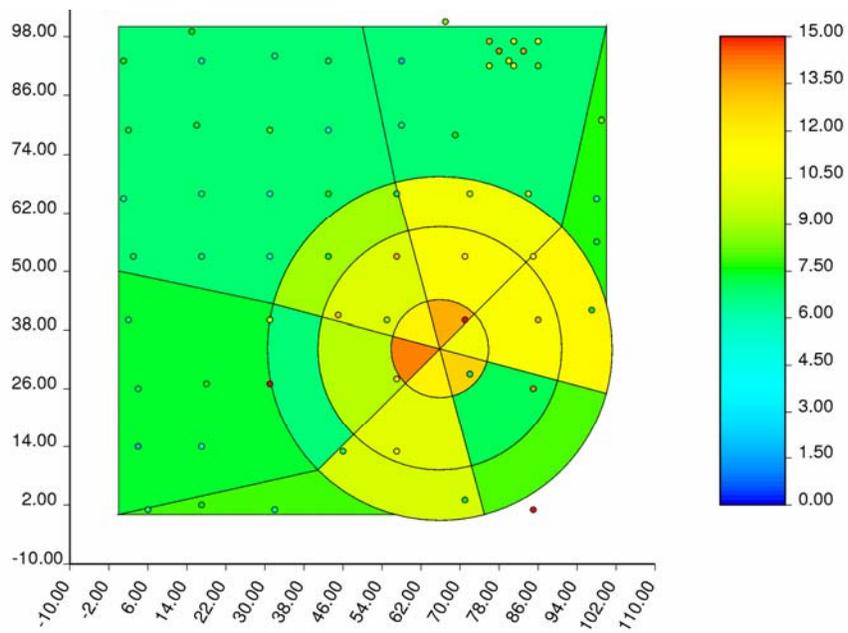


Figure 6: Unstructured grid plot with sample data overlaid.