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NOVEL APPROACH TO GEOLOGICAL MODELING WITH COMBINATION OF MACHINE LEARNING

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Research Mission

- ✓ The widely used for petroleum reservoir simulation computer geological models are digital, but not mathematical. They simply show what values correspond to certain reservoir's points. It means that an experienced geologist with solid background can produce better hand-drawn maps than those created by the models.
- ✓ The fact that the computer models are only digital has limited their development, which has been mainly understood in a purely extensive way as an increase in the number of cells of the models. However, any identical transformations can not enlarge the models' information content.
- ✓ Following the nowadays priority research direction of the machine learning implementation in different areas of petroleum exploration and development including reservoir simulation, our work is devoted to discuss a novel approach of building truly mathematical geological models based on cascades of fuzzy square matrices.

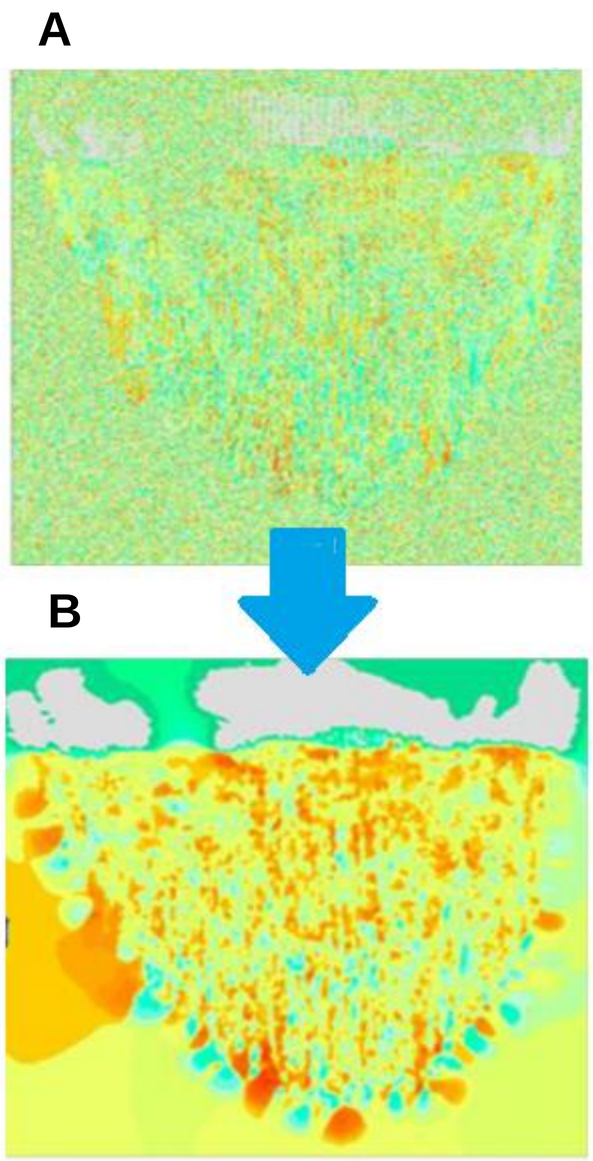
Existing challenges of digital geological modeling

- ✓ In the computer geological models, horizontal dimensions of cells (often 50 m) significantly exceed their vertical size (usually no more than 0.4 m). If the lateral position of the cell among several wells can be determined with an error less than 50 m, then there is no certainty that a specific layer of the models with a thickness of 0.2 - 0.4 m, for example, the fifth from the bottom in any well, coincides with the fifth from the bottom layer in the adjacent wells, since a detailed correlation of such thin layers is impossible. However, each thin layer with a certain serial number has implicitly implied the same in the whole model.
- ✓ The computer geological models are deterministic, i.e. any parameter, for example, porosity, is rigidly assigned to each of their cells with one value for each cell. Meanwhile, any cell has a certain area, for example, 0.25 ha, and it is obvious that the porosity changes at different points of such cell. Therefore, the value of porosity attributed to the cell should be considered as average. However, in this case, the mathematical apparatus of computer geological modeling should include standard variance in an explicit form.

Novel approach to mathematical geological modeling

- ✓ Assume that for each point of a petroleum reservoir, there is a vector consisting of two lateral coordinates *X* and *Y* and a vertical coordinate *Z*, as well as a set of such vectors along a wellbore (i.e., vertical) with a resolution of 0.4 m. Each vector has three specified coordinates and a value of any seismic parameter (*S*).
- ✓ Since the lateral and vertical dimensions of vector's coordinates are different, they need to be equalized. To do this, both coordinates are standardized in the range from -1 to +1 using the hyperbolic tangent function: $X_i = tn\ (X – AX)\ /\ DX$, where *AX* – an average value of one coordinate and *DX* – its standard deviation.
- ✓ After standardization, the vector's coordinates can be compared with each other. The main conditions are that there is no strong correlation among all coordinates, and the starting points for which vectors are defined are evenly distributed in the multidimensional space.

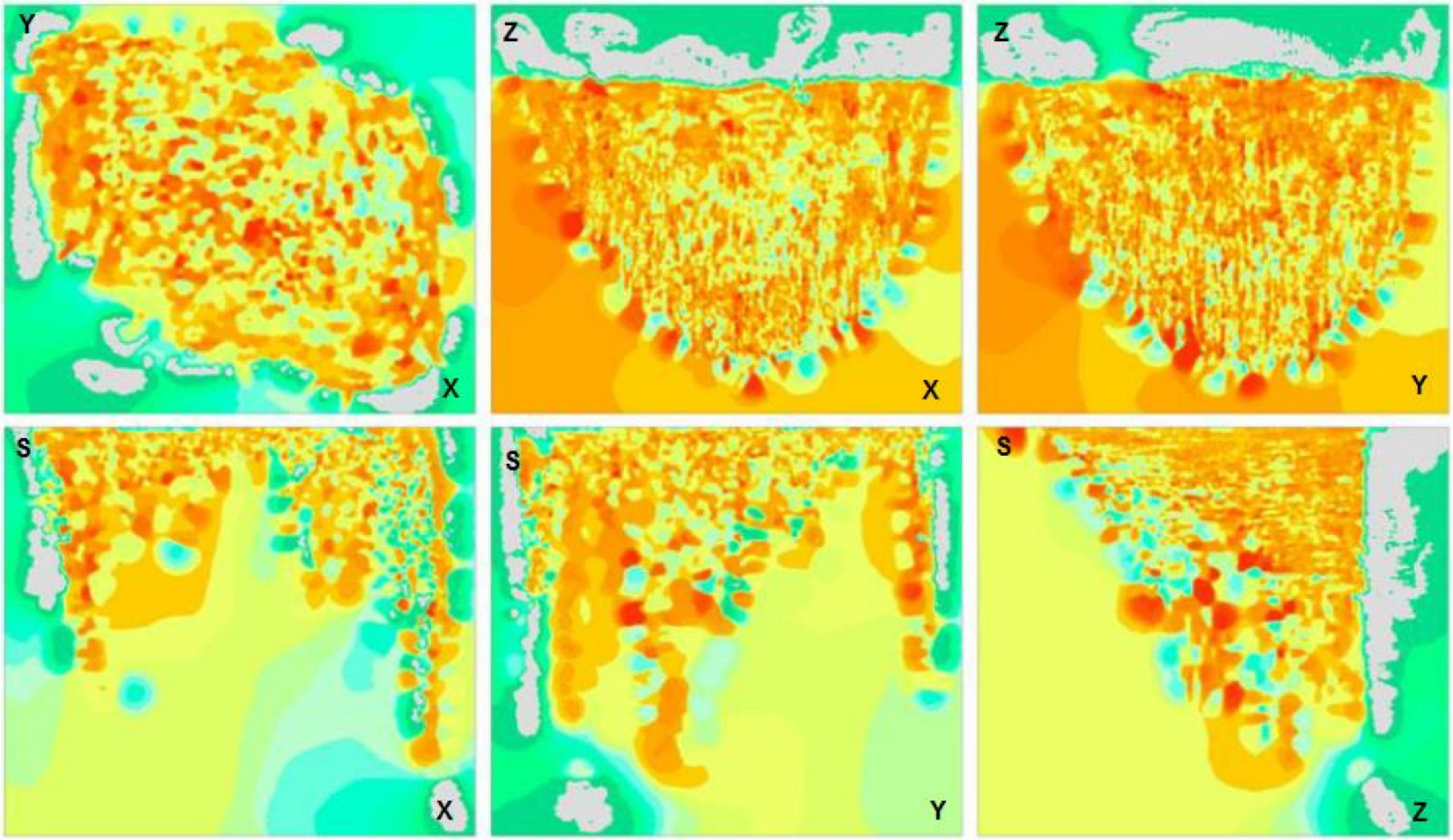
- ✓ There are various methods of working with the multidimensional space, our work proposes its own - a new machine learning algorithm of cascades of fuzzy square matrices. It has a classical analysis - synthesis scheme: first, the space is divided into components, the regularities of each of them are identified, and then the synthesis or integration of those components is performed, as a result of which forecasting is obtained.
- ✓ For a vector with coordinates *X*, *Y*, *Z* and *S*, six independent pairs of input values can be compiled. The first, most familiar *XY* is the spatial coordinate pair. In the second *XZ* and third *YZ*, each of the lateral coordinates forms a pair with the vertical. In the remaining three pairs *XS*, *YS*, *ZS* - three coordinates intersect with the chosen seismic parameter.
- ✓ For each of these six pairs, a matrix is built, the size of which can be from 100 x 100 to 1000 x 1000. If the matrix size is 400 x 400, it respectively has 160 000 nodes, which ensure a satisfactory resolution of such model.
- ✓ The set of six matrices forms a cascade. Note that an additional standard deviation matrix, which is also necessary for modeling, is added to each of the six matrices. Thus, twelve matrices are obtained, or six pairs of linked matrices.



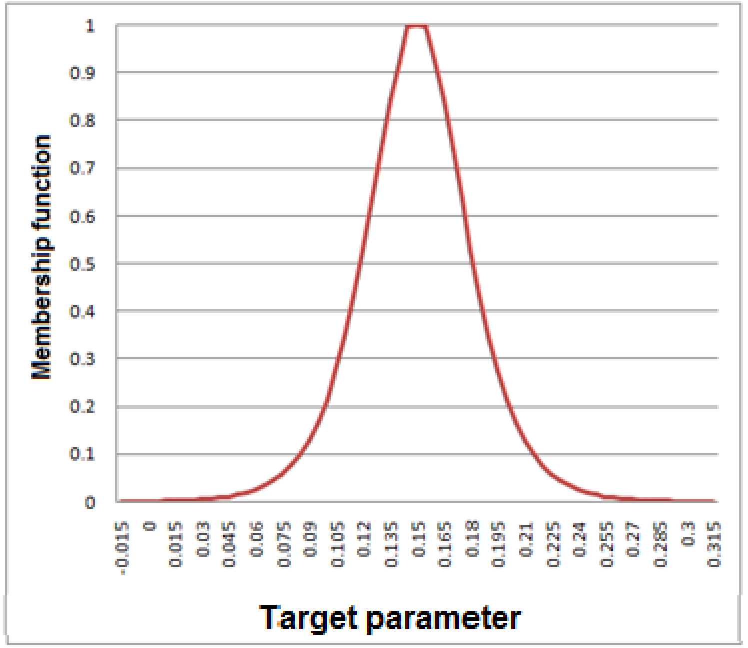
Results of matrix initialization (A) and calculation (B)

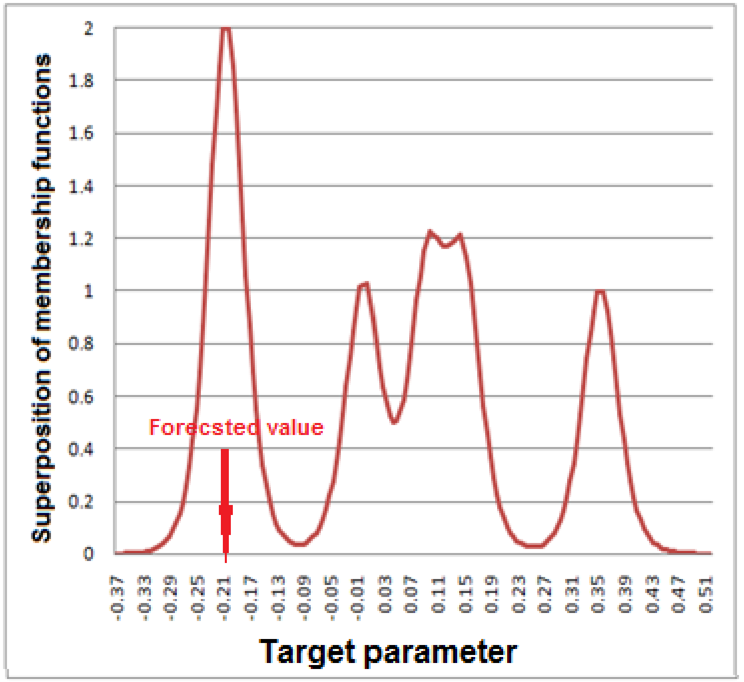
- ✓ At the points determined by a pair of coordinates, each matrix is filled by the actual values of a target geological parameter, for example, porosity. Similarly, the corresponding matrix of standard deviations is initialized.
- ✓ Since there are fewer points with the target parameter than all nodes of each matrix, and all nodes should be filled by the target parameter value, the following procedure is used:
  - The nodes with the actual values are fixed and their values are not changed in the future;
  - For the remaining nodes, the values are determined randomly, according to their actual distribution of the target parameter. The obtained results are chaotic maps (*Figure A*). The linked standard deviation matrices are calculated in the same way;
  - In the next step, an optimization mechanism is launched, based on the idea of lattice Boltzmann equations. The exchange of values among neighboring cells is performed in such a way as to minimize the differences of these values in those cells. At the same time, the cell values in the standard deviation matrices also change. As a result, the correctly organized maps are achieved (*Figure B*).

- ✓ Figure below presents the formed six matrices of the novel mathematical geological model, which have an unusual appearance, but contain all the regularities of parameter distributions.



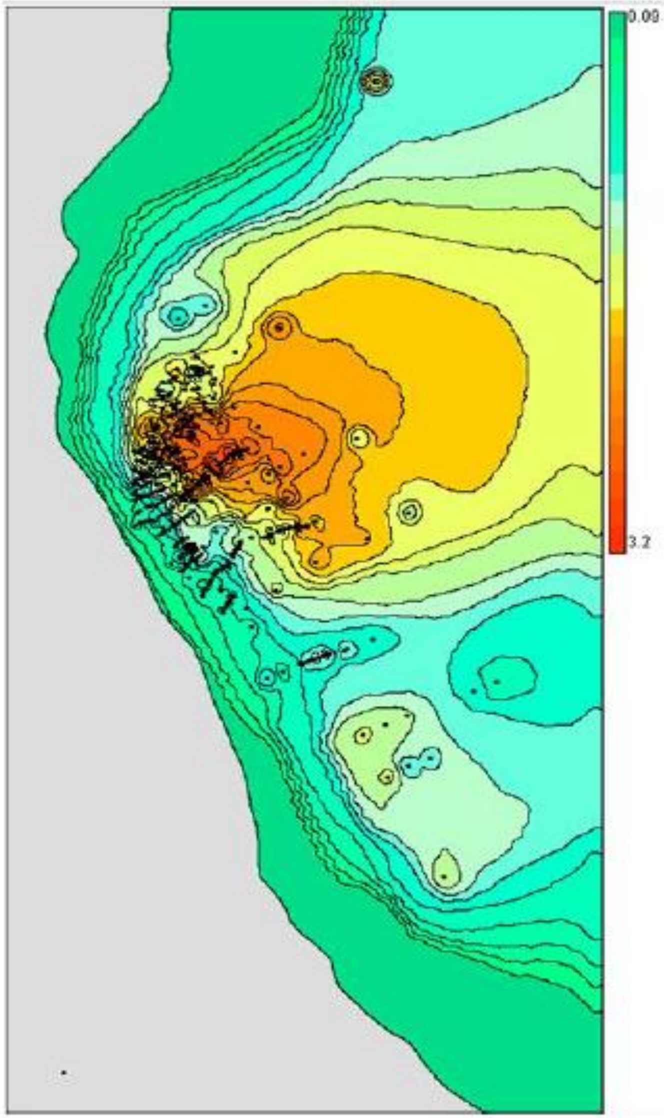
Cascade of six fuzzy square matrices of four input parameters (X, Y, Z, S) and porosity as the target parameter





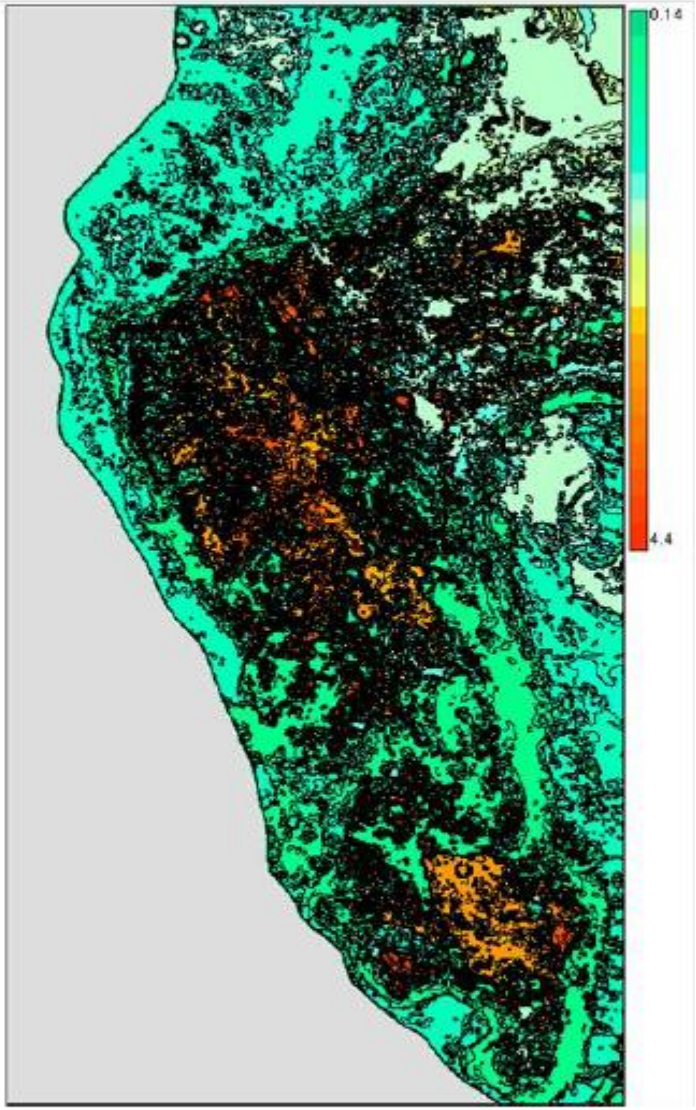
- ✓ For any reservoir point by means of each of the six pairs of matrices, one can get the forecasted value (*V*) and its standard deviation (*DV*) of the target geological parameter. Using these two numbers, it can be possible to built the membership function: $Y = 1 - tn\ (((X - V) / DV) * N)^2$, which is defined in the interval from V - DV to $V + DV$. At the point of V, $Y = 1$, at the boundaries of the interval, $Y = 0$. The coefficient N is necessary to achieve the zero values at the boundaries.
- ✓ Using six pairs of matrices, a superposition of six membership functions can be obtained. As a result, the maximum value of this superposition is selected as the forecasted value of the target geological parameter, which occurs where two or more membership functions overlap each other.
- ✓ It is possible to take a larger number of vector coordinates by adding, for example, new seismic parameters and increase the number of matrices, which will allow to get a superposition with a more stable maximum. Thus, a cascade of several tens or even hundreds of matrices can be used.

Example of modeling results



Structural map built by an ordinary interpolation technique

- ✓ Using the fuzzy square matrix cascade, it is possible to get a distribution of any forecasted parameter. Figure to the left shows a structural map of a heavy oil sandstone reservoir in the Timano - Pechora region of Russia constructed by the ordinary interpolation method, and Figure to the right shows a structural map of the same reservoir obtained using the cascade of six fuzzy square matrices. Both are built on the identical initial data.
- ✓ It can be seen that using the proposed machine learning algorithm, it is possible to get a more meaningful and realistic structural map.



Structural map built by the fuzzy square matrix cascade algorithm

Conclusion

- ✓ It cannot be argued that the proposed methodology is fully developed and there is nothing to add to it. On the contrary, it is most likely just an idea of how to move from a digital geological model to a pure mathematical. However, such idea has been already realized in a workable software package.
- ✓ And although it can be further strengthened, the idea already shows that there are no complexity limits for the novel geological modeling approach, therefore it is suitable for almost any petroleum reservoir including ones with unconventional reserves, which are characterized by serious deficit of geological information not allowed using any traditional options for their computer simulation.