# The Integrated Program Complex of the Composer of Geological Models. The Concept, Solutions

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**Abstract.** *Problems of development, tool filling, usages of the integrated program complex of the composer of digital geological and geoecological models are considered. The advantages of an offered process engineering of assemblage of components of the complex by synthesis of program units of computer algebra systems and geographic information systems are substantiated. Methodical and technical decisions of problems of construction, analysis of digital fields of distributions of parameters of reference objects characterizing geological bodies with possibilities of imitation of typical elements and features of such distributions are stated.*

# 1 Introduction

The construction of digital geological, geoecological models nowadays is a mandatory part of expert's decisions in several domains, particularly while monitoring the state of environment, subsoil, while solving the problems of rational usage of mineral-resources base, in the projects about the protective measures related to the description of relief and engineering-geological structure of terrain, while planning the underground gas storages. A special roll have geological models for rationale of hydrocarbon exploitation projects, as these models are the main part of ongoing geological and technological models of oil fields. The modern geological model includes general description of composition, structure and shape of the studied objects, the state of the studied fragment of the Earth's crust at different stages. Geological model has to include not only the picture of the geological structure but also its digital characteristics, providing graphical visualization of the volume distribution of its real-space structural in the geological space with the necessary accuracy, including all of the layers more or less homogeneous in lithological and physical way.

Geological simulation is an independent stream, which includes the progressing of mathematical methods and algorithms; development of computer programs, which provide the cycle of models' construction, database creation, provisioning and maintenance. The corresponding software includes the loading from different sources and data preprocessing, correlation, creation of digital cubes of reservoir properties, interactive data analysis, visualization with the help of any type graphics, mapping. The construction of digital geological models is rather young stream among the CIS countries, it's developing rapidly, but still large state-owned and private companies, consumers of corresponding software systems, prefer the developments of global leaders. For example from the reviews and analysis of the current state of the problem of creation and usage of geological-hydrodynamic models of oil recovery processes it can be said that in the world's practice inside the world's biggest oil companies the majority of computer models of the particular oil production facilities are built with the help of the following software systems: Schlumberger Information Solutions (USA), Landmark Graphics (USA), Roxar Software Solutions (Norway). These software systems even with the minimal equipment functionally complete cost more than 5 millions of dollars. Also the mentioned foreign systems are focused on special expensive computing equipment. That's why development and implementation of alternative computer geological models are relevant. One of the most important part is an estimation of adequacy and accuracy of proposed digital models, but automation of installation, adaptation the models according to constantly incoming additional data, as well as the audit of results of processing initial data within the new methods of interpretation are especially relevant. Coding, implementation of visualization algorithms and adaptation of geological models are time consuming, involves the usage of unique mathematic methods. For example based on the experience of the development, maintenance and implementation of system "GeoBazaDannych" ([1] – [4]), we can see that keeping it in up-to-date state, reflecting to constantly increasing software capabilities requires a large team of experienced programmers.

It seems that nowadays more effective, less drudgery, and not as time-consuming will be an approach based on combination and integration into one software system the modules of modern versions of computer algebra system (CAS) and geographical information system (GIS). Moreover it should be considered that to solve the problem of processing initial data including the results of remote sensing, seismic and magnetic exploration, simulation, there's no specific GIS to be the full set of space-analytical methods and analysis tools. In many cases it's necessary to combine the tools provided by GIS with programs for static data analysis, tools for mathematically complex computations which include implementations of modern methods and algorithms of analysis and interpretation of spatial data.

## 2 Basic Concepts

In proposed approach while solving the problems of mathematical simulation of the objects of geology, subsurface hydrodynamic there is a growing idea that the digital description of bounding surface is a core and basis for building a computer geological model. However, the basic stage is building generalized surfaces which describe the topology of object, sequence of occurrence of geological bodies, layers, so called "set of shelves" ([5, 6, 2]). For structured by layers 3D geological model there's an approach to build a model in a "constructor" mode, when building and editing of the model are made piece by piece, where the pieces are separate geological elements. Distributions of studied parameters for the layers are included in the description. For example, the type of collecting pipe, capacity, porosity, permeability, oil saturation of formation can be considered as parameters. Initial data for these descriptions is usually the values of observed parameter in points with known geometrical locus, in the points which are placed on the area not regularly (for example, measurement data of seismic profile, exploration hole). Let's mark out proposed and implemented methodical and technical solutions, software components, which are included into integrated computer system "The generator of the geological model of deposit" (GGMD). System is assigned for creation and estimated accuracy of configurable geological model based on the usage of CAS and GIS, "smart" methods of model adaptation while in service, "self-tuning" of models considering additional data from the actual development of processes.

Development platform is computer algebra system *Mathematica* [7], language is Wolfram Language [8, 9], geographical information system is Golden Software Surfer [10]. While programming in Wolfram Language technical solutions, described in [11], [12], were implemented, moreover software system in a particular configuration can be used after it's built and saved in computable document format – CDF format ([13]). Calculations, user work with CDF version of application are possible on every personal computer. When viewing CDF version, hosted on webserver, viewer is automatically loaded in the form of browser plugin. Offline work is possible after the installation of free distributed CDF Player. Alternative additional configurations, which provide an interactivity of CDF version, are described in [11, 14].

# 3 The Components of Computer System GGMD

Let's make some clarifications for the illustrations of implementations marked above, the results of the usage of program modules which are selected and modified for the problems we're solving. Below we mention the components, which are actually standalone program modules. They can be also considered as parts of automated workstation of specialist, who during the computational experiments works out techniques of adaptation of digital fields.

We should specifically note an important technical solution – all the work steps with the complex of modules are provided with the possibility of import and export of obtained result with several configurations of output format. It provides the user with additional possibilities for performing similar calculations in different (including the others) applications, the comparison of results.

It is necessary to understand that creation and maintenance of geological model don't expect to have unique solution to a mathematical problem. Subjective opinion, the qualification of an expert – are the factors that always take place in such activity. While working a user have to operate with data of different accuracy, some initial data is even conflicting; data density with measurements differs on different parts. That's why for construction digital models it's important to have tools for interactive data processing, simulation of possible situations of receiving and correction of input data.

All the steps of working with data in GGMD include various options of graphic visualization, logging and comparison of incoming and placed to archive results.

Complex's tools give a user possibility to "play" with initial data and compare the results with prepared etalons, what is more it's allowed to import and export the data and images and to scale them. Extensive data exchange possibilities are important for simultaneous work in several software environments.

In computer system GGMD the following tools are implemented:

- tools and patterns for preparation of reference (calibration) model of digital field, which corresponds to the specified properties ("Digital field constructor");
- tools and several options of "distortion" of reference model;
- tools for data capture simulation, which are used in simulation practice ("Generator of profile observer");
- modules for calculation, visualization, comparison of digital fields approximation by several different methods ("Approximation component");
- tools and adaptation modules for digital model being formed ("Adaptation component").

# 4 Preparation Stages of a Reference Model

Digital field constructor (DFC). Software components from this group provide in interactive mode the construction of the model's surface from standard elements with accompanied visualization of mathematical description (analytic function), model's surface is interpreted as a relief – set of surface shapes.

The construction is made in the module which is programmed in system *Mathematica* and includes the generation of surface equation – function of two arguments x and y which is continuous (or piecewise continuous) and defined in the rectangle. User defines the boundaries of domain xMin and xMax, yMin and yMax and surface height limits zMin and zMax. Let's mark out that all the notations are given in format of InputForm (string format), that is accepted specially as some users can use application written in Excel, Delphi, C or others, where mathematics notation isn't supported inside the program code.

There are mathematical expressions (elements) which allow us to reproduce the behavior of the areas, which are typical for relief, in the set (library) of components of the function being formed. User at the first stage of reference model formation sets up a piecewise-defined function $zBasic(x)$, basic profile $fOriginA(x,y) = zBasic(x)$ – tape of specified width and length, which imitates the types of relief with the elements of plateau, slope, cliff. Then user can add perturbations of different shapes, sizes and orientations to the base surface.

The construction with DFC of basic profile from the fragments is possible with continuous transition "fragment – added fragment", smooth transition, a jump (imitation of split). In case of continuous, smooth transitions the "connection" parameters of piecewise-defined functions are defined automatically by program module.

The way to define a function and set a basic profile is written in expression (1):

$$
\begin{gathered}
zBasic(x) = If[xOtk1 < x \leq xOtk2, fOtk(x,0), 0]+ \\
+If[xMin \leq x \leq xOtk1, fPlt(x,0), 0]+ \\
+If[xSkl2 \leq x \leq xMax, fSkl(x,0), 0], \\
fPlt(x,y) = zPlt, \quad fPlh(x,y) = fOtk(x,y) - perkoef \cdot (x - xOtk2)^2, \\
fOtk(x,y) = \tan(ugOtk) \cdot (x - xOtk1) + zPlt, \quad zOtk2 = fOtk(xOtk2, 0), \\
fSkl(x,y) = \tan(ugSkl) \cdot (x - xSkl2) + zSkl2, \quad zSkl2 = fPlh(xSkl2, 0).
\end{gathered} \tag{1}
$$

There is an illustration on the fig. 1, where in the right part you can see a 3D plot with gradient coloring by surface level (tones blue with value of a saturation on surface height), and in addition 10 intermediate lines-levels which are showed with dotted lines (uniform grid with respect to z).

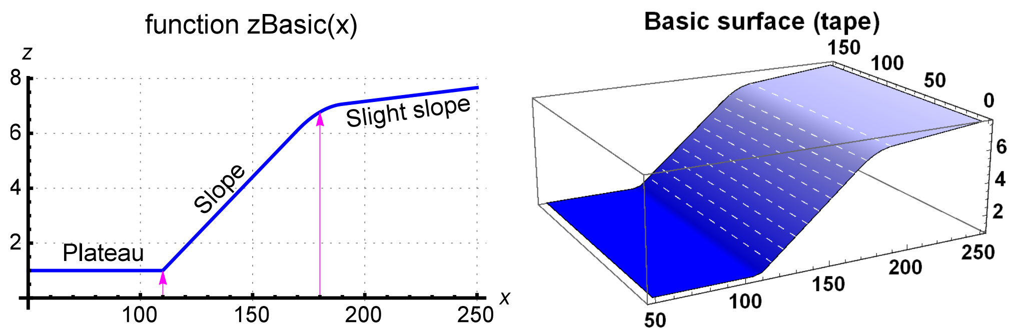


Figure 1: Plot of basic surface. Profile and 3D view.

The constants in expression (1): xMin=50, xMax=250, yMin=0, yMax=160, zMin=0, zMax=10, xOtk1=110, xOtk2=170, xSkl2=190, ugOtk=0.08, ugSkl=0.01; xOtk1, xOtk2 – are coordinates of transition points "plateau – slope", "slope – slight slope", ugOtk, ugSkl defines the inclines of slope, slight slope, zPlt=1. In the given example the base surface model is quasi three dimensional (the level of z doesn't depend on y). Basic surface (tape) is made up of 3 typical sectors: flat horizontal (plateau), flat with fast rising level (slope), flat with slow rising level (slight slope). The connection between the sectors is continuous. Transition "plateau - slope" is made at a selected angle, transition "slope - slight slope" is continuous and smooth.

The next step of construction – is usage of program module's tools to add perturbations, fragments of typical elements of relief to a basic profile. Template (patterns) library includes elements which correspond to perturbations (areas of distortion of basic surface) of different geometrical shape. While connecting the patterns it's possible to set interactively their position and size. Described mathematical elements, which imitate the following shapes of relief: hill, embankment, pit, excavation, trench, canal, quarry, ravine, vug, are included in basic package. It should be mentioned that all the elements listed above can be specified by just two expressions like $z = fFrgm(x,y)$. Besides it, those are written for the square $[1,1] \times [1,1]$, and then in the final function the arguments are scaled (the ways they can be written you can find below). For example, function (2) can be used to describe a shape of a hill type

$$fHill(x,y) = \begin{cases} \cos(\pi x/2)\cos(\pi y/2), -1 \leq x \leq 1 \cap -1 \leq y \leq 1, \\ 0. \end{cases} \quad (2)$$

It should be noticed that description of perturbation of a pit type – is the same expression but with minus. The same expression can be used to imitate smooth shapes like embankment, excavation, canal, quarry, ravine by changing the factors in front of the arguments.

An expression for an element of a trench type (with vertical walls):

$$fTrench(x,y) = \begin{cases} -1, -0.5 \leq x \leq 0.5 \cap -1 \leq y \leq 0.5, \\ 0. \end{cases} \quad (3)$$

The shapes of elements of embankment, canal, quarry, ravine types with vertical walls can be also described with an expression (3). System *Mathematica* includes a big amount of spatial graphic primitives of which cone, ball, cylinder, cuboid are used in DFC, also different pyramids are included to the library, particularly the simplest form, which is described by expression (4)

$$fPyramid(x,y) = \begin{cases} 1 - max(|x|,|y|), |x| < 1 \cap |y| < 1, \\ 0. \end{cases} \quad (4)$$

An example of reference surface model formation, which is obtained from the basic surface, by adding elements of the listed types (2 pyramids, 2 hills, pit, trench, embankment) is shown on the fig. 2. There are 3D plots of the constructed surface in two different aspects angle views (view points), in addition specific lines-levels are drawn in the pictures of surface shape. It should be considered that perturbation elements automatically being "tied"to a basic surface on all types of areas (plateu, slope, slight slope). The analytical expression for the surface formed and shown in the fig. 2 is the following:

$$\begin{gathered} zSurfB(x,y) = fOriginA(x,y)+ \\ +3 \cdot fPyramid2(0.05 \cdot (x-75), 0.03 \cdot (y-124))+ \\ +3 \cdot fPyramid1(0.06 \cdot (x-76), 0.07 \cdot (y-24))+ \\ +3.1 \cdot fHill(0.1 \cdot (x-117), 0.04 \cdot (y-25))- \\ -0.8 \cdot fTrench(0.03 \cdot (x-115), 0.02 \cdot (y-150))+ \\ +1.4 \cdot fHill(0.08 \cdot (x-168), 0.08 \cdot (y-30))+ \\ +1.5 \cdot fTrench(0.04 \cdot (x-230), 0.02 \cdot (y-144))- \\ -5 \cdot fHill(0.05 \cdot (x-220), 0.04 \cdot (y-36)), \\ fOriginA(x,y) = zBasic(x). \end{gathered} \quad (5)$$

It's important that in the resulting equation (5) the coefficients in the formulas of perturbation elements fHill, fPyramid, fTrench are chosen by user while visual construction. While visual examinations of the plots in DFC module, user have a possibility to define the coefficients of function expression by moving sliders or

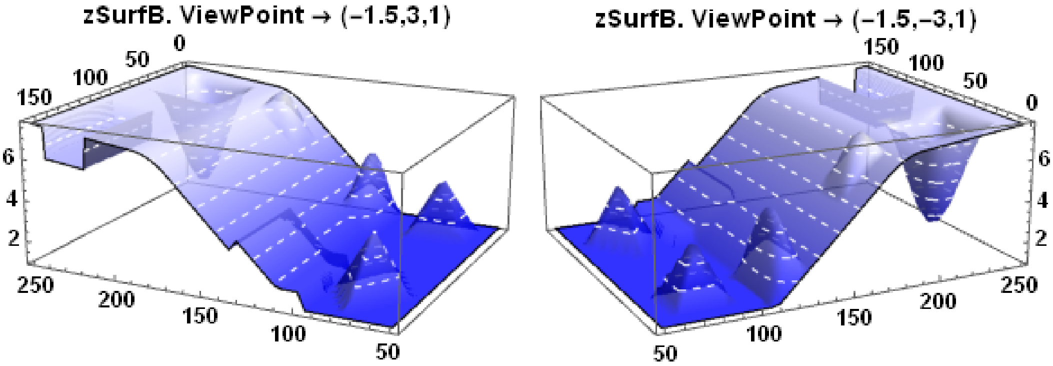


Figure 2: Plots of surface with typical elements of relief.

setting specific values on the panels which are the part of the interface of Manipulate function in system *Mathematica* (more in [11], [12], [15]).

On fig. 3 the example of creation of model of a reference surface with a little bit other positioning is reduced. For an example the sizes of two units also are changed. The surface zSurfA is raised on 3.0, level of depth of a hole 5 is substituted on 3, the height of embankment is changed. The appropriate analytical exposition is set by expression (6):

$$\begin{gathered} zSurfA(x,y) = fOriginA(x,y) + 3+ \\ +3 \cdot fPyramid2(0.05 \cdot (x-75), 0.03 \cdot (y-124))+ \\ +3 \cdot fPyramid1(0.06 \cdot (x-76), 0.07 \cdot (y-24))+ \\ +3.1 \cdot fHill(0.1 \cdot (x-117), 0.04 \cdot (y-25))- \\ -1.8 \cdot fTrench(0.03 \cdot (x-115), 0.02 \cdot (y-150))+ \\ +1.4 \cdot fHill(0.08 \cdot (x-168), 0.08 \cdot (y-30))+ \\ +1.5 \cdot fTrench(0.04 \cdot (x-230), 0.02 \cdot (y-144))- \\ -3 \cdot fHill(0.05 \cdot (x-220), 0.04 \cdot (y-36)), \\ fOriginA(x,y) = zBasic(x). \end{gathered} \tag{6}$$

Illustrations of surfaces on fig. 3 can be interpreted as a top and a base of a layer. Both surfaces are output with different levels of a transparency online customised by the user (in the given example they are 0.8 and 0.4).

Model visualization tools. More than ten options of 1D, 2D and 3D plots were implemented in GGMD system, including modules for obtaining and designing maps and inserts on them, plots on profiles, 3D visualizations of possible incisions (vertical, horizontal), clipping (simple and complex). The illustrations of the usage of several visualization tools are given below. Results are presented in the second part of paper.

# 5 Conclusion

The tools of automated workstation of specialist, who during the computational experiments can work out techniques of adaptation of digital fields, which applied

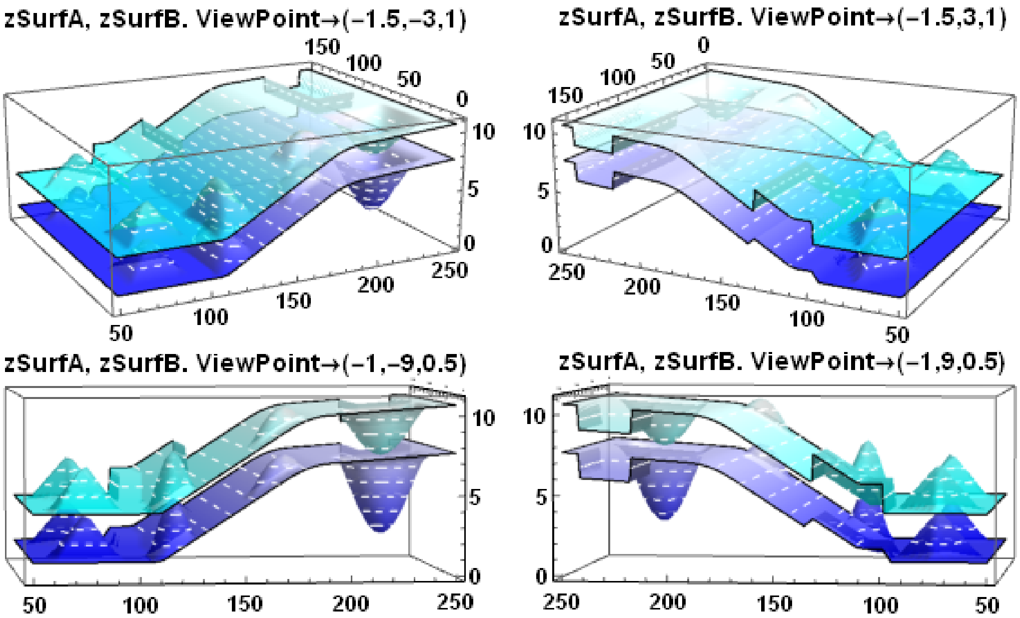


Figure 3: Plots of two similar surfaces of different levels.

to problem of geological models formation, are described. The developed integrated computer system gives manipulation possibilities initial data, the analysis and comparison of interpretations and variants of the experts received in the different ways of results and standards.

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