

# 3D modeling in GIS

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*Lecture notes on the masters course ITM-E3DM E at the  
Eötvös Loránd University – Faculty of Informatics*

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## Introduction

This subject is aimed for those students, who are already familiar with GIS applications like ArcGIS, Grass or QGIS. **The aim of the subject is to get acquainted with the GIS base of 3D modeling and to put this knowledge in practice.** This aim is targeted with both theoretical and practical classes during the semester.

The theory and the practice together tightly fit into 1.5 hour classes in weekly schedules of one semester. The theoretical topics are focusing on a general approach to 3D modeling. Since 3D modeling tasks can be extremely different from each-other, modeling projects are discussed as series of tasks in many different digital environments. Usually in a real-life task the case is like this: one gets a bunch of very different data, and a deadline to create something in 3D. If the connection between these data-sources is not established, the system will not work.

The exercises are focusing on the use of a simple GIS tool (Global Mapper), a surface modeling tool (Surfer) and a 3D modeling tool (Jewel Suite). In general the exercises contain step-by-step guides for the tasks. This way using these notes, students can practice and explore the discussed tools on their own if they missed one of the classes.

The course material is designed for 10 demonstrative classes and two, or three guided classes. The demonstrative classes contain theoretical parts, but gradually the emphasis shifts to the exercises towards the second part of the semester. On the guided classes students should work on a special modeling task, which simulates a real-life problem. Their work is monitored and if it is necessary, help is given to them to proceed.

### Themes of the semester

- Weeks 1–2: Concepts and theoretic base of 3D modeling. Types and the “scale” of 3D models. Data and objects in the model. Types of different modeling applications, and the usage of 3D models in the Earth sciences.
- Weeks 3–4: Hierarchical data management. Data management systems of the 3D model and their functionalities. The source and the management of primary data. Converting raster into vector and further into numerical data or converting raster directly into numerical data. The structure of GIS databases.
- Weeks 5–6: The 2D GIS base of the 3D model. GIS topology types. Connection between the sub-systems. Data mining, data classification and data analysis.

- Weeks 7–9: The modeling procedure. Classification of 3D modeling methods. Comparison of the regular and irregular data-model. Simple and complicated irregular models. The concept of tessellation.
- Weeks 10–11: Simple and complicated regular models. Processing and storing grid data. Calculation of grid point values. The concept of scalar-space and vector-space. The medium and the requirements of the visualization. The conceptual 3D model. Models in the virtual space. Tools for visualization and querying.
- Week 12-13: Own work, practice, consulting.

The following material was edited according to the sequence of the above mentioned topics. Theoretical parts are represented as slides of presentations, while the practical parts – usually following the theoretical slides – contain detailed instructions for the students how to use certain GIS tools and modeling applications (Global Mapper, Surfer and Jewel Suite). The practical parts contain references to sample files which can be accessed from the server of the Eötvös Loránd University, at each time this course is advertised.

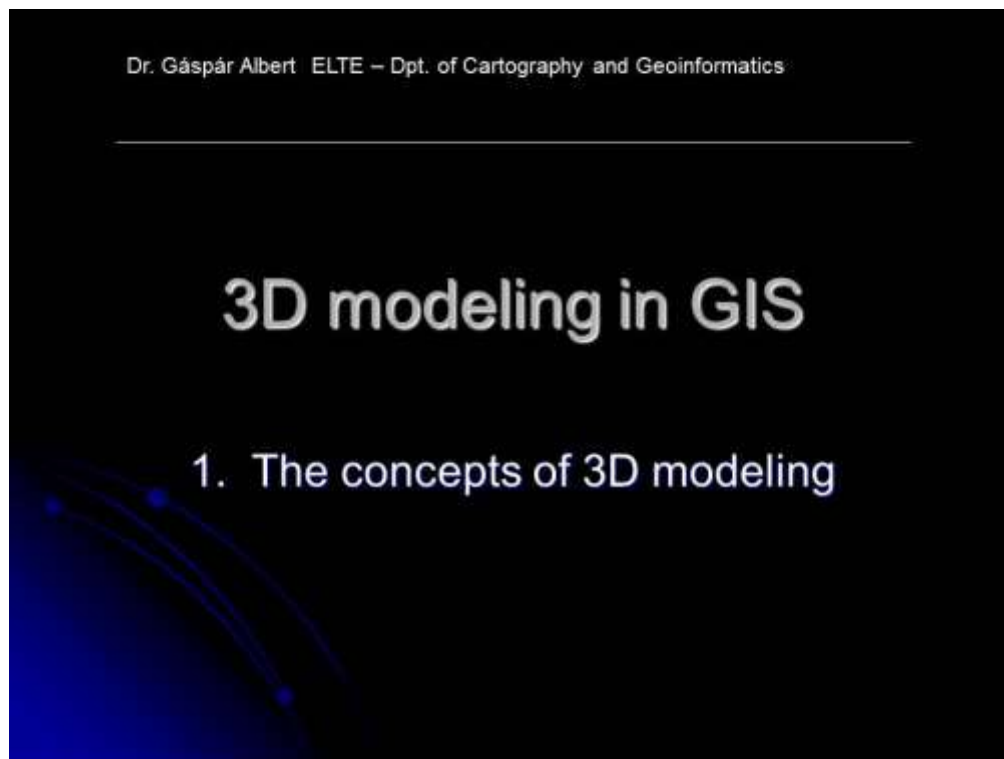
## Lesson 1.

The topics of this class are the followings:

- Concepts of 3D modeling (definition of a model, mockup, modeling, 3D or 2.5D or 4D models).
- When do we construct models?
- Models before the IT age.
- Practical use of 3D models.

Practice: Types of 3D models. 2D components of 3D models. The use of Global Mapper – data I/O. working with SRTM data.

### Concepts of 3D modeling



Slide 1 Welcome slide of the first theoretical class

# Introduction / history



BASED ON:

- Digital map-editing and design (CAD)
- Thematic databases
- Remote sensing technology

Slide 2 Overview of the evolution of 3D GIS mentioning the base technologies.

## Definition of the scope of modeling concepts

The model is a logic pattern, plan, representation, or description, designed to demonstrate the structure and functioning of an object, system or concept.

*3D modeling: interpretation and display of information (data) the 3D Euclidean space.*

A digital 3D model primarily is a:

- computer model
- datamodel

Necessary requirements of scientific models

But it also can be:

- *abstract (or logical) model*
- *cause-and-effect model*
- *mathematical model*

...or:

- *mental model*

Scientific model: describes observable phenomena.

Slide 3 Defining the concept of modeling, with an emphasis on "scientific models"

## Definition of the scope of modeling concepts – cont. I.

Stereographic plot: abstraction of a plane in 3D

- the **abstract (or logical) model** is a conceptual element or abstraction which is used to produce the formula for forecasting the behavior of a subject. It works in an idealized logical framework and uses variables in mathematical sense. The logical and quantitative relationships between these variables are also included.
- the **cause-and-effect model** is an abstract model that uses the logic of cause-and-effect relationship for describing systems.
- A **mathematical model** is an abstract model, which is formulated in the language of mathematics.



$$q = \sin\left(\frac{\pi}{2} - \varphi\right)$$

$$x = q \times \sin \lambda$$

$$y = q \times \cos \lambda$$

Formule of stereographic projection

Slide 4 Definition of the abstract, the cause-and-effect, and the mathematical models with samples

## Definition of the scope of modeling concepts – cont. II.

- A **computer model** is a computer program that attempts to simulate an abstract model of a particular system.
- The **data model** is a description of a database system.
- A **mental model** is a person's cognitive image of a certain concept or thought-process.

Slide 5 Definition of the computer model, the datamodel, and the mental model

## Other known expressions

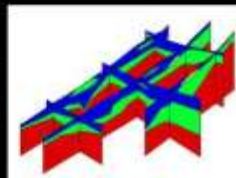
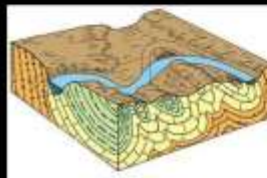
- 2,5D model: surface model, where the „3rd” dimension is only an attribute.
- 4D model: a 3D model which is used to simulate a process in time.

Slide 6 Definition of common expressions like 2.5D and 4D models

## A historical overview of 3D modeling

Three-dimensional models are not tied to the release of the „IT revolution”.

- hand drawn:
  - block diagram
  - section grids
- tangible:
  - plaster models



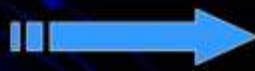
Purpose: to display the spatial information in more picturesque form than the two-dimensional methods (like sections or maps).



Slide 7 Hand drawn and tangible models before the digital era

## A historical overview of 3D modeling – cont. I.

- The hand-drawn models were compiled with the application of the rules of geometry and engineering.
  - axonometric representations (isometric, orthogonal)
  - perspective representation (one-, two-, three-point directions)
- Not well suited for data analysis, it is difficult, to read data from them.



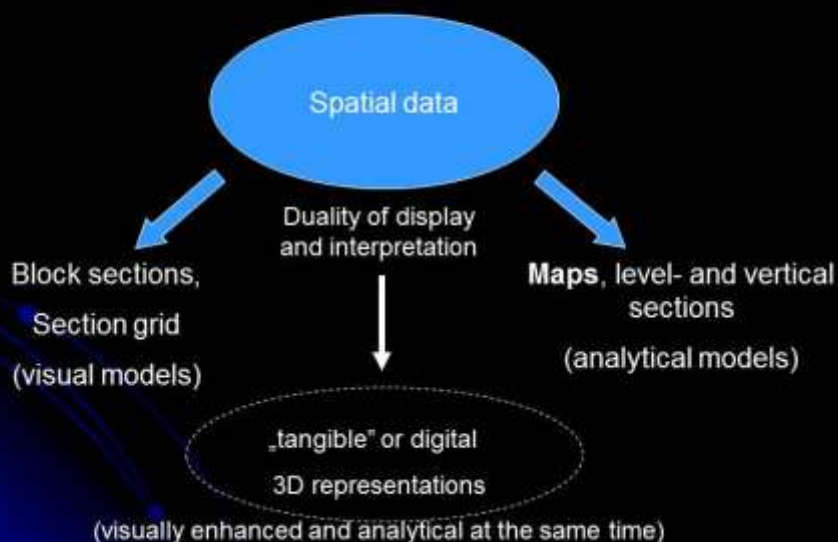
Prior to the appearance of the virtual 3D models *maps, horizontal and vertical sections* were the most suitable for data analysis, because they can be displayed on paper easily.



2D, or "paper" paradigm

Slide 8 Introducing the data reading difficulties of spatial representations

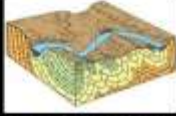

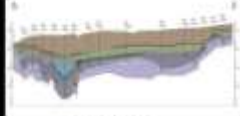
## Duality of data display in 3D



Slide 9 The duality of data display in 3D



## Advantages - disadvantages (ca. 1995)

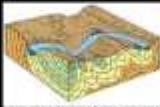

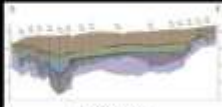
|               |  |  |  |
|---------------|---|---|--|
|               | block diagram   | tangible mock-up  | section  |
| data analysis | ☹️  | ☹️  | 😊  |
| sight         | 😊   | ☹️  | ☹️   |
| time          | ☹️  | ☹️  | 😊  |
| expense       | ☹️  | ☹️  | 😊  |

↓
Nice but not practical
↓

solution for visual models
Preferred solution (best for analytical models)

Slide 10 Advantages and disadvantages of the block diagrams, mock-ups and 2D sections

## Comparison of the favorites

|               |  |  |  |
|---------------|---|---|---|
|               | block diagram   | digital 3D model  | section   |
| data analysis | ☹️  | 😊   | 😊   |
| sight         | 😊   | 😊   | ☹️  |
| time          | ☹️  | ☹️ → 😊  | 😊   |
| expense       | ☹️  | ☹️ → 😊  | 😊   |
| utilization   | ☹️  | 😊   | ☹️  |
| interactivity | ☹️  | 😊   | ☹️  |

The „best“ solution is always decided on the money and time options, but 3D is becoming the most favorable.

Slide 11 Comparison of the block diagram, digital 3D model and a 2D section from different aspects (utilization refers to the possibility to use the model for different purposes).

## Survival of the "paper" paradigm

- The slow response of scientific "community",
- To disseminate spatial information we still use paper (or screen, but static 2D).

It is difficult to break away from a tried and tested method, even when working with digital 3D model. However, it slows down the editing process and the evaluation.

Slide 12 Reasons for the survival of the "paper paradigm" today

## Why is it wrong, the "paper" paradigm?

- The vertical and horizontal sections, or even three-dimensional still images are available only for a **limited range of data display**.\*
- We see three-dimensional objects in predefined views; there is **no interactivity**.
- The limit of the data display is also a **restriction on interpretation**.
- Plane projection of the 3D modeling environment **consumes valuable time**.

\* More and more data are stored in several spatial database, which means that smaller and smaller proportion can be displayed in 2D „sections“.

Slide 13 Reasons why we should abandon the "paper paradigm"

# Using 2D data during modeling

...or reversing the paper paradigm.

- The structure of the model is defined by the modeler.

This is called: „explicit modeling”

e.g.: the sections are imported into the 3D modeling environment as base data.



2D data can be:

- Maps with qualitative/quantitative data
- Vertical and horizontal sections

**In general:** 2D sources which originally contain spatial information and are created for analytical purposes are used in explicit 3D modeling.

Slide 14 Introducing the basic model-building methods – the explicit modeling

# Leaving the 2D paradigm behind

Implicit modeling:

- The measured data is processed automatically with mathematical functions and statistical processes within the modeling environment.
- The modeler adjust the mathematics behind the process (and not the model itself).

The base data is a **pointcloud** data from different sources:

- Lidar,
- photogrammetric,
- seismic,
- meteorological,
- individual measurements, etc.

Slide 15 The implicit method

## Practical part of lesson 1 – the use of Global Mapper (part 1.)

The topics and exercises of the first practical class are listed below. The level of details of the discussion concerning each topic depends on the experience of the students.

1. Locate the webpage of SRTM (Shuttle Radar Topography Mission) on the Internet and download data from it.
  2. Read the readme file before opening the downloaded data.
  3. Import the data into Global Mapper.  
During opening: Why GM is good for us? – Overview of file formats in the import menu.
  4. Reviewing the File menu items:  
File-Open, Unload, Catalogue, Download online data (Landsat), Workspace, Script (online help), Export, Combine Layers, Generate contours, Rectify
  5. Reviewing the Tools menu (try out each of them)
- 

Data traffic I-O:

6. Cut an area from the workspace (export raster to kml/kmz with defined bounds), then open it with Google Earth.
  7. Draw polygons, polylines, and points in GE and export them to kml-files.
- 

Transformation of data from kml to different formats (without GM i.e.: <http://www.zonums.com>)

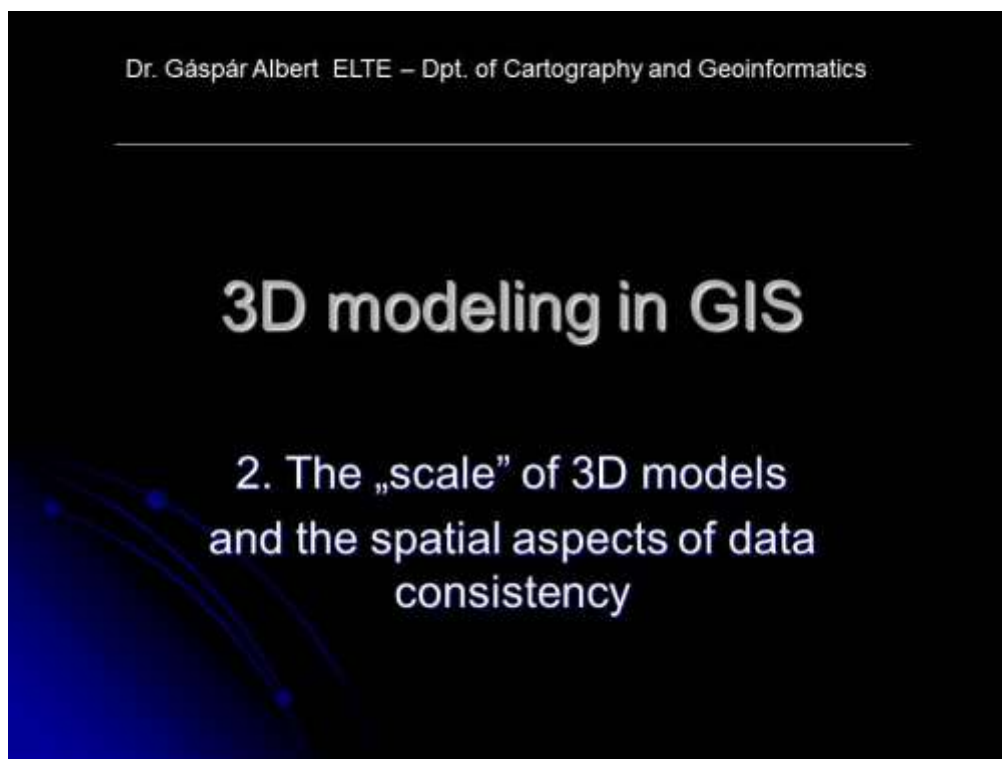
## Lesson 2.

The topics of this class are the followings:

- The scale of 3D models (resolution, the concept of thematic scale/resolution).
- The coherence of data (mashup of measurements in one system).
- Objects in the model (point, line, polyline, plane, surface, polyface mesh, solid).

Practice: overview of different modeling software for earth sciences (Surfer, Rockworks, Modflow, Petrel, JewelSuite, Move, Vulcan, etc.). Working with GlobalMapper – definition and analysis of the data structure (new features, adding attributes), composition of cross-sections and extracting elevation data from surface models (file export).

### The „scale” of 3D models and the spatial aspects of data consistency



Slide 16 Welcome slide of the theoretical presentation

## The preconditions for 3D modeling

The first and most important task is to outline the purpose of the model.  
(or in other words: to decide what the model will be used for).



Selection of the modeling environment:

- *RockWare?*
- *Move?*
- *ArcGIS?*
- *Mapinfo 3D?*
- *FeFlow?*
- *GoCAD?*
- *Kingdom?*
- *Maya?*
- *AutoCad Map?*
- *Jewel Suite?*
- *MATLAB?*
- *Open GIS?*
- *Surfer?*
- *Petrel?*
- *PhotoScan?*
- *X3D?*

Slide 17 Start the modeling with defining the purpose of the model

## Modeling software, which meet every requirement, does not exist!

- Technologically (web, server, pc, op-system)
- Data model (finite element, voxel)
- Coordinate system (Cartesian, polar)
- Visualization (orthogonal, perspective)
- Ergonomically (input-output formats, GUI)
- Price

...enormous differences may exist.

Slide 18 Keep our expectations in bounds: tools for all purposes are dreams!

# The general-purpose 3D models

- Possible tasks with a general 3D model:

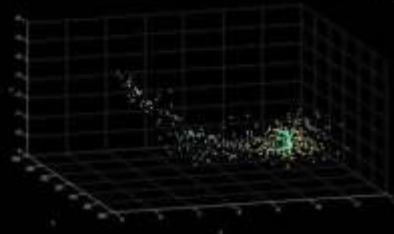
- Modeling of identified surfaces
- Modeling solids with boundary conditions
- Modeling intersecting surfaces

- *Real 3D modeling of objects:*

A modeling process, when we can produce any 3D shape and we can analyze the spatial properties of it (eg. **volume** and the **surface**).

Slide 19 The general purposes of 3D models and the “real 3D modeling”

# Three-dimensional shapes in the model



Point clouds:

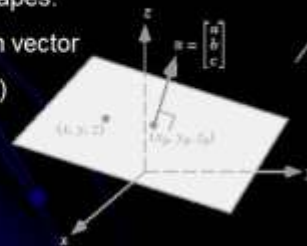
- with- or without attributes

3D polylines:

- directional / non-directional
- data-like / smoothed

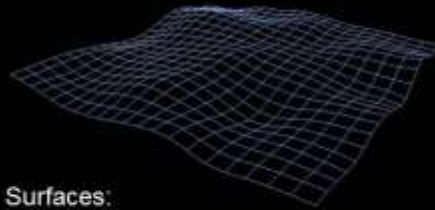
Simple planar shapes:

- Point + direction vector
- 3 point (triangle)



Slide 20 Object and shapes in a 3D model – point clouds, lines, polylines, planes

# Three-dimensional shapes of the model

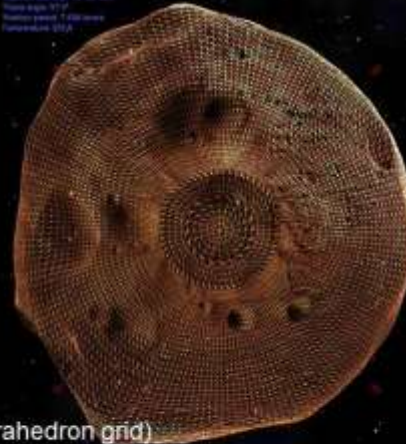


Surfaces:

- 2D data grid, TIN
- Smoothed surfaces (Beziér, NURB)

Photo: Mars 1

Latitude: 57.000000  
Longitude: 137.000000  
Elevation: 1000.000000  
Scale: 1:1000000  
Projection: UTM  
Datum: WGS 84



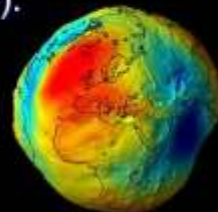
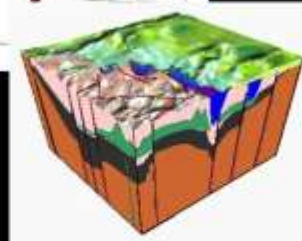
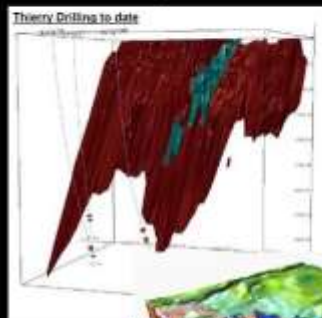
Solids:

- 3D data grid (voxel, FE / tetrahedron grid)
- parameterized surfaces (polar-sphere, -ellipsoid)

Slide 21 Object and shapes in a 3D model – surfaces, solids

# Data density categorization (nominal scale)

- Local model (e.g. *engineering geological models*).
- Regional model (e.g. *basin models*).
- Geosphere models (e.g. *geoid model*).



Slide 22 The different (nominal) scales of the models demonstrated with geological models



# The scale of the model

The scale of the model is a theoretical concept that can be characterized by the frequency of observations (number per volumetric unit).

|          | Nominal scale | Number of observations per 1 km <sup>3</sup> |                       |
|----------|---------------|--|-----------------------|
| Regional | 1: 250 000    | 0,06   | ↑<br>Geosphere models |
|          | 1:200 000     | 0,13   |                       |
|          | 1:100 000     | 1  |                       |
|          | 1:50 000      | 8  |                       |
|          | 1:25 000      | 64   |                       |
| Local    | 1:10 000      | 1 000  | ↓<br>Micro models     |
|          | 1:5 000       | 8 000  |                       |
|          | 1:1 000       | 1 000 000                                    |                       |
|          | 1:500         | 8 000 000                                    |                       |
|          | 1:100         | 1 000 000 000                                |                       |

Slide 23 Definition for the different nominal scale categories

# The scale of the model

- Calculation of required number of points per km<sup>3</sup> [P] for a given nominal scale [M]:

$$P = \frac{10^{15}}{M^3}$$

- Calculation of the nominal scale [M] from a given number of observation [P] per km<sup>3</sup>:

$$M = \sqrt[3]{P^{-1}} * 10^5$$

Slide 24 Calculations of the nominal scale from the number of data points and the required number of data for a given scale.

# Data correction prior to use

- Where is the data from?
  1. own measurements
  2. elsewhere (database, maps, measure logs, etc.).
- What is the accuracy of the data? – are there any metadata attached to it?
- Is it fit into our model?
  - Polar <> Cartesian coordinates
  - Difference of projections (of maps) and coordinate systems
  - Different measurement system (m, ft)
  - different calibration between the measured datasets
  - ... may cause visible or hidden mismatch.

Slide 25 Data correction prior to use.

# Is the data fits in our model?

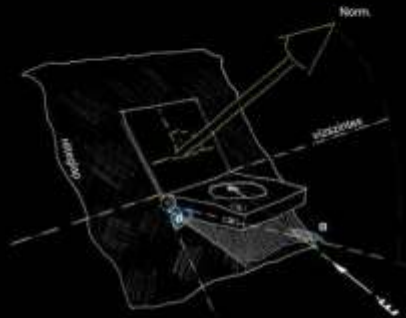
Task:

1. Identify the direction and the dip angle of planar and linear elements on a rock surface.
2. Insert the measured data into a Cartesian space.

What was measured?

1. XYZ, or  $\phi \lambda$  ?
2. The direction and the dip angle compares to what?

The measured values are relative angles to the Earth's current magnetic meridian lines (Declination lines).



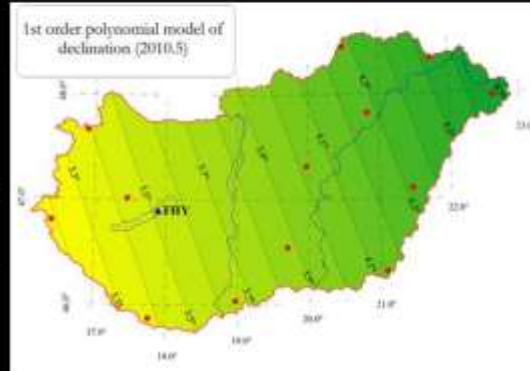
Slide 26 Introducing the problem of data import into a modeling environment

## Magnetic measurement data correction

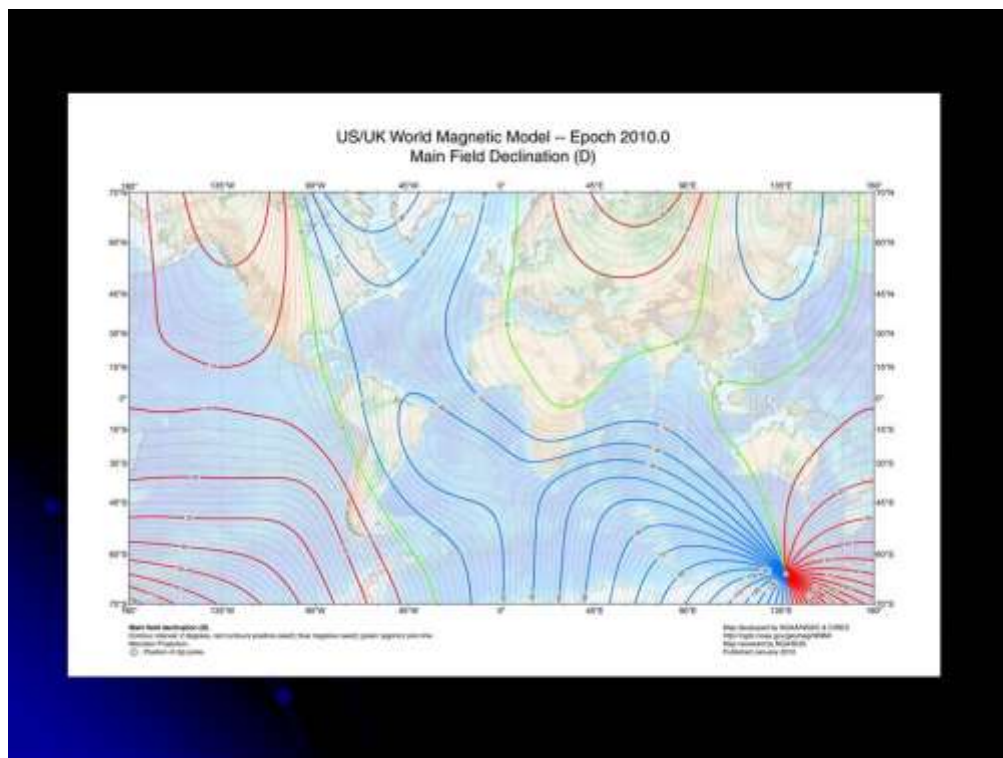
The northern axis of a Cartesian coordinate system usually differ from the actual geographic and magnetic north. The difference increases with the distance from the starting-meridian of the actual projection.

Above: The normal spaces of the magnetic declination (D) in Hungary for the epoch 1995.0. The magnetic isolines represent  $0^{\circ} 6'$  (Kovács and Körmendi 1999).

Below: the same 15 years later (Kovács et al. 2010)



Slide 27 A discrepancy in the coherence of data may originate from the different time of magnetic measurements because the magnetic declination is continuously changing.



Slide 28 The source of magnetic data in recently used navigation systems is the WMM (World Magnetic Model)

## The benefits of a well constructed model:

- It is good for **rapid data analysis**.
- The view of the visualized data from multiple (virtual) point, may lead to **new interpretations**.
- The spectacular 3D display is suitable for the **professional presentation** of results.
- The visual images **can reach wide audience**, and thus the value of information will increase.

Slide 29 The possible benefits of a well-constructed model

### References in the slides:

Kovács, P., Körmendi, A. 1999: Geomagnetic repeat station survey in Hungary during 1994–1995 and the secular variation of the field between 1950 and 1995. – Geophysical Transactions, 42 (3-4) pp. 107–132.

Kovács, P., Csontos, A., Heilig, B., Koppán, A. 2012: Hungarian repeat station survey, 2010 – ANNALS OF GEOPHYSICS, 55, 6, 2012

Mihályi Sz. 1995: The descriptive catalog of the Hungarian geodetic related projection systems - 4. ed – Institute of Geodesy, Cartography and Remote Sensing, Budapest

## Practical part of lesson 2 – the use of Global Mapper (part 2.)

The aim of the class is to get familiar with the general file formats describing points, lines, polylines, and to study the attributing capacity of these formats.

### Importing raster map into the GIS environment

1. Load a raster map (open->All supported raster types). If the file isn't georeferenced, then: rectify (select a coordinate system, add 4 points).  
Find the 74\_423.jpg file; say yes to the popup question. An Image Rectifier window appears. On the lower part of the panel set the Ground Control Point (GCP) Projection to Hungarian National Grid and press OK. Set the coordinates of the four corner points according to the following table:

|                    | Easting | Northing |
|--------------------|---------|----------|
| <b>Upper left</b>  | 612 000 | 268 000  |
| <b>Upper right</b> | 618 000 | 268 000  |
| <b>Lower right</b> | 618 000 | 264 000  |
| <b>Lower Left</b>  | 612 000 | 264 000  |

Press OK when finished.

### Digitization

2. Configure the attribute to be added to the line type (*Tools-Configuration, Line Styles panel*). Choose the line type you want to use, or create a new one, then clicking on the *Attributes* button, specify the attribute you want to add to the line during digitization – create an ELEVATION attribute (you can also set default values, if you choose). On the *Vector display* panel you can set that only those types of lines be selectable, what you had used.
3. Digitize some contour lines as for an exercise. Give descriptive name to the objects (try to add identical names, see if it is allowed).  
*Attention! In the database, managed by the GM in the background, the identity of the names is not a problem, because the objects aren't identified on this basis. GM creates its own unique identifier field in its database! The name is only an attribute assigned to the object.*
4. Look at the information of the lines with the query *Feature info tool*. We can see that the geometric data of the program is also stored in the background database (number of vertices, length), and we can look into the stored data pressing the *Vertices* button.
5. Select vertices in the *Feature Vertex List* window and see that the selected vertices are highlighted in the map window. Press the *Edit position* button to relocate the selected vertex. Press the *Add Elevation* button to create a new ELEVATION field in the Feature vertex table (Note that you can also modify the elevation values, although in the map view this will not change anything!).

6. Rename the created feature in the *Control Center* (push the right mouse button – Edit the selected Layer’s description).

### Output formats

7. Export the overlay into different vector formats (ascii), and see how they look like in notepad.  
File formats: xyz (Simple Ascii text); bln (Surfer line); dxf (Autocad); kml/kmz (Google Earth); gpx (GPS Exchange).

Look at the content of the file! Notice how coordinates are written, what the name of each line is, what the file structure look like, etc...

Important observation! Which file type can store attributes and how it is formulated? To start working in a modelling environment, one has to know how to convert data into the proper format.

### Differences of data structures

8. Open the AG001.kml in Global Mapper, and inspect the point with the *Feature info tool*. Do the same with the AG001\_Global.kml.
9. Open both files in Google Earth, and inspect the points with clicking on them.
10. In Notepad we can compare the structure of the two kmls.

Questions concerning the study-kmls:

- Are these kmls database?
- What is the purpose of each?

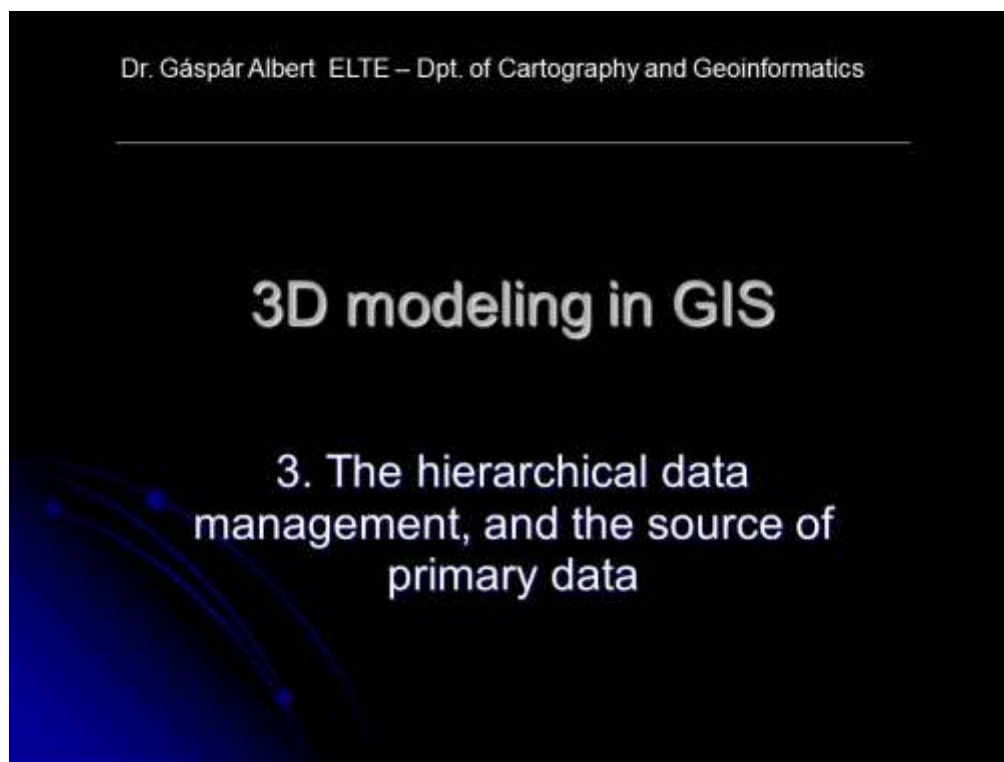
## Lesson 3.

The topics of this class are the followings:

- Hierarchical management of data (primary-, or base data, secondary-, or compiled data)
- Data system of 3D models (connecting completely different subsystems into one, management of the data system).
- The functionalities of the data system (processing, storing, analysis and visualization).
- The source of primary data (maps, notes, log files, measurements in air/ on surface/ underground).

Practice: Constructing surface models from Excel. The use of Surfer – data input (points/lines/surfaces), and the parameterization of the modelling process.

### The hierarchical data management, and the source of primary data



Slide 30 Welcome slide of theoretical class No. 3.

# The functionalities of the data system in a 3D model

The *data system* = Informatical (GIS) background of the model

- *Processing*
- *Storage*
- *Representation*

You can call the structure of an information system optimal, if — based on these three functionalities — the time and energy invested in the operation and development of the IT apparatus is at least one order of magnitude lower, than if the same results would have been achieved without operating the system.

Slide 31 Basic functionalities of the data system of a 3D modeling project

## Processing

The data processing tool is responsible for the digital recording of text, alphanumeric (and logical) elements, images and vector-geometry.

- Word processing
- Using spreadsheets, tables
- Image processing
- Vector graphics (CAD)

The question is:  
Is the modeling software able to handle these tasks by itself?

Slide 32 Usual types of the processed information in a 3D modelling task



# Storing

Data storage devices provide secure data store and availability.

- Alphanumeric (and numerically coded) and logical data -> (databases)
- Images (photos, scanned manuscripts)
- Texts (documents)

Digital data is located on mass storage devices in its appropriate format.



The question is:  
Is the modeling software able to handle these tasks by itself?

Slide 33 The aspects of data storing

# Representation (visualization)

The tool, which represents the data as a 3D model is a complex application which not only visualize the data, but most often serve as the modelling environ.

Data visualization depends on the type of the data.

- For spatial data (points, lines, planes, meshes, solids), create the visual experience of space.
- For texts, formatting and readability is important.
- Images should remain true to their color and shape.

A modeling software is a visualization tool itself. Can it handle these tasks?

Slide 34 The aspects of data representation (visualization)

# Could the software be used?

A generalized summary of the main criteria imposed on a modeling software, used to produce three-dimensional models (Albert 2003). The software should:

1. be able to **import** and **export** 3D (xyz) data in the easiest and most commonly used form;
2. be able to build up surfaces easily, quickly and **without the deformation of the original data** (or with the controlled modification of them);
3. support the handling and the build up of a **complex entity structure** in a "user friendly" way (e.g. turn layers on and off, rename them, select objects on them, group objects on layers, etc.);
4. be able to **construct, and reconstruct the entities** of the model (including the surfaces) **dynamically** using the latest incoming data;
5. have the possibility to **rotate the model arbitrarily**, and perform geometric operations in the virtual space;
6. support the **modification of the entities in any view**, the optional projection of the visualization, and the peeling off of generated surfaces;
7. support the automatic **creation of sections (polylinear vertical, horizontal, oblique)**, including any surface that has been defined in the model;
8. have the option to **run executable scripts** to avoid repeating the same orders;
9. have the possibility to **represent scenarios** in a way that is **close to reality** (to produce rendered images of the 3D model);
10. **have GIS options**, in order to analyse the entities of the model and their attributes which are stored in different databases.

Slide 35 Criteria for the usability of any software from the aspect of 3D modeling

## Additional criteria

- The generally expected requirements imposed on a GIS software i.e.:
  - Display coordinates correctly
  - Point, line, polygon production
  - length, area calculations

These are also valid for programs, which are used in modeling, but completed with the functionality required for *true 3D modeling*.

---

*True 3D modeling* is usually seen when any shape can be created with the modeling software, and the spatial properties can be analyzed (e.g. volume and surface).

Slide 36 Criteria for any software, which is used for GIS purposes

# The Hierarchy of Data

The modeling\* methods are mainly based on mathematical estimation methods (e.g., linear interpolation, kriging etc). With these operations, new data are generated from the existing spatial data. The original and the new data are distinguished.

- **Primary** or static data value is unchanged\* in the modeling process.
- **Secondary** or derived data varies depending on the modeling properties and the amount of the primary data.

\*or accessible in original form

Slide 37 Definition of primary and secondary data

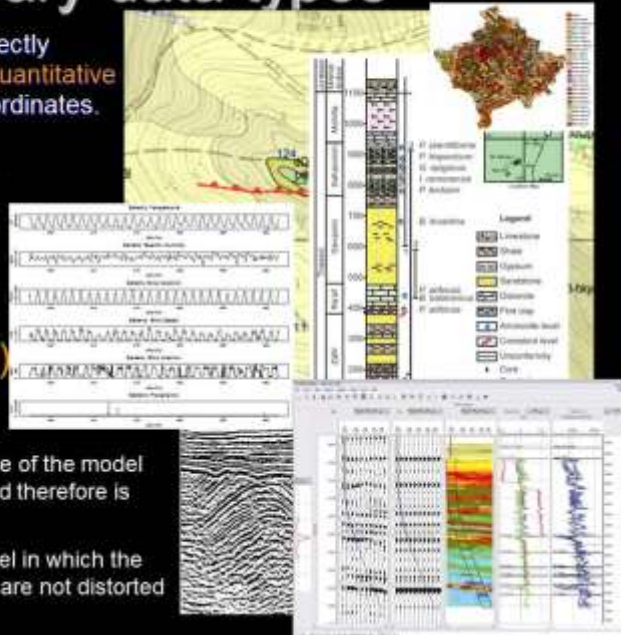
# Primary data types

The primary data is a directly observed **qualitative** or **quantitative** data associated with coordinates.

- **Qualitative** (e.g. rock type)
- **Quantitative** (e.g. concentration)

The primary data is the base of the model (and all other analyzes), and therefore is also known as **basic data**.

Our goal is to create a model in which the basic data and their values are not distorted



Slide 38 Types of primary data (differentiating quantitative and qualitative)

# Derived data in the model

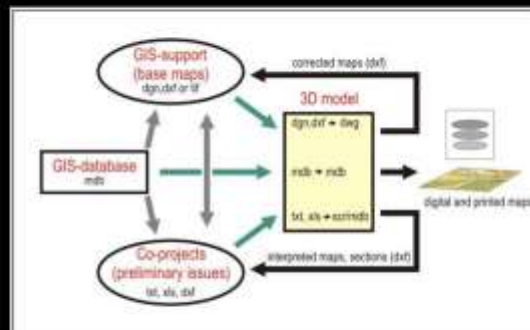
They can provide estimation for qualitative or quantitative parameters in any spatial point in the model.

- The derived data are formed during estimation procedures.
- The resulting data points can be overridden newer, higher priority data (e.g. new measurements).
- Depending on the modeling method they may occur in the model as regular or irregular geometric objects.

Due to the variability of the derived data, **linear** or **iterative** model building process can take place.

Slide 39 Derived data in the model

## Linear and iterative model building processes



The data is queried from one or more database, which are often under development during the process. The model needs to be iteratively rebuilt.



- automation
- interactive editing

Slide 40 Linear and iterative model building processes

# The source of primary data

The base of 3D models are the static data, which may include:

- Thematic maps.
- Topography data (maps, measurements).
- Observation records (base data collections).
- Sampling records.
- Instrumental measurements.

Questions (relating primarily to the timing of our work):

- Are these data organized systematically?
- Can we fit them into the model without any modification?

Slide 41 Different sources of primary data

## Organized / Unorganized topographic map data

Vector map in a topographic coordinate system.

- suitable for DTM
- the topology can be analyzed



Scanned raster map

- not suitable for DTM
- no topology

Slide 42 Maps as primary data sources, and the aspects of data acquisition from them (organized/unorganized map data)

# Systematization of observations

Database of observations, photos

- Suitable for analysis
- Quick data retrieval



Hand-written manuscripts

- Hard to analyze
- Slow data retrieval

Slide 43 Organized and unorganized primary data stored in digital and analogue “databases”

## Checklist prior to modeling

- Consider the data system (use of the processing, storage and visualization tools).
- Consider other assets (e.g. applications, software utilities to develop) for supplementing the data system
- Pay attention to the naming system and accessibility of the files during the data model planning (e.g. folder structure, file naming guidelines).

Slide 44 Important considerations prior to the modeling

## References in the slides:

Albert G. 2003: Modelling of subsurface geological structures on a future disposal site of low- and intermediate-level radioactive wastes. – European Geologist. Journal of the European Federation of Geologists, Dec. 2003, pp. 23–26.

Elek I. 2006: Introduction to geoinformatics – ELTE Eötvös Kiadó, Budapest, 2006.

## Practical part of lesson 3 – Use of Surfer (part 1)

Surfer is a GIS tool with 2.5D modelling capacity.

Aim of the class is to compile maps using Surfer 10 from point data. Use the available Excel table (*Peldaadatok.xls*).

1. Available items in the Map menu:

a. *Base Map* – load one map (dxf, shp, bln file) from the working region.

Go back to the *Grid* menu and cut the grid with the *Blank* menu option.

b. *Contour Map* (New, Labels, Export)

c. *Post Map* (post point names and texts from a database or a map file onto a map as a new object).

d. *Image Map* convert the grid values into 0-255 greyscale raster on a given resolution (TIF-files can be created).

e. *Shaded relief* (creates shades on the surface according to the elevation)

f. *Vector map* (shows the direction and the rate of the difference between data points in the grid as a vector on the map). Two grids can be also combined.

g. *Wireframe* (3D view wireframe)

h. *Surface* (3D view colour)

In the next subchapters exercises with these menu items are described.

## Creating point maps

2. Map – New – Post map (select *Peldaadatok.xls* worksheet: Munka1). In the Object manager (upper left panel) select the “Post” object from the tree structure. In the property manager (lower left panel) set the X and Y coordinates to LAT and LON (say yes to the popup message).

Set the sizing method to “proportional” and press the “scaling” button. In the popup window, select the column F for “worksheet column containing height”. Try different symbol styles in the “marker properties”.

3. Export the post map into a kml (File – Export); in the popup window, select the kml/kmz panel and turn on the “render marker symbols” option. Open the file with Google Earth and look at the “object IDs” of the points (the IDs were assigned to the objects by the Surfer and the original IDs were not used).

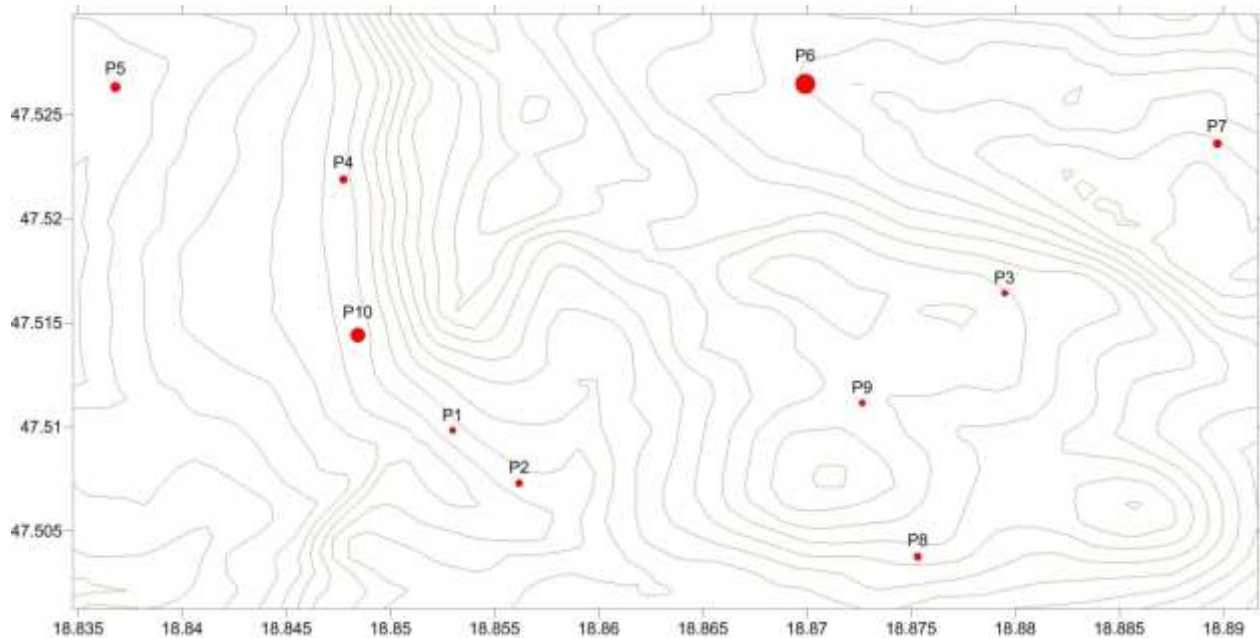


Figure 1 The layout of the post map overlay (Peldaadatok.xls) and the base map (contours.dxf) overlay

### Creating line maps

4. Map – Add – Base map (select contours.dxf) and press ok for the popup questions. In the Object manager the “Base” base map will occur. Slowly double-click on it and rename to: “dxf contours”. Expanding the + sign the objects (polylines) will be listed.
5. Map – Add – Base map (select landsat rgb.tif) and press ok for the popup questions.

### Creating surfaces

6. Grid – Data... menu (importing the table); specify the parameters of the grid, select the interpolation method, specify the output file name. [This method will be discussed in details in the next lesson]

Interpolation in Surfer:



Yang, C.-S., Kao, S.-P., Lee, F.-B., & Hung, P.-S. (2004). Twelve different interpolation methods: a case study of Surfer 8.0. Paper presented at the XXth ISPRS Congress Technical Commission II, Istanbul, Turkey. <http://www.isprs.org/proceedings/xxxv/congress/comm2/papers/231.pdf>

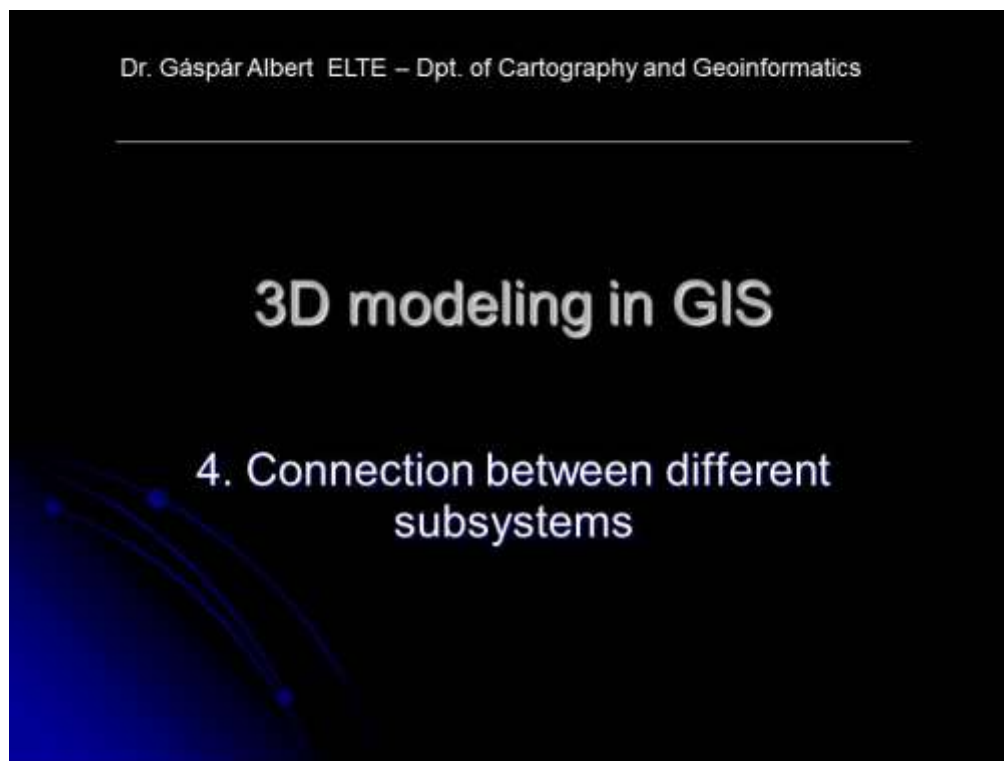
## Lesson 4.

The topics of this class are the followings:

- Connection between the different subsystems in the *data system* (3D measurements linked to GIS).
- Management of primary data (definition of the structure of the data: i.e. predefinition/post-process revision).

Practice: The use of Surfer – data analysis and visualization. Different output file types for different applications (e.g. for AutoCad/Global Mapper/JewelSuite/ArcGIS).

### Connection between different subsystems



Slide 45 Title slide of the 4<sup>th</sup> theoretical class

## Types of the subsystem

*Functionalities of the subsystems :*

- *Processing (text, raster, vector)*
- *Storage (database, folder structure)*
- *Visualization (map, 3D)*

The subsystems can be connected into a datasystem if:

- The **data transfer** is well established (documented).
- The **quantitative** data sets are in the same unit system.
- The **qualitative** data sets are defined on the same contextual basis.

Slide 46 Main prerequisites of connected sub-systems in a modeling project

## Transfer of data

It can be reconstructed if the rules and methods are well documented.

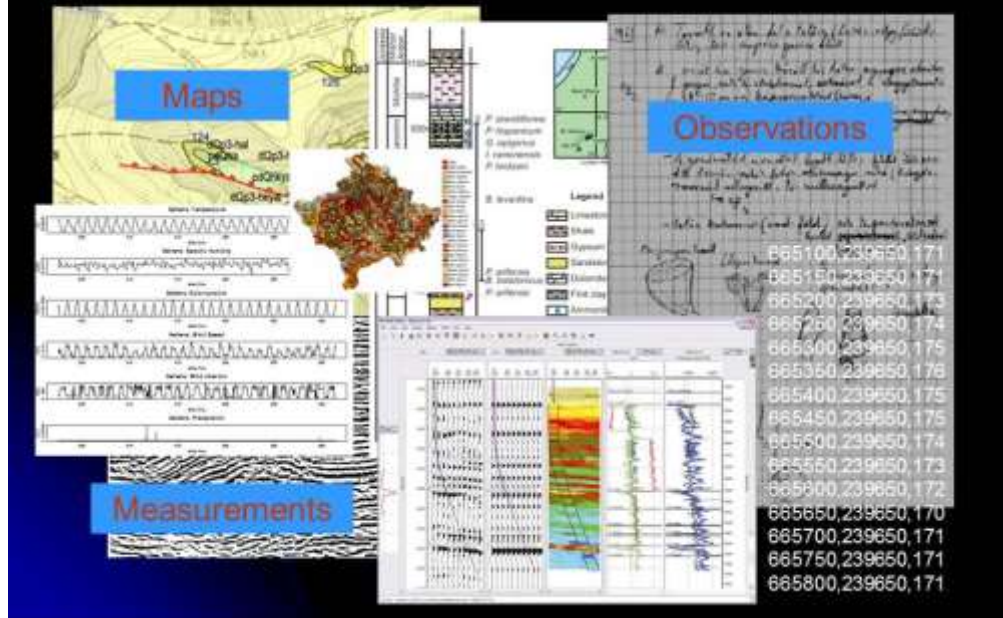
e.g.:

- Database connections (queries, table names, field types, etc.)
- Automated processes (logic of file and folder naming, relations to the database)
- Process sequences
- Error computing methods

Documentations

Slide 47 Important aspects of the data transfer between the sub-systems in a modeling project.

# How to connect these?



Slide 48 Illustrating very different data types, which may be gathered into one system

## Important similarities

- |   |  |
|---|--|
| Qualitative   | Quantitative   |
| <ul style="list-style-type: none"> <li>● Similarity of conceptual categories (e.g. Lithology vs. formations)</li> <li>● Handling aliases</li> </ul> | <ul style="list-style-type: none"> <li>● Similar methods to define quantities (e.g. calibration of measuring tools)</li> </ul> |



Namely: a quantitative value can have a qualitative meaning as well

Similarity of reference systems

Slide 49 Similarities in different types of quantitative and qualitative data sets: conceptual categories and aliases in the first case, measuring methods and quantities in the second case. In both case the reference system must be the same.

## The condition of source data

- During observation the data was collected for different purpose, NOT AS SOURCE DATA FOR A 3D MODEL → REVISE the data prior to modeling
- The purpose of a 3D model defines the quantity and type of data to collect → Prepare a database TEMPLATE (Active project)

Usually the original documents (like field reports) can be considered as PRIMARY DATA, but all other representations (like maps) are NOT.

Slide 50 Management of the primary data: predefinition or post-process revision

## Content of a documentation

- Definition of the goals and introduction to the topic  
(e.g. prepare a voxel model of the Gellért-hill (Budapest) in 25x25x25 m resolution using interpolation of topographic maps and borehole database – who, when and how has prepared such model?).
- Description of the base datasets  
(e.g. Maps, observations – their resolution and accuracy, date of creation, etc.)
- Methods  
(software, interpolations, analysis, error estimation)
- Results (or preliminary results)  
used time and resources, contradictions in the source data, recommendations for modifications (in the base data).

Slide 51 The content of a documentation file about the modeling process.

## Practical part of lesson 4 – Use of Surfer (part 2.)

The goal is to create interpolated surfaces with different interpolation methods, compare the results, and learn to calculate the error of the used methods.

Load the 3D GIS class 03.srf file into Surfer 10. This workspace file contains the results from the previous class (No. 03).

### Creating surfaces:

- Load the *Peldaadatok\_VAL\_Surf\_krig1.grd* interpolated surface into the workspace (Map – New – Contour map), and rename it to “krig1”.
- Using the data of the *Peldaadatok.xls Munka1* sheet to create a different map from the previous one with the Triangulation method! Method: Grid – Data... menu (importing the table). You can specify the parameters of the grid by selecting the LAT, LON and VAL\_SURF columns as X,Y and Z. Select the “Triangulation with Linear interpolation” method from the dropdown list as the gridding method, and specify the output file name *Peldaadatok\_VAL\_Surf\_TIN1.grd*.
- Load the result (Map – Add – Contour map) to the workspace rename it to “TIN1” and compare it with the other interpolated surface (krig1).

NOTE: both the TIN1 and the krig1 were created from the same point set, but with different methods. Thus, the two grids will be different.

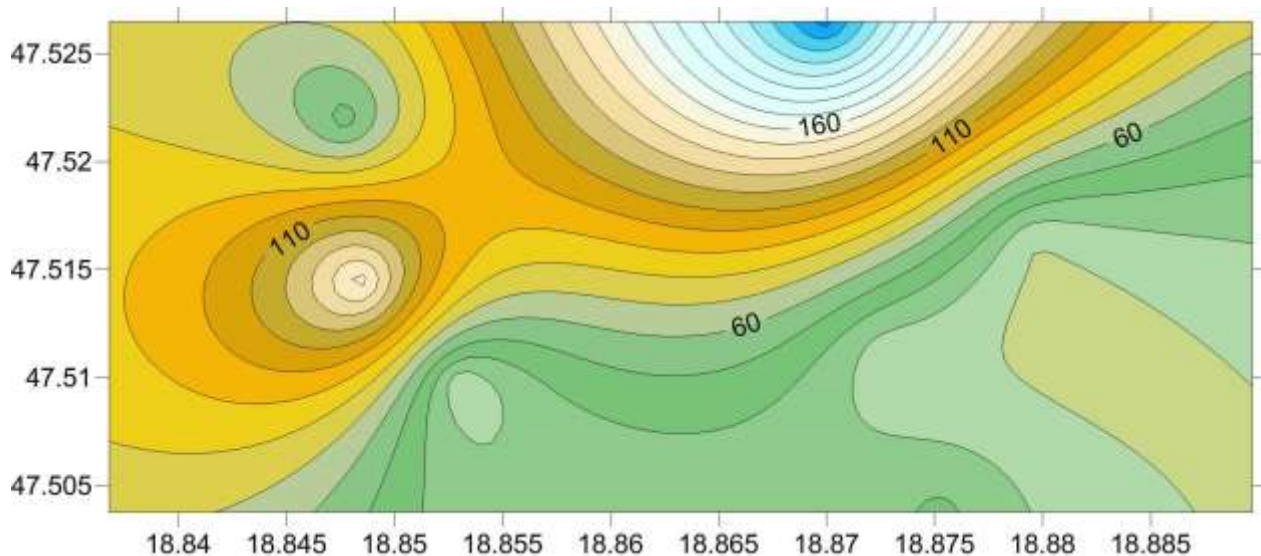


Figure 2 Contour map from the the *Peldaadatok\_VAL\_Surf\_krig1.grd* file

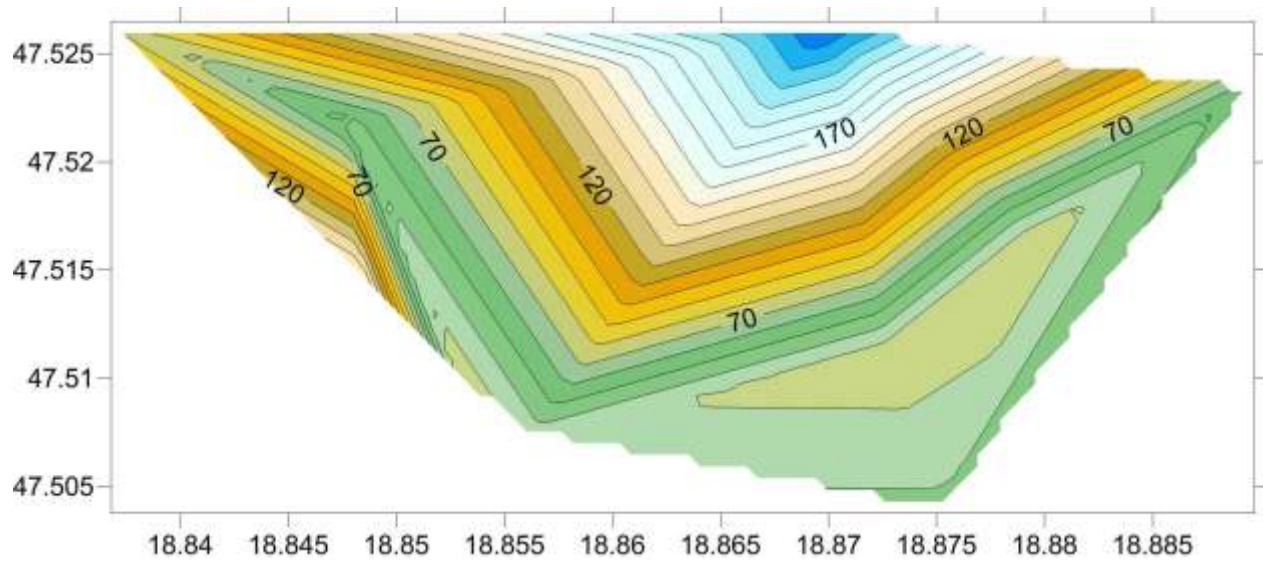


Figure 3 Contour map from the *Peldaadatok\_VAL\_Surf\_TIN1.grd* file

### Comparison of surfaces

- Using the Grid – Math menu point select the two interpolated surface: *Peldaadatok\_VAL\_Surf\_krig1.grd* as A and *Peldaadatok\_VAL\_Surf\_TIN1.grd* as B. Define a function A-B and create a new grid as *Krig1-TIN1.grd*. Add this new file to your workspace as a contour layer. Observe the result, which represents the difference between the two modelling methods (kriging and linear interpolation).

NOTE: This is a relative comparison and both methods have their own error.

### Error checking (cross validation)

- During modelling the methods have errors on those points, where there is no primary data. To estimate the error of the method chose the same dataset (*Peldaadatok.xls*, sheet: *munka1*) and carry out the initial steps of the gridding procedure (Grid – Data, specify the X,Y and Z fields). Select the kriging method and press the cross validate button.

Given the known values at N observation locations in the original data set, cross validation allows you to assess the relative quality of the grid by computing and investigating the gridding errors. In Surfer, these errors are calculated by removing the first observation from the data set, and using the remaining data and the specified algorithm to interpolate a value at the first observation location. [error = interpolated value, minus the observed value]. Then, the first observation is put back into the data set and the second observation is removed from the data set (and so on until the N<sup>th</sup> data). In the case of *Peldaadatok.xls* we have only 10 points.

9. In the cross validate window leave the preset parameters as they are, and specify the output filename as *PeldaadatokXV-Krig.dat* click Ok.
10. Open the *PeldaadatokXV-Krig.dat* in surfer or Notepad. The “Estimate” column contains the interpolated value at the specified point calculated from the remaining 9 data. The “Residual” value is the absolute error at that point.

NOTE: the residuals in our case are extremely larges, which means that the dataset is too small to execute sound geostatistics on it. Thus, in this case the method will have very low confidence, although it is mathematically correct. The Report file (see: *CrossValidationReport-PeldaadatokXV-krig1.rtf*) contains information about the cross validation process. Consulting these reports help us to decide whether our method is acceptable or has too much error in it (see the yellow rows in the file).

11. Add the *PeldaadatokXV-Krig.dat* to the workspace in Surfer as a Classed Post map (Map – Add – classed post map), and display the Residual column (Classes –Edit classes –Load – residuals.cls in the Property Manager).
12. Check the “show legend” checkbox in the “General” panel of the Property manager to display the legend. Manage the appearance of the legend object (click on it in the Object manager and adjust its properties in the Property manager) to create a nice layout.
13. Compare the two post maps (the original *Peldaadatok.xls* VAL\_SURF column and the *PeldaadatokXV-Krig.dat* Residual column).

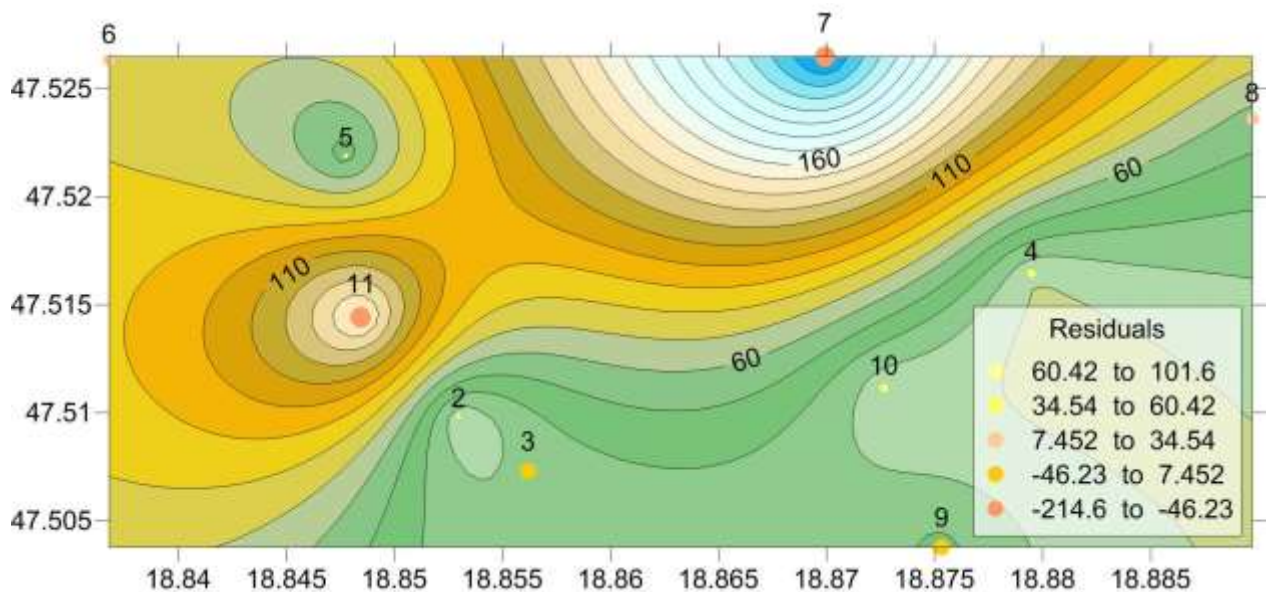




Figure 4 Layout with the classed post map of the estimated error (PeldaadatokXV-Krig.dat)

### Creating slices (cross sections).

**Slices are used to study** the variability of the data in a 3<sup>rd</sup> dimension (z) along a line, which is defined in 2D (x,y plane).

1. Select one of the maps (e.g. *Post*) in the Object Manager and digitize a new polyline in the coordinate system of this map (Map – Digitize) from the P5 through the P4 and P9 to the P8 data point. A popup window appears with its own menus and the list of the digitized points. After P8 save the polyline in bln (ASCII text) format “*digitized\_sectionP5-P8.blm*”.
2. Create a slice of the selected surface (grid) by selecting the Grid – Slice menu point. In the file selection window specify the grid what you want to slice (*Peldaadatok\_VAL\_Surf\_krig1.grd*) at first, and the line-file (*digitized\_sectionP5-P8.blm*) at second.
3. Two different files will be created:
  - a. The first will be a polyline (in .blm format), but it will contain all the points where the digitized line crossed the gridlines. Save this with a descriptive name (e.g. *sliced\_sectionP5-P8.blm*).
  - b. The second is a database table (dat file e.g. name it *section\_VAL\_SURF\_Krig1\_P5-P8.dat*) which is an extended version of the previous polyline file. It contains the distances of each points along the line from the starting point. The measure unit of this distance will be the same as the measure units of the coordinate system.

WARNING! The here presented sample files are in geographic coordinates, thus, the created dat-file will contain length distorted data in the 4<sup>th</sup> column.

4. Open the file *sliced\_sectionP5-P8.blm* in Notepad and compare it with the digitized version. Open it with Surfer as an added base map (Map – Add – Base map).
5. Open the file *section\_VAL\_SURF\_Krig1\_P5-P8.dat* in Surfer (or Notepad), and compare it with the simple sliced section file. Note that the 5<sup>th</sup> column contains only “1”. This is the ID number of the polyline which produced the slice (It means that blm files with more polylines can be used to slice a grid).

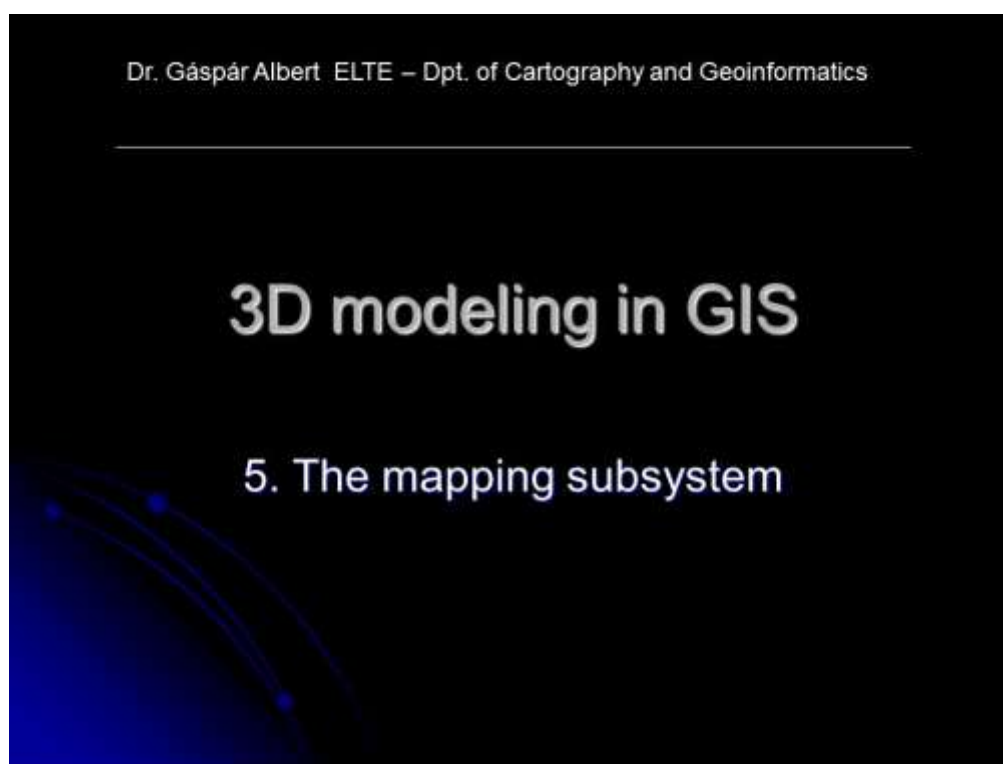
## Lesson 5.

The topics of this class are the followings:

- Creating maps for the data system (revision/correction/topology).
- Topology types in GIS.
- The use of topographic data.

Practice: Spatial representation of the data in a 3D modeling environment (and 3D models). The use of Jewel Suite – data creation, visualization, data model, and importing points.

### Creating maps for GIS – the mapping subsystem



Slide 52 The welcome slide of the 5<sup>th</sup> thematic class.

## Possible subsystems of a 3D model

- Mapping subsystem (e.g. 2D maps)
- Data (managing) subsystem
  - Database (e.g. measurements)
  - Folders and documentations (e.g. photos, survey records)
- Subsystems of applications (e.g. exe and other types of files).

Slide 53 Possible subsystems of a 3D modeling project.

## Creating a map for GIS

Evaluation of a digital mapping data is necessary in every GIS.

Main steps of work:

1. Checking the map content.
2. Correcting the map content.
3. Evaluation of the digital map (GIS).
  - Cleaning the linework.
  - Building topology.
  - Designing the layout (visualization).

These steps are always necessary, even if the digital map was created by ourselves.

Slide 54 Main steps of creating maps for GIS purposes.

# 1. Checking the map content

Is the digital map suitable for GIS purposes?

1. Check the **coordinate system** (is it geospatially referenced or was it drawn without any constraint?)
2. Check the **internal structure** of the digital map (overlays/ feature classes).
3. Check the **coherence of the map contents** (are the objects placed on the right type of category/overlay?)
4. Collect the **qualitative and quantitative categories** in database and compare the map data with the other sources you plan to include in the GIS.

Slide 55 The first step: checking the map content.

|     | Overlay name    | Content of the digital map                           |
|-----|-----------------|--|
| 1.  | _fence          | Map boundary line                                    |
| 2.  | 0               | Operator overlay                                     |
| 3.  | Ft_1szft_hat    | Outcrop boundary – continuous lines (___)            |
| 4.  | Ft_2tft_hat     | Boundary of debris – dashed lines (- - -)            |
| 5.  | Ft_3fft_hat     | Boundary of buried formations – dotted lines (. . .) |
| 6.  | Fti_11szft_idx  | Geological index of outcrops                         |
| 7.  | Fti_12tft_idx   | Geological index of debris                           |
| 8.  | Fti_13fed_idx   | Geological index of buried formations                |
| 9.  | Ftx_15ftsorsz   | Serial number of the observation point               |
| 10. | Ftx_doles       | Signs and data of structural measurements            |
| 11. | Ftx_egyeb_obj   | Other objects (e.g.: fossils, karst phenomena)       |
| 12. | Ftx_furasok     | Borehole data and sequence                           |
| 13. | szin_szft       | Coloring patterns of outcrops                        |
| 14. | szin_tft_fed    | Coloring patterns of debris and buried formations    |
| ... | tkt_eszl_feltol | Lines of thrust faults                               |

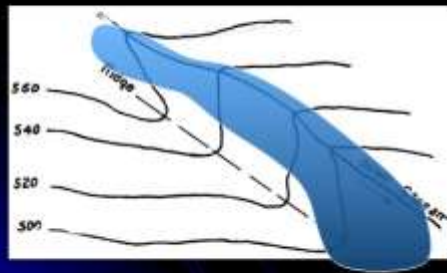
The overlay structure is usually defined in the „Editor's instructions" in the case of a complex mapping project.

Slide 56 A CAD overlay structure defined in the “Editor's instruction” at the Geological Institute of Hungary.

## 2. Correcting the map content

Formal and substantial aspects:

- Correct fitting of maps on the edges (if more than one is involved).
- Coherence between the topographic and the thematic contents.



e.g.: proluvial sediments be positioned in valleys.

The difference may come from:

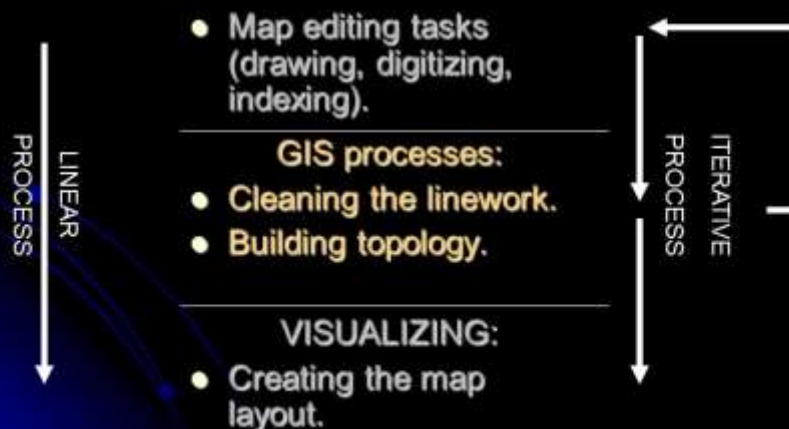
- the incorrect digitization;
- incorrect transformation of the map projections;
- base maps with different scales, and different levels of generalization.

Slide 57 Step 2: Correcting the map content

## 3. Evaluation of the map

„A map is never finished, we only stop working on it“

The sequence of the process is well defined and does not depend on the technological background:



Slide 58 Step 3: evaluation of the map.

# Cleaning the linework of a map

The linework of a map contains those linear objects, which represent substantial geographic information on the map.

Fitting polylines:



- A **polyline** is a sequence of straight line sections (vectors) which connect to each other at the endpoints.

**Closed network of polylines:** the starting and the ending points of all polylines connects to one or more polylines, or the starting point is identical to the ending point.

**Open network of polylines:** If at least one of the polylines has a free starting-, or ending point (i.e. it does not connect to other polylines).

A topological data model can be created from the polyline network in a GIS. The type of the topology depends on the open-, or closed condition of the network.

The linework is clean if the desired topological model can be created in a GIS without problems.

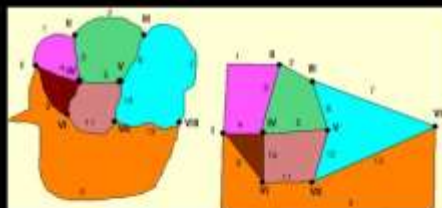
Slide 59 Definitions for linework, polyline, closed, and open network of polylines.

# Building a topology

Topology is the relation between the geometrical objects (e.g. point, line, polygon), which is undisturbed if the linework is continuously transformed (i.e. rotated, scaled, skewed, etc.).

These relations are:

- crossing,
- fitting,
- containing,
- neighboring,
- connecting,
- sameness.



Topologically similar shapes  
(Sárközy F. – Térinformatika)

Slide 60 Definition for topology.

# GIS topology types

Topology building in a GIS is always aimed to create a data model of the geometry which will be used in a spatial analysis.

Based on the geometry of the linework the topological model can be:

- Point topology
- Network topology
- Polygon topology

Slide 61 GIS topology types.

# Using topography data

Cartographic materials are under legal protection in most countries, and reproducing or using spatial data of a map may require the permission from the data owner.

- If the topographic data is surveyed for the modeling project (e.g. Lidar scanning):
  - We can use the data without restrictions (except the subject of the survey is a disclosed facility).
- If we digitize the data from a map or we buy the digital data:
  - The original owner of the data must be referred!

---

In many countries (e.g. in Hungary) state topographic data is not free yet. A fee has to be usually payed to the government depending on the condition and size of data used in the model.

Slide 62 Aspect of using topographic data.

## Practical part of lesson 5 – Use of Jewel Suite (part 1.)

This software is a full workflow framework that supports and describes every step which is needed to build complex 3D voxel models. The files are called “solutions” as they represent only one solution of a problem (like where can I find water below the surface?). When you start a new project in Jewel, you will create and save a project file with an extension *.jewel*. This file contains all Jewel settings associated with a given project, and when you open a *.jewel* solution file, you have access to all the geometric data in a database form too. To see what type of models can be built with Jewel, load the *Wells\_TOC.jewel* file into Jewel Suite 13. This workspace file contains an interpolated voxel model based on the data of the *Wells\_TOCvalues.xls* table. In Jewel only one solution file can be opened at a time, but several models can be defined in one file.

NOTE: the Z-axis in the modelling environment points downward and is called **tvss** (true vertical subsea depth).

### The basic functionalities (New Solution):

1. Window – New window – Start Page: select the New Solution icon. This will unload the *Wells\_TOC.jewel* project. An empty 3D View panel (in the middle of the screen) show up.
2. The settings of the user interface can be changed (Tools – Options – User Preferences). Layout changes to the JewelSuite user interface are stored per user and will be used when starting JewelSuite. This allows you to customize the JewelSuite user interface for each user. Select the “User Preferences” panel in the “Options” dialogue window and with pressing the “select default unit system” button set the unit system to metric.

Try other settings in the options dialogue, and explore the tree structure of the user preferences panel.

3. On the right side of the screen there is a Workflow Guide. All of your work is outlined as a set of workflows in the Workflow Guide. The main **processes** are written in bold characters (e.g. **Data Import**). The processes are divided into several *panels* (e.g. Point Set Data). The sequence of the processes is the usual sequence of a workflow in 3D modelling.

### Data creation

This exercise is aimed to illustrate the database structure of the software, and to demonstrate the active connection between data tables and 3D objects.

4. During modelling the database of your project can be accessed and edited. To get familiar with it, try the **Data Creator** process, Create Objects Control panel. A new *viewer* panel will appear next to the 3D View panel in the middle of the screen where you can create different data objects using the manual process. Each object type has its own *sheet*. Select the “Point Set” sheet and create a New point set with the name: “locations”. The Type should be “Undefined” for now. You can type data in the table rows and pressing the Create button the Point Set will be created.



5. For real data Open the *Wells\_TOCvalues.xls* and type the Northing, Easting, and Tvss coordinates of points P1-P10. After finishing this, press the Create (or Update) button and change the view panel to the 3D View.

NOTE: All the spreadsheet views in the Create Objects View support Copy and Paste functionality. This is useful when you have your data available in a spreadsheet format such as an Excel table. Make sure the data is in the correct format, and in the proper columns!

6. The “locations” Point Set is created and it can be selected in the Solution Explorer (The Solution Explorer is a window to view all data objects and properties that you have created or imported). Right-clicking on the data object, a popup menu appears where you can set parameters and execute processes.
7. Select the “locations” Point Set – right click – execute the *Triangulate* process. A new data object (a Tri-mesh = TIN surface) is created with the same name.
8. Change the view panel to Create Objects Control and select the Trimesh sheet. Here the created “locations” tri-mesh can be selected as an existing data object.
9. There are two tables: 1) on the left a 4-columned one containing all the nodes (with an automatically created ID); 2) on the right a 3-columned table which lists the individual triangles and the node IDs of each of them.
10. Try to modify the Tvss value of node No. 9 from -229.61 to 0. Press “Update” and go back to the 3D View and see what happened. To practice this functionality creates new nodes and triangles manually.

NOTE: this exercise demonstrates that the database structure is a RDB (Relational Database), and the 3D View is only a visualization of the data (NOT a model!).

## Visualization

11. Select the “locations” tri-mesh in the Solution Explorer (or by left clicking on it in the 3D View). Right click (popup menu) – Properties – Depth – Depth (double definition means: several other depth-type property can be defined additionally). The tri-mesh will be coloured according to a colour-scale. Note that the Azimuth, Dip and Smoothness properties are also selectable (try them). These are automatically-created properties.
12. Right click (on the tri-mesh) – Solid > change this to “Solid and mesh”. The TIN structure appears.
13. Right click (on the tri-mesh) again – check “Contours”. Contour lines appear (a hypsometric colouring is the result).

14. To enhance the vertical differences between the nodes on the tri-mesh you can increase the vertical scale using the General View Toolbar below the 3D View (up-and-down arrow and a textbox).
15. Here in the General View Toolbar you can set pre-defined views, or change the cursor into a measuring tool (all functionalities are explained when the cursor is moved over a toolbar icon).

## Data Import

This exercise focuses on the workflow of importing a simple point database, originally stored in Excel.

16. Remove the point sets (Solution Explorer – select the Point sets – right click – Remove all Point sets).
17. In the Workflow Guide go to the **Data Import** process, and then select the **Point Set Data** panel. A dialog window appears where you can define the file where the Point set data is stored. In the file type list, select the “User-defined Formatting for Column Files” and select the *Wells\_TOCvalues.txt* in the 05 folder.
18. In the next window each column can be defined separately. Check all columns to be in use except the first. Below the first line of the table there are 3 dropdown lists in each column: the first dropdown list contains the selectable types, the second contains the methods and the third the measure units. Set the second column to Easting/Distance/meter; the third to Northing/Distance/meter; and the fourth to Tvss/Depth/meter. On the left side of the dialogue window, set the “Start import at line” to 2, select only the ‘Tab’ as a delimiter (uncheck the “space” if checked). At the “columns” sector check, and set the “Properties from col” to 6, and the “Names from line” to 1. Press Next.

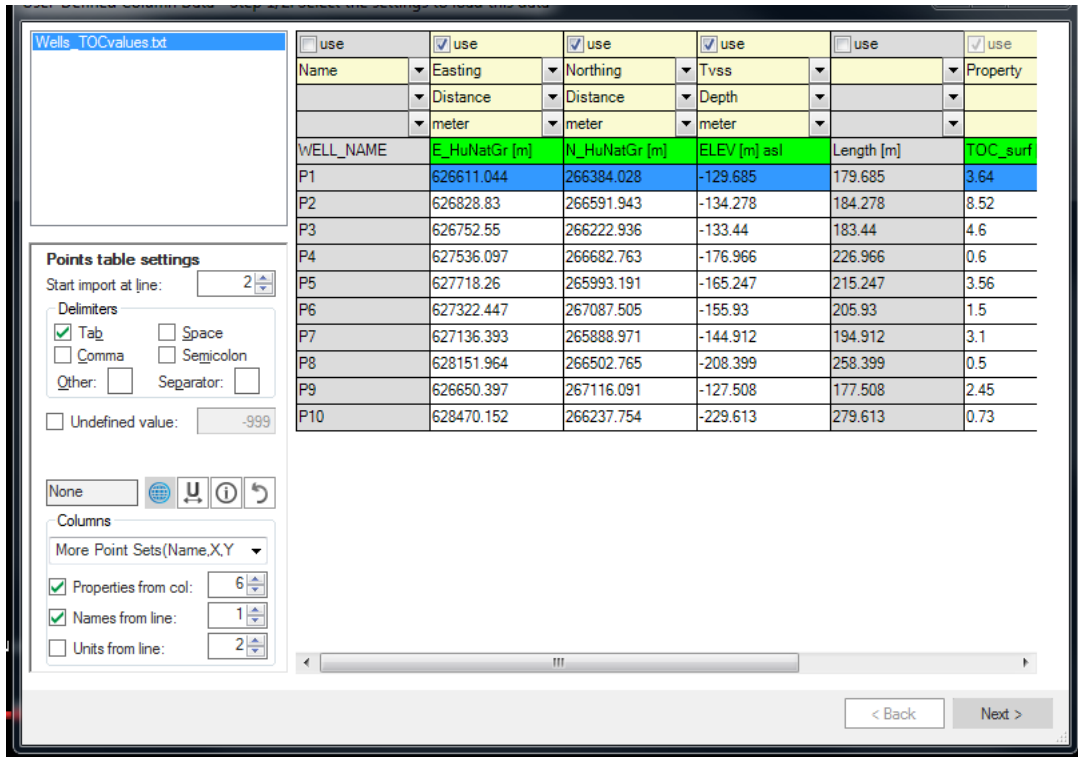


Figure 5 Dialogue window for defining the fields of the imported database in Jewel Suite 13

NOTE: when importing points into Jewel as point clouds, the names of the individual points are indifferent. Thus, we ignore the name column in the above exercise, and we will create a point set object which will be defined with one single name.

- In the next window there are two tables. The upper one shows the data objects and its parameters (in this case there is only one line in the table, because all the points are handled as one entity: a point-set). Change the name to "Wells\_TOC\_surf". The lower table contains the list of imported properties. Check only the first one (TOC\_surf [%]) and set its "Template name" (second column) to "Ratio" and the "Unit" (third column) to percent. Press Finish.

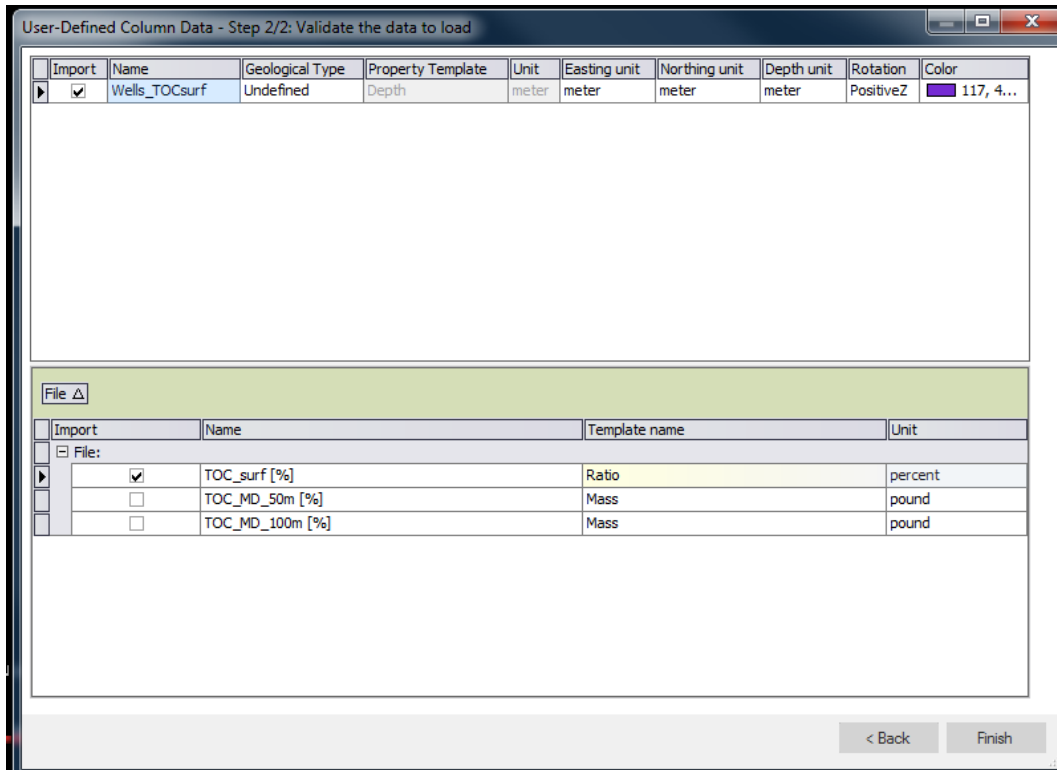


Figure 6 Validation dialogue window to properly define the type of the imported data

- In the Solution Explorer the point set object appears. Explore the properties of the created point set (press the + sign next to the name). Check the TOC\_surf [%] property to visualize the different values.

NOTE: this exercise demonstrates that you can import several attribute data into the modelling GIS environment using Point sets.

- However, in the Create Objects Control panel these properties are not accessible to modify (only the X, Y, Z coordinates). Once you imported the property data, it remains the same.

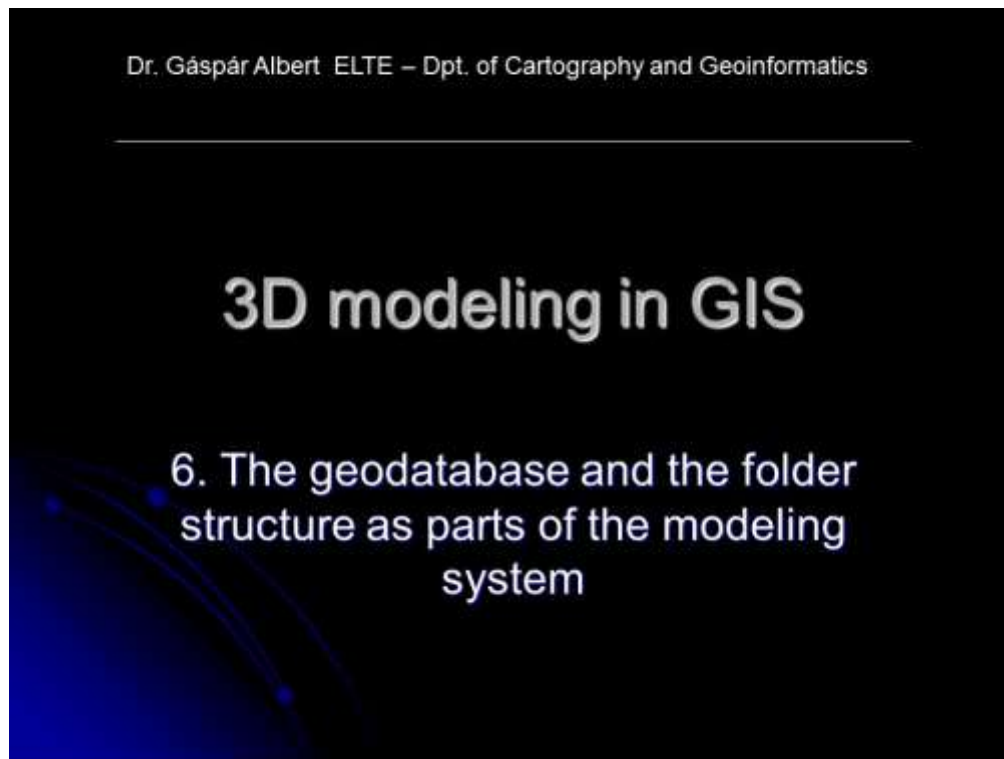
## Lesson 6.

The topics of this class are the followings:

- Folders and files as database systems (e.g.: doc, xls, txt, dxf, xml).
- Data mining for GIS purposes.

Practice: The use of Jewel Suite – importing point clouds, creating and editing simple surfaces, importing grid surfaces, and creating cross-sections.

### The geodatabase and the folder structure as parts of the modeling system



Slide 63 Welcome slide of class 6.

## Consideration of important elements as subsystems

In a 3D modeling project not only the content of a database, but the paths of the different types of data are also parts of the whole system.

- Folder structure contains:
  1. Files responsible to sustain the work of applications (e.g. exe files)
  2. Data (raster/vector, ascii/binary, etc.)
  3. Documents (log, doc)
- Database contains:
  - Observations (or other primary data)
  - Map object data (the geometry of a map – a representation of conceptual categories)

Slide 64 Elements of the subsystems: folder structure, observations and map object data.

## The system folder

In system folders those files and sub-applications are stored, which are responsible to sustain the functionalities of the whole modeling system.

*The three basic functionalities:*

- *processing*
- *storing*
- *visualization*

... may suffer critical damage if a system folder is removed.

The system folders are usually automatically created and maintained by the installed applications of the computer, and these folders are well differentiated from those, which can be used to manage data and documentation files. This concept should be followed in the case of self-developed applications too!

**IN SYSTEM FOLDERS SELF-CREATED DATA SHOULD NOT BE STORED!**

Slide 65 The system folder.



# Database types

Primary data (such as observations) has usually higher priority in a database managing system (e.g. the database is only readable, or simple users have limited access to it).

## Conceptual distinction of database types:

- Database of observations (real word objects)
- Map object database (virtual objects)

A data subsystem in a modeling project is coherent if:

- The **quantitative** data types are comparable to each other (i.e. categories are the same).
- The **qualitative** data is in the same reference system (e.g. same measure units are used).



- set up the key fields in the database
- review the different qualitative categories
- unify measure units and coordinate systems

To do list  
prior to  
modeling

Slide 68. Database types and the “to do list” prior to modeling.

# A database of observations (and digital archives)

Digital archives are those collections, which contain primary data in digitalized format, but not systematically organized in a database (e.g. scanned documents).

- Unique ID
- Qualitative category
- Coordinates
- Attributes
- Connected data reference:

- type
- name
- location

**ID Code:** DGDH-0000

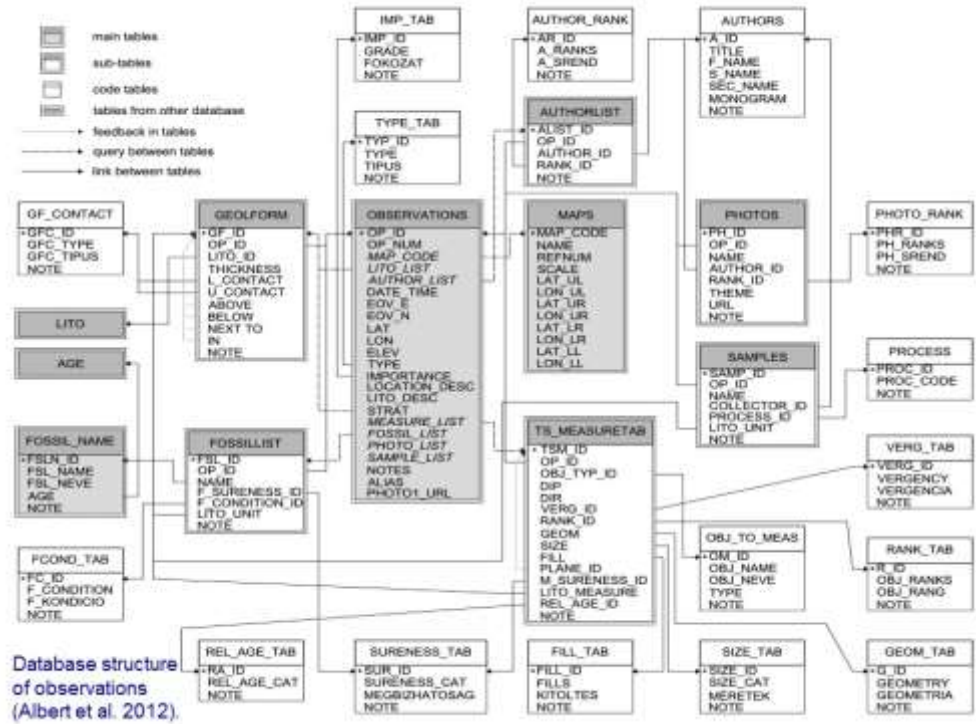
**Order:** 1, PK2  
**Observation:** Dobro 1, PK2  
**Date:** 12. Okt. 2010, 13:30:00  
**Elevation:** 500 m  
**Type of outcrop:** In debris and covered  
**Importance:** moderate  
**Location:** Northward from the Margheš hilltop on a small clearing after the Csaszmatart cultivated forest, on a road along a down sloping ridge.

**Lithology:** Very coarse, poorly sorted, polymictic sandstone-conglomerate can be found in the debris. The gravels and rock fragments in the debris are mainly greenish, brownish-grey siliceous clay stones (similar to red stones), and white flint stones, but occasionally well rounded quartz pebbles (1-2 cm) are also occur. The red stones (and the siliceous clay stones) are poorly rounded, and often have 3-6 cm long elongated form. Well rounded carbonaceous sandstone (C1-2) debris was also found amongst the rock fragments in the debris, but the origin of it is unclear.

**Stratigraphy:** L, M2  
**Photos:** 4891-62.00  
**Notes:** If the carbonaceous sandstone (C1-2) is part of the formation then it is younger than the Hőszőlő-Gulácskő Conglomerate (M2/C1, M2). In this case it can be Eocene or Oligocene terrestrial deposit.  
**Map:** point no.: 352 of O. Császár

Slide 69 A sample for the database of observations.





Slide 70 A relational database structure for geological field observations (Albert et al. 2012).

# Database of map object

The database of map objects is part of a digital map, and can be used to connect the map with the observations, but this requires a clean topology in a GIS.

## Steps of creating maps for GIS purposes:

- Cleaning the linework
- **Building topology**
- Designing the layout

The database of map objects contains unique identifiers and attributes for all graphical objects. If this database contain a key field which is common with a database of observations the two of them can be connected.

Slide 71 The database of map objects.

# The structure of a database of map object.

Part of a geological map object database:

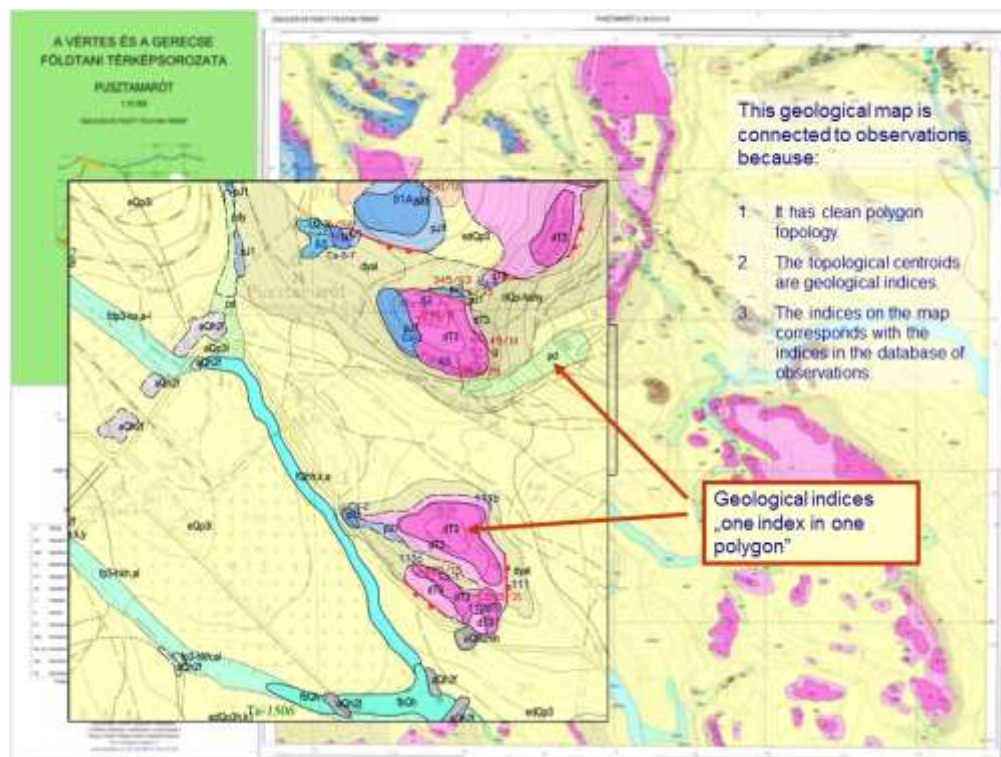
| ID | Type   | String      | x      | y      | Coverage      | Index  |
|----|--------|-------------|--------|--------|---------------|--------|
| 01 | String | Pebble      | 7744.9 | 2153.3 | FTI_12TFT_IDX | f_Qp2k |
| 02 | String | Eolian sand | 8432.5 | 2234.7 | FTI_12TFT_IDX | e_Qp3s |
| 03 | String | Miocene Fm. | 5334.9 | 2325.4 | FTI_12TFT_IDX | kPa1-2 |

Explanation of column names: ID = unique identifier; Type = type of map object; Sting= the text shown on the map; X, Y = coordinates of the string (paper or geo); Coverage = name of the layer/coverage in the digital map; Index = the formal geological index of the object. This is the key field which connects the map object to the database of formations.

Index + coordinate = topological centroid

The topological centroid is created in the process of topology building. It can identify a single object (point, text, or closed polygon) and connect the object to other database (e.g. observations).

Slide 72. The structure of a map object database and the explanation of a topological centroid.



Slide 73 A sample map which is connected to a database through topological centroids.

# Use of unique identifiers in a 3D modeling environment

A 3D model may contain objects, which become unique entity only in the modeling environment by assigning them into groups (e.g. point clouds).

Typically:

- Objects and groups of objects (e.g. surfaces)
- Layers / coverages
- Queries, processes

In the case of complex models, or models with large extent, these categories may contain large number of elements. To manage these categories, a unique identifier is assigned to each element.

The identification of these elements should be based on descriptive indices

Slide 74 The use of unique identifiers in a 3D modeling environment.

# Descriptive indexing of lines

The ID number is not descriptive!  
What else can be displayed?

General attributes of a structural line:

|              |           |
|--------------|-----------|
| ID:          | 001       |
| Type:        | Fracture  |
| Property:    | sinistral |
| Sureness:    | sure      |
| Importance:  | 1         |
| Active:      | yes       |
| Orientation: | -         |
| Name:        | ?         |

In kml-s there exists a „name“ field.



```
<description>Fault</description>
<name>001</name>
<styleUrl>#fault_line1</styleUrl>
<LineString>
  <coordinates>
    19.6416797755,47.5161430293,0
    19.8497933117,47.5864798612,0
  </coordinates>
</LineString>
```

Slide 75 demonstrating the descriptive indexing of lines – a structural geological sample (Albert 2014).

# The use of the „name” property

General attributes of a structural line:

|             |           |
|-------------|-----------|
| ID          | 001       |
| Type        | Fracture  |
| Property    | Sinistral |
| Sureness    | Sure      |
| Importance  | 1         |
| Orientation | -         |
| Active      | yes       |

Describe these property with one name

FT1s\_S

Slide 76 The use of the name property in the kml, as an index.

# Codes of the „name” property

„type-property-orientation”

The first part contains the **type**, the order of magnitude and the sureness of the structural element.

|     |          |
|-----|----------|
| FT  | Fracture |
| DT  | Ductile  |
| 1-3 | order    |
| s   | sure     |
| u   | unsure   |

FT1s\_N\_E

The third part contain the **orientation** of the fault/thrust plane\*, defined by letters.

The second part refer to the **geodynamic property** of the tectonic element.

|   |           |
|---|-----------|
| N | normal    |
| R | reverse   |
| D | dextral   |
| S | sinistral |

\* The dip direction towards the hanging wall is indicated.

|   |       |
|---|-------|
| N | North |
| S | South |
| E | East  |
| W | West  |

Slide 77 Descriptive codes (indices) of the “name” property of a kml which contain structural lines. The method – besides the benefit of comprehensive naming – can be used in structural geological modeling, to automatically process linear objects, which are stored in a geodatabase.

## Reference in the slides

Albert G, Csillag G, Fodor L, Zentai L. 2012: Visualization of geological observations on web 2.0 based maps – In: Zentai L, Reyes Nunez J (eds.): Maps for the future – Springer.

Albert G. 2009: Digital processing/archiving of geological field maps – Annual Report of the Geological Institute of Hungary 2007, pp. 45–53.

Albert G. 2014: Inventorizing tectonic elements in geological maps and 3D models – Problems, Concepts, Solutions - In: Beqiraj A, Ionescu C, Christofides G, Uta A, Beqiraj Goga E, Marku S (eds.) Proceedings XX Congress of the Carpathian-Balkan Geological Association. Tirana: p. 459.

## Use of Jewel Suite (part 2. – Explicit Data Modeling)

This class is about the explicit model building in the modelling environment. Load the *class05\_pointsets\_from\_wellsTOC.jewel* to continue your work where you left it in the previous class, or repeat the steps of the Data Import as an exercise (see steps 17-21 in Lesson 5.).

### Importing the point properties from the 50 and 100 m depths

The *Wells\_TOCvalues\_ext.txt* table contains TOC values from three different depths: 1) zero depth (surface); 2) 50 m below the surface; 3) 100 m below the surface. The horizontal positions of the points are valid for all the three, but the vertical positions are calculated from the "ELEV [m] tvss" column values for each points. These are the ELEV-50 and ELEV-100 columns containing the height data of the measured points.

1. Using the *Wells\_TOCvalues\_ext.txt* repeat the importing process (2-4) to create two additional point sets containing the attributes: TOC\_MD\_50m [%] and TOC\_MD\_100m [%] respectively. Name the new point sets as Wells\_TOC\_MD50 and Wells\_TOC\_MD100.

IMPORTANT! The *Wells\_TOCvalues\_ext.txt* contains elevation data as height above sea level! Since Jewel works with depth data, these **a.s.l.** values must be converted to **tvss** values in step 3, where the upper table of the upcoming dialogue window contains a "Rotation" column. Left click on it and select the "Negative z" from the dropdown list to convert a.s.l. to tvss.

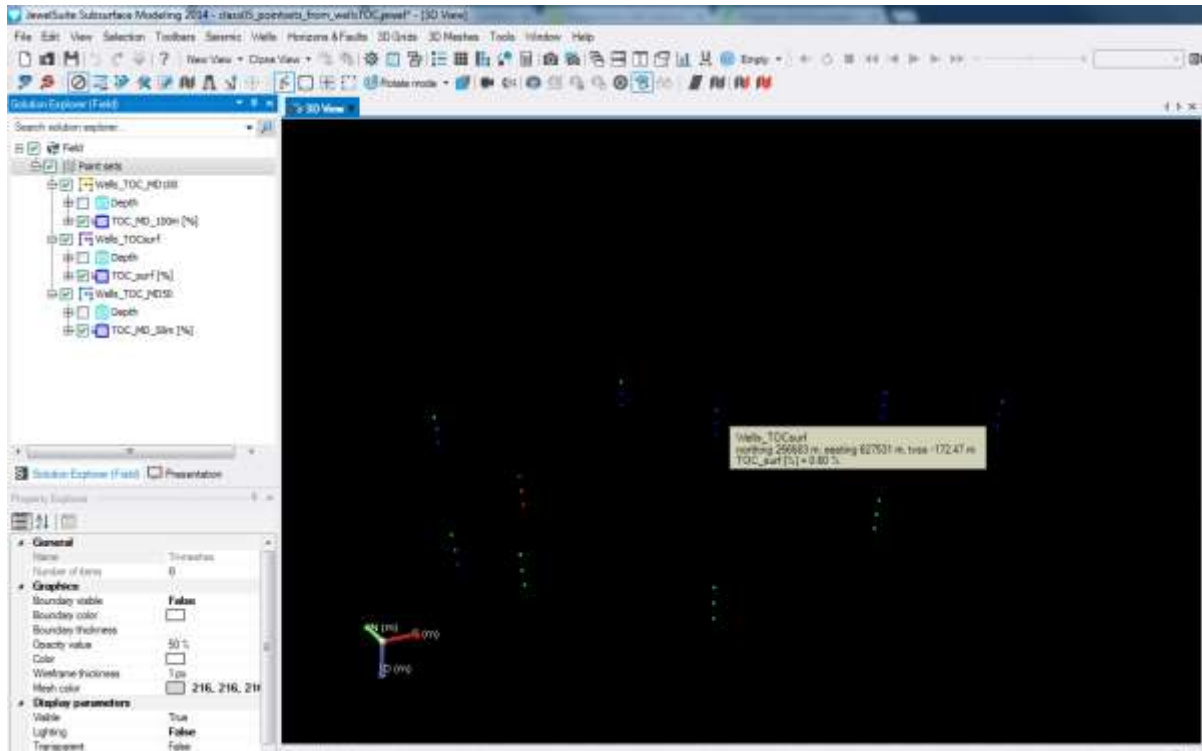


Figure 7 Point sets of the different levels (imported from the Wells\_TOCvalues\_ext.txt) in Jewel Suite 13

### Creating triangulated surfaces

2. Either in the Solution Explorer, or in the 3D view select the “Wells\_TOC\_surf” Point Set – right click – execute the “Triangulate” process. A new data object (a Tri-mesh = TIN surface) is created with the same name.
3. Modify the visualization with right clicking on it, and selecting “Solid and mesh” from the pop-up menu (clicking on the default “Solid” menu object).

### Editing tools

4. In the picking Toolbar select the hammer and pencil icon (Enable picking for the editing tools). A popup window and a new toolbar (Editing Tools Toolbar) appear. Minimize the popup window (but do not close it!). All icons in the new toolbar are explained with a cursor message, if the cursor is moved above them.
5. At first try the “Add triangle” tool (a grey triangle icon). To activate it, click on it once with the left mouse button, and the cursor will change to a combined arrow - triangle symbol. Complete the shape of the Wells\_TOCsurf to a convex polygon with this tool. To add a triangle click on the

existing surface near 3 corner-points (a green ball appears if a point is selected). To deactivate this tool click on the icon once again.

6. Check the result in the Trimesh sheet of the Data Creator View panel selecting the Existing Wells\_TOCs surf object. A new row appears in the database of the triangles.
7. Save a copy of this tri-mesh by clicking on it and selecting the “Create a copy” pop-up menu item. With the copied TIN try more editing tools which are about triangles or tri-meshes (avoid the use of polyline editing tools on TINs, because it may cause malfunctions!).

### Importing terrain surface into the modelling environment

Digital terrain data can be accessed from SRTM datasets. The downloaded free access data of the area is in the *srtm\_40\_03\_original.zip* file, but it is too big for the Wells\_TOC project area and uses geographic coordinate system instead of Hungarian National Grid. To convert the data into the right format use Global Mapper (GM).

8. From the start view of GM, open the *srtm\_40\_03\_original.zip* file. This file is in Geographic (Lat/Lon) coordinates and the datum is WGS84. Because of this the whole GM workspace will be in this coordinate system.
9. Import the point file *Wells\_TOCvalues.txt* as a “point set data”. Prior to this, check the file structure in a text viewer (e.g. Notepad), and observe the sequence of the columns.
  - a. In the “Generic ASCII text file import options” dialogue window, check the “Point Only” as import type, and the “X/Easting/Longitude Coordinate First” radio buttons. Type 1 to the “Fields to skip at Start of Line” textbox. Check the “Include attributes from lines with coordinate data” and the “Column headers in the first row of file” check boxes. Press OK.
  - b. Select the Hungarian National Grid and the Hungarian Datum 1972 as the projection and the datum for the *Wells\_TOCvalues.txt* coordinate data. The automatic coordinate conversion will be performed during the import, and the points will be displayed in Geographic (Lat/Lon) coordinates in the workspace.
10. In the Tools – Configurations menu convert the projection of the whole workspace into Hungarian National Grid (HD 72 datum). Check the cursor coordinates in the lower right corner of the window.

11. Export the SRTM as a **surfer 6 binary grid** (File – Export – Elevation Grid Format). In the “Surfer Grid Export Options” dialogue window set the resolution to 25 by 25 m in the “Sample Spacing” region of the “General” panel. In the “Export Bounds Panel” check the “Global Projections” radio button and define the export boundary using the following values: North: 267150; West: 626575; South: 265850; East: 628475. Save the file as *wells\_TOC\_topography.grd*.

Import the *wells\_TOC\_topography.grd* file in the Jewel modelling environment. Switch to the active Jewel solution (or open the solution, you left at point 7).

12. In the Workflow Guide go to the **Data Import** process, and then select the 2D Grid Data panel. Select the file created in step 11.
13. In the “Import as” dialogue window specify the file type as “**Surfer 6** Grid Files”. Don’t forget to switch the z-axis in the “Data Import Validation” window (Rotation column)!
14. Modify the appearance of the surface by clicking on it with right mouse button and

### Definition of cross sections

15. Select the “Add planar section” tool in the “Cross Sections Toolbar” and define a cross section between two arbitrarily defined points. Notice that the section expands until it cuts the whole extent of the imported surface!
16. Click on the cross section with right mouse button, and press the “show cross section view” menu point. A new main window appears.
17. In this view select the visualized planar section in the Solution explorer. Scroll down in the Property Explorer to the “Geometry” section and modify the value of the “Data points projection distance” to 200 m. The data points in the buffer zone of the section are displayed.
18. In the picking Toolbar select the hammer and pencil icon (Enable picking for the editing tools). A popup window and a new toolbar (Editing Tools Toolbar) appear. Minimize the popup window (but do not close it!).
19. Press the “Add polyline” tool once, and draw a polyline on the cross section. To finish a polyline, use double clicks with the left mouse button.
20. Switch back to the 3D view to see the 3D polyline.

This tool will be used in later exercises to demonstrate the digitization method of explicit models.



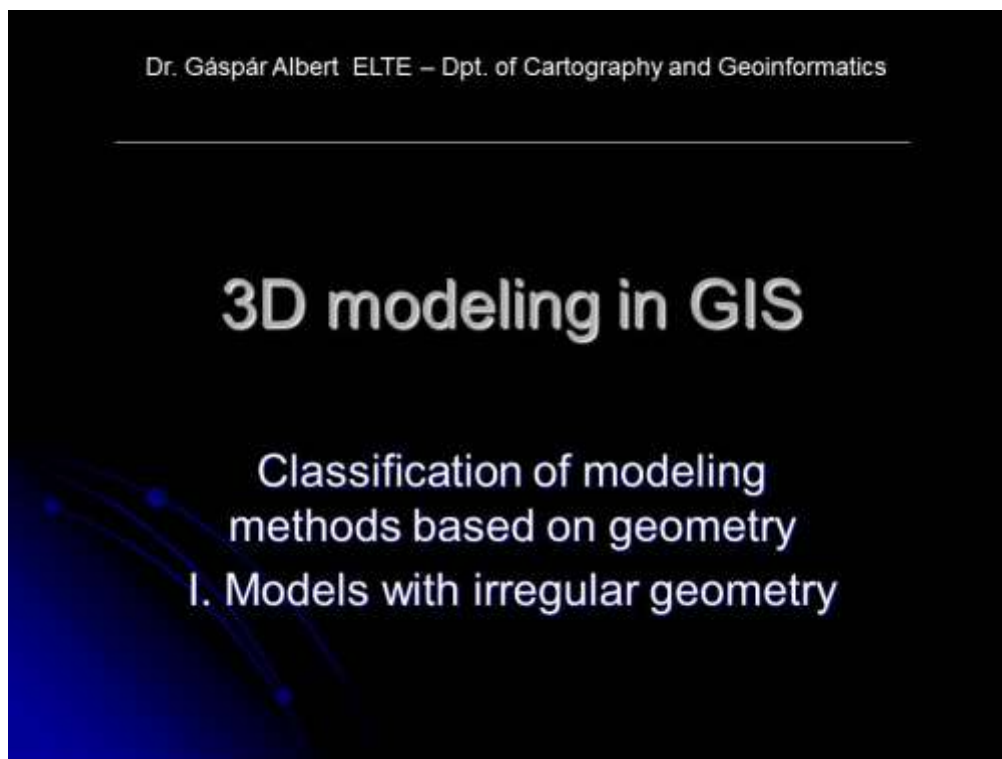
## Lesson 7.

The topics of this class are the followings:

- Modeling process: the concept (mathematics, step-by-step definition).
- Classification of 3D modeling methods based on geometry.
- Comparison of the regular and irregular models.
- Irregular models 1: point-cloud, parametric point-clouds, TIN surfaces.
- Delaunay triangulation and voronoi-polygons.
- Irregular-shaped solids, and irregular tetrahedron-mesh (tessellation of voronoi polyhedrons)

Practice: use of Jewel Suite – importing shapes, data manipulation in Jewel, Spatial querying, importing images for explicit modeling

### Classification of modeling methods based on geometry – I. Models with irregular geometry



Slide 78 Welcome slide of the 7<sup>th</sup> class.

# Introducing 3D modeling methods

The purpose of scientific 3D modeling is to create estimations for spatial phenomenon using mathematics.

For this, we can use different methods and tools, depending on the:

- Aim of the modeling,
- Nominal scale,
- The specialties of the subject of the model.



A modeling process is always unique but the sequence of work contain a list of known methods which together are the *proceedings of the modeling*

Slide 79 The Uniqueness of a modelling process, despite of the use of well-known methods.

# Proceedings of the modeling

The *proceedings of the modeling* compose the mathematical frame of the data processing (e.g. interpolation, weighting and error estimation), which are included in the modeling software in most cases.

The conditions of data managing methods depend on these proceedings, and the requirements have two aspects:

1. Aspects of data  
The data is suitable for a modeling purpose, if it is punctual enough
2. Aspects of methods
  - **Quick**: processes are automatized, or scripts can be used to manipulate the processes.
  - **Spectacular**: visually enhanced representation of the model in a modeling space.
  - **Correct**: the difference between the estimated values and the measured values at the same location is smaller than the acceptable (defined) error limit.

Is the modeling process acceptable for our purpose? To answer this question we have know exactly the proceeding of the modeling.

Slide 80 Definition of the “proceedings of a modeling”.

# Classification of models based on geometry

A digital 3D model is always composed of object with certain geometry. These geometries can be described as variables and equations, and can have database attributes as well.

From the geometrical aspect 3D models can be classified as:

- **Irregular models:**
  - I. Parametric points and point clouds
  - II. Vectors
  - III. Simple planes
  - IV. Irregular network of tessellated plains (TIN) modell
  - V. Models of irregularly shaped objects
- **Regular models:**
  - I. surface grids
  - II. Spatial grids (tessellation of voxels)

The geometric approach classifies models according to the geometric pattern seen in the representation of the model.

Slide 81 Classification of models based on geometry.

# Pros and contras of regular and irregular models

- | Regular   | Irregular   |
|---|---|
| <ul style="list-style-type: none"><li>● Easily automatized processes;</li><li>● Data points are described as positions in a grid, which requires less storing capacity, so data is highly compressible;</li><li>● Computational requirements increase in quadratic scale with the size of the grid in recalculating model data;</li><li>● Slow data processing on low-end computers;</li><li>● Primary data is usually not seen in the results;</li><li>● The modeling space is a scalar space – implicit modeling is usually done;</li><li>● It is not recommended for modeling detailed geometry;</li></ul> | <ul style="list-style-type: none"><li>● Automatization of geometrical analysis is problematic so human interaction is usually required in the model building process;</li><li>● Data points are stored as coordinates, which requires larger storing capacity;</li><li>● Big models are hard to be visualized</li><li>● Data points are accessed quickly (better for processing);</li><li>● Primary data is usually the base of the visualization;</li><li>● The modeling space is a vector space – explicit modeling is usually done;</li><li>● It is suitable to create model with detailed geometry;</li></ul> |

Regular models are recommended if the data is well distributed, and the expected scale is medium or small.

Irregular models are recommended if the distribution of data is sporadic, and the expected nominal scale of the model is relatively large.

Transfer of the data between the two types is NOT without data loss or distortion!

Slide 82 Comparison of regular and irregular models.

# Irregular models

The information is stored in geometrical objects, which are described as unique entities with unique geometry.

## Parametric points and point clouds

If the spatial information is represented as individual points, the complex geometry of the subject is seen, but cannot be analyzed.

| ID  | X     | Y     | Z    | Attr. |
|-----|-------|-------|------|-------|
| 01  | 125.5 | 254.1 | 13.4 | 0.2   |
| 02  | 127.5 | 255.2 | 14.1 | 0.3   |
| ... | ...   | ...   | ...  | ...   |

\* The surface is usually created by meshing algorithms, and belongs to a different category of irregular models.



e.g.: a 3D laser scanned (LIDAR = Light Detection And Ranging) model shows millions of points, but the points are individual entities and the complex surface is yet to be created\*.

One measurement = one grey dot in the picture

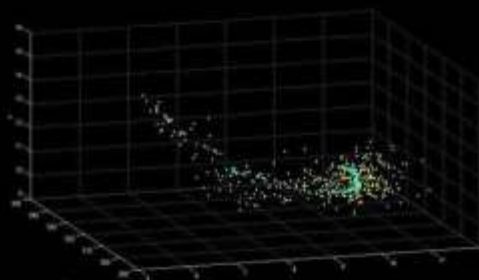
Slide 83 Simple irregular models – points and point-clouds.

# From point clouds to vectors

Data in the parametric point clouds can be represented as symbols (e.g. isometric or complex) and besides the type, the size and color of the symbol may represent different attributes.



*Usually isometric symbols are recommended because they look the same from any point of view.*



e.g.: the elements of a point cloud can be colored based on an attribute.

If one of the attributes refer to direction, the point may have a new geometrical property, which makes it a 2D unit vector.

Adding a plunge (dip) value and a size to this, a 3D vector is created.



*Arrow signs are common representations of vectors. The type and color may represent additional attributes.*

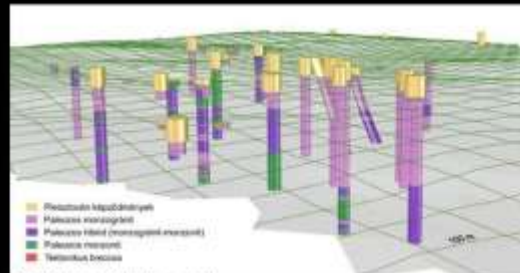
Slide 84 transition between points and vectors in the data model.

# Vectors in real 3D models

## Borehole and stratigraphic data as a vector model

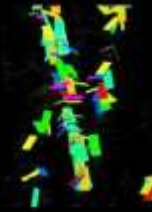
A borehole (well) in a database is represented with surface coordinates, length and a spatial direction (dip and azimuth). Different sections of the borehole reveals different lithology (Pict. 1), which is stored as an attribute in the database.

Planes measured on the surface, or in boreholes, have spatial orientations too. Although the normals can be represented as vectors, these objects are better visualized as uniform-sized planes (Pict. 2).



Pict. 1. (top): lithological data represented with different colors along 3D vectors (as boreholes).

Pict. 2. (right): planes measured in boreholes with uniform size, but different colors.

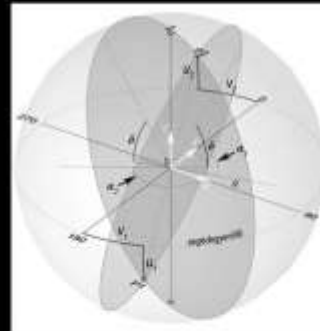


Slide 85 Vectors in real 3D models – Borehole and stratigraphic data as a vector model.

# Definition of simple planes

Spatial parameters of a plane (or a vector) are not always measurable at one point. In this case the definition of planes involves correlation of point-like objects.

- Definition of planes:
  - Dip and direction is measured at **one point**.
  - Dip is measured at **two points**, and the direction is selected (see figure).
  - Correlation of **three points**.



Planes containing two points, and having the same dip.  
 Explanations:  $P_{1,2}$  = points;  $\delta$  = dip;  $\alpha_{1,2}$  = azimuths;  
 $u_{1,2}$  = parameters for meta-latitude;  $v_{1,2}$  = parameters for meta-longitudes;  $Z$  = zenith;  $O$  = origin;  $R$  = radius.

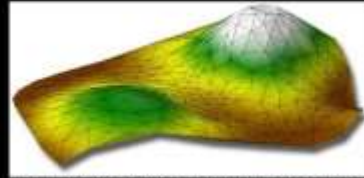
Slide 86 Definition of simple planes.

# Irregular network of planes as a TIN surface

TIN = Triangulated Irregular Network

The corners of a spatial triangle are observations of a spatially continuous phenomenon (e.g. topographic surface). To create TIN at least 4 points are necessary

- Surfaces can be:
  - Hypsometric surfaces;
  - Bathymetric surfaces;
  - Isopressure surfaces;
  - Geochemical surfaces;
  - ...



The TIN is a collection of spatial triangles with zero thickness. The dip direction and dip angle of each triangle is calculated which is the base of a morphometric analysis.

e.g. this attribute can be pressure data.

| ID  | X     | Y     | Z    | Attr. | PolyID | ID #     | Nghbrs |
|-----|-------|-------|------|-------|--------|----------|--------|
| 01  | 125.5 | 254.1 | 13.4 | 0.2   | A01    | 01,02,03 | A02    |
| 02  | 127.5 | 255.2 | 14.1 | 0.3   | A02    | 02,03,04 | A01    |
| 03  | 122.2 | 249.5 | 12.1 | 0.4   | ...    | ...      | ...    |
| 04  | 125.1 | 234.8 | 15.2 | 0.6   | ...    | ...      | ...    |
| ... | ...   | ...   | ...  | ...   | ...    | ...      | ...    |

The background database of a TIN surface is usually composed of three tables:

Points, Polygons, and the surface itself.

Slide 87 Irregular network of planes as a TIN surface.

# Generating TIN surfaces

A TIN surface is composed of nodes and edges, and the GIS data model describes this as one single entity.

In general a spatially continuous phenomena is suitable for two types of TIN model:

- If the subject of the model can be orthogonally projected onto 2D a TIN surface can be created;
- Otherwise, if the subject is spatially overlapping itself from every directions, a TIN mesh can be created.

A TIN surface is generated through the *Delaunay triangulation* which uses the lines perpendicular to the midpoints of a *voronoi polygon*.

Around each point a polygon can be constructed in which the internal points will be closer to the center point itself, than to all the other points. Such (voronoi) polygons are convex ones, and covers the plane continuously (see figure).



The network consists of  $2n-2-k$  piece of triangles, if  $n$  is the number of points on the plane and  $k$  is the number of points on the convex hull (de Berg et al. 2008).

Slide 88 Generating TIN surfaces or TIN meshes.

## Models of irregularly shaped objects

We create models of irregularly shaped objects as solids, if we are interested in the shape/size or volume of the subject.

There are two ways of the use:

- Unique objects are created which have irregular shapes (e.g. explicit models).
- A tightly fitting set of irregularly shaped objects are created as a tessellation of space (e.g. finite element methods, or implicit methods using primary data).

There exists tessellation of regularly shaped object too as 3D grids of voxels (voxel=volume pixel).

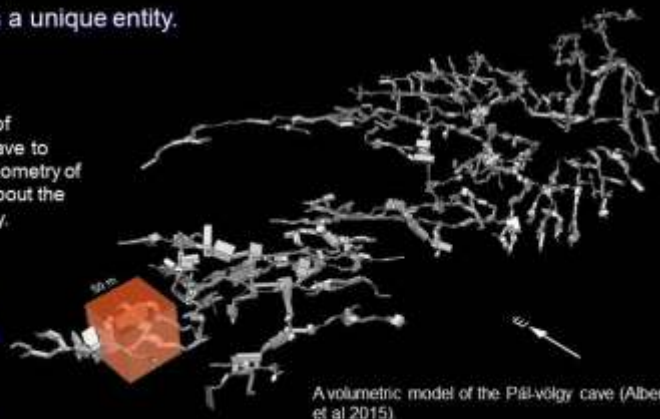
Slide 89 Models of irregularly shaped objects – the ways of use.

## A model of an irregularly shaped object – a case study

A model is considered irregularly shaped object if the hull of the:

- The object is a spatial phenomenon (it has extent in all directions);
- The shape is irregular, meaning that the edges and the angles are not equal within the hull;
- It can be defined as a unique entity.

To create an irregular shape of something (e.g. a cave) we have to know everything about the geometry of the subject, but information about the surroundings is not necessary.



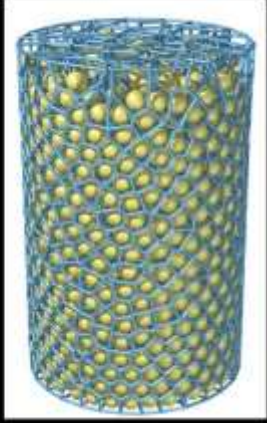
A volumetric model of the Pál-völgy cave (Albert et al 2015).

Slide 90 A model of an irregularly shaped object – a case study of the Pál-völgy cave (Albert et al. 2015).

# Tessellation of irregular tetrahedrons

The shape of the irregular object in the tessellation is generally tetrahedron. Calculation of these shapes is based on the Delaunay triangulation (i.e. creation of Voronoi polyhedrons instead of polygons).

The tessellation of irregular tetrahedrons are the 3D versions of the TIN-s, and the calculation method is also based on the .



Voronoi tessellation in a cylinder by the Voro++ open source web app. Voronoi polyhedrons are convex and fills the space continuously.

Slide 91 Tessellation of irregular tetrahedrons. Both the tetrahedrons and the polyhedrons may serve as the base geometry of the model.

## References for the slides

Albert G., Virág M., Erőss A. 2015: Karst porosity estimations from archive cave surveys - Studies in the Buda Thermal Karst System (Hungary) – International Journal of Speleology, 44 (2):151-165. Tampa, FL (USA)

Bellian, J.A., Kerans, C. and Jennette, D.C. (2005) Digital outcrop models: Applications of terrestrial scanning LIDAR technology in stratigraphic modelling. Journal of Sedimentary Research, 75, 166-176.

Gold C. M. 1991: Problems with handling spatial data - the Voronoi approach. CISM Journal ACSGC. Vol. 45, No. 1. Springer 1991. pp. 65-80.

Kidner, D., Dorey, M., Smith, D. 1999: What's the point? Interpolation and extrapolation with a regular grid DEM. – IV International Conference on GeoComputation, Fredericksburg, VA, USA – [http://www.geovista.psu.edu/sites/geocomp99/Gc99/082/gc\\_082.htm](http://www.geovista.psu.edu/sites/geocomp99/Gc99/082/gc_082.htm)

de Berg, Mark; Otfried Cheong; Marc van Kreveld; Mark Overmars 2008. Computational Geometry: Algorithms and Applications. Springer-Verlag.

Voro++ open source web application, <http://math.lbl.gov/voro++/about.html>



## Use of Jewel Suite (part 3.)

The explicit method of model building may include the import of polylines, images and (in case of geological modelling) borehole data. This class is aimed to practice the import of shape files and images in the workflow.

### Data Import

1. In the Workflow Guide go to the **Data Import** process, and then select the Shape Data panel. A dialog window appears where you can define the file where the shape file is stored and select the *outcrop\_bdn.shp* in the 07 folder. Notice that the shape is positioned on the 0 tvss level.

### Data manipulation in Jewel

Shapes in Jewel can have multifunctional use. A shape can represent a mapped line on the surface, but it can be considered as a trace line of a cross section. In the first case it usually needed to create a 3D polyline set in the modelling environment which is draped on the surface. However, this can be achieved in several ways. The following exercise demonstrates two of them.

2. In the solution Explorer right click on the "outcrop\_bdn" object which has a 0 at the end (referring to the vertical position).
3. Select the "create vertical arbitrary section" sub menu. A "outcrop\_bdn 0 Section" object is created in the Solution Explorer. And a grey vertical section object is displayed in the 3D view.
4. Right click on this object and press the "Show cross section view". A new main window appears showing the planar view of the curved plane. The section line of the *wells\_TOC\_topography* surface is displayed.
5. Click on this section line with right mouse button and select the "Create – intersection with cross section" sub item in the popup menu. A polyline set is created with a name similar to the surface of which it was created from.

NOTE: the same is achieved if you click on the *wells\_TOC\_topography* surface object in the Solution Explorer with the right mouse button.

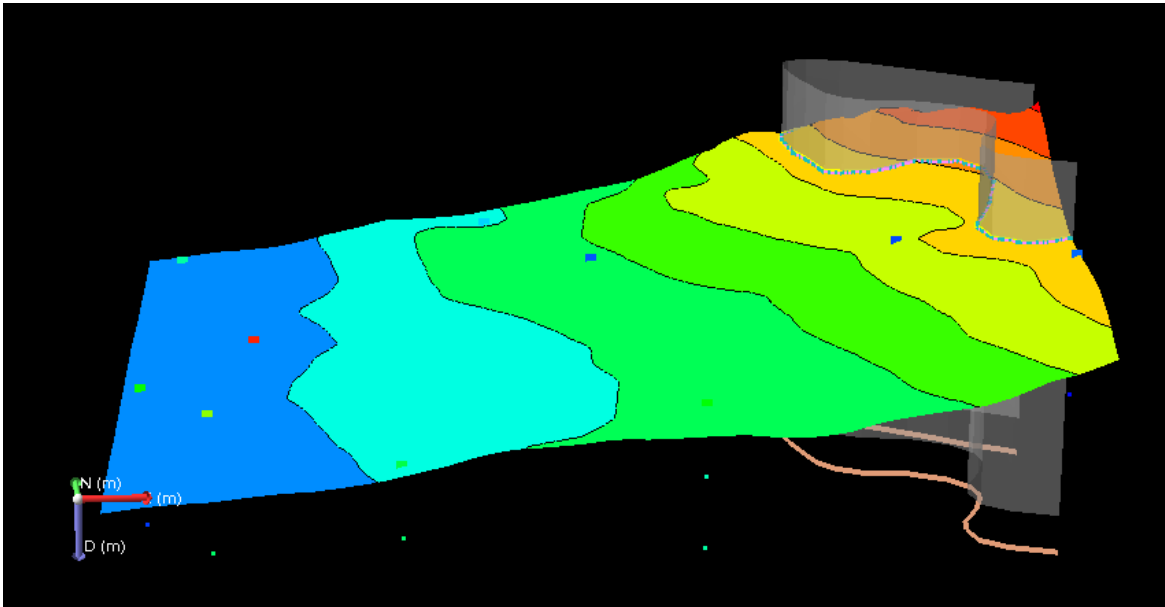


Figure 8 The surface model with the imported shape at zero elevation (lower right), and the grey transparent vertical-section surface, which was used to project the shape-line onto the surface.

Although this is a quick way to create the 3D polylines draped on the surface, it is problematic if we are working with a shape, which consists of several polylines. The other way to create a draped polyline set is to transfer the depth property of the surface to the vertices of the shape entity.

6. Right click on the “outcrop\_bdn 0” shape object. A new polyline set with the same name appears. Select this object in the Solution Explorer
7. Click on the “open calculator” icon in the “window toolbar” The “Property Calculator” sub application appears, which is a database querying and manipulating tool in Jewel.
8. In the Functions panel (left part of the window) explore the “Property extraction” and select the function: PropertyExtraction... with double clicks.
9. A new window appears where we can define the type of the object from which we want to extract the properties. Select the “2D grids” from the dropdown list.
10. The *wells\_TOC\_topography* surface is listed. Check the checkbox next to it (if not checked), and select the “depth” property from the dropdown list below the list of objects.
11. Explore the available interpolation methods in the dropdown list. For now select the nearest neighbour method and check the vertical projection radio button.
12. Press OK. A query expression appears.

NOTE: this query method has nothing common with the usual SQL language but builds on the “if, then, else” logic.

13. In the right side of the window change the Property name to depth, and press “Update Property” in the lower right corner. Close the Property Calculator.
14. Observe the result in the 3D view. Compare the two polyline sets! Check the database structure of the two of them in the “Data Creator View”. Explain the difference!

### Importing images

15. In the Workflow Guide go to the **Data Import** process, and then select the Image Data panel. A dialog window appears where you can define the file where the image file is stored and select the *P3-P8 cross section.jpg* in the 07 folder.
16. In the next dialogue select the simple image type.
17. In the next window you have to define the insertion point, the orientation and the size of the image. Insertion point: is the P3 well (Easting: 626752.550; Northing: 266222.936), bearing -11.5 degree (azimuth)<sup>1</sup> and 1 pixel=1 meter. Set the inclination to 90 (vertical) and the tvss to 250.
18. In the “Picking Toolbar” select the hammer and pencil icon (Enable picking for the editing tools). A popup window and a new toolbar (Editing Tools Toolbar) appear. Select the “Add polyline” tool icon in the toolbar and the list of the available polylines appears in the popup window. Select one of the existing polyline sets.
19. In the 3D view, digitize the bottom line of the “Oligocene Sandstone” with this tool. To finish digitizing double click on the last point.
20. Close the toolbar with clicking once again on the hammer and pencil icon (Enable picking for the editing tools).

---

<sup>1</sup> Although in Jewel it is called like this, in reality this value is not azimuth because it represents a counter clockwise rotation angle from the easting axis, while azimuth represents a clockwise rotation angle from the North axis.

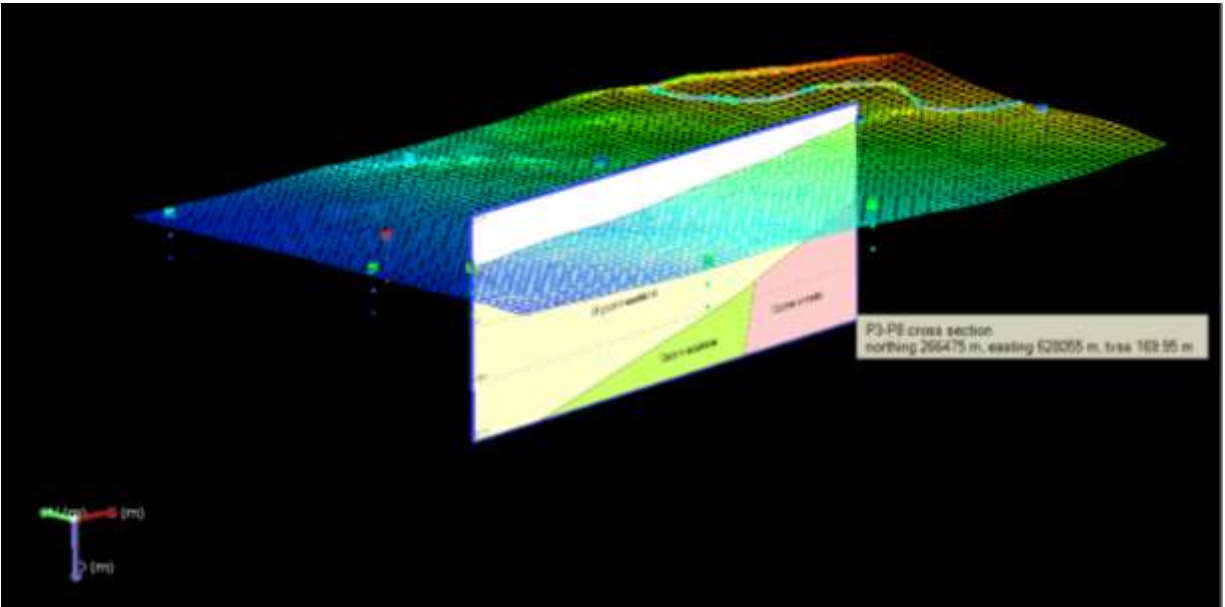


Figure 9 Image file (*P3-P8 cross section.jpg*) of a geological cross-section after modifying the angle and the dip value to place it in a geographically correct position in the modelling space.

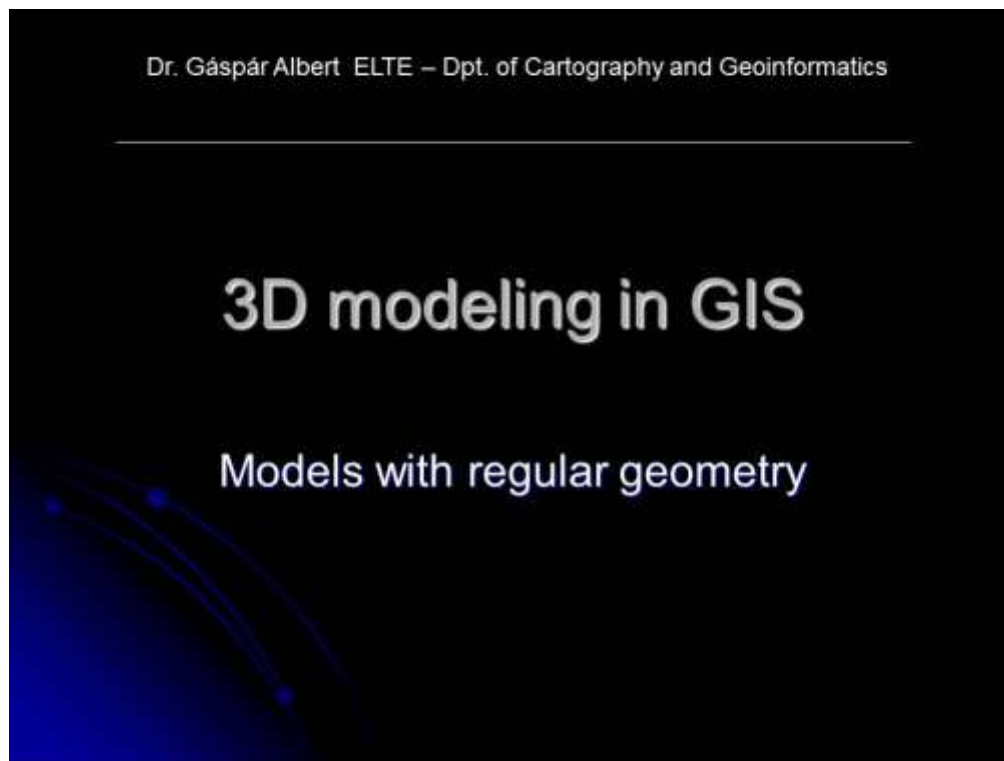
## Lesson 8.

The topics of this class are the followings:

- Tessellation of regular polyhedrons (isometric-anisometric; isotropic-anisotropic).
- 2D grids (the nature of grids: primary or compiled data?);
- Processing and storing grid data.
- 3D grids (types of voxels)

Practice: spatial modeling (creating voxel models from different input data). Quantitative 3D modeling from sample point-cloud data.

### Models with regular geometry



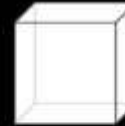
Slide 92 Welcome slide of the 8<sup>th</sup> theoretical class.

# Tessellation of regularly shaped objects

In models with regular geometry data points are distributed in 2D or 3D according to defined mathematical rules <sup>[1]</sup>.

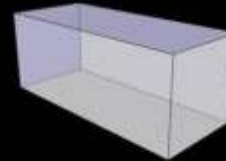
## Isometric regular models

Distances between nodes are equal and constant in the axis directions of the Euclidian space.



## Anisometric regular models

Distances between nodes are not equal, but constant in the axis directions of the Euclidian space.



<sup>[1]</sup> There exist a more tight definition (Sárközy): regular objects are those, which has equal sides and internal angles. Thus, the tessellation of regularly shaped object use only regular objects as elementary voxels like cubes, tetrahedrons, etc., but not prisms or parallelepipeds.



Slide 93 Isometric and anisometric grids

# Isotropic or anisotropic?

In the data structure of regular models it is usually enough to define a key position, the resolution (cell size), the grid size (numbers of rows and columns) and the rotation angle about one or more coordinate axis. Each of these parameter is a constant or a variable.

- In **Isotropic** models  
The cell shape is constant, so the grid node positions can be considered as matrices.
- In **Anisotropic** models  
The cell shape varies according to a mathematical rule (e.g. cyclically grows and shrinks). The change may occur in one or more direction.

The mathematics behind the changing cell shape in anisotropic models can be a function of an attribute and modify not only the size, but the direction of the edges.

In fractal models the edges are visualized instead of the cells, and the function modifies the size and the direction at the same time (fig.). However, models like this have only fractal dimensions, and are not considered as tessellated models.



Regular? Yes!

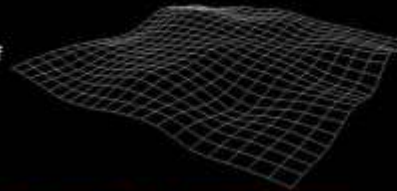
Slide 94 Isotropic and anisotropic models

# Grid (regular network) models

Observations are usually done in irregular patterns, and grid nodes are calculated from the original data, which makes them secondary (estimated) data.

Why is a grid called **raster** data type?

The data model of grid is similar to the data model of a raster image. Like the pixels of an image, the grid cells are base units of the grid. These units – if they are put next to each other – compose continuous model.



These parameters are usually true for regular shapes (triangle, square, octagon, etc.)

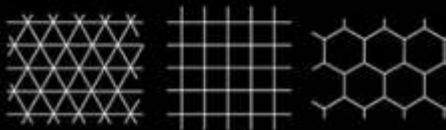
To construct a raster data type the following parameters are necessary concerning the shape of the base unit:

- I. It must be a base unit which – putting them repeatedly next to each other – can be used to construct any size of models.
- II. Sliced into self-like pieces, any resolution must be available.

Slide 95 grid models as surfaces

# Tessellation

The shape of the base units is usually square, but regular triangle, hexagon is also common, and in the case of anisometric models any irregular shape can be used.



The methods which are designed to store and process data, are more effective in the case of the simplicity of the base unit.



M. C. Escher: Fish & Birds

Slide 96 what is a tessellation?

# Processing and encoding data in a raster data model

In a raster data model the information is indexed according to the cell's position in the grid. The index is a code which is generated in the modeling application.

- Encoding methods for the data of a raster model:
  - run-length encoding
  - chain encoding
  - medial axis transformation
  - **quadtree encoding (fig.)**
  - fractal encoding



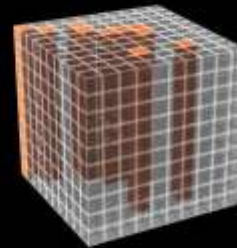
The *quadtree* is the most widespread encoding method in GIS for isometric grids. (Samet 1990).

Slide 97 Data encoding in a grid – the quadtree method.

# Regular spatial (voxel) grids

Regular spatial grids are created for models of spatially continuous phenomenon (e.g. concentration, porosity, natural gamma radiation, magnetic field, etc...).

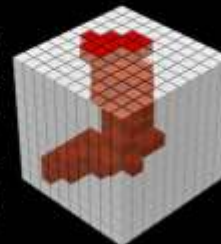
- A voxel is considered as a:
  - statistical parameter;
  - simplified representation of real objects.



The term „voxel“ is used in spatial modeling and originates from the combination of the terms *volume* and *pixel* (meaning picture element).

On the top: 10% of the top surface is differentiated and extruded into the larger cube (this way the complex shape of the dark voxels doesn't matter only their proportion).

On the right: a complex shape is modeled with dark voxels and fills 10% of the large cube (this way the shape matters)



Slide 98 The different meanings of a voxel in a model.



# Voxel types

- Tessellation with regular convex polyhedrons:
  - Regular tetrahedron
  - **Hexahedron (cube)**
  - Octahedron
  - Rhombic dodecahedron

} Platonic solids

- Anisometric and anisotropic regular models.
  - e.g.: prismatic honeycombs
  - ...
  - Countless variation of shapes

Slide 99 Voxel types (convex polyhedrons).

# Encoding data in a voxel grid data model

The regular voxel grids are tessellated usually with cubes, because of the simplicity of this model.

- In the case of a cube the octree encoding is used, where the cube is dissected into eight smaller cubes in every level of detail (Samet 1990).

Slide 100 The octree encoding (Samet 1990).

## References for the slides

Samet H. 1990: The design and analysis of spatial data structures – Addison-Wesley Publishing Company, Inc. 1990.

## Use of Jewel Suite (part 4. – Implicit Data Modelling)

In this class a 3D voxel grid modeling is demonstrated by importing quantitative data into the modeling environment and defining the model parameters and calculation methods.

Window – New window – Start Page: select the New Solution icon. This will start an empty project with the default settings. An empty 3D View panel (in the middle of the screen) show up.

### Import point set and surface data:

1. In the Workflow Guide go to the **Data Import** process, and then select the Point Set Data panel. A dialog window appears where you can define the file where the Point set data is stored. Select the Wells\_TOCs surf.joapointset file.
2. Repeat the import process with the Wells\_TOC\_MD100.joapointset and Wells\_TOC\_MD50.joapointset files.
3. Import the wells\_TOC\_topography.grd file as a 2D grid. Be prepared to rotate the Z axis during the process!

### Model Area definition

To create a model first we have to define an area where the application will calculate the secondary data from the original ones.

4. In the **Model Definition** workflow process select the Model Area Definition panel.
5. In step 1 define the name of the modelling area (e.g. TotalArea), and press the “Create” button. A grey outline of a 3D regular block appears in the 3D view. Notice that a new object type appears in the Solution Explorer.
6. Try to modify the extent of this block by holding the Ctrl button and dragging the sides of the block with the left mouse button.
7. In step 2. select the “Calculate from model data” and press the “Calculate” button.

8. In step 3 set the location to 626575 (E) and 265850 (N), the size to 50x50 m and press update in step 5.
9. Modify the Tvss value to -300 and the Length to 300 in step 4.

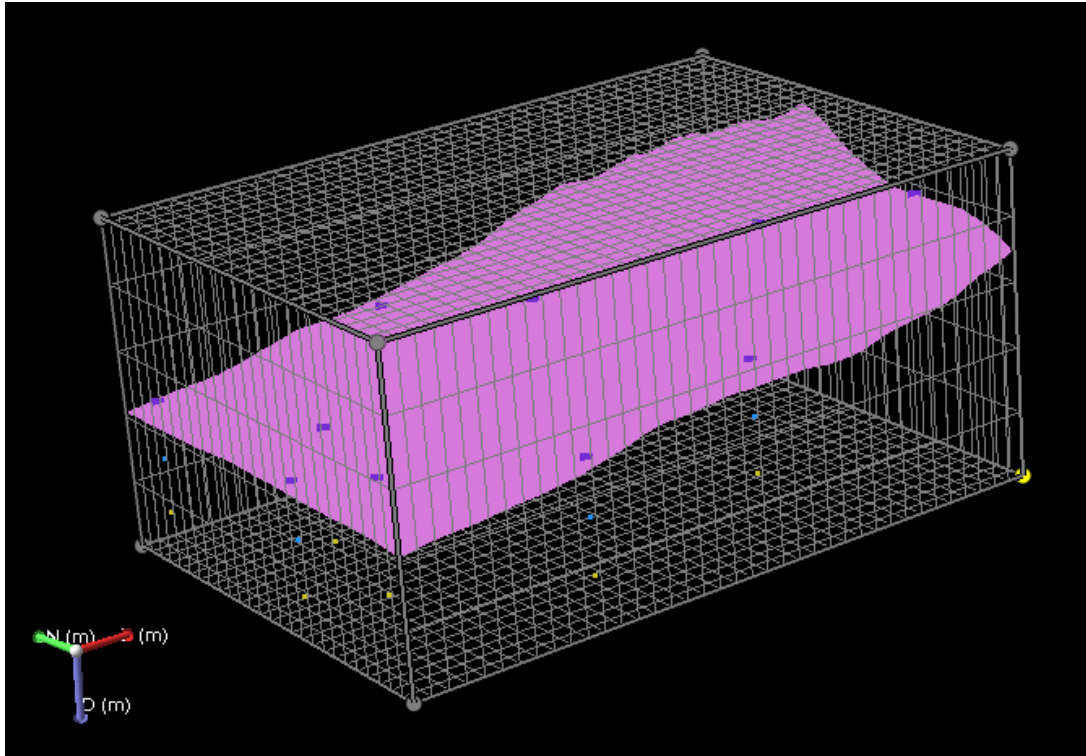


Figure 10 setting the modeling area (represented with a white “cage”)

Set the scale in depth value to 3 in the General View Toolbar to see this display.

### Model Layer definition

The modelling process is partly based on an idealized vertical sequence of entities (surfaces, point- and polyline sets, etc.). This sequence must be true in all parts of the model. However, it is possible that one or more elements are not present at every position (i.e. certain layers are missing in one area of the model, while they are present at other locations). This is usually called the “**layer cake**” modelling method, and it can produce surface entities which are not folded under themselves.

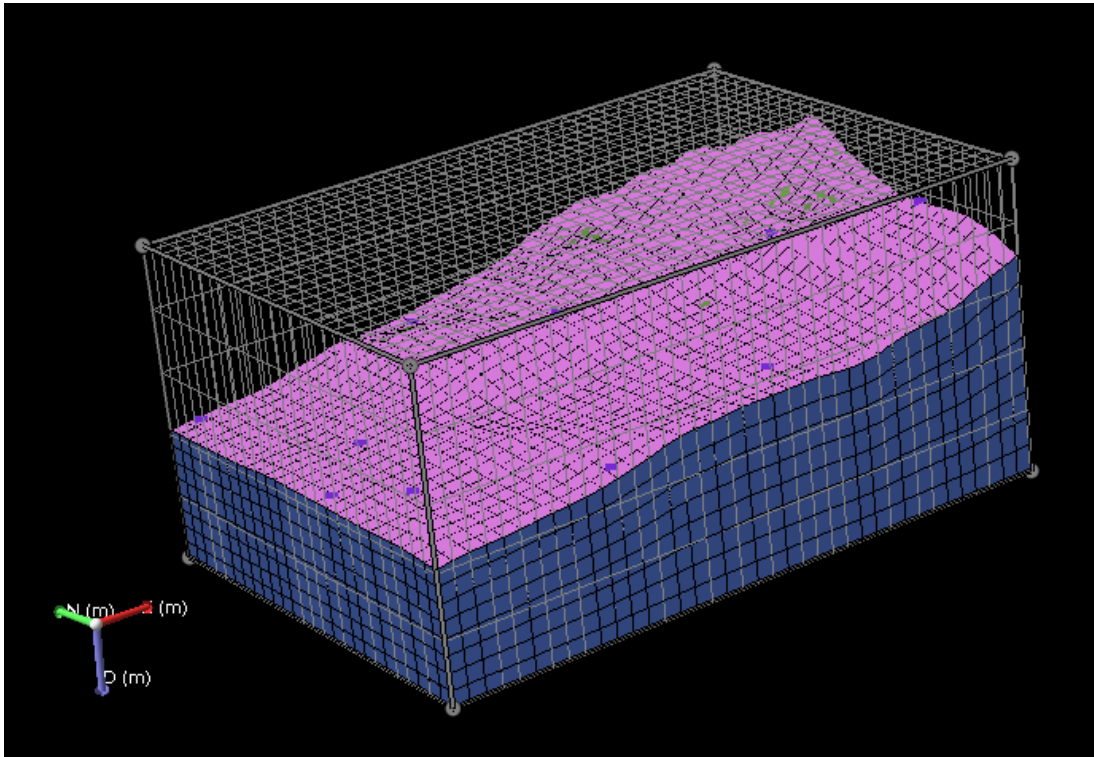
10. In the **3D Gridding** workflow process select the Model Layer Definition panel.
11. In step 1 (Show the model layer definition) press the Show button. A new main window appears. This window shows the idealized sequence of the model layers from bottom to top.

12. In this window left click on the grey rectangle (Reservoir) and select the “Set internal layers” submenu. In the popup dialogue type 8, and press OK.
13. In step 5 rename the main object from Reservoir to Oligocene Sandstone, and set the Thickness value to 400.
14. Set the Top surface with selecting the wells\_TOC\_topography 2D grid object from the dropdown list. Since no other surface is created at this point, the base surface cannot be defined. Set the Conform type to “proportional” and the Conform direction to “Top”.
15. Press the home icon (or the “close workflow panel” link).

### 3D gridding

In this exercise a **voxel model** is created using the bounding parameters of the previous steps.

16. In the **3D Gridding** workflow process select the Jewel Gridding panel.
17. In step 1 create a new 3D grid object with the name: TotalGrid. In step 3 select the existing TotalArea as the active Area (if not selected).
18. In step 5 check only the “insert stratigraphic surfaces”, and press Execute.
19. Switch back to the 3D view and observe the result.



**Figure 11 The Jewel model of an eight-layered rock body – further modification of the geometry is possible with modifying the type and direction of stratigraphic conformity in the “3D Gridding” panel.**

In the Solution Explorer a new object appears which the voxel model is. The created model is bounded by the modelling area and the topographic surface. It contains 8 sublayers which follow smoothly both the top and the bottom bounds. It is because in step 14 of this exercise the Conform type and directions were defined to behave like this.

20. Open the Model Layer Definition panel again and change the Conform type to “Conform” and the Conform direction to “Bottom”. Close this workflow panel and open the Jewel Gridding panel. In step 5 press “Execute”. Say “Yes” to the popup questions.

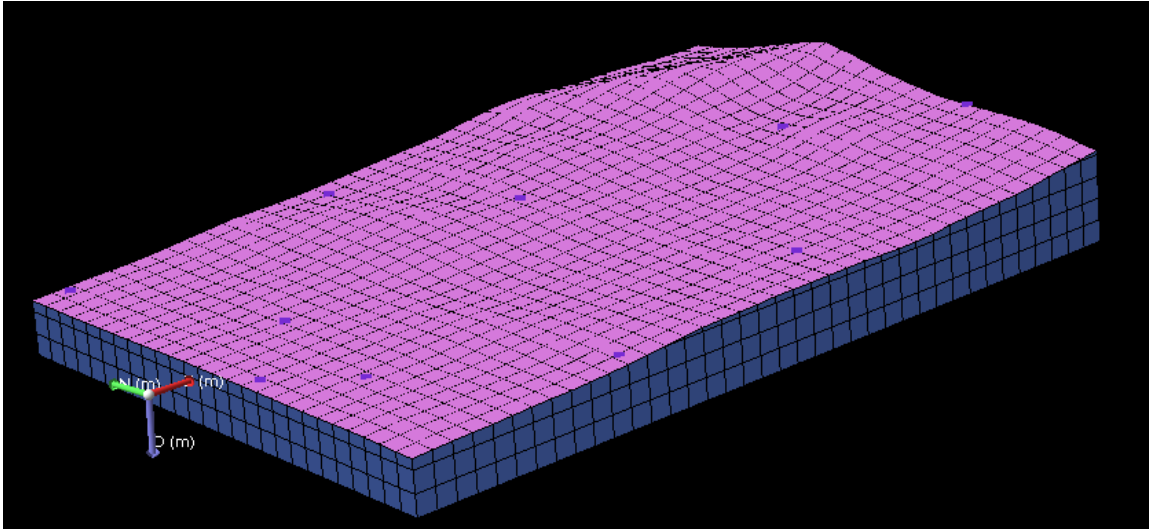


Figure 12 A 3D model having uniformed 3d cells (voxels=volume pixels).

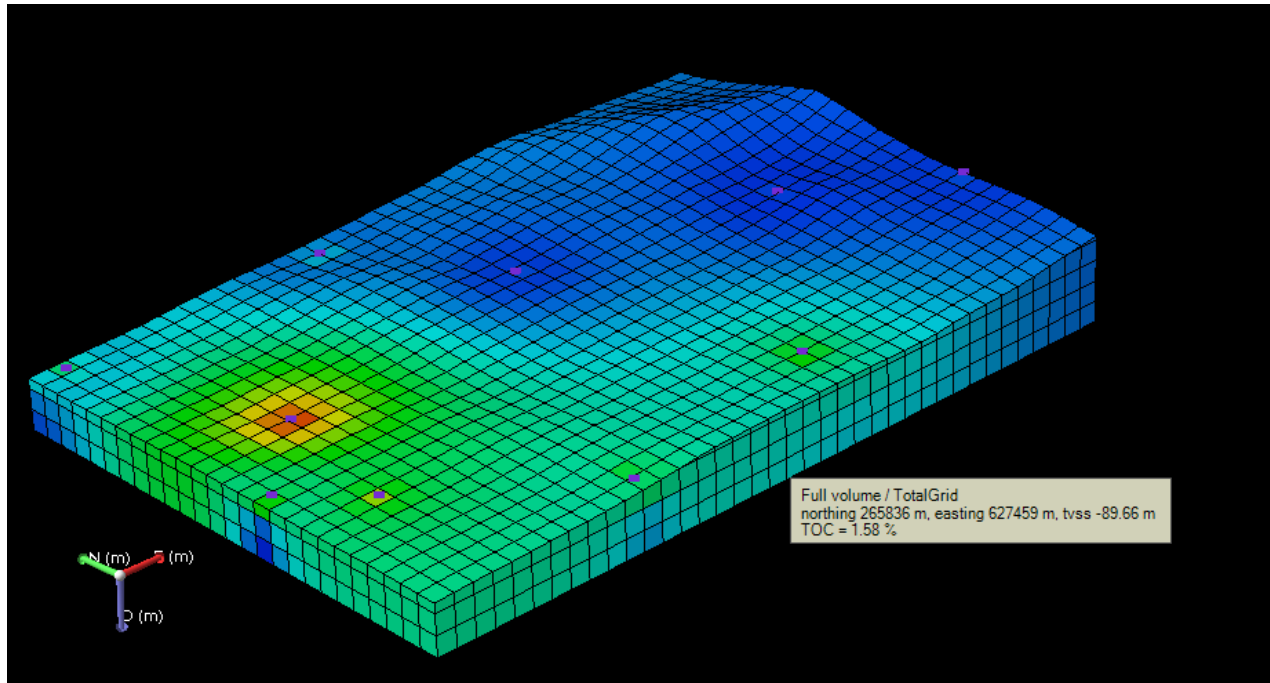
This new pattern represents a voxel grid with the resolution of 50x50x50 m (see step 12 and 13 of this exercise: 400 m divided by 8), but the topmost voxels are cut by the topography. Set the scale in depth value to 1 in the General View Toolbar to see this display.

### Extracting property data from the point clouds

The property modelling is the final step of an implicit modelling method. Using the original data, new secondary data is created on those spatial positions, where originally no information was available.

21. In the 3D view or in the Property Explorer select the TotalGrid object. Open the “Property Calculator” sub application (click on the “open calculator” icon in the “window toolbar”).
22. In the Functions panel (left part of the window) explore the “Property extraction” and select the function: PropertyExtraction... with double clicks.
23. A new window appears where we can define the type of the object from which we want to extract the properties. Select the “Point sets” from the dropdown list, and check all the listed point sets.
24. Select the “TOC” property from the dropdown list below the list of point sets.
25. Explore the available interpolation methods in the dropdown list. For now select the inverse distance weighted method and check the without projection radio button.

26. Press OK. A query expression appears.
27. In the right side of the window change the Property name to TOC (if not listed type it in), and press “Create Property” in the lower right corner. Close the Property Calculator.
28. Observe the result in the 3D view.



**Figure 13** Interpolated TOC values are generated for each cells (voxels) in the 3D grid. The 3D interpolation method used the original measurement data from the imported point cloud.

Try other interpolation methods (e.g. nearest neighbour and kriging) in the Property Calculator.

## Lesson 9.

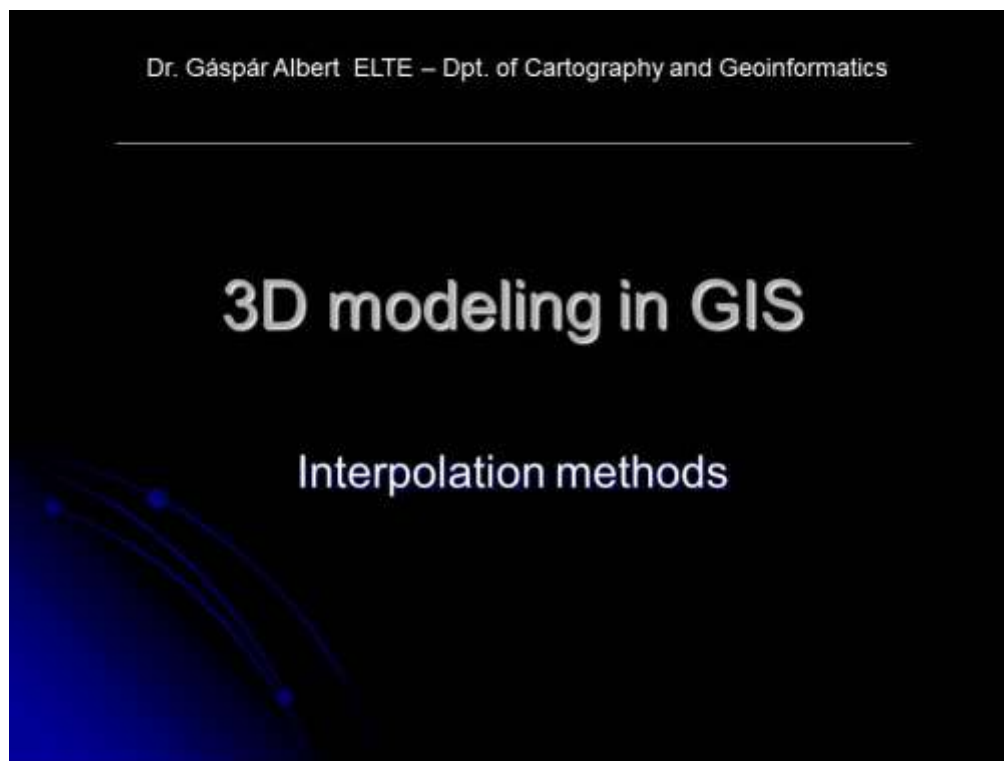
The topics of this class are the followings:

- Calculation methods of grid-point values (interpolation and spatial statistics).

Practice: Converting TIN-s into grids and vice-versa. Draping and rectifying image files into the model.

Extracting data from a 3D model. Working with extracted data

### Interpolation methods



Slide 101 Welcome slide of the 9<sup>th</sup> theoretical class – interpolation methods.



# Basic types of interpolations

An interpolation creates new values from existing ones (control points), in the bounds of the original (spatial) extent of data.

1. Deterministic method is used if we are 100% sure in the validity of the original points.

- In this case we suppose that the control points represent values of a variable in a **function**.

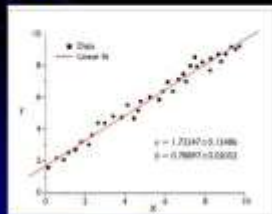
2. Stochastic method is used if we suppose that the original control points have errors (and we also want to calculate the error itself).

- In this case we try to fit a function on the control points. The error of the fitting is minimized with linear algebra, and the method is simply called **curve fitting**.

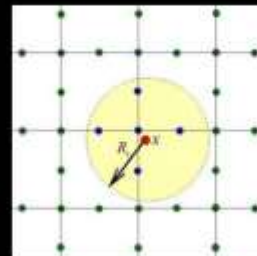
Slide 102 Types of interpolation– deterministic and stochastic methods.

## Classification

- **Global methods:**  
All control point are used in the estimation process (e.g. calculation of trends)



- **Local methods:**  
Only control points near the location is used in the estimation.



Slide 103 Classifying interpolations – global and local methods.

## Classification by the results

- Exact methods:

On the locations of the control points, the method exactly produces the original value.

- Inexact methods:

The estimated value will be different from the original value at the exact location of the control points.

Some of the error estimation methods use this logic too. For example the „pick one out“ or the cross validating is an objective method used for assessing the quality of an interpolation method. We pick one point out from the original dataset, process the interpolation and examine the difference between the estimated value and to original value at the picked point. Repeating this in statistical quantities the objective error of the interpolation method is assessed.

Slide 104 Classifying interpolations by the return values (results) – exact methods and inexact methods.

## Calculating the grid pint values

The grid point values are usually estimated with (geo)statistical methods like interpolation. In GIS many methods are available, which may produce very different results from the same primary data set.

*Commonly used methods:*

- *Nearest neighbor method*
- *Bilinear interpolation*
- *Inverse distance weighting – IDW*
- *Polynomic interpolation*
- *Spline interpolation*
- *Gaussian linear regression & kriging*

Experiments show that using higher grade functions in the estimation process, will produce more realistic surface models (Kinder et al. 1999).

Slide 105 Commonly used calculation methods.

# Classifying the usual methods

| Global               |                        | Local   |                          |
|----------------------|------------------------|---|--------------------------|
| Deterministic        | Stochastic             | Deterministic   | Stochastic               |
| Polynomials* (exact) | Polynomials* (inexact) | voronoi polygon methods – e.g. nearest neighbor and triangulation with linear ip. (exact) | Kriging (exact)          |
|                      | Regression (inexact)   | IDW (exact)   | Moving average (inexact) |
|                      |                        | Spline (exact)  |                          |

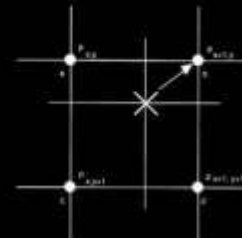
\* Exact, if the order of the polynomial is less with one than the number of control points (n). Inexact, if the order of the polynomial is smaller by more than one than the n.

Slide 106 Classification of the commonly used interpolation methods.

# When do we use?

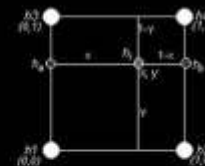
## 1. Nearest neighbor method

The nearest control point is selected with trigonometry, or using the voronoi polygons. This method is used if more than one variable should be estimated in a short time (e.g. quickly resizing RGB images). *Not recommended for precise modeling!*



## 2. Bilinear interpolation

Two axis-parallel linear interpolation is done in the plane in a sequence to estimate the value of the new point. This method is used if the original data is already in a grid, and the aim is to continuously represent the model on a plane (e.g. on the screen). It is also used for *resizing or down sampling existing grids.*



Slide 107 The use of the nearest neighbor and bilinear methods.

# What should we use?

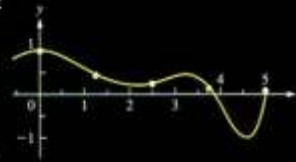
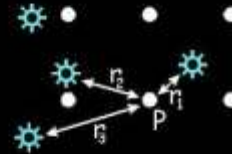
## 3. Inverse distance weighting

The value of the new point is calculated from all the existing ones. For weighting the value of a given control point, it is multiplied with the inverse of the distance on a power (which usually equals 2).

It is an exact and quick method to convert irregular control points (TIN-s) into a grid data model.

$$z_0 = \frac{\sum_{i=1}^s z_i \frac{1}{d_i^k}}{\sum_{i=1}^s \frac{1}{d_i^k}}$$

$z_0$  estimated z value at the new point  
 $z_i$  the z value at the i control point  
 $d_i$  distance of the i control point from the new point  
 $k$  weight parameter  
 $s$  number of the control points



## 4. Polynomial interpolation

A deterministic method where we fit a polynomial function with the order of n-1 on all control points (n). This method is used only in the case of small number of control points. In practice the spline method, or a polynomial regression is used instead.

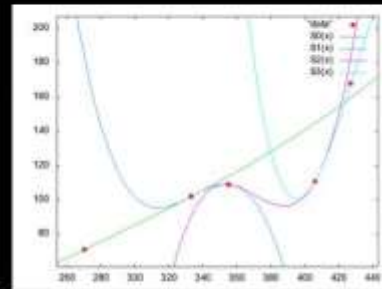
Slide 108 The use of the inverse distance (IDW) and the polynomial methods.

# Deterministic methods for precise estimations

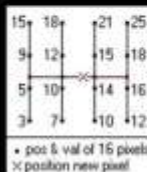
## 5. Spline interpolation

In surface modeling applications this method is usually represented by the *bicubic interpolation*. It is a sequence of two third order (cubic) polynomial interpolation done respectively in two of the principal axis directions.

It is suitable to create high quality 2D representations from grid data, or to modify (e.g. refine) the resolution of a grid.



A third order polynomial as a one dimensional function.



For the estimation of the value at X, a cubic interpolation is done in four vertical and one horizontal direction.

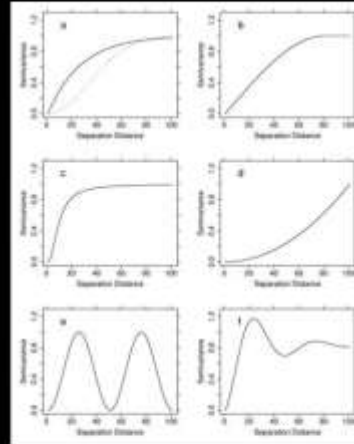
Slide 109 Deterministic method for precise estimations – the spline interpolation.

# Stochastic methods for precise estimations

## 6. Polynomial regressions and kriging

Using the least square method these interpolations use the control points in a given direction to create an estimator function (a variogram) at the position of the new point.

The method is usually used if the phenomenon which is modeled has normal distribution and do not change in time. It is also good for data which is loaded with noise.



Different types of half variograms

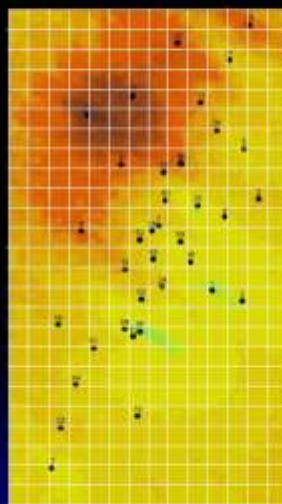
Depending on the variogram, the value at the new point will have an uncertainty, which can be calculated

Stochastic modeling

It can be supposed that several other estimations can be produced on the given location, which will have the same uncertainty.

Slide 110 Stochastic methods for precise estimations – polynomial regression and kriging.

# Stochastic modeling

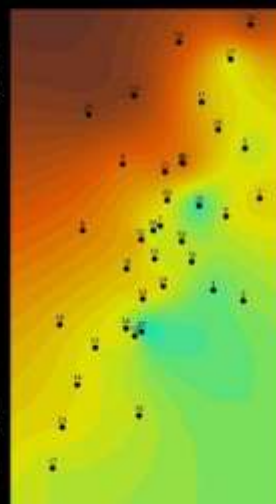


In a credible interval (representing the uncertainty at the location) there are endless numbers of solutions, which has the same probability.

### Attention!

Over increasing the grid resolution may give false impression about the true level of details!

The representation of a stochastic model is much more detailed than the smooth map of a surface model done with kriging, although the probability of the two is the same.



The two maps show a stochastic model (left) and another one done with kriging (right) using the same data points (Geiger J.)

Slide 111 Stochastic modeling.

# Calculation of 3D grid points

A 3D grid model is used in implicit modeling, and the estimating methods are usually similar to those, which are used in 2D.

- Nearest neighbor
  - This method uses the voronoi polygons in 3D
- Trilinear interpolation
  - A sequence of three linear interpolation is done in the three principal axis directions.
- Tricubic interpolation
  - A sequence of cubic interpolation in the three principal axis directions.
- IDW (inverse distance weighting)
  - Omnidirectional method which is good if the resolution of the target grid and the average distance between the dispersed original points are at the same scales.
- Kriging
  - In this omnidirectional approach, the variogram model is constructed in the vertical direction too. Prior to kriging a variogram analysis is necessary.

Slide 112 Calculation methods in 3D grids.

## References for the slides

Kidner, D., Dorey, M., Smith, D. 1999: What's the point? Interpolation and extrapolation with a regular grid DEM. – IV International Conference on GeoComputation, Fredericksburg, VA, USA –

[http://www.geovista.psu.edu/sites/geocomp99/Gc99/082/gc\\_082.htm](http://www.geovista.psu.edu/sites/geocomp99/Gc99/082/gc_082.htm)

KN Zelenika, T Malvić 2011: Stochastic simulations of dependent geological variables in sandstone reservoirs of Neogene age: A case study of the Kloštar Field, Sava Depression – Geologia Croatica 64/2, Zagreb, Croatia, pp. 173-783.

## Use of Jewel Suite (part 5. - Extracting data from the 3D model)

In this class a secondary data from a 3D voxel grid model will be extracted in different formats.

Window – New window – Start Page: select the New Solution icon. This will start an empty project with the default settings. An empty 3D View panel (in the middle of the screen) show up.

## Import point set surface and 3D grid data:

1. In the Workflow Guide go to the **Data Import** process, and then select the 3D Grid Data panel and import the *TotalGrid.joasgridset* file as a 3D grid data.

## Extracting data from the grid

### Property

- Extract property values from the whole grid as point set, then export the point set to an xyz file.
- Extract property values from a horizontal (K) segment of the grid as point set, then export the point set to an ascii point set (txt) file.
- Extract property values from a vertical (I or J) segment of the grid as point set, then export the point set to an ascii point set (txt) file.
- Create a point set with one point at one given coordinate and use the property calculator
- Create a well at an x, y coordinate and create a log
- Create a well (X1) at the position:

| EASTING [m] | NORTHING [m] | TVSS [m] | MD [m] | INCLINATION [deg] | AZIMUTH [deg] |
|-------------|--------------|----------|--------|-------------------|---------------|
| 627002      | 266311       | -144.0   | 300    | 0                 | 0             |

- With the calculator, extract the TOC and the vertical thickness property from the TotalGrid into the well X1.
- Export the logs of the X1 into an AscII file.

### Geometry

- Modify the model (or a copy of the model) to be conform from the top and create a horizon tri-mesh at the K=3 level. Create a 2D grid from this and export it as a surfer grid.

### View

- Copy the view content to window
- Save the view content to a file.

## Working with extracted data

- Filter the extracted point cloud data (TotalGrid\_Full volume.txt) with excel and keep only those points, which have TOC values between 1.4% and 1.5%. Save this as a new txt, and import it back

into Jewel (using the “user defined formatting...” method). During the import process define the geological type of the point set as “Horizon” .

- In the **Model Definition** process, add the new point set to the model in the “Model Data Selection” panel.
- In the **Structural Framework Modeling** select the Triangulation and create a Tri-mesh from an aspect, different from the top view (see step 4 in the workflow manager).
- Open the extracted property values from a horizontal (K) segment of the grid as an Excel sheet and modify the sequence of the rows E, N, TOC be the first 3.
- Open the text table with Global Mapper as an elevation data file
- Extract the result as a kmz and open it with Google Earth.

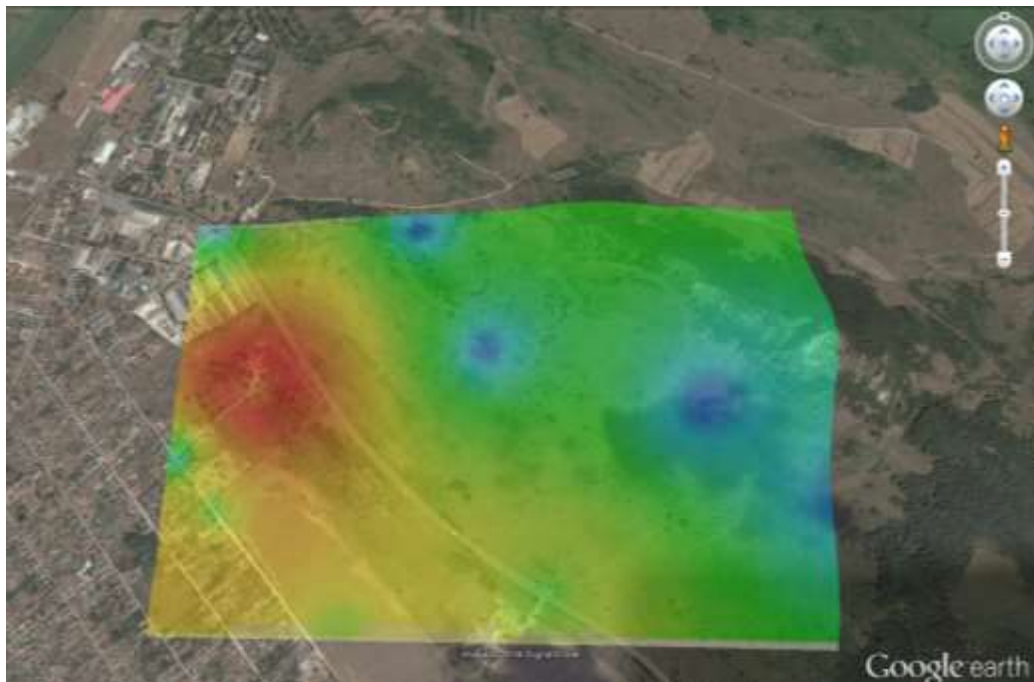


Figure 14 The extracted horizontal level of the Jewel grid can be displayed in Google Earth after some preparation in a GIS software (e.g. Global Mapper)



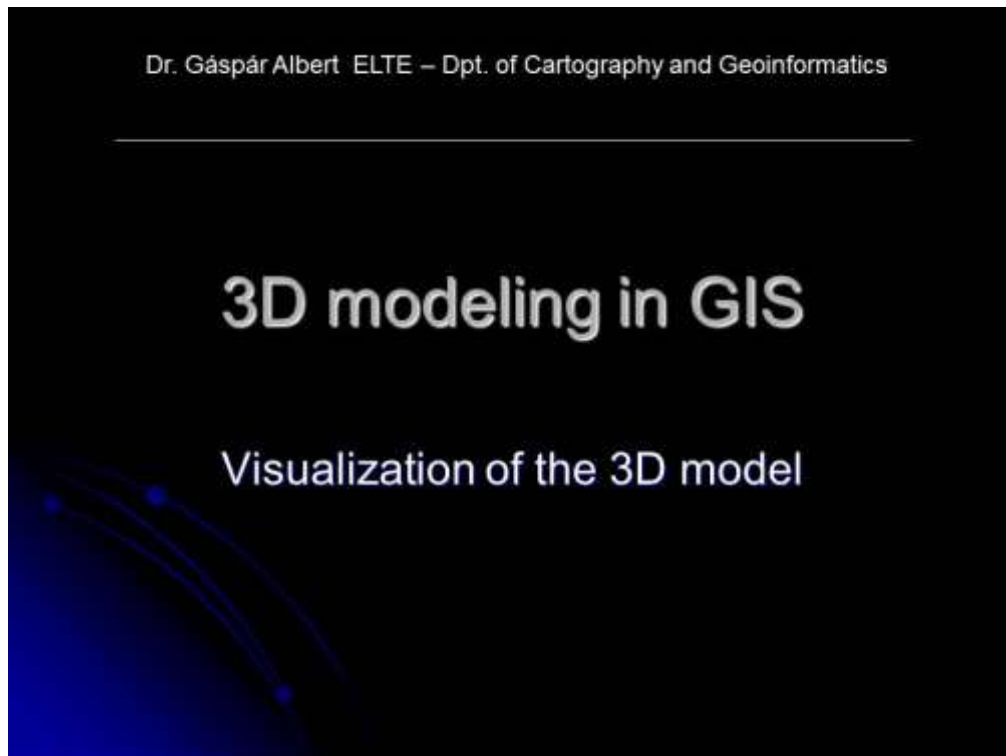
## Lesson 10.

The topics of this class are the followings:

- The media of the 3D visualization (paper/screen).
- Visual requirements of the model in 2D, 2.5D and 3D (perspective/orthogonal/vertical exaggeration).
- The conceptual 3D model.
- Models in the virtual space (when do we really see models?).
- Viewers and query tools.

Practice: Modeling without a 3D modeling software. The modeling log and the modeling report.

### Visualization of the 3D model



Slide 113 Welcome slide of the 10<sup>th</sup> theoretical class – Visualization.

## The medium of the visualized model

- Traditional 2D figures (paper paradigm) on:
  - Paper;
  - Screen.
- Representation in the virtual space through:
  - 2D interface (screen);
  - Augmented reality.

Although the 2D still images have the greater impact, the emphasis is shifting towards the representations in the virtual space. Open source and free modeling tools, user interfaces and standards facilitate this process.

Slide 114 The medium of the visualized model: paper, screen, virtual reality.

## Requirements of visualization

Visualization is a method of computing. It transforms symbolic data into geometries. Usually the geometries are 2D shapes (either on paper or screen) representing 3D data. **The main difference between the paper and the screen method is the possibility of interaction**

3D object can be visualized in 2D in three ways:

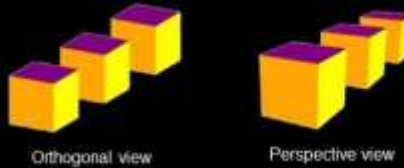
- 2D projection of the top or side view of the subject. This includes **horizontal and vertical sections and maps** representing a constant value of the third dimension.
- 2.5D models also projected onto a plane but the third dimension is represented with symbols (e.g. **shading or contours**) of the height/depth/distance. However, visualization of complex 3D objects is problematic.
- 3D representations visualize all extent of the subject in the Euclidian space. This includes **block sections and perspective views**.

Slide 115 Requirements of visualization.

# How can we make it good?

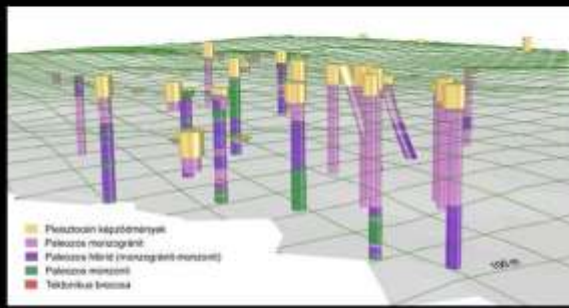
It is a general requirement to create visualizations which represent the model in the most understandable form.

- In 2D representations:
  - Users got used to symbols of certain phenomenon on a map (e.g. water is blue, geological formations are colored by their age, etc.). To create an optimal visualization, it is suggested to use standard symbols.
  - If the modelling tool does not allow modifications of symbols in the output format, be prepared to process the result in other applications.
- In 2.5D and 3D representations:
  - Besides the use of usual symbols the plasticity of surfaces and 3D object usually enhance the visualization (e.g. use of shading).
- 3D representations:
  - The still images of a 3D model visualization are best understood if the view has explanatory semiology. This means that the symbols of a block section should be well known, and legend to the view should be added.
  - It is also an advantage if the view can be perspective and not only orthogonal.
  - Spatial relevance of certain parameters should be emphasized with coloring or overscaling.
  - The use of 3D screen and anaglyph methods.



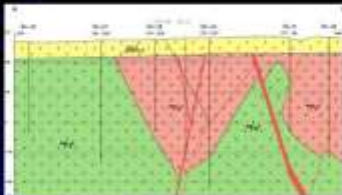
Slide 116 How can we make good visualizations? General requirements of 2D, 2.5D and 3D representations.

## Visualization on static 2D surfaces



3D method (left): perspective view, with legend.

2D methods: horizontal (top) and vertical (right) sections



2.5 D method (below): shading, hypsometric coloring

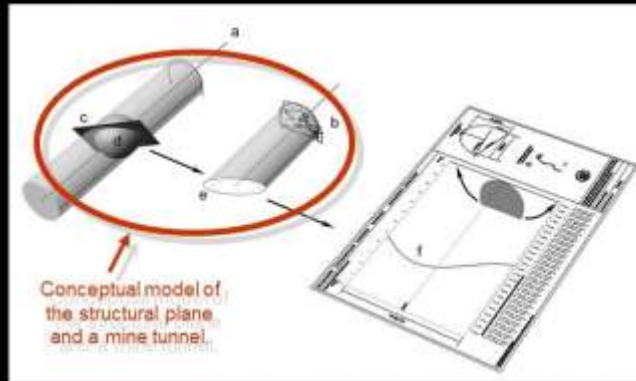


Slide 117 Visualization on static surface (still images on paper or screen).

# Conceptual 3D model only with 2D representations

It is usual that the proceedings of a 3D modeling<sup>[1]</sup> is planned but only a 2D representation is needed in the end. This is called **conceptual 3D modeling**.

The 3D model and the projection of the model onto a plane is described with mathematical formulae (equations of projection).



Process of 2D visualization of a plane measured during a tunnel construction onto a tunnel-wall map (Albert et al. 2006), explanation: a = tunnel axis; b = tunnel front; c = measured plane; d = reference sphere; e = projected 3D shape of the plane; f = projected line of the plane.

[1] The proceedings of the modeling compose the mathematical frame of the data processing (e.g. interpolation, weighting and error estimation).

Slide 118 The conceptual 3D model.

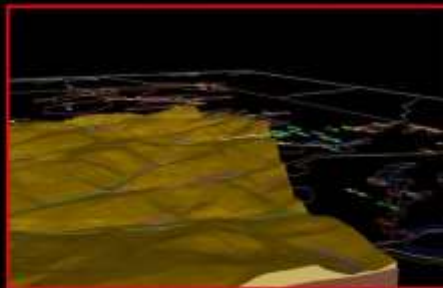
# Representations in the virtual space

A 3D model in the virtual environment is also visualized in a 2D surface (screen), but the visualization can be interactive or constrained. In the case of the latter only a sequence of 2D views is enough (e.g. a flythrough videos) and none of the original data is needed. **In the case of an interactive visualization all the data should be accessed.**

A modeling environment can visualize and manage all the loaded data.

If we step out from this environment the visualization is usually limited to:

- Still images
- Videos
- Viewers



Slide 119 Model representations in virtual space – a viewer or a video?

# 3D viewers and query tools

3D viewers and query tools are created for those users who are interested to see the data in a 3D visualization with access to the data in the background.

Such tools are usually the simplified versions of the modeling tools themselves, and use standard or own data formats.

- **Open standards:**

- vector data (GML [Krahl], X3D [VRML], DXF ...);
- raster data (OpenRaster)
- database (XML, MySQL, ODF, ASCII ...)

...but these apps usually handle industrial standards too.

- **Industrial standards:**

- vector data (SHP, TAB ...);
- raster data (GeoTIFF, IMG, PNG, JPG, ...);
- database (DBF, MDB, XLS, ...)

The viewer is usually a PC-based executable or a client-side application, which allows users to query and manipulate data depending on their level of access.

Slide 120 3D Viewers and query tools.

## References for the slides

Albert G., Orosz L., Gyalog L. 2006: [Cartographic representation of geological information, observed on tunnel walls and fronts](#) – *Proceedings of the 5th European Congress on Regional Geoscientific Cartography and Information Systems (Earth and Water), Barcelona, Spain 13–16/06/2006*, Vol. II. pp. 89–91.

Müller, H., Curtis, E. 2005: Extending 2D interoperability frameworks to 3D – Snowflake Software Ltd., <http://www.snowflakesoftware.co.uk/news/papers/3DFrameworkPaper.pdf>

Vries, M. de, Zlatanova S. 2004: Interoperability on the web: The case of 3D data. – Delft University of Technology, [http://www.gdmc.nl/zlatanova/thesis/html/refer/ps/Mv\\_sz\\_esociety.pdf](http://www.gdmc.nl/zlatanova/thesis/html/refer/ps/Mv_sz_esociety.pdf)

McCormick, B.H., DeFanti, T.A., Brown, M.D. 1987: Visualization in Scientific Computing – a synopsis. 1987. IEEE Computer Graphics 21, 6. ACM SIGGraph, New York

## Modeling without 3D modeling software

In this class a 3D modelling is demonstrated by creating a series of horizontal 2D models and cutting them with a section line, where the data is extracted. This extracted data subsequently is used to create a vertical 2D model. The compilation of 2D distribution maps (surface, horizontal, and vertical) with Surfer can produce the same result what we can calculate in a 3D modelling environment.

### Interpolating horizontal sections.

1. The “*Peldaadatok2.xls*” Excel sheet contains fictional Fe-ion concentration of 10 observation wells in several a.s.l. levels (surface, +200, +100, sea level, -100, -200 m). Use the interpolation methods (see class 03 and 04) in Surfer to compile a distribution map for each level.

Grid-> Data menu (importing data from the excel sheet); set the resolution of the grid; select the interpolation method; define the output file.

### Creating cross sections from the horizontal maps either with Surfer or Global Mapper

|   |   |
|---|---|
| Stay in Surfer.   | Import the created output grid-files in Global Mapper (GM). Be aware of the coordinate settings!  |
| Create a post map for each level stack using the “ <i>Peldaadatok2.xls</i> ” sheet.   | Import the well locations with point name into GM. The well coordinates are in the “ <i>Peldaadatok2.xls</i> ” Excel sheet. Convert the data into the right syntax if necessary (i.e. simple text file) |
| Use the Map – Digitize tool to digitize two points P4 and P3 and save it as <i>sectionP4-P3.blm</i> . For correct coordinate data use the <i>Peldaadatok2.xls</i> file. | Draw a line feature (name it as <i>section-P4-P3</i> ) across a wells P4-P3 in GM which will represent the line of a cross-section.   |
| Create a cross section for each level along the <i>section-P4-P3</i> line (using the <i>sectionP4-P3.blm</i> ) with the “ <i>Grid-Slice</i> ” tool in Surfer.           | Create a cross section for each level along the <i>section- P4-P3</i> line using the “ <i>Path Profile/Line Of Sight</i> ” tool in GM.  |

|   |   |
|---|---|
| Two types of file are created in each step: a bln file and a dat file. Name the files descriptively (e.g. <i>section_VAL_100_Krig1_P4-P3.dat</i> )! | In the Options menu of the PP/LOS window select the “Set Sample Count/Spacing Distance” and set the value to fixed 100 m.   |
| Since the level maps are concentration maps, the dat files contain concentration data at a given elevation (e.g. 100 m a.s.l.).                     | For each level, create a data export ( <i>File-&gt;Save Distance/Elevation file</i> ) from the cross section to get the interpolated distribution values along the <i>section-1</i> line.   |
|   | Name the export file clearly (like: <i>section-P4-P3_level0.xy</i> ). The created xy-files are simple texts and contain two columns of data: The first column of the xy-files is the distance along the section line, and the second column is the interpolated concentration value on the level. |
|   | On the surface level, the elevation values can be captured from the SRTM using the same method.   |

### Assigning elevation value to the linear sections

1. Open the section (dat or the xy) files in Excel and assign the proper elevation value in an additional column in each of them. The elevation value should be given according to the level of the grid, of which the section-file was created. For example: if we created a section file from the level 100, the elevation in the third column should be 100. Save each file with a new name (i.e. *section-P4-P3\_level-100\_elev100.txt*).
2. Create a mash up table (*section-P4-P3\_mashup.xls*) from the created files. It can be done in Excel by opening each of them, and with selecting the whole content copying them below each-other in the first three columns.
3. Compile an interpolated distribution map in the vertical plane of the cross section in Surfer from the *section- P4-P3\_mashup.xls*. Be aware of the order of the columns during data import!

## **Deliverables at the end of the semester**

Starting from class 11, students should work on their own task. The final marks for each student will be calculated from their work progress, the result (the model file) and the quality of documentation (report file). All these three aspects worth one mark [1-5]. The average of these three will be the final mark of the student.

The progress of the work is continuously monitored, while the model files and the report should be delivered at the end of the semester.

### **General comments**

The report is a scientific text. Write simple sentences, and take care of the exact formulation and the use of technical terms. The report aims to present the results of the modeling in the most meaningful way, so it is recommended to compose data in tables and separate the equations from the paragraph text. It is also recommended to illustrate the report with snapshots of the work. The images and tables must always have captions and cross-references in the text!



# Report Template

Author

Date

## *Participants and their tasks*

[optional] List of the participants and their responsibilities in the project (in the exam report for the 3D modelling in GIS subject, this chapter can be omitted).

## *Introduction*

Write about the general summary of the circumstances and the aim of the project. Introduce the prerequisites and prior projects. [max. 200 words]

## *Base data*

Make a list of the base data of the project. Include the type, source, name and owner (if applicable).

## *Methods*

Describe the applied methods clearly. Use the exact terminus for specific methods and details (like primary and secondary data instead of data, interpolating a surface instead of making a surface, etc.). [max. 400 words]

## *Results and discussion*

Write about the results of the project, and refer to the aims (you achieved/ failed to answer the proposed questions). Discuss the results (write about the error of your methods). [approximately 200 words]

## *References*

[optional] list of papers which were cited in the introduction.

## Recommended readings

- Albert G, Csillag G, Fodor L, Zentai L. 2012: Visualisation of geological observations on web 2.0 based maps – In: Zentai L, Reyes Nunez J (eds.): Maps for the future – Springer.
- Albert G. 2003: Modelling of subsurface geological structures on a future disposal site of low- and intermediate-level radioactive wastes. – European Geologist. Journal of the European Federation of Geologists, Dec. 2003, pp. 23–26.
- Albert G. 2009: Digital processing/archiving of geological field maps – Annual Report of the Geological Institute of Hungary 2007, pp. 45–53.
- Albert G. 2014: Inventorizing tectonic elements in geological maps and 3D models – Problems, Concepts, Solutions - In: Beqiraj A, Ionescu C, Christofides G, Uta A, Beqiraj Goga E, Marku S (eds.) Proceedings XX Congress of the Carpathian-Balkan Geological Association. Tirana: p. 459.
- Albert G., Orosz L., Gyalog L. 2006: [Cartographic representation of geological information, observed on tunnel walls and fronts](#) – *Proceedings of the 5th European Congress on Regional Geoscientific Cartography and Information Systems (Earth and Water), Barcelona, Spain 13–16/06/2006*, Vol. II. pp. 89–91.
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- Bellian, J.A., Kerans, C. and Jennette, D.C. (2005) Digital outcrop models: Applications of terrestrial scanning LIDAR technology in stratigraphic modelling. *Journal of Sedimentary Research*, 75, 166-176.
- Bohling, G. 2005: Introduction to geostatistics and variogram analysis, 20 p. <http://people.ku.edu/~gbohling/cpe940/Variograms.pdf>
- de Berg, Mark; Otfried Cheong; Marc van Kreveld; Mark Overmars 2008. [Computational Geometry: Algorithms and Applications](#). Springer-Verlag.
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- Gold C. M. 1991: Problems with handling spatial data - the Voronoi approach. *CISM Journal ACSGC*. Vol. 45, No. 1. Springer 1991. pp. 65-80.

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- Voro++ opensource web application, <http://math.lbl.gov/voro++/about.html>
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- Yang, C.-S., Kao, S.-P., Lee, F.-B., & Hung, P.-S. 2004. *Twelve different interpolation methods: a case study of Surfer 8.0.* Paper presented at the XXth ISPRS Congress Technical Commission II, Istanbul, Turkey. <http://www.isprs.org/proceedings/xxxv/congress/comm2/papers/231.pdf>