VISUALIZATION: SPECIFICATION, DEFINITION, DOMAIN (IN CARTOGARPHY AND GEOGRAPHY)

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SUMMARY

The paper deals with the specification of the new interdisciplinary scientific field — visualization. The author is giving an overview of the contemporary cognitively, computetionally and communicationally orientated definitions and also commenting the visualization domains. At the end of the paper the necessary hardware and software are commented.

1. INTRODUCTION

Since time immemorial cartography and geography have been connected with visualization, i. e. the visualizing of the knowledge spread in a large space that man with his sensual perception could not conceive.

In spatial and time elaboration of different themes, cartography makes use of traditional, but, in its own way irreplaceable, medium — a map. Progress of technologies enables to compile maps by new means, on a higher level and with higher information capacity. Informational explosion resulted in the rise of a lot of new means enabling efficient data presentation with the use of different methods and by means of media (multimedia) different from paper or plastic foil. Progress in this area resulted in the rise of a new scientific tendency called „visualization".

Cartography and geography are disciplines reacting sensibly to the progress of new technologies. Taylor [20] noted some time ago that geography seemed to be the Latin Amerika of academic disciplines since he was able to identify seven revolutions in just one generation.

For last twenty years, cartography has undergone a number of changes concerning data acquisition as well as manipulation with them. Data acquisition has been namely affected by remote sensing of the Earth, GPS (geopositional systems), laser scanners, and digital landscape models (topographic-cartographic information systems). Manipulation of data answers mainly the problem of the controlling of data explosion caused by electronical technologies but at the same time it makes use of these technologies for controlling this explosion.

The computer revolution brings about new dimensions of our discipline ranging from maps compilation, their analysis to spatial planning applying the following implements: automatic scale changes and resolution, statistical filtration and smoothing.

Geography and cartography as scientific disciplines are much older than computer science. In spite of this fact, computer science is said to be passing in through the second revolution. While the first revolution was connected with information processing, the second one is different because being concerned in visualization. Both revolutions in question have been affecting also the definitions of cartography last five years.

J. L. Morrison [16] in his presidential speech at ICA conference in London formulates the definition of cartography as follows:

'Cartography. — An information transfer process that is centered about a spatial data base which can be considered, in itself, a multifaceted model of geographic reality. Such a spatial data base then serves as the central core of an entire sequence of cartographic processes, receiving various data inputs and dispersing various types of information products.'

D. R. F. Taylor [21], a new president of ICA in his keynote presentation at the Bournemouth conference comes back to a map as a basic presentation means of cartography and offers the following definition:

"The organization, presentation, communication and utilization of geo-information in graphic, digital or tactile form. It can include all stages from data presentation to end use in the creation of maps and related spatial information products".

Taylor also articulates that further development of cartography will be highly affected by cognition, communication and visualization (Fig. 1).

Even though visualization as a whole does not belong to geography nor cartography, both disciplines with their traditions of spatial presenta-

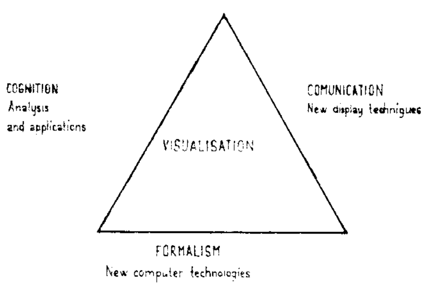

Fig. 1. Visual Impression of the Basic Relationships to Cartography [21]

tion must have been one of the main aspects of inspiration for the rise of this research tendency. Visualization gives the possibility (namely in connection with geographical information systems — GIS) of a new dimension of interpretation of spatial processes and phenomena.

With the use of visualization one can apply all one's experience and knowledge on a higher level, which can be combined, for instance, with a number of other visual and non-visual media.

2. WHAT IS VISUALIZATION

One of the initial characteristics of visualization was defined by Bruce H. McCormick, Thomas A. DeFanti and Maxime D. Brown [14], who devoted themselves, withing the framework of the project sponsored by the American National Science Foundation (NSF), to the specification of this new field of research in scientific computing:

"Visualization in scientific computing is emerging as a major computer-based field, with a body of problems, a commonality of tools and terminology, boundaries, and a cohort of trained personnel. As a tool for applying computers to science, it offers a way to see the unseen. As a technology, visualization in scientific computing promises radical improvements in the human/computer interface and may make human-in-the-loop problems approachable." Authors pointed out visualization as an infant giant (Fig. 2).

Visualization... can bring enormous leverage to bear on scientific productivity and the potential for major scientific breakthroughs, at a level of influence comparable to that of supercomputers themselves. It can

Visualization: The Infant Giant	
Communications Media	**Number of Years Old**
Sight	5×10^8
Speech	5×10^5
Writing	5×10^3
Print broadcasting	5×10^2
Visual broadcasting	5×10^1
Visualization	5×10^0

Fig. 2. Visualization: The Infant Giant [5]

bring advanced methods into technologically intensive industries and promote the effectiveness of the (American) scientific, and engineering communities. Major advances in visualization in scientific computing and effective (national) diffussion of its technologies will drive techniques for understanding how models evolve computationally, for tightening design cycles, integrating hardware and software tools, and standardizing user interfaces.

Visualization... will also provide techniques for exploring an important class of computational science problems, relying on cognitive pattern recognition or human-in-the-loop decision making. New methods may include guiding simulations interactively and charting their parameter space graphically in real time. Significantly more complexity can be comprehended through visualization in scientific computing techniques than through classical ones".

The authors in question carried out a comprehensive specification of visualization as a scientific discipline affecting the whole spectrum of other sciences.

The aim of this paper is to think of the specification and definition of visualization namely in relation to GIS and computer cartography.

"Though the capture of spatial information is accomplished principally by digital means, the encoding strategy and design of the data schema must reflect the visualization task and the nature of spatial information to be studied. Spatial modelling, pattern and trend analysis, inference and guidance in decision making are examples of GIS activities where researches may benefit from use of visualization" [4].

As the utilization of visualization in geography, natural sciences and cartography depends on the assistence of GIS, let us pay some attention to it.

3. GIS AND VISUALIZATION

Considering the world scale, GIS develop in an unusual pace as a tool of scientific research, both at the field of remote sensing and computer cartography, and bussiness. As pointed out A. U. Frank, M. J. Egenhofer a W. Kuhn [7] "Geographic information systems have matured from an attractive idea to an entire industry. This development can be observed in the market, in companies, academia, and the professions related to geographic information."

By means of new technologies, namely remote sensing — but even other methods mainly of computerized data acquisition, a lot of information appears to be processed. The results should be presented by means of new ways and methods whose aim should be intelligibility and simplicity. It is visualization that makes the process lucider and simplier from the point of view of a user. An argument may be presented for the rise of visualization as a discipline based on several needs: to access pertinent information from an overwhelming volume of collected data; to comunicate complex patterns effectively; to formalize sound principles for presentation of data that optimize visual processing skills; and to steer analytical computations for data modelling and interpretation" [4].

The role of visualization is not restricted only to the analysis of maps and satellite images but it also used in numerical and statistical analyses.

Graphical display has been a cornestone in recent developments in statistical description and exploration, attesting to its worth as an efficient tool for understanding statistical trend and structure. The approach is not quite new. The transition of interest in visualizing the statistical landscape began to take hold in the scientific community in the late sixteenth century, with empiricist interests shifting from the physical to the abstract (statistical) word [6, 4].

Formalization of principles for graphical design has only recently been introduced. Efforts to derive formal principles for graphical design can be found in several disciplines. Bachi [1] in [4] developed an iconic system whose meaning might to be simultaneously understood metrically or synoptically (for use on statistical charts and thematic maps). That is, precise values could be determined values by counting modules within each icon,

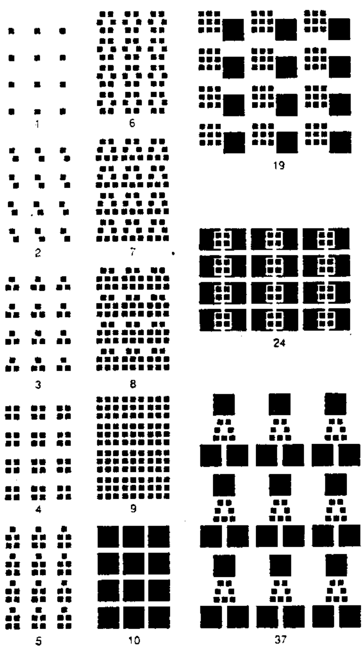

Fig. 3. Graphical Rational Pattern Templates for Selected Values between 1 and 100 (Bachi [1] in [4])

or by viewing relative magnitudes in greytone progression from white to black (Fig. 3). There are also iconic and geoiconic systems defined.

Geoiconics as a discipline was defined by Berlyant [3] as:

"a new synthetic discipline with the system of cartographic science, given to developing the theory and methods of analysing, processing, and recognition of earthly (planetary) objects on maps, images and other geopictures... Geoiconics stresses the differentiation of mapping sciences and, at the same time, makes for closer integration of cartography and remote sensing method. It represents a necessary link between two different branches of knowledge, which bring them together to constitute a uniform system. At present the research at the juxtaposition of two sciences is progressing at a rapid pace; therefore there exists an imperative need to develop a system theory of geopictures, which would draw on the progress achieved in cartography, remote sensing, psychology of perception and image recognition theory. The development of such synthetic discipline may be beneficient for physical and economical geography, geology, geophysics, planetology and other Earth and social sciences having to do with maps, remote images and other geopictures (Fig. 4).

Reseachers use similar methods in work with maps and imagery: identical techniques of visual analysis, very similar measurement procedures, universal methods of mathematical processing, etc... There is also much in common in man's perception of maps and images".

Berlyant specified in advance the structure of geoiconics, which will include three basic parts:

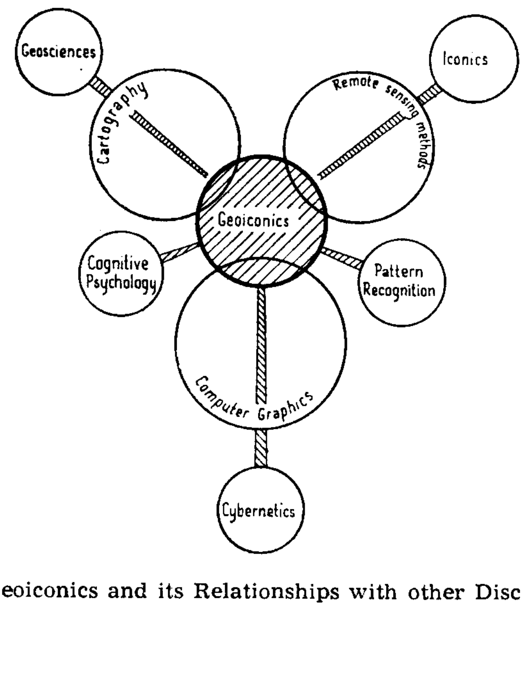

Fig. 4. Geoiconics and its Relationships with other Disciplines [3]

1. Theory of images..., the formulation of the classification of graphic features, the creation of systems and catalogs of standards for various natural and socioeconomic phenomena and processess; the systematization and elaboration of a theory and methods of indicational analysis of imagery; the study of common problems of generalization, and analysis of its impact on geometric accuracy, fidelity and information qualities of imagery; investigation of the laws of visual perception of maps and photographs, psychological factor, principles of the teaching of perception, mechanism of the reading of imagery; development unified approaches to the planning of computing and image recognition systems; the study of "boundary" problems at the interfaces of geoiconics with other sciences (with psychology and the psychology of vision, the theory of image recognition and cybernetics, optics, structural linguistics, etc.); the development of contacts with the earth sciences.

2. Should consist of methods of image processing and feature recognition, where methods of quantitative analysis will developed, including cartometry and thematic morphometry in their broad meaning, mathematical statistics, photogrammetric techniques, photometry, structurometry, etc.; methods of image transformation and enhancement, correction, elimination of interference and noise, filtration, smoothing, contrast enhancement, methods of image decomposition and synthesis, methods of digitizing imagery, the creation of digital models their storage and reproduction; methods, algorithms and technical means for future recognition and classification in batch and interactive modes; methods of analyzing the reliability of visual, algorithmic, heuristic, and combined approaches to feature recognition on imagery.

3. Image interpretation, its a field of applied geoiconics, which should rely on close connections with the geographical, geological-geophysical, and social-from them. The mechanisms of the origin of graphic images of diverse natural and human phenomena and processes must be studied in this "boundary" area of geoiconics. The possibilities for the practical application of geoiconics, apparently, will be diverse, although it present they are difficult to foresee. The task of this third branch of geoiconics is to search for and expand these possibilities" [3].

4. DEFINITION OF VISUALIZATION

The visualization was defined first by McCormick et al. [14]:

"Visualization is a method of computing. It transforms the symbolic into the geometric, enabling researches to observe their simulations and computations. Visualization offers a method for seeing the unseen. It enriches the process of scientific discovery and fosters profound and unexpected insights. In many fields it is already revolutionizing the way scientist do science.

Visualization embraces both image understanding and image synthesis. That is, visualization is a tool both for interpreting image data fed into a computer, and for generating images from complex multi-dimensional data sets. It studies those mechanisms in humans and computers which allow them in concert to perceive, use and communicate visual information."

Visualization unifies the largely independent but convergent fields of computer graphics, image processing, computer vision, computer-aided design, signal processing, user interface studies.

Morrow in [23] defines visualization as "a method of computing where data is presented to the researcher geometrically, rather than numerically. Visualization techniques seek to make use of our pattern recognition abilities and the ability of the eye to absorbe large amount of information vary rapidly".

Mc Eachren [12] define visualization as "... first and foremost, an act of cognition. It is a human ability to develop mental representations that allow us to identify patterns and create or impose order". Visualization describes the process of "creation and manipulation of (mental) images" [19].

For Buttenfield and Mackaness (1991, 432) seem resonable to incorporate a third aspect of visualization in addition to the cognitively based and computetionally base definitions. This aspect incorporates the construction of visual displays and the principles of graphic communication guiding that construction. Visualization extends beyond the confines of hardware and software. It croases the human/machine divide and inciudes computer vision/pattern recognition, remote sensing and mechanical data collection, as well as the cognitive processes of visualization, and principles of graphic design. The role of visualization for GIS tasks lies at the interface between these three (computation, cognition and graphic design). All are embraced in the following definition:

"Visualization is the process of representing information synoptically for the purpose of recognizing, communicating and interpreting pattern and structure. Its domain encompasses the computational, cognitive, and mechanical aspects of generating, organizing, manipulating and comprehending such representations. Representations may be rendered symbolically, graphically, or iconically and are most often differentiated from other forms of expression (textual, verbal or formulaic) by virtue of their synoptic format and with qualities traditionally described by the term "Gestalt". Vision is an extraction of world data, visualization may be defined as a product of vision.

5. VISUALIZATION DOMAINS

Buttenfield, Mackaness [4] illustrate various scientific domains, linking up with other icons and computation, cognitive and mechanic transformations that transfer the spatial information among domains. The arrows in Fig. 5 represent transformations studied often within the framework of "computer vision, computational vision" and mechanic image compilation and analysis. Arcs represent arenas of the framework in which information transformation may be modelled either by means of cognitive or computer processes. The implication of the eye turned inward towards the circular arcs is that a large part of visualization is internal, and this justifies the relationship of cognitive science and computer science within the scope of the framework. The characteristic of the separate components is follows [4]:

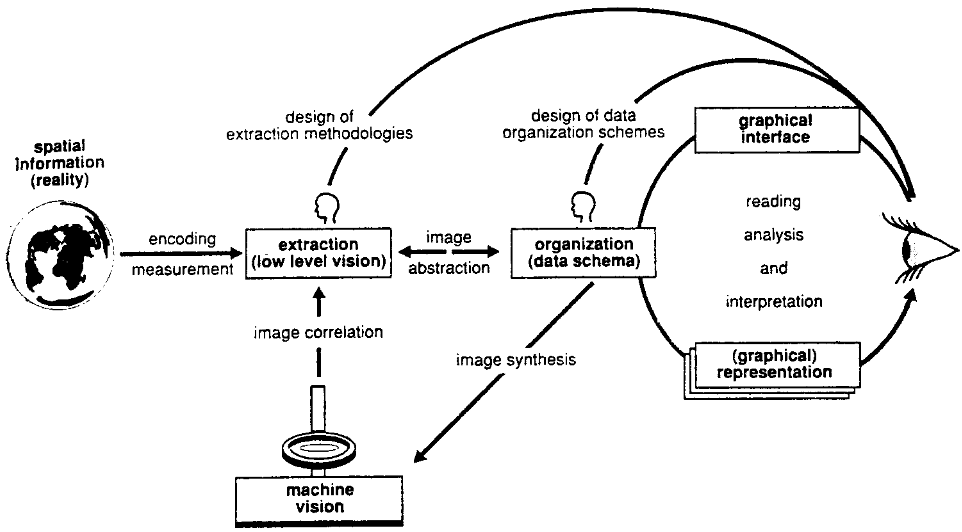

Fig. 5. The Interrelated Disciplines of Visualization Research (see text for explanation) [4]

5. 1. Encoding and measurement

Spatial information could be obtained by the searching, measuring, decoding, etc. The connotation "reality" means that information is continual, the connotation of measuring and coding means, that the discrete representation is sampled by photography, survey (geodetic or statistical), scanning or sensory input. The information may encode the view outside an office window, a satellite recording multi-spectral images of the Earth or it may be someone's remembered representation of a part of reality.

The purpose of the visualization in a partricular situation dictates the internal representation of spatial information (its format, substance, composition) which in turn determines what detailes need to be filtered out or selected. The nature of the data dictates which sensing device is appropriate for the task. For example scanning in the infrared bandwidth might be used to extract information in 1 — 10 m wavelenghts for a task involving the analysis of crop disease. Information that the sensor is not sensitive to will not be encoded, and thus the extracted scene can be thought of as a discrete sample of the (continuous) information.

5. 2. Extraction

The extraction process equates to what computer scientists and cognitive scientists term "early vision" (or "low level vision). This domain of visualization research includes "... feature analysis, whereby information about colour, motion, shape, texture, stereo depth and intensity edges are extracted. Another aspect of early vision is image segmentation, whereby the feature information is used to segment the image into regions which have a high probability of having arisen from a single physical cause" [23].

In geographical analysis, it may be considered that the sampling frame or sampling design will bias the data collection, and this will impact upon the extraction of enumerated variables [24]. Variables (education, income, etc.) form the extracted spatial information. Visualization of the data (as scatter diagrams, factor loading plots, etc.) provides a statistical equivalent to low level feature analysis. Abstraction and synthesis by regression, clustering or factoring is used to recover higher level descriptions of social structure, quality of life, and other geographical interpretations. The sampling strategy will course impact upon the nature of the collected data, the form of the descriptive statistical plots, and subsequent interpretation and inference.

5. 3. Image abstraction and image synthesis

The image abstraction together with image synthesis, it is reffered to in computer science as scene analysis. Image abstraction uses the feature descriptors extracted in low-level vision to construct higher level image descriptions, by incorporating shape analysis, object recognition and object localization [22]. These descriptions must be organized in some form of data schema to permit subsequent use in image synthesis [2]. Image synthesis uses the higher level descriptions to attach labels identifying the image regions in more detail. E. g. the scene might represent an asphalt road through a grassy area next to a lake. Identification requires abstracting the low-level descriptors based on knowledge about the nature of roads, vegetation and water bodies.

5. 4. Organization within a data schema

Knowledge about the nature of spatial information is organized in a data schema and can take many forms. The nature of the data dictates the organizing schema, and will bias the image abstraction and synthesis. To continue the above example, the rules formalizing the geometry of roads, the visual texture of grassy patches, and the variations in water colour caused by light refraction must be organized in a manner that the future labels (road, lake, etc.) can be inferred based on input of the low-level descriptions, and rules guiding interpretation of their expected relationships (e. g. roads do not customarily cross water bodies, although bridges and causeways do).

The organizing schema may be a data structure (soil parcels, census categories, etc.). Knowledge organization and its relation to visualization may be generalized into several research discipline. E. g. in database management investigation focuses on the multiple representations of a single geographical landscape that are recorded at differing resolutions, and the formation of database links to connect a single feature stored in each digital version. The purpose of the links is render database update more efficient and consistent, that is, to have all versions of a feature 'inherit' the modification applied to any single version. The challenge for visualization is that as geographical features vary structurally with resolution, the updated operations may not be uniformly applicable.

5. 5. Machine vision

The research domain of machine vision is also reffered to as computer vision, computational vision, image understanding, or robotics, etc.

Topics of interest in computer vision include the generation of images from identified features (image synthesis). Image correlations research applies the synthetic image descriptions to facilitate subsequent feature extraction for a particular task.

In GIS research the relevance of machine vision is apparent in data input (semi-automatic and automatic digitization) and pattern recognition ("reconstructed" graphics objects and attaches geographical labels to them).

5. 6. Reading, analysis and interpretation

Use of any GIS requires a fluid interaction between human vision and graphical representation, and this is a major distinction between machine and human vision. Access to spatial information stored in a GIS is often most efficently accomplished by intermediating the process with visual tools, to provide synoptic interaction for synoptic tasks. This in turn requires a data schema which allows for ease of generating graphical study thus allowing for a more efficient and effective redesign of the process being investigated.

De Fanti [4] in [22] suggests a three-tiered hierarchy of computational environments for visualization. Each of these computing environments is characterized by distinctive hardware, computing power, information bandwidth, the location of the computing facility, software support and administrative considerations.

1. The most sophisticated level is that of the supercomputer or super image computer. This has a high bandwidth for information transfer of about 10^9 bits per second. It is located in a central facility, has software for the most sophisticated number crunching but at present there are few programs for interactive display in this environment. Usually the numerical results are downloaded and manipulated on a less powerful computer. In administrative terms the computer is centralized and has its own support staff.

2. The computational environment involves the use of a minisupercomputer or image computer. The information bandwidth may be two or more orders of magnitude lower, ranging from about 10^7 to 10^8 bits per second. This type of machine might be located in a laboratory and act as a network server. Commercial intevactive software packages are becoming available for these machines but most packages are still only available for image enhancement and manipulation. More discipline-specific interactive packages are required. The main weakness of this type of system is that it usually requires specialized support staff, althought not to the extent required for a centralized supercomputer facility.

3. There are the advanced workstations and high-end personal computers with bandwidths from 10^1 to 10^6 bits per second. These may be networked, especially if they are simply used as output devices and the number crunching is done elsewhere, or they may act as stand-alone machines. Commercially available software including public domain software is widely available for these machines. It is a decentralized solution and in many cases no dedicated support staff would be needed.

De Fanti [4], Waters [22] note that software can be classified by its data of introduction and its degree of sophistication. They mentioned four categories of software:

A. The representation of the surface by the block diagrams and polygons.

A. 1. The earlist programs such as SURFACE II [17] drew lines in 3-D and projected them on to a 2-D surface to produce block diagrams which could be subjected to such transformations as rotations, scaling and translation. These concepts are typical for almost of the CAD CAM products in the 1980s.

A. 2. Surface representation by polygons is the next step up in complexity. Hidden surface removal and antialiasing is usually incorporated into the software and recently this whole approach has been built into hardware as well. These approaches using patches have so far only been developed in software. They incorporate antialiasing and complex lighting effects such as transparency, translucency, refraction and reflection. Software under development includes motion blur, depth of field, follow focus, constructive solid geometry and radiosity effects.

B. Image processing software is rather different and includes specialized functions for image enhancement of two dimensional rasters. Among these functions are convolutions, Fourier transforms, edge detection and edge enhancement, noise reduction and thresholding. Many of these functions are available in hardware form as well. Animation software has also developed independently but may become an important component in a visualization lab or understanding the dynamics of complex processes.

C. Another separate group of programs has become known as 'glue'. These programs include software for picture composition, picture saving and restoring, for rotating, moving and copying, painting and colour manipulation. In a visualization environment these procedures are as fundamental as the operating system in a normal computing environment. Software must also be compatible with windowing systems.

D. Finally, there is a problem of volume visualization. This is a research frontier. Algorithms for volume visualization are developed, but no software is available for hidden volume removal, for 3-D paint programs or for 3-D glue programs. Such programs would be extremely useful for resolving problems concerning athmospheric pollution and in the meteorological, geological and oceanic sciences.

7. CONCLUSIONS

1. Visualization is a new scientific discipline which is very important to develop in geography and cartography.

2. It is necessary to accept and develop visualization as a discipline with three basic aspects: cognitive, computational and the construction of visual displays and the principles of graphic communication.

3. Visualization could progressively enriched the contemporary possibilities of displaying the partial or final results of the geographic and cartographic scientific research.

4. Using visualization techniques will probably renovated interest of cartographers about how is real human perception of displaying information.

5. At the Czechoslovak contemporary situation it is absolutely necessary to start with arrangement of adequate visualization laboratories supported by recent hardware and software.

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