Virtual reality as an instrument of computer visualization

Vladimir L. Averbukh
Institute of Mathematics and Mechanics, UBRAS
INSM, Ural Federal University
Yekaterinburg, Russia
averbukh@imm.uran.ru

Natalya V. Averbukh
Department of Psychology
Ural Federal University
Yekaterinburg, Russia
natalya_averbukh@mail.ru

Pavel Vasev
Mathematics and Mechanics
Ural Branch of Russian Academy of Science
Yekaterinburg, Russia
Vasev@imm.uran.ru

Ilya I. Gvozdarev
Institute of Natural Sciences and Mathematics
Ural Federal University
Yekaterinburg, Russia
ilyagvz@gmail.com

Georgy I. Levchuk
Institute of Natural Sciences and Mathematics
Ural Federal University
Yekaterinburg, Russia
levchukgeorgy1@gmail.com

Ilya Starodubtsev
ESITTCS
Ural Federal University
Yekaterinburg, Russia
starodubtsevis@robolab.tk

Majid Forghani
Institute of Natural Sciences and Mathematics
Ural Federal University
Yekaterinburg, Russia
Forghani@urfu.ru

***Abstract*—The paper is devoted to the development of computer visualization systems based on virtual reality. Some of these systems are designed for scientific visualization and some of them are designed for software visualization. The systems of scientific visualization are used for tasks of ”pure mathematics”, computational mathematics, chemistry and biology. The systems of software visualization are used for visual programming, visualization of program objects, and performance evaluation of supercomputers. The tasks of interfaces for such systems are considered. Also the problems of the human factor for virtual reality environments are considered.**

***Index Terms*—virtual reality, scientific visualization, software visualization, interfaces, human factor**

I. Introduction

Computer visualization is an essential component of computer modelling, providing interpretation and analysis of data.

Generally, the following subbranches of computer visualization are distinguished:

– scientific visualization;
– information visualization;
– software visualization.

Scientific visualization deals primarily with presenting data about objects, processes and phenomena, modelled with scientific calculations.

Information visualization is connected with visual description and presentation of abstract information acquired in the process of collecting and processing data of different types and purposes.

Software visualization deals with presenting software objects both for specification and for presentation of objects in the process of creating programs, and for efficient software operation.

Virtual reality is a historically formed term, which defines a specific environment created by a computer with the help of special devices (a headset, screens with 3D illusion etc.) and is perceived by the user as a real world, where they are located (instead of being an outside observer), and with which they interact directly, in the same way as they do with the real world [1].

This paper will discuss examples of computer visualization based on virtual reality environments, which have been developed by our research group. Projects of researching the human factor when working with these systems will also be discussed.

978-1-7281-4401-6/19/$31.00

II. Examples of Applying Virtual Reality for Scientific Visualization Purposes

In this chapter, we will analyze the examples of using visualization, including visualization based on virtual reality for the purposes of pure and computational mathematics, as well as biology and chemistry.

A. Visualization of several specific graphs in 3D space

The paper [2], based on [3] (connected with group theory and graph theory), has found some symmetrical 2-extensions of a 3-dimensional cubic lattice. An illustration of visualization for these objects was made, including the use of virtual reality, see Fig.1.

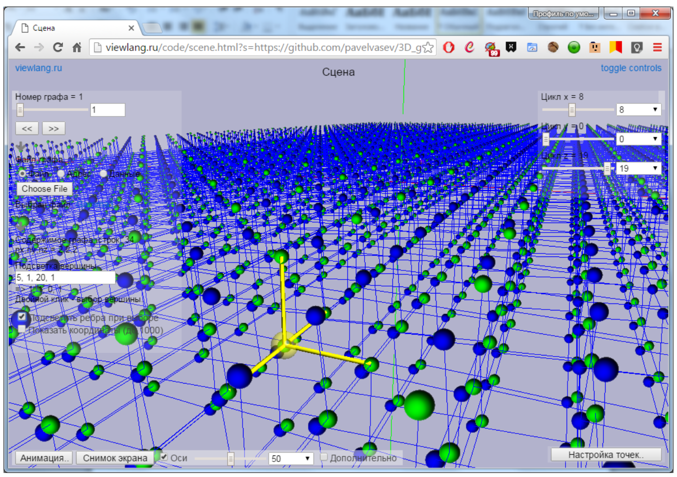

Fig. 1. The view of specialized graph visualization

The source object comprises several specific kinds of graphs in 3D space. Imagine a regular infinite cubic lattice. Replace each node with two new nodes, located near the original node. Then remove all the edges of the lattice. Now we have a set of points (e.g. new nodes) in 3D space. These will be the nodes of a new graph. In such a new graph, one can add edges in compliance with the following limitations:

1) Allowed edges between nodes corresponding to the neighboring nodes of the original lattice, but without diagonal edges.
2) Allowed edges between nodes corresponding to one node of the original lattice.
3) Another restriction is that a new graph must be symmetrical.

It has been mathematically proven that only about 3000 different graphs of this type are possible.

The task is to provide software to visualize the described graphs given by coordinates of their nodes and edges. Special metaphors for the presentation seem unnecessary. The graphs should be shown as is.

The graphs are determined by their core a set of nodes and edges unique to the graph. These nodes and edges are repeated along X, Y, and Z axes, virtually forming an infinite graph. This provides the user with the ability to visually understand how many times a graphs core should be repeated.

We used the *viewlang.ru* visualization framework for the task. The program allows a user to choose a graph from a set of precomputed graphs or from a custom file. Then it shows the graph using 3D graphics. It uses sprites to show nodes and lines to demonstrate the edges. The program has, among others, the following abilities:

- rotating, zooming, moving the camera,
- managing the number of repetitions of the graphs core along axes,
- highlighting a particular node,
- making screenshots.

This example has been implemented on the basis of virtual reality.

The program works in web browsers. It uses WebGL for rendering, and javascript to transform the loaded data into visual objects. The program supports virtual reality mode using WebVR technology. We have tested the VR mode with the Oculus Rift DK2 headset. It was quite interesting to perceive yourself being inside an infinite graph. However, the use of VR turned out to be not in high demand with mathematicians: they were satisfied with a regular 3D version. Thus, VR was not used in the mainstream cognition process and remained experimental. The question of what fields VR may bring additional understanding to in the described visualization task is a subject of further investigation. The program is available online at http:/viewlang.ru/3dgrid.

Interaction with visual objects in the case of using virtual reality provides the opportunity to get a more comprehensive idea of the examined objects and the essence of the mathematical model under study.

B. Visualization of computational grids

This specialized system is designed to help develop new methods of generating a non-degenerate system of computational grids. A prescribed set of requirements to the systems functionality, including the ability to display the cells on the edges and inside the blocks, to show the individual cells and their insides, to visualize nodes and the output units, to show the contents of several files (order of tens) and the ability to view the boundaries of zones, for example, two adjacent cells of the boundary layer. The program is intended to visualize the structure of the meshes and render them. It supports the visualization of uniform grids with hexagonal cells. Because the program is implemented as a web application, the user must have a web browser supporting WebGL in order to be able to work. The program loads local files and network data at the address (from the Internet, a supercomputer, etc.). Acceptable sizes of nets and performance depend on the amount of free RAM and on the video card. The capabilities of the system were augmented in the process of development. In particular, it was provided with a display of all the grid cells, including the interior; a line and plane with pseudoprotocol with a choice of colors, directions and step planes were implemented; the system acquired transparency, and displays of faces (set of cells), provided with filtering to select the inner part of the parameters. In addition, the possibility was added to show the values in the nodes, and the nodes are color-coded making it easier to indicate a node to view its information (coordinates, numeric values, block number). The system can operate in two ways: with the use of a monitor and with virtual reality goggles. See Fig.2.

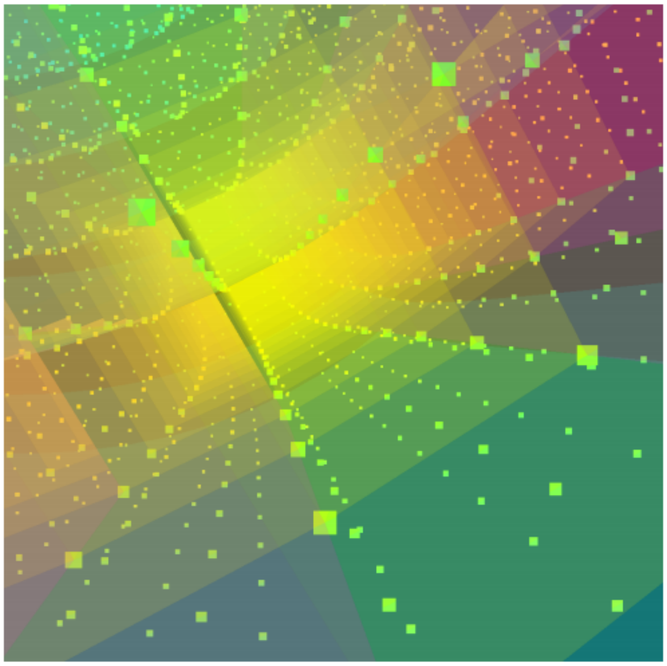

Fig. 2. Inner view of the grid

Using virtual reality lets users examine the developed computational grids in more detail.

C. Three-dimensional visualization of biological objects

Traditionally, phylogenetic trees are shown as two-dimensional (flat) diagrams; however, the difficulties of interpreting such trees are growing in size and complexity [4]. Trees can be represented in a variety of ways, for instance, as circular radials, phylograms or dendrograms.

In a 3-dimentional visualization, a tree is displayed in a circular (radial) mode with an additional dimension, which makes it 3D. A high-resolution 3D phylogenetic tree can be constructed with such parameters as isoelectric focusing, molecular weight and immuno-cross reactivity or any other relevant attributes of a character or trait that provides discrete phylogenetic relationship [5].

In addition to 2-dimensional and 3-dimensional visualizations, the representation of trees in a virtual reality environment is implemented. Virtual reality is provided by the Viewlang system. It allows to create interactive 3D graphical applications running in browsers. Virtual reality can significantly enrich information content of visualization and it can provide a wide range of views. This makes it possible to see the overall picture of the tree (even when it is a large tree) in all the details, unlike with traditional visualization methods, which have monitor screen size limitations. VR provides us with a wider space view than monitor screen, which allows the user to change certain visualization parameters such as the thickness of the tree, tree scaling parameters and the size of the leaf label. In order to see an individual leaf or branch the user simply needs to come closer to it by moving through the VR environment. This is much more convenient than zooming in /out in a 2D format. In this respect, VR visualization is more flexible than 2D presentation. It provides a new quality of visualization and enables the user to see the general picture with the details still visible (see Fig.3).

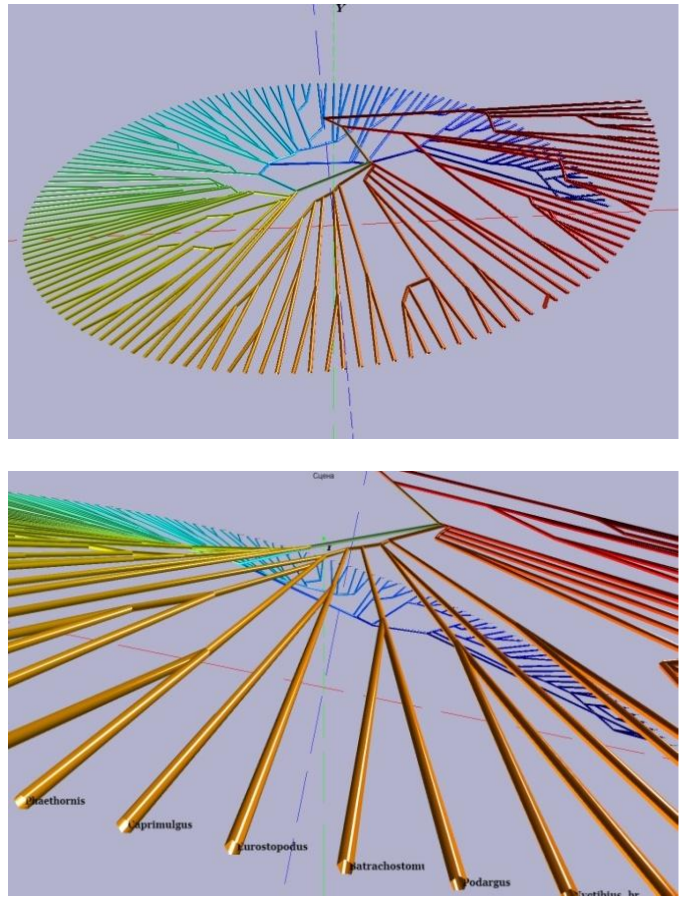

Fig. 3. Virtual reality presentation of a circular tree without clustering through the Viewlang system calling from Matlab [6].

Additional features of virtual reality provide a wide range of views. Immersion into three-dimensional space and easy navigation within it should provide researchers with more opportunities to study the structure of trees. In future work, the system will be enhanced by adding alignment and tree reconstruction modules, which will make it possible to work with the FASTA format and different types of trees (rooted and unrooted). In addition, the virtual reality interface will be more interactive that will provide direct tree customization in virtual space. In summary, this preliminary study shows that visualization of a phylogenetic tree can be improved by adding a new dimension that illustrates the relationship between tree leaves and provides a viewpoint for a better examination of tree leaf objects.

D. Visual modelling of physical and chemical properties of crystals

The paper [7] describes a computer model of a complex substance. Further, a visualization example was developed for modelling physical and chemical properties of this crystal with the use of virtual reality. A user could get inside the crystal and examine its properties, moving in different directions and observing separate parts of the modelled object. These results extended the possibilities of researching a computer model. See Fig.4.

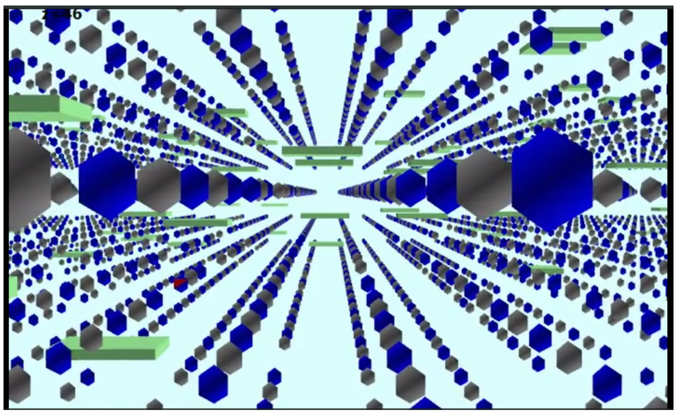

Fig. 4. A screenshot of an animated visualization of a crystal.

III. Virtual reality for software visualization

This chapter discusses the examples of using virtual reality for the purposes of software visualization, and the prototypes of such systems developed by us, featuring the option of using virtual reality environments.

An important constituent of designing software visualization systems is a visualization metaphor, which is understood as the main idea of approximating the notions of an applied field with a given imagery. Visualization metaphors underlie the display media, the design of which is crucial when determining the cognitive component of a specific specialized visualization system. Metaphors are used to determine the activity of a software systems user and their perception of objects and operations with the them. Among the metaphors used in software visualization systems, spatial metaphors are especially popular; they are key to building display media in debugging systems, testing and monitoring systems of parallel and distributed programs, as well as programs processing events and providing reactions to them. One can assess the possibility of using a certain metaphor for specific applications by analyzing their properties [8].

Software visualization systems with the use of virtual reality environments are often based on a city metaphor, which features software objects represented as structural urban blocks, buildings, rooms etc. Examples of such systems were published in numerous papers, including the recent years [9]–[16].

A software visualization project is being developed to be used by developers and testers, with a possibility to use virtual reality. The prototype of a software visualization system is based on an extended city metaphor. The city metaphor is supposed to be extended through adding active agents by entering parameters into specific functions and methods. The agents can move around the city, determining the locations where they are used, altered, and estimating the algorithm work process. The agents can help carry out debugging, testing and comparative analysis of the code performance with various data types, logic and other features responsible for the quality of the code. See Fig. 5.

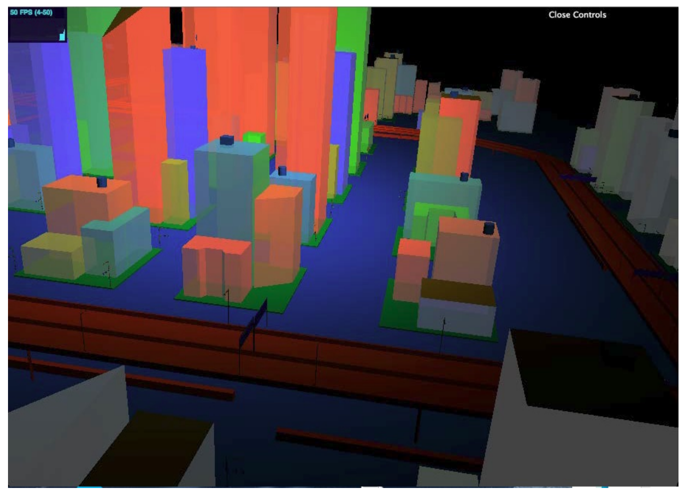

Fig. 5. Presentation of a software project as a city in virtual reality

The structure of a virtual city complies with the structure of a directory tree and file tree of the corresponding project. The next level of a software project is presented as building interiors. Other objects of the software complex may be displayed as trees, plumbing, power plants etc.

Our software visualization developments also implement heliocentric and geocentric cosmic metaphors.

Currently under consideration is a project of a programming system based on a virtual language developed on the principles of object-oriented programming. The aim of the project is to create a virtual programming environment with the option of thinking beyond the rules and requirements of a specific language, which would make it possible to focus on the problem at hand when coding. This way, software engineers can understand the structure of the program better by manipulating graphic objects on different levels of abstraction, and can minimize the number of mistakes, such as type discrepancies, syntax breakdown etc. A modern-sense heliocentric worldview cosmic metaphor is chosen as the visual programming environment. At the same time, part of the programs entities are presented as planets, their satellites, rings (like Saturn rings) and other elements of the cosmic space (see Fig.6).

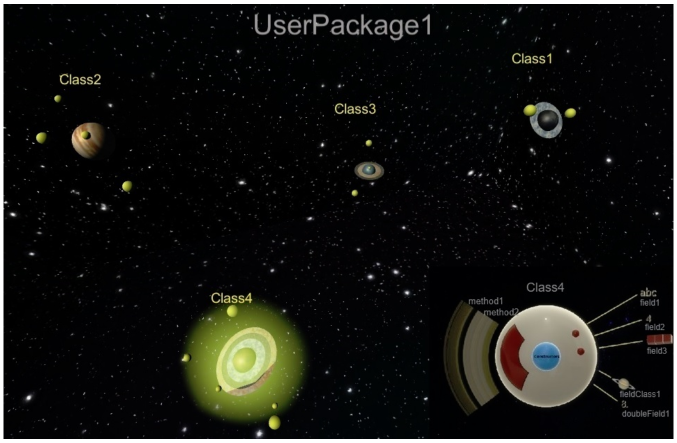

Fig. 6. View of a visual programming environment

For the presentation of hierarchically distributed data, one can use another option of a cosmic metaphor, supported by the old geocentric model of the universe. This model postulated the Earth as a static center of the universe. Solid transparent spheres revolve around the Earth with celestial bodies attached to them: first the Moon, then the Sun, then the Solar system planets (each planet in its own sphere), then stars. The whole model includes a set of spheres enclosed in each other. This metaphor makes it possible to present large volumes of multilayered information. In the case of using virtual reality, this metaphor provides convenient navigation and moving around in this virtual world. The geocentric system metaphor in 3D space is used to present data about a supercomputer performance at a certain moment of time. A parallel supercomputer consists of a set of processors. System administrator receives data about the performance of a supercomputer in order to increase its efficiency.

An example of the presentation view described above is given in Fig.7.

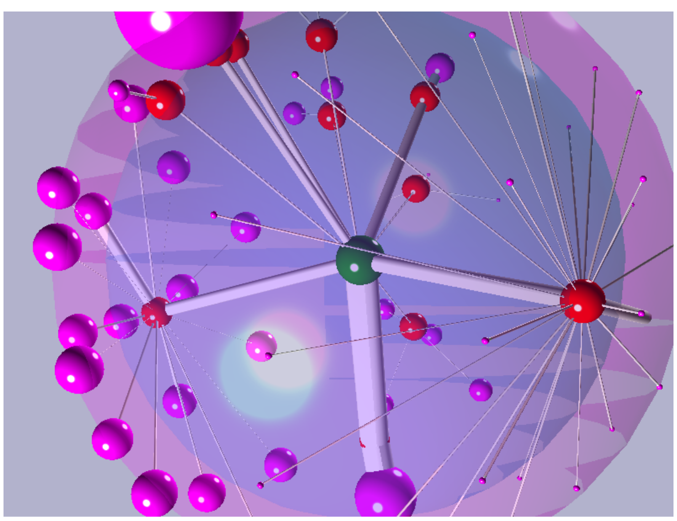

Fig. 7. Visualization of the load on the file system of a supercomputer, which uses a geocentric metaphor.

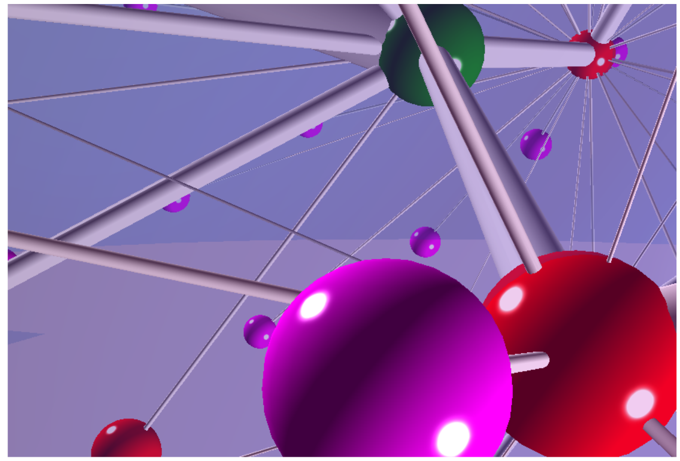

Fig. 8. A fragment of the state of the supercomputer at a certain moment in time, made from within a 3D geocentric system model.

Visualization program within the metaphor of a 3D geocentric system is built on the basis of the Viewlang.ru 3D graphic web library. This library relies on the WebGL standard. It is also provided with a WebVR virtual reality technology support. An example of an image that can be seen by the user in the VR mode is given in Fig. 8 [8].

IV. Interaction in Virtual Reality

Virtual reality systems are currently using a variety of special devices; for example, gloves with sensors, which detect the position of a users hands when put on. Special joysticks can also be used, which can provide control in virtual reality environments. However, all this requires additional activity from the user. That is why it is necessary to develop natural interfaces, including gesture ones.

A special sign language was developed for the purposes of using virtual reality, to facilitate performance control and navigation in a virtual environment. This sign language includes a gesture to identify the object which the user wants to interact with, gestures facilitating movement in space, and gestures for work. Users of the system pointed out the necessity of implementing gestures providing the turns of the grid and its parts. The implementation of sign language technology is based on motion capture (Leap Motion).

V. Human Factor

One of the main problems of interacting with virtual reality is the complexity and the need for simultaneous monitoring of the brain, the virtual space and the real world. In this respect, problems of a psychological and even physiological nature may occur. Implementation of conventional input devices is often difficult. There is the issue of the human factor in spatial orientation and navigation in structured spaces that constitute a 3D grid. Some ways of interacting with the environment or moving about in it can be inconvenient for the user and may cause strong discomfort; others distract them from fulfilling the task.

In psychology, virtual reality is traditionally defined through the presence phenomenon a feeling of being in the virtual reality as if it was real. Slater in his paper [17] states that presence is defined by the degree to which a person remembers virtual reality as a location that they visited, instead of thinking about it as an image.

Typically, this refers to realistic environments used in training simulators, in systems developed for psychotherapeutic purposes, in entertainment etc. However, computer visualization systems are often created without taking into consideration the realism parameter, because it is not key to the goals that these systems are designated for. The issue of the human factor for such environments is just as critical as for entertainment, educational or therapeutic environments; however, they are much less understood. Nowadays, these questions are studied, for instance, by [16].

The task of visualizing computational grids, described above, marked the beginning of this research. The grids are used for computing in the tasks of mathematical physics, modelling complex phenomena. The users of these grids are required to assess the type and the shape of the grid, the colors of the meshes presented in it, reflecting the properties of the modelled objects, and, based on this assessment, to make conclusions regarding the model under study.

In order to model the interaction of a person with the system of computer visualization, the tasks that the user is presented with were divided into two classes. The first one represents solving a task that requires spatial reasoning, analysis, synthesis, interpretation of the visual information etc.

The paper [18] discusses the issue of a person working in virtual reality when solving the Kohs Block design test.

It has been demonstrated that presence does not influence the efficiency of solving the task based on spatial reasoning.

The second direction deals with visual search tasks. Whatever the designation of a computer visualization system is, the user is always required to detect the necessary elements in the available scene and to make certain conclusions based on the findings. At this moment, a system is being developed where users have to choose points of a given color in a cube of 5x5x5. This task partially repeats, although in a more simplified version, the task facing a user who is working with a computational grid: highlighting elements of a specific color. Of interest here is the question of experiencing presence in the process of solving such a task.

VI. Conclusion

We have described some examples of the visualization systems based on the virtual reality as both computer modeling and software development. These examples of visualization shows great possibilities in this direction. There is an opportunity of using such systems in practice. Among such practical fields, one can emphasize virtual test-beds.

Virtual testing benches are software and hardware environments providing the opportunity of multiple launches of modelling programs with various parameters, of changing the modelling parameters during calculations and, importantly, of interactive visualization of the calculation results with the use of virtual reality environments. Such systems can be used in enterprises and construction bureaus dealing with the development of aircraft, missilery and other complex machinery.

A crucial field of using visualization based on virtual reality is medicine. This direction is paid great attention to. For example, here are some latest papers [19], [20].

In particular, this opens new possibilities in monitoring the state of internal organs, in medical training, especially surgical, in preparation for surgical procedures, and in helping a surgeon during the operation.

Comparison and analysis of views based on traditional graphics and virtual reality will be the issue of the next study.

We have discussed the opportunities of presenting anatomical organs in virtual reality with the option of full immersion inside the object, navigation within it and interaction with objects. For the purposes of interaction, not only traditional interfaces are used (as in the case of 3D presentation on a usual screen), but also interfaces based on gestures, with possible feedback from the system by means of tactile stimulation of a specialist users hands. In future, the development of special interfaces for the VR-based system is necessary. In this case, the involvement of computer psychology experts is required in order to make the VR interfaces usable for medical professionals. It is also necessary to study the activities of various categories of users.

References

[1] S. R. Pettifer, *An operating environment for large scale virtual reality*. university of manchester, 1999.

[2] E. A. Konovalchik and K. V. Kostousov, "Symmetrical 2-extensions of the 2-dimensional grid. ii," *Trudy Instituta Matematiki i Mekhaniki UrO RAN*, vol. 23, no. 4, pp. 192–211, 2017.

[3] V. Trofimov, "The finiteness of the number of symmetrical 2-extensions of the d-dimensional grid and similar graphs," *Proceedings of the Steklov Institute of Mathematics*, vol. 285, no. 1, pp. 169–182, 2014.

[4] N. Kim and C. Lee, "Three-dimensional phylogeny explorer: Distinguishing paralogs, lateral transfer, and violation of" molecular clock" assumption with 3d visualization," *BMC bioinformatics*, vol. 8, no. 1, p. 213, 2007.

[5] M. Milner, V. Patwardhan, A. Bansode, S. Nevagi, S. Kulkarni, R. Kamakaka, and S. P. Modak, "Constructing 3d phylogenetic trees," *Current Science*, pp. 1471–1478, 2003.

[6] M. Forghani, P. Vasev, V. Averbukh, and I. RAS, "Three-dimensional visualization for phylogenetic tree," , vol. 9, no. 4, pp. 59–66, 2017.

[7] M. Kostenko, A. A. Rempel, S. Sharf, and A. V. Lukoyanov, "Simulation of the short-range order in disordered cubic titanium monoxide tio 1.0," *JETP letters*, vol. 97, no. 11, pp. 616–620, 2013.

[8] V. Averbukh, N. Averbukh, P. Vasev, I. Gvozdarev, G. Levchuk, L. Melkozerov, and I. Mikhaylov, "Metaphors for software visualization systems based on virtual reality," in *International Conference on Augmented Reality, Virtual Reality and Computer Graphics*, pp. 60–70, Springer, 2019.

[9] T. Glander and J. Döllner, "Automated cell based generalization of virtual 3d city models with dynamic landmark highlighting," in *Proceedings of the 11th ICA Workshop on Generalization and Multiple Representation, Monpellier, France*, pp. 20–21, 2008.

[10] J. Vincur, P. Navrat, and I. Polasek, "Vr city: Software analysis in virtual reality environment," in *2017 IEEE international conference on software quality, reliability and security companion (QRS-C)*, pp. 509–516, IEEE, 2017.

[11] L. Merino, M. Ghafari, C. Anslow, and O. Nierstrasz, "Cityvr: Gameful software visualization," in *2017 IEEE International Conference on Software Maintenance and Evolution (ICSME)*, pp. 633–637, IEEE, 2017.

[12] R. Oberhauser and C. Lecon, "Virtual reality flythrough of program code structures.," in *VRIC*, pp. 10–1, 2017.

[13] R. Oberhauser, “Immersive coding: A virtual and mixed reality environment for programmers,” *ICSEA 2017*, p. 261, 2017.
[14] R. Oberhauser and C. Lecon, “Gamified virtual reality for program code structure comprehension.,” *International Journal of Virtual Reality*, vol. 17, no. 2, 2017.
[15] N. Capece, U. Erra, S. Romano, and G. Scanniello, “Visualising a software system as a city through virtual reality,” in *International Conference on Augmented Reality, Virtual Reality and Computer Graphics*, pp. 319–327, Springer, 2017.
[16] S. Romano, N. Capece, U. Erra, G. Scanniello, and M. Lanza, “The city metaphor in software visualization: feelings, emotions, and thinking,” *Multimedia Tools and Applications*, pp. 1–37, 2019.
[17] M. Slater, “Measuring presence: A response to the witmer and singer presence questionnaire,” *Presence, Teleoperators and Virtual Environments*, vol. 8, pp. 560–565, October 1999.
[18] A. N., “Subjective-situational study of presence,” in *Lecture Notes in Computer Science*, vol. 8525, pp. 131–138, Crete: Springer, 2014. Proceedings of Augmented and Mixed Reality. Designing and Developing Virtual and Augmented Environments Conference.
[19] O. Topsakal and M. M. Çelikoyar, “Surgeries that would benefit from augmented reality and their unified user interface,” in *International Conference on Augmented Reality, Virtual Reality and Computer Graphics*, pp. 303–312, Springer, 2019.
[20] G. Turini, S. Condino, U. Fontana, R. Piazza, J. E. Howard, S. Celi, V. Positano, M. Ferrari, and V. Ferrari, “Software framework for vr-enabled transcatheter valve implantation in unity,” in *International Conference on Augmented Reality, Virtual Reality and Computer Graphics*, pp. 376–384, Springer, 2019.