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Sources of Computer Metaphors for Visualization and Human-Computer Interaction

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Abstract

This chapter is devoted to finding sources for metaphors of computer visualization and human-computer interaction. Computer metaphor is considered the basic idea for the development of interfaces, visualization views, and scenarios of visualization and interaction. Global metaphors map the main design idea. These ideas depend on global events and changes in society, art, and science. In the "pre-computer" era, such ideas formed the basics of cartography, engineering drawings, and drawing function graphs on the Cartesian plane. When designing visualization and interactive systems, computer metaphors use "magic features" beside analogies with daily life. Nowadays ideas of visualization are often based on "gamification." This approach presupposes creating tools that provide software engineers with an interface similar to that of computer games. In this chapter, ideas drawn upon fairy tales, science fiction books, fantasy films, and other similar spheres are considered as sources of computer metaphors. Such metaphors are very interesting when designing visualization systems based on virtual reality.

Keywords: computer metaphor, visualization, human-computer interface, fairy tales, magic features, fantasy

1. Introduction

The chapter analyzes the sources of computer visualization metaphors and human-machine interaction. The metaphor essence consists of interpretation and experience of the phenomena of one sort in terms of the phenomena of other sort.

A metaphor is the main idea of forming the types of visualization views, interfaces, and scenarios of visualization output and interaction with it.

Metaphor sources are objects of the surrounding world, scientific ideas, ideas derived from literature, folklore, sci-fi cinema, computer games, etc.

Metaphorization is based on interaction structures of source and target domains. In the process of metaphorization, some objects of target domain are structured on an example of objects of target domain, and there is a metaphorical mapping (projection) of one domain onto another. That is how the metaphor can be understood as a map from source domain onto target domain, and this map is strictly structured [1]. Metaphor ideas are often based on real life as well as on abstract scientific ideas. Worth mentioning are such examples of pre-computer era visualization as cartography, engineering graphics, and Cartesian coordinates, which

played a crucial role in the development of modern civilization. Cartesian coordinates were the basis for the idea of computer graphics during the first period of its development. The use of new ideas is connected with developing the means for human-computer interaction. It is in this field that such metaphors as a light button and light button menu appeared. The most well-known and still popular desktop metaphor is also connected with interfaces intended to provide interaction in office work computerization. The desktop metaphor is almost entirely based on office work realities. However, there is a double-click, which can be called a magic feature and is unparalleled in real life. Further, such magic features were added in a whole range of metaphors used in computer visualization systems. The emergence of virtual reality as an environment for computer visualization made the use of metaphors relevant. Conditions inherent to virtual reality are somewhat similar to magic and science fiction. That is why fairy tales and sci-fi in literature and cinema may become an interesting source of new metaphors.

Below we shall discuss the main ideas of pre-computer visualization, the potentials of metaphors based on real-life phenomena and on scientific ideas. Then we shall analyze the potentials of fairy tales as sources of metaphors. We shall also provide several examples of metaphors based on science fiction and discuss the evolution of visualization from a comic book to immersive cinema.

2. Global visualization metaphors

The concept of metaphors is popular in publications on computer visualization and human-computer interaction. One may reveal the following two cases of using this concept:

A **metaphor** as the basic idea of data presentation, the idea of convergence of entities of a computer system, and a source domain.

A **metaphor** as the idea of interaction with the [virtual] environment created by computer systems.

The following hierarchy of computer metaphors is considered:

- Global metaphors of design

- Basic visualization and interface metaphors

- Local metaphors

Global metaphors map the main design idea. For example, considering the world as a "super office." (**The whole world is an office, and all the men and women are merely clerks in it**).

Let us consider global visualization metaphors. These ideas depend on global events and changes in society, art, and science. We are interested in global metaphors that have a visual ("pre-computer" and computer) representation. These ideas formed the basics of cartography, engineering drawings, and function graphs on the Cartesian plane.

We review the interference of metaphorical ideas and the challenges facing economy, science, and education in the past and now.

Modern cartography is the result of geography development and a prerequisite for the Age of Exploration. The use of the Mercator projection and the grid of parallels and meridians in the modern age is a great achievement in the visualization of geographical and navigation data.

Variations of geographical metaphors are used now in data visualization and software visualization systems.

Engineering drawing is the product of the Industrial Revolution, its prerequisite and an important tool. Multiple views and projections, a set of rules depicting product features, compile a certain explicit code.

Engineering drawing in the form of CAD systems is an integral part of computer tools of modern engineers.

One of the most powerful visualization ideas of the modern age is the idea to draw function graphs in Cartesian coordinates. The idea of function reflects rather abstract concepts, but due to graph drawings, even very young students may become familiar with them.

2D and 3D graph drawings are the bases of modern scientific visualization and an important part of data and software visualization [2].

3. Computer metaphors

For a start, let us revise the way things were in the field of human-computer interface before the emergence of visual metaphors. In those times software engineers (who comprised the basic quota of users all over the world) still remembered working with bulky computer consoles. Command-line interface prevailed in interactive systems. For instance, text editing commands included operation indication, the number of source line (sometimes the number of a symbol in the line as well), and (if necessary) the new text for correction or pasting. Such an interface, although it required from the user to keep in mind a continuously changing text, and despite occasional mishaps with saving the changes, was tolerable enough for professionals. Graphic displays gave a new impetus to human-computer interaction. Along with the tools of data visualization, program interface tools came into use. Based on that, light buttons (an output primitive used to emulate a functional key) and light button menu came into exploitation. With their help one could easily interact both with the program's system and with the user's program.

The mass arrival of personal computers simply could not have happened without the emergence of visual interaction tools, new devices, and brand-new concepts of interface organization with the user, for example, the concept of direct manipulation.

The concept of direct manipulation was suggested in the early 1980s by Professor B. Shneiderman, a famous expert in the field of computational sciences, who combined and analyzed new trends in organizing the interface. Currently, this concept prevails in interface design.

B. Shneiderman determined the following features of an interface created on the basis of the direct manipulation concept:

1. Continuous depiction of the object of interest

2. Physical actions (manipulations with the mouse, joystick, touch screen, etc.) or using a functional keyboard instead of commands with complex syntax

3. Quick operations, divisible into steps and allowing resets, with an instantly visible effect on the object of interest

The essence of this approach to interface creation is in making the user perceive their activity as direct manipulation with the objects displayed on the screen, rather than as a dialog with the computer regarding these objects. Instead of using

command language to describe operations with objects, the user manipulates visible perceptions of these objects on the screen.

The interface metaphor is considered as the basic idea of convergence and similarity between model objects of an applied field and interactive objects. The role of an interface metaphor is to facilitate better understanding of interaction semantics, as well as to provide a visual idea of dialog objects and define the set of user manipulations with them.

The interface metaphor in this respect is seen as the basis of the semiotic system, which in turn underlies the interactive language. With the help of this language, the user forms their task and achieves the solution by means of a computer. The interface metaphor does not only help describe abstractions but also structures the understanding of a new applied field and defines objects of the interactive [visual] language [3].

The most recent global metaphor is the basis of modern computerization. For a variety of economic and social reasons, people at the end of the twentieth century understood the world around them not as a workshop where employees work but as an office where clerks and managers spend their time. The cornerstone of a desktop metaphor success is tightly linked with this change in the awareness of the world. Results of modern computerization (and the desktop metaphor) reflect global ideas of modern "postindustrial" world. However, "office" interfaces generate office activity techniques in such "non-office" domains as medicine or education. This often involves non grata effects.

Originally, this metaphor was offered for office automation systems, but then its use was expanded for operating systems interfaces. *These ideas were linked with end-user programming, as the means for office clerks and managers to simplify their work using computers.*

The desktop metaphor became the most frequent practice in the 1990s. This metaphor is in many respects the basis of modern visual interfaces. The success of a desktop metaphor, undoubtedly, is connected not only (and not so much) with the natural figurativeness of icons that are [not always] clear to users but with logicality and systematic nature of all activities within visual environments based on this metaphor.

The formula of a desktop metaphor is described in [1]. Apart from borrowing office work realities, this metaphor has a "magic" idea: all actions within the system are made by means of double-clicking on icons.

Significantly, desktop metaphor extensions toward an office desk metaphor, office space metaphor, and a filing cabinet metaphor were not very successful, despite interesting solutions and the use of several magic features.

4. Fairy tales and science fiction as a source for metaphors

By providing calculation results, visualization ensures interpretation and analysis of the acquired data. The following subfields of computer visualization can be distinguished: scientific visualization, software visualization, and information visualization. *Scientific visualization* presupposes using the means of computer graphics and human-computer interaction to provide data on objects, processes, and phenomena, modeled in scientific calculations. *Software visualization* means a combination of methods of using graphics and human-computer interaction tools used for better understanding of phenomena and for efficient exploitation of the software, as well as for specification and presentation of software objects in the process of program creation. The term *information visualization* relates to visual description

and presentation of abstract information acquired as a result of gathering and processing data of different types and functions.

Typically, scientific visualization uses traditional (pre-computer) methods of displaying mathematical, physical, chemical, biological, and other models (e.g., two-dimensional and three-dimensional function graphs). Sometimes the imagery natural and/or typical for a given application is also used, for example, molecule presentations in modeling chemical processes. Traditional imagery, sometimes borrowed from the pre-computer static graphics, is also used in information visualization. One may conclude that the use of metaphors in scientific and information visualization is limited.

Computer metaphors became most widely used in software visualization systems. These metaphors are based on objects and phenomena of the real world or on models derived from specific branches of science. Among these metaphors the most popular are spatial metaphors: the city metaphor or the landscape metaphor and their variations in particular. Spatial (three-dimensional) metaphors are actively applied in developing presentation views in visualization systems used for monitoring, testing, and debugging parallel and distributed programs, as well as programs for processing events and providing reactions to them. These metaphors are widely used in the systems based on virtual reality [4–7].

Using a city metaphor presupposes structuring the input data by means of internal city structure containing separate blocks, streets, and buildings. The naturalness of metaphors causes both simplicity of orientation in space and navigation ease. In software visualization systems within a city or a landscape, metaphor transport arteries are often used to represent control flows and data flows, as well as various connections between objects and program components. When using these metaphors in the systems based on virtual reality, a flight over the city is possible. There are examples of software visualization systems based on an extended city/building/room metaphor with the use of teleportation for immediate relocation between city districts or buildings representing different elements of a big software complex.

A cosmic metaphor in its modern sense, with a heliocentric worldview, is chosen as an idea for a visual programming medium. At the same time, parts of the entities of the program are represented as planets, their satellites, rings (like the rings of Saturn), and other elements of outer space. It seems that in the case of virtual reality application, the most archaic 3D version of a geocentric model may be more convenient, with the Earth represented as being flat and celestial bodies located on hemispheres covering the flat Earth [8].

Based on scientific views, a molecule metaphor in particular can be used to visualize performance traces and graphs for parallel programs. This metaphor provides representation view of a large volume of structured data. Interpreting a physical molecule (particle) metaphor and its modifications is generally simple and natural, although it requires certain (basic) knowledge of physics from the user. Moving and navigation can be executed by means of flying around the molecule (or a set of particles). This means, a molecule metaphor, in the same way as a city/landscape metaphor, includes some magic or fantastic features.

The paper [9] describes the original brain metaphor, which is used for animated representation of a parallel program performance. The idea of visualizing brain activity when presenting it with some stimuli is transferred onto a program or an application's performance visualization (activating procedures and functions, input/output, etc.). Let us note that this metaphor does not have any magic features; possibly, this is what hampers perception of a large volume of information based on it.

Currently the idea of gamification has been gaining popularity. It implies the use of computer game ideas in non-gaming fields of application. When developing software visualization systems, this approach presupposes creating tools that provide software engineers with an interface similar to that of computer games. The paper [5] discusses a software visualization system based on virtual reality with the use of virtual reality. A city metaphor is the basic metaphor for this system. However, both the imagery and the method of interaction in the system strongly resemble popular computer games.

Gamification in software visualization system development based on virtual reality is also mentioned in the paper [10]. An environment based on virtual reality is described, which should provide work with the structures of a program code using city metaphors and cosmic metaphors for visualization, navigation, and program code data transfer in an interactive mode. Games have been released that have demonstrated the potential of gamification for the purposes of enhancing the understanding of structural dependencies and code modularization.

Thus, everyday reality, scientific ideas, and modern computer games serve as sources for metaphors. Further, we shall look at fairy tales and science fiction, where objects with magic features are used and characters have magic abilities, as sources. Magic ideas described in fantasy novels or in literary processed folklore fairy tales are the most functional and consequently the most useful ones for our purposes.

An important issue when forming scientific and, in particular, computer metaphors is the question of where to find the source [11, 12]. The description of the constructive procedure of searching and/or generating interface metaphors is presented in [13]. This multistage procedure provides (among other things) the consideration of application domains, user tasks, and user characteristics.

Interest to "magic" in connection with HCI and interface metaphors has been shown in the early 1990s. Significant attention has been given to the concept of "magic features." This concept in the context of HCI was introduced for the first time by [14].

The issue of magic and magic features as a source for metaphors when developing interactive visual software complexes is also discussed in the paper [15] (see also [16]).

The word "magic" is very popular as part of metaphoric names for interface techniques, for example, a "magic lens," a "magic mirror," a "magic lancet," etc. In [17] a number of specific examples from stage magic are presented, and application of its principles and techniques in human interface design is discussed. The article [18] is devoted to sources of metaphor for tangible user interfaces. Authors suppose magic and paranormal phenomena could be a fruitful place to look for new metaphors for tangible user interfaces. Also, voodoo magic is considered an interesting idea for interfaces with virtual objects. In [19] Voodoo doll technique is used as a two-handed interaction technique for manipulating objects at a distance in immersive virtual environments.

Ideas for interface metaphor design, linked with magic fairy tales, fantasy, and science fiction novels, are described in a number of articles. In [20], for example, the magic metaphor of a flying carpet is mentioned, but in [21] the metaphor of a magic carpet is realized, for instance, moving in the virtual reality environment. In [22–26], the ways of using a "magic wand" are described. A magic wand is considered a manipulation metaphor to form an interface in systems with elements of virtual reality. Interesting ideas of wonder objects (e.g., a magic mirror) were proposed (and realized in prototype versions) for storytelling in modern museums [27]. In [28] an information system using a city metaphor is described. In this system, magic/fantastic opportunities are used on a regular basis. Among these

opportunities there is "tunneling through space" presenting the typical adoption from science fiction. Rooms with "magic windows" may also be considered as a magic (science fiction) feature. A "magic window" is an interesting expansion of a well-known information wall metaphor.

Here we consider fantastic magic features, selecting the samples that are fruitful for interface and visualization metaphors.

Magic transport: In fairy tales and science fiction novels, one can find:

a. Teleportation—an instant movement by means of verbal influence (spell) or by means of manipulations with any objects or uses of such devices as teleports

b. A rather slow movement by means of magic transport. A magic transfer may take place both for subjects and for (animated and inanimate) objects of magic

Magic navigation means: An example is a milestone with a magic legend or a magic clew, following which one may reach Fairyland.

Magic communication means: An example is a magic mirror tuned on an interesting character for his/her protection or observation.

Magic (additional to normal) **opportunities for manipulations** with objects, processes, and even natural phenomena. In some options a superpower, invincibility, etc. Generally speaking, one can use the term "magic power" (or "superpower"). These manipulations and powers may be executed through spells and objective magic, as well as through the universal manipulator, a **magic wand**.

One can set out the general class of **magic objects** as objects possessing "magic properties." Thus, magic expansion of usual functionality is possible (for example, seven-league boots), as well as attributing additional, unusual in real life functions to objects (for example, Aladdin's magic lamp used to summon, activate and neutralize **magic beings**). For the purpose of magic objects used as manipulators, transport and communication means one can also use the term "magic tools."

Magic transformations of objects: As an example, one may consider the construction of palaces by the Genie in the Arabic fairy tale or the transformation a pumpkin into the carriage for Cinderella.

Similarly to magic objects, magic subjects may be set out, i.e., evil, good, or neutral (with respect to the characters) magicians possessing superpowers. (As an option—magic anthropomorphic beings, e.g., fairies, gnomes, trolls, genies, etc.)

Magic transformations of persons: In fairy tales such transformations may be spontaneous, unexpected for the characters, or they may result from magic actions (some magic spells or manipulations). These transformations can be carried out in view of sympathetic magic (i.e., magic based on a certain similarity).

Our attention was focused on two "magic-fantastic" metaphors from the novels (and also the films) about Harry Potter. These are speaking and moving portraits and the Marauder's Map, which even showed people's movements on it. In this case, portraits of dead people are the active objects. They may address the living characters of the novel without requests and even move from one portrait frame to another to pay visits to each other. The map continuously traces and shows the location of the person under observation.

There are many active, anthropomorphic, and speaking characters in fairy tales and in science fiction novels such as Golem, robots of K. Capek and I. Asimov, and so on. Similarly, there are numerous variations of magic/fantastic means of navigation and search both in fairy tales and in fantasy.

In these magic metaphors, visual characteristics are not as important as spontaneous activity inherent to generated objects and subjects. Spontaneous activity can be considered the means of imitating reasonable behavior. Of importance is also the character's existence independently of users, imitating reasonable behavior. In sci-fi and popular scientific literature and films such active computer, "subjects" appeared several decades ago. In modern computer practice, agents who are active under their own initiative frequently cause irritation. We started our research of active intellectual agents to understand what, why, and where active intellectual agents have to do.

The idea of an "active" map showing a real landscape and movements of objects was considered. The "activity" of a map can be connected to events, in the same way as in navigating systems: moving around, turning, crossing, and so on; but "activity" can also be spontaneous, connected with time events. Another idea that may be possible is the development of an "active" scheme of a protected apartment or territory. In this case tracking systems and "highlighting" persons may be necessary. Movements of all characters without exception may be shown on the scheme, and labels will allow identification. In the context of the given ideas, it may be noted that works in this direction, on the basis of such systems as GPS, are underway and there are examples of interactive maps serving as guide advisers. Moreover, now it is easy to develop speaking anthropomorphic avatar agents, and there are many examples of such implementations.

We have decided to link the idea of active agents based on a metaphor of a speaking portrait with the expert system. The point is that an active agent with its (possibly) importunate activity is authorized only in the case of teaching systems. The logic of project development led us to the following idea of an "active textbook." This textbook has to be able to analyze the student's behavior in the process of studying, for example, the time of reading, manipulations with the text, and so on. Based on these analyses, the "active textbook" may detail teaching material, search new data sources, or turn to other things. The analysis of a user behavior may be accomplished at a syntactic level (at a level of operations with a mouse and a keyboard, eye tracking, etc.) and on a semantic one (monitoring opened files or sites, running applications, recording events, etc.). Such analysis and elements of programming by demonstrations will allow our system to learn how to teach in the process of its use and to operate in the given direction "independently." It is also possible to supply the system with adviser functions. The system will be like an intelligent human adviser and will not impose its opinion but provide recommendations and solutions. This human-like behavior may be provided by psychologically driven slowdowns in the system's activity.

Expansion of a city metaphor used in software visualization systems is suggested by means of adding active agents by inputting parameters into certain functions and methods. The agents can move around the city, determining the locations where they are used and changed and the way the process of algorithm work plays out. This way, an extended metaphor creates such additional properties as the opportunity to observe software objects inside buildings or rooms, reflecting particular entities while active agents move around the city.

In visualization systems based on virtual reality environments, there are such tasks where complex manipulations with objects are necessary, for example, pulling something out, cutting, or zooming in. As a metaphor of the tool for such tasks, first of all, the idea of a magic wand comes into designer's mind. However, a magic wand does not have differentiated actions and hence requires the means to change operating modes. In specialized systems, it is more natural to use specialized "magic tools." For example, in medical information system as manipulator's metaphor, the idea of a "magic lancet" is offered. The lancet allows to "dissect" this or that

organism area for profound exploration. When "dissecting" any human organism object, all physical changes are visualized, as if we did it in a reality. In case of a combination of a "magic lancet" metaphor with a three-dimensional model of a human body, one may obtain the virtual model of operations, and a prototype system of information visualization for medical purposes is in progress now. Systems based on this metaphor may be used, for example, to teach surgery [29].

Science fiction may be an implicit source of metaphors used to control visual objects in virtual reality environments. Thus, for instance, the paper [30] describes an environment for an experiment studying psychological states in virtual environments. A user has to manipulate cubes to compose a given pattern. These cubes in the virtual environments are "caught" with a special trap, in which an antigravity movement mode to a necessary point or a cube rotation mode may be activated. When using a special command, the cube rises over the virtual table and flies in the location set by the user.

Our preliminary research shows the applicability of "magic" metaphors for tasks in interactive systems and systems based on virtual reality environments. For example, the search of metaphors for movements in virtual environments may require magic transportation techniques, such as teleports and flights of various types (the flying carpet, the flying ship, Roc, a winged horse). Metaphors of intellectual agents-informants may also be based on magic means of navigation.

In fairy tales and science fiction novels, one can find a lot of magic phenomena, such as magic knowledge, war magic, fulfillments of desires, telepathy and thought-reading, etc. But we do not know for sure yet, whether these features are useful for metaphor search. However, for a choice of metaphors for manipulations with objects and processes in virtual environments, "the war magic" may be of interest. War magic is connected with transferring the events taking place in the magical world into reality. For example, any variations of "magic chess," where games with chess pieces are transferred into land battles, or the "naval" military magic where models of fight in a vat of water are transferred into sea battles. One may find these ideas (partially close to voodoo magic) in a number of folk and literary fairy tales.

Note that folk fairy tales are governed by rigorous logic of plot development and a choice of characters. By the way, in literary fairy tales and fantasy novels, this logic is also typically observed.

Analysis shows that exotic "magic" metaphors may be used to form any interface features. However, implementation of interactive systems on their basis may be both complex and contradictory. Magic metaphors are frequently transformed into abstract interface opportunities, losing the appreciable connection with initial ideas. For example, in case of a speaking portrait metaphor, the anthropopathy of an agent turned out to be unnecessary. But it is necessary to endow it with the function of a magic assistant/conductor into the world of knowledge. Of course, the transmuted abstractness of metaphors is an advantage rather than a defect of their use. In the systems created, for example, for office automation or for end-user programming, the presence of magic interface manuals may appear as a distracting or even irritating factor. However, using such "magic features" as automatic return of electronic analogs of paper documents on their place at the end of processing may be carried out without any special warnings even for non-expert users. Such features are well-conformed to common sense of clerks and do not demand unnecessary efforts during operations. Infringement of magic logic due to any absurd ideas or too farfetched subjective likeness may lead to serious mistakes. Sharp criticism of interface metaphors as such is connected with the infringement of magic logic in the early version of Apple's interface (using the trash can metaphor to eject disks) [14].

5. Metaphors for systems based on virtual reality

Virtual reality environments were initially used for aviation and space simulation training systems. They gained widespread use in entertainment systems and computer games. They are also used in medicine and psychology for therapeutic purposes. We are interested in virtual reality as a basis for computer visualization systems development. The imagery used in virtual reality systems can be adopted from the imagery inherent to a certain computer model. However, for software visualization, systems based on virtual reality metaphors are typically used. Such systems can benefit from (or even require) fairy tale features described above. In this respect, we are interested in interface metaphors which are applied in virtual reality.

The role of interface metaphor is to promote the best understanding of interaction semantics and to determine the visual representation of dialog objects and a set of user manipulations with them. A metaphor, considered as a basis of the sign system, in turn underlies a dialog language. A user articulates the problem with the help of this language and achieves solution from the computer. The metaphor helps to describe abstraction and provide structural understanding of a new applied area but also assigns dialog [visual] language objects. Interface metaphors may be considered a special case of scientific metaphor used for generating new or additional senses to understand new facts and phenomena.

Virtual reality is characterized by a set of specific states, above all, presence, involving a human perceiving themselves inside a virtual environment with various features. Due to experiencing presence, a person finds themselves in situations similar to those of fairy tales and science fiction, even if no magic metaphors were applied (e.g., finding oneself inside a brain or a molecule). In such conditions, the use of magic features described above is reasonable, both for navigation and movement in a virtual environment and for interaction with the objects of this environment.

A project of a virtual environment designed for modeling visual search in large space may use either emerging magic signs or talking objects to facilitate user navigation. In virtual reality systems, a magic wand may be useful as an interface metaphor to point at objects and interact with them. The idea of teleportation is interesting in virtual reality systems for movement organization, as it provides the possibility of instant movement to a new virtual scene.

6. The butterfly effect

Interesting metaphors may be adopted from science fiction works. Thus, a time machine metaphor and a butterfly effect metaphor were used in a project of an environment for adjusting parallel programs dealing with software visualization systems [31].

One may consider time as an axis that is analogous to traditional spatial axes. And the event stream may be depicted along this axis. Any change in this stream may break the whole chain of cause-and-effect relations. In this case, the idea of traveling in time in both directions seems to be natural. One may consider a set of parallel processes as consistent streams of events flowing and changing along this time axis. In this case, effects of an event in the process cause a reaction, affecting both the process in which it has occurred and other processes. It is possible to correct errors by going back in time along the axis and interfering with the sequence of events at the moment. This approach can be described as the "time machine"

metaphor. Note that the use of the time machine metaphor does not require any knowledge of the source (science fiction novels). We have developed a prototype of a visualization component for a parallel process control and representation system. This system can be used for debugging parallel programs. We use 3D imagery to visualize processes. Processes are represented by color cylinders connected with each other by thin "threads" (similarly to visual representations in the VisuaLinda system [32]). Globules representing data move along these threads. The states of processes are depicted by colors. A user may navigate along the time axis and change the processes' states. The time machine metaphor may be considered similar to a traditional record player metaphor. However, in the case of a time machine, there is a possibility of event changes described by the well-known butterfly effect metaphor, which is connected with the situation when a small change of initial conditions causes significant and often unpredictable effects.

A time machine metaphor seemed promising for software visualization of parallel computing. However, after analyzing its implementation, this impression may change. In this case further development of fully fledged debugging and visualization facilities for parallel programs is needed, for example, trapping events, online visualization, and other tools similar to those implemented in the debuggers of the 1990s, such as [33, 34]. These metaphors may also be applied in the systems of software visualization based on virtual reality [31].

7. Visualization texts: From interactive comics to motion pictures with immersion

Present-day comics and manga may be described in terms of visual texts. You can describe rich and complex languages of pictorial art based on natural imagery, but in this case, the task of a detailed language description is rather complex and often uncertain. One can also describe complex and weakly formalizable dynamic languages of cinema and animation. Similarly, one can define graphical texts associated with computer visualization. The examples of those visualization texts are:

- Isolated displays

- Dynamic, logically related shot changes with the inclusion of interaction

- Animations also with the inclusion of interaction

The goal of visualization is to leverage the existing scientific methods by providing new scientific insight into visual methods. Virtual reality environments are actively used to practice leaping into a new quality of cognitive visualization. Virtual environments are characterized by such features as egocentric points of view and user-centered, often multisensory, interactions. Virtual reality environments are dynamic, rather than static. The user's experience of the virtual world may combine a visual channel with auditory or haptic feedback. Immersion and sense of presence (the feeling of "being there") are factors which define virtual reality. The sense of presence distinguishes virtual reality from "traditional" 3D computer graphics. Users "immersed" in virtual reality control the graphics output. Users may also participate in adaptive control of the application system. The essence of virtual reality is in the interaction between the user and the virtual environment. The interpretation principle for graphical texts was formulated as follows: interpretation of such texts is possible only if the "readers" of the text have external information.

This principle is similar to the principle of intuitive use. The interpretation principle is very important in the case of visualization based on virtual reality.

One may consider the evolution from comic-like visualization methods to controlled animation-like movies and from these movies to full insight and controlled immersion processes. In its own right, visualization languages of virtual reality may be considered; however, a visualization language in the case of "immersion movies" becomes much more complicated and needs further description. It appears that a new quality of visualization can be achieved primarily through the following media:

1. Immersion in virtual reality

2. Creation of an interactive "movie"

3. Presence of a controlled and modifiable "screen story" ("movie" script)

The language of this script is the language of visualization description (and possibly of visualization depiction—in the case of visual languages). The languages have to support history tracing, including visualization and interaction traces and fixing insight experiences. Examples of "immersion movies" will be used in computer visualization systems.

8. Conclusion

The issue of finding the sources arouses a whole range of questions. First, an assessment of metaphor applicability is necessary both for the given applications and for a specific task. When assessing the applicability of a metaphor, one should evaluate the way this metaphor can depict the features of a certain application, for which the visualization system is built. However, imaging precision does not necessarily guarantee success for the system. For example, a brain metaphor, precisely depicting the work of a parallel program, is not very convenient in terms of perception, which strongly hampers visualization perception. Magic features are useful in addition to the complex of computer metaphors but are not sufficient. There are examples when a metaphor, for various reasons, was not successful even after introducing these features. Gamification is an interesting idea. However, the question remains whether game components risk distracting the user from their intellectual activity by putting them into a silly, playful mood. Distraction from the main task may also be caused by the magic features of metaphors, especially in environments based on virtual reality. When using virtual reality, one should also analyze the potential user states in terms of increasing or decreasing performance. All these thoughts show that research of substantial user groups is necessary. It is worth noting that in case of software visualization, this research is relevant, as there is a considerable number of tasks and a significant number of experts.

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