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Approach to Semiotic Theory of Computer Visualization

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Abstract

The purpose of this paper is to discuss the Semiotic approach to forming of Theory of Computer Visualization. Such theory (or rather theories) should be the foundation of design, development, and evaluations of specialized visualization systems. The semiotic analysis of visualization is defined. The paper contains the scheme of the semiotics analysis during designing of visualization systems. The semiotic analysis helps in design and development of the real visualization systems. Also such conceptions as Computer Metaphor, Metaphor Action, Metaphor Formula are defined and discussed.

Keywords: *Computer visualization, semiotic metaphor, Visualization Metaphor.*

1. Introduction

The goal of this paper is to discuss the semiotic approach to formation of theory of computer visualization.
The theory is necessary, firstly, to analyze an existing state of the practice, secondly, to train new professionals and thirdly, (and this is, in our opinion, the main) to use in the practical work. Without the theory there are no reliable methods of adopting and sharing really valuable experience, instead of the casual ideas, which have appeared in connection with a certain level of hardware for interfaces and Computer Graphics and/or Software Engineering.
The scientific theory should satisfy some requirements. Among them there are the discipline structurization, supporting of analytical functions in its frameworks, and the prediction of new phenomena. One may say about the explanatory and predictive force of the theory. Thus, on the basis of the satisfactory theory (at a given period of the discipline development) one may analyze and explain any known phenomena, predict the emergencies of new phenomena, concepts and facts, carry out a systematic description of the discipline as a whole. Thereby there is a possibility to fix available achievements, to transfer them in courses of study, to create conditions for the further development of the discipline. An important result of the satisfactory theory of the computer visualization should be a scientific basis for the quality design, the development and the evaluation of visualization systems.
Below we'll consider one of the approaches to the theory of visualization, which in our opinion form a base of designing, developing and education in this area.

2. Related Works

The description Computer Visualization as the independent discipline summed up the great practice of Computer Graphics since beginning of 60-th. In this issue the main conceptions of the new discipline were defined. The visualization is considered as a method of computing. It transforms the symbolic into the geometric, enabling researchers to observe their simulations and computations. Visualization offers a method for seeing the unseen. The goal of visualization is to support the analysis and interpretation stages in framework of the computer modelling cycle.
One can consider three main directions in researches and developments for of Computer Visualization domain. That is – Computer Graphics (Hardware and Software including mathematical and algorithm components), Software Engineering, and Human Factors. Our interests lie in the Human Factor subdomain.
In the scientific literature one can find three main approaches to a choice of foundations for the theory of the computer visualization which can be roughly described as

perception, cognition and semiotics that is naturally connected to the processes in a human mind.

Semiotic analysis is an important tool for the visualization system design and development. Below we consider the "direct" semiotics analysis of the visualization that reveals Other popular approaches to a choice of foundations for the theory of the computer visualization are based on the theory of perception, Gestalt theory and the consideration cognition processes in visualization. We may say about the almost complete description of cognition aspects of Computer Visualization Theory (though shared for the present in the different publications).

One can present the process of Human dealing with visualization consisted of three stages "*Perception -> Cognition -> Interpretation".* Thus the last but not least stage of Visualization theory is Semiotics studied Interpretation proper.

A "semiotics" approach to the theory of visualization and human-computer interaction began to develop in the 80-th years of the twentieth century. The statements of the classical semiotics were used to describe visual sign processes in connection with a computer graphics and visualization [6], [11], [12]. Using semiotic engineering of human-computer interaction is described in work [3], [4].

It is shown that the human-computer interaction and visualization have a semiotic nature. The conceptions of a visualization language and a figurative (visual) text described on this language are considered. The computer metaphor is considered, as a basis of the visualization language. The semiotics analysis of computer metaphors allows to evaluate known metaphors and to search new ones for specialized visual systems. Thus, the semiotics analysis can be an important tool for the visualization systems design and development.

Semiotics, dealing with sign systems and with practice of their functioning, may be considered as tools for descriptions of theories of HCI and Computer Visualization just as Mathematics is tools for descriptions of Physics Theories.

The obvious semiotic nature of the human-computer interface and visualization allows to reveal sign systems that determine interactions, visualization and communications. Human-computer interaction in this connection may be described precisely as sign process. Visualization also may be described as sign process similarly to human-computer interaction. Processes of human computer interaction and visualization contain user interpretation of visual and dialog objects as their essential part. In turn the process of sign interpretation is researched in frameworks of semiotics. That is why one may consider semiotics as the base of theories of HCI and Computer Visualization.

If human-computer interface and visualization have the sign and language nature then each interface and "Who is Who" in the process of the visualization semiosis. It allows to describe problems arising at developments of specialized systems in the terms of the semiotics and showing how this analysis can serve as a tool for the visualization systems design. visualization system contains the language as its core. The language in this case is understood as the systematical description of entities under consideration, methods of their representation, modes of changes of visual display, as well as, techniques of manipulations and interaction with them. The language (or rather a base sign system) is built upon some basic idea of similarities between application domain entities with visual and dialog objects, i.e., upon a computer metaphor (that is interface metaphor and visualization metaphor).

We consider the conception of "metaphor action" that is important for the analysis of computer metaphor. This conception has formed a basis for the analysis actions of concrete interface and visualization metaphors. The analysis has to reveal criteria for evaluation of metaphors and for its searching and selecting. Computer metaphors promote the best understanding of interaction and/or visualization semantics, as well as provide visual representation of the appropriate objects and determine the user's manipulations set. A metaphor, considered as a basis of the sign system, underlies in a basis of an interactive visualization language in its turn. The understanding of a metaphor as a sign system gives us a basis for evaluations of metaphors offered in concrete cases. If the used affinity (comparison or a set of comparisons) matches the systemness requirements, then we may speak about existence of a useful metaphor. "Semiotic" approach to HCI and computer visualization theories makes it possible to choose computer metaphors as the key point of HCI and computer visualization systems design and development. Analysis of metaphors is the useful tool for this design. Also the analysis forms the set of criteria for evaluation of metaphors. One can choose a metaphor, as well as construct on its base a correct set of views for a visual interactive system. Criteria of a choice may be considered as criteria of metaphor quality.

3. Semiotical Analysis

The sign process (or semiosis) is considered on the five-term relation between a sign, its meaning, its interpretant, a context where the sign meets and, at last, a sign interpreter. The sign causes in the interpreter certain reaction or predisposition to it (interpretant) on a certain kind of object under certain conditions (in some context).

The human-computer interaction and visualization, necessarily, have a semiotic nature. The sign nature of visualization allows to reveal sign systems, determining

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interactions, visualization and communications. There are relationships between the visual representation of an object, that is, relationships between a signified (a denotatum), and a visual sign. A user or an observer (an interpreter) in determined context recognizes the idea caused by visualization that is the interpreting idea (an interpretant). There are all relations described semiosis (the process of interpreting signs or the sign process).

A set of classical semiosis “roles” in human-computer interaction should be broadened. There is another process actor - the author of the message. The author putting an idea to a message determines its meaning. This (“primary”) idea may differ from the interpretant.

We consider the “direct” semiotics analysis of visualization that reveals “who is who” in the process of the visualization semiosis. It allows to describe problems arising at developments of specialized systems in terms of the semiotics and showing how this analysis can serve as a tool for the visualization systems design.

First of all, it is necessary to pay attention to the pair “sign-denotatum”. Revealing of denotatum and a corresponding choice of a sign is the important problem of the semiotics analysis. Note, that in any concrete case of visualization there are “nonsign” aspects. Not everything is reduced to sign forming. There are some simple examples.

Suppose we need to represent the progress of a simple process. One may use the conventional technique to represent – to draw a usual 2D graph. Here the process is the denotatum, and the whole of graph is the sign. If further the task to represent the change of the progress of a process then change the direction of the graph simply and obviously indicates the change of the progress of a process. In this case the denotatum is the change of the progress of a process and the sign is the change of the graph direction (but not the whole graph as in the previous case). For more complex cases one may use the more complex (and more interesting) technique of visualization. For example – to animate the process basing on its natural imagery. But in this (animation) case one has to construct the more sophisticated and complex sign to represent the same denotatum (the change of the progress of a process)

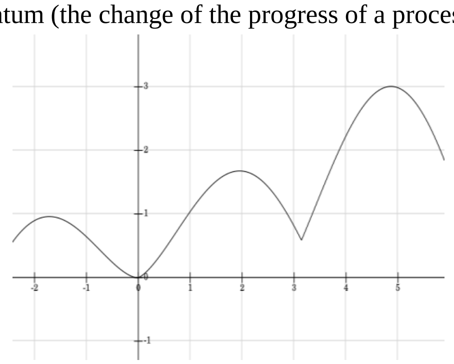

Figure 1: Sample of the plot of a function.

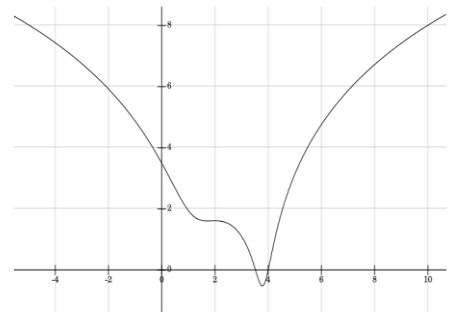

Figure 2: Changing of the direction of a process

Let’s consider the next example that is the simplification of real specialized system of scientific visualization for the model of pollution of the environment. In the beginning of the system development the task on visualization provided the real imagery of pollution and animation – the smoke from factory chimneys is diffused in the town air and the dirt from the factory tubes is diffused in the town pond. This animation may be interesting for regional authorities, factory managers and environment defenders. That is originally the process of pollution was considered as a denotatum. The realistic animation has to be the basis of sign representations. Note, that in this case the realistic animation is not too suitable to depict the process uniquely. However analysis revealed that the main problem of this mathematical and computer modeling the resided in the reconstruction of values of emission rates basing on available information. Thus the denotatum and the subject of visualization was not in the least the process of pollution of the environment but some properties of the same mathematical model. The use of an abstract imagery to visualize the model is not surprisingly. Just we used the 3D surface to depict the model. In particular isolines showing equal pollution loads are the sign for the process of pollution (Fig. 3).

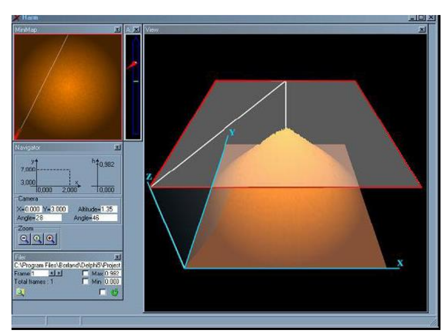

Figure 3: Visualization for modeling of environment pollution.

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Another real example is the simulation of excitative process in cardiac chambers. At once note that in this case the excitative process in cardiac chambers is the denotatum. Experts suggested the scientific metaphor to represent pathways of myocardium as the set of interconnected cells. These cells may send signals each other. The model depicts myocardium and simulates the excitative process in cardiac chambers by means of simple animations. Basing on this animation we succeeded to model such pathologies as tachycardia and extrasystoles. Simulation of one or another pathologies was carried out by means system parameterization. In particular, time intervals, corresponding to different states of the cells were succeeded (preparedness to receive/transmit; process of receive/transmit; unpreparedness to receive/transmit). The presence of pathology was depicted by types of hesitation. Really dangerous pathologies are chaotic animations. Not even the norm but stable animation is a sign out of the deadly condition. 3D model of the heart generated at the first stages of development, was rejected because, firstly, it was inadequate chosen scientific metaphor and, secondly, visual perception of 3D animation was difficult. Flat representation in this case turned out to be more accurate and winning in terms of user experience. Despite a number of restrictions, the model completely satisfied the expert requirements. In this case, the sign indicating the presence of simulated pathology, is the type of oscillation. The heart itself, which is not a matter of designation, does not need in visualization in this case (Fig.4).

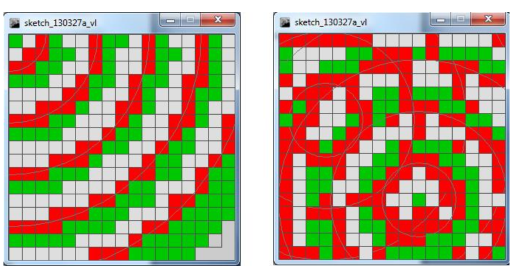

Figure 4: Normal (left) and pathological (right) variants of excitative processes in cardiac chambers.

Consider the following examples related to the algorithm visualization.

Algorithm visualization and animation systems are considered as education means but they may be used as instruments for algorithm evaluation and debugging. Let's ask a question – what is denatatum in the case of algorithm animation. It will be recalled that in the frameworks of Theory of Visualization the conception of "Algorithmic Operation" is considered. Algorithmic Operations are such operations of the algorithm that are important to understand the program's semantics. For example "Compare" and "Exchange" in a sorting algorithm [14]. That is in the case of algorithm visualization its base operations may be considered as denotatum rather than the algorithm itself. (As we know Algorithm is rather complicated conception.)

Starting in 80-ies of the twentieth century, a number of algorithm animation systems were developed. In these systems the designation was conducted by creating dynamic images that demonstrates the behavior of the algorithm. Here visual dynamic images are considered as signs.

In the "classical" systems of algorithm animation only "Exchange" operation was depicted when sorting algorithms were realized. "Compare" operation seemed as self-evident for users – observers of animation.

In 90's years we have researched some problems of representation of both operations in sorting algorithms. On our opinion the value of variable is preferable to depict by the size of bars. Whereas the color for that end may be used only in certain cases. Some approaches for visualization of "Compare" operation were suggested. For example a harpoon (or an arrow) was used for this purpose. A "harpoon" is moving up from the end of current (lower) object to compare next objects. If the "harpoon" collides with other object then it becomes lower, and the former current object goes up one step (Fig. 5).

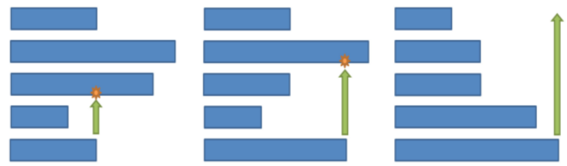

Figure 5: Animations of sorting algorithm using "harpoon" for depicting "Compare" operation.

There are also a number of other successful examples of algorithm animation systems but majority of these animations deals with sorting and graph algorithms. Sometimes systems depict and animate the process of program execution rather than algorithms.

Considered examples of revealing of a denotatum at semiotics phase of the visualization design show that answers two questions are important:

- "what are the objectives of visualization?"
- "what are the subjects of visualization?"

The answer to the second question as one may see needs the special analysis; it is not trivial but sometimes it is unknowns.

Searching methods of the denotatum representation and designation is connected with the conception of a computer metaphor.

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4. Computer Metaphors

The metaphor essence consists in interpretation and experience the phenomena of one sort in terms of the phenomena of other sort. Metaphorization is based on interaction structures of source and target domains. During 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 the metaphor can be understood as a map from source domain onto target domain, and this map is strongly structured.

Cite an example of a classical metaphor LIFE IS A JOURNEY, where LIFE is target domain, and JOURNEY is source domain. Some structures of JOURNEY (beginning, ascent, descent, end, etc.) are considered in the given metaphor as a basis for the description of life structure.

Image-schemas are image-like reasoning patterns, consisting of a small number of parts and relations, made meaningful by sensori-motor experience. There is a CONTAINER schema (things that have an inside, an outside and a boundary), a PART-WHOLE schema (something can be seen as a whole or as its constituent parts), a LINK schema (two or more things have a link between them), a SOURCE-PATH-GOAL schema (or sometimes, just a PATH, which goes from a source along a path to a destination). There is an UP-DOWN schema, a BACK-FRONT schema and so on. Schemas are gestalts - structured wholes - that structure our direct experiences. Image-schemas may in fact be the kind of structure which is preserved by computer metaphors. [8], [9]

One can define a computer metaphor (interface and/or visualization metaphor) as an operator from concepts and objects of the application domain under modeling to a system of similarities and analogies generating a *set of views* and a set of techniques for interaction with and manipulation by visual objects. Computer metaphor is considered as the basic idea of likening between interactive visual objects and model objects of the application domain. Its role is to promote the best understanding of semantics of interaction and visualization, and also to determine the visual representation of dialog objects and a set of user manipulations with them. Visualization metaphors form the basis of *views* of specialized visualization systems whose design is the important part of whole design the "human factor" aspects of these systems.

A set of requirements imposes on source and target domains during the selection of metaphors for visual interactive systems. Among them there are such as *similarity of properties of source and target domain objects; "visualizeness" (in a broad sense) of source domain; habitualness (recognizability) of its objects; rich structure of interrelationships between objects.*

The concept of habitualness and recognition in the specialized visualization systems should be connected mostly not with everyday realities, but with potential user activity in that sphere for which the interactive system is created. In general using of computer metaphors doesn't refer to exact matching of reality but conversely needs in additional "irreal" (or "magic") opportunities. "Magic" in the computer metaphor means that "metaphorical" interfaces and visualizations do not imitate prototypes from real world. The presence of "magic" attribute in a metaphor means that its target domain have properties nonexistent in the source domain. "Magic" in metaphors is closely related to the conception of intuitively usable interface. Let's cite the definition of intuitively usable systems:

A technical system is intuitively usable if the users' unconscious application of prior knowledge leads to effective interaction [10].

The "correct magic" of the interfaces and visualizations have to be based on this principle of intuitive usage. Understanding of the magic is interlinked as of cultural background of potential users as of context of using interfaces and/or visualizations. In connection with this context one should be paid attention to the requirement of the *metaphor naturalness*. There are a variety of approaches to appraisal of its role. Some authors consider as metaphor such only those where source domains have based on everyday realities. Really such metaphors, for example, *Mosaic, Information Wall, Fish Tank* gain widespread acceptance in interfaces and in information visualization systems. But no less frequently then "natural" (real life) the "quasi-natural" (habitual for a given domain) imageries are used in visualization systems. There are such examples as the techniques of molecule depictions in Chemistry or Biology. Also one may consider the visual formalisms as some kind of metaphors. Such visual formalisms as flow charts, data flows, Petri nets, etc. are actively used in diagrammatic visual programming languages. The visual formalisms have abstract imageries but these imageries are interpreted monosemanticly by users-specialists.

We consider the metaphoricalness of any visualization. In our opinion in the general case there are no "metaphorless" visualizations of computer models and program entities. The survey of the corresponding bibliography shows on "pictureness" of all metaphors and accordingly on metaphorness of any images in computer visualizations. Per se every computer visualization may be considered as a metaphor because it associates model entities and images and represents one by another for adequate user interpretation. One may show the community of metaphor design and usage in all subdomains of Computer Visualization. In the case of visualization metaphors the

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transition to some world of visualization, where imageless objects obtain their visual representations, takes place.

The process of metaphor generation (metaphorization) first of all includes (may be implicit) analysis of target domain of the future metaphor. The hierarchical structure of object interrelations of target domain and their properties is revealed on a basis of the metaphor objects and its properties. At the following stage a source domain and its main object are searched. Criteria of a choice are criteria of metaphor quality.

Firstly, the main object of a source domain should have the properties, similar (closed) to properties of metaphorization object. The structure of these object interrelations and its properties should be *similar* to structure of interrelations of object under metaphorization and its properties, at least on the first level of a structural tree. Secondly, a *source domain* should be **visualized**. *That's mean that the nature of the source domain should be like, that its objects have dimension, extent, length, form, color or other visual characteristics.* (For example - a metaphor of the railway for the functional description of operational systems.)

5. Metaphorical Domain

The goal of metaphorization consists of the expansion of expressiveness for objects under researches. Metaphorization is based on interaction structures of source and target domains. During 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. Moreover, not all objects are selected (and not even all of their properties, or structure elements), but only those that are the most interesting for us. Analogues of these objects are searched in the source domain (in frameworks of structures, the qualitative properties, etc.). Further the following operation takes place. Object of target domain together with object from source domain are located now in common "*metaphorical domain*" or more exact in doing so this "*metaphorical domain*" is generated. In this domain the investigated object now starts to function. (It is possible to consider, that it is already a new object of a new domain.) The metaphorical domain gets autonomy from domains generated it. Many properties of its objects only mediately are connected (if at all are connected) to properties of source domain objects. By means the projection of some characteristics of the target domain onto the source domain its own logic of development of metaphorical domain appears. So, for example, the use of the scientific metaphor of an electromagnetic field its intensity is studied. But it is obviously absent on a field of wheat.

There are the questions - what are nature and structure of metaphorical domain; how its generation is produced? First of all the metaphor generates some sign system, that is the integral sign set, in which existing internal relations between signs somehow map relations between designates. Our metaphorical domain as a matter of fact is a sign system. The understanding of *a metaphor as a sign system* gives us a basis for evaluations of metaphors offered in concrete cases. If the used affinity (comparison or a set of comparisons) matches the *systemness* requirements, then we may speak about existence of a useful metaphor. If not, if condition changes of source domain objects are connected with changes of target domain objects poorly, then such comparisons usage can't help us to understand an investigated situation better. See the approach to semiotic model of interface metaphor in [2].

In case of a metaphor the generation of a sign system is possible to consider as the adaptation of two metaphor operators, the basic:

"*Let A is similar to B*"

and the additional operator:

"*The following attributes /elements/characteristics of A are selected for assimilation to the following attributes /elements/characteristics of B*"

Where ***A*** is a source domain, and ***B*** is a target domain.

6. Metaphor Action and Metaphor Formula

Let's define the conception "*Metaphor Action*" to describe [potential] results of metaphor uses. This conception allows to analyze structurally specific computer metaphors. In turn the analysis is necessary to understand causes of successes of one and failures of another visualization and interface metaphors. Also the analysis of the logic of metaphor searching and choice enables to formulate evaluation criteria for "human factor" aspects of visualization systems.

The conception "*Metaphor Action*" is connected with answers to the following questions:

"How can this metaphor assist to represent the information? "

"How can this metaphor assist to interact with data or to manipulate them? "

"What properties of metaphorical objects (that is visual and/or dialogue objects generated by the metaphor) take place?"

"What actions or ideas are arisen from the process of the user interaction (including observations of pictures) with metaphorical objects?"

It is possible to construct a "formula" of metaphor actions. The metaphor "formula" includes simplified descriptions of source and target domains, an idea of likening using in the metaphor and results of metaphor actions.

Already in the description of the source and target domains those sets of objects and operations on them, which are used in the description of similarities, are partially included. Note that the computer metaphors no need to obtain the completeness and precision of similarities. Therefore, in Formula (as in a metaphor) only a limited set of required objects is described.

In the general case Metaphor Formula is as follows:

Source domain: *description* [+ *set of the objects participating in a metaforization*]

Target domain: *description* [+ *set of the objects participating in a metaforization*]

Idea of likening:

{object of Source domain_1} = {object of Target domain_1}

…

{object of Source domain_n} = {object of Target domain_n}

{operations over objects of Source domain_1} = {operations over objects of Target domain_1}

…

{operations over objects of Source domain_n} = {operations over objects of Target domain_n}

[**Magic idea**]: *the description additional, often impossible in reality, but useful properties of new objects and/or operations over them.*

[**Result**]: *the description of resultant (metaphorical) domain with a set of objects and operations over them.*

The purpose of our analysis is to reveal structures of successful metaphors and to build a basis for comparison and evaluation of metaphors. Such concepts as "metaphor action" and "metaphor formula" are considered to construct the basis of analysis. We begin our analysis with one of the most popular "Desktop" metaphor. Originally this metaphor was offered for *office automation systems*, but then it was expanded for the general case of the interface for operating systems. "Desktop" metaphor in the 90th years of the XX century became the most frequent practice. This metaphor is in many respects a basis of modern visual interfaces. The success of "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 systemacity of all activity in frameworks of visual environments based on this metaphor. "Desktop" metaphor generates the unfussy" sign system that is the base of corresponding metaphorical domain.

In the case of desktop metaphor the formula may be written as follows:

Source domain: Desk with folders containing documents (documents are structured, but folders may be disordered);

Target domain: Office automation system;

Idea of likening: "Folders with papers" = "structure of the data, a set of files";

"Opening of a folder " = "demonstration of file structures and/or files";

"Processing of documents" = "execution of functions, by means commands of the visual language".

Result: The direct access to data structures by means manipulations of icons placed on the screen; calls of some [user] predetermined functions by means a visual dialog language.

Early versions of Microsoft Windows uses the extended version of this metaphor.

Addition of source domain:

A desk is combined with control panel where starting buttons are placed.

Besides the "*magic*" idea is added: All actions within the framework of system are made by means of ***double click*** on icons.

Result: icons that can represent as data structures as programs calls.

The data structures and programs are executed the same way (as it should be in the classic von Neumann machine).

There is also one more idea - opening of new windows when program executions are begun.

One can speak about carrying out of "metaphorical" interface domain, constructed on the basis of desktop realities. But not all entities of real desktops (the source domain of the metaphor), which are richer and poorer than metaphorical objects in the same time, were equally useful in new metaphorical domain. Often icons moving on the screen are needed only for its grouping and for concrete user work convenience. Images of folders do not play a main role in users' actions with operational system and frequently they are not placed on "desktop". But the major value (not having analogues in initial area) double "click" using for program starts has obtained. Usually double "click" results in new window opening, and, in Internet-browsers case windows are opened almost in literal sense. In result we have logical commands system of visual (iconic) language, based on basic double icon "click" operation.

7. Metaphor Action and Metaphor Formula

Objects of the new metaphorical domain, the relationship between them and the possible actions in this domain have a number of properties, which we call ***metaphor properties***. As well as the analysis of metaphor action and metaphor formula we analyze the properties to consider the possibility of metaphor using for specific applications.

We'll analyze metaphor properties by the example of hierarchical sequence of natural metaphors room- building-city (landscape). These metaphors are used in a variety of information visualization and software visualization systems [1], [5], [7], [13], [15].

7.1 Room Metaphor

The room metaphor possesses the following properties:

1. *Ability to contain any objects inside itself*.
The room not only represents separate object, but also is the container for others ones.

2. *Restriction of a perception context*.
Objects inside a room are considered in a separation from "external worlds".

3. *Closeness.*
There are no any additional elements to use Room metaphor (excepting possible inner objects).

4. *Inclusion in structure*.
It is possible "to build buildings of rooms", that is to consider set of rooms. Therefore the room may be an element of construction of some complex construction.

5. *Naturalness of a metaphor.*
The room is natural metaphor, with presence of corresponding objects in the real world. This property makes intuitively understandable all above described properties. There are no additional analogies and unnatural images. Functionality and characteristics of real objects are transferred in the virtual world with only minor extended understanding.
Property of naturalness, first of all, is connected with using within the framework of "room" metaphor such basic image-schemas, as CONTAINER, UP-DOWN, BACK-FRONT. These image-schemas and other visual characteristics are the base of depiction techniques in those visualization systems, which use "room" metaphor.
As the room is the container it is natural to use as a primary way of representation the location objects into it. It is possible to consider various ways of objects locations inside a room. On the one hand information may be represented by the type (kind) of the objects without considering their location. On the other hand one can consider one-type objects and the main information will be represented by their location in the room. It is more natural to place visual objects onto "walls" of the room. (For example, in kind a picture hanged on a wall.) It is possible to use for information representation the location of 3D objects indoors. Of course one may use both methods together and also forms and colors of objects. The collection of rooms may represent a set of program classes. It is possible to observe dynamics of program execution "on the inside" by using the special form to depict kinds of program constructions. The color in the room may be determined on the base of contents of the "room-function", for example a number of classes-inheritors or a value of executed data.
One may consider a set of different types of rooms. In this case, the connection between the rooms may represent structural relationships in a complex object. In such an analysis can be applied two more features - room location in space and its position relative to the other rooms. It is also possible to provide a predetermined, strictly defined location in the room space (wall, skyscraper, etc.). However, such arrangement can represent less information about the rooms forming the structure. Dynamically change the characteristics of the room in time may be an additional source of information. It is possible to use the animation at all rooms. In addition, the animation may affect not only the change in space, but also other characteristics of the room – object colors, sizes, shapes, etc.

7.2 Building Metaphor

Building Metaphor possesses the following properties:

1. *Ability to contain any objects inside itself*.
The building is is the container for others objects. In comparison with a room metaphor, a building metaphor possesses bigger "depth". This metaphor suggests not so much the presence of some visual information objects as the presence of containers with the objects.

2. *Restriction of a perception context*.
Everything that is placed inside the building, is perceived as connected in a whole, affinitive through some characteristics.

3. *Closeness.*
Building metaphor inherits *Closeness* property of Room metaphor in the sense that in frameworks of this metaphor it isn't required external objects, however internal filling of the building is very important.

4. *Inclusion in structure*.
This property is similar to the corresponding property of Room metaphor. It is possible to construct the city including single buildings or collecting them in structures (city quarters).

5. *Presence a structure inside.*
Necessary to distinguish between the use of the Building metaphor from the multiple arbitrary structured use of Room metaphors. The building in this sense has quite fixed structure in the kind of a location of "rooms" on "floors", and also a set of variations in structure of each of floors, for example, available general "corridor" between them in Hotel metaphor, in a strict location of rooms of rather UP-DOWN neighbors, etc.

6. *Naturalness of a metaphor.*

Building also is a natural metaphor. There is the analog for it in the real world. The metaphor doesn't associate additional analogies and unnatural images.

7.3 City Metaphor and Landscape Metaphor

Consider now properties of City Metaphor and Landscape Metaphor. They are rather similar because these metaphors themselves are similar.

1. *Unlimited context.*
The user context isn't limited artificially in City Metaphor and Landscape Metaphor. As result users need additional efforts to identify an object among others. It is plus, or minus - depends on concrete realization, and also on the purposes of the visualization system which uses this metaphor. When visualization of a large volumes of data is needed, unlimited context allows to have a look-see round all picture and to allocate key places quickly.

2. *Naturalness.*
It is known that naturalness of a metaphor reduces efforts on interpretation of the resultant image. In the cases of City and Landscape metaphors except naturalness of spatial orientation, naturalness of navigation takes place also. In case of a city metaphor the method of navigation is defined by the metaphor itself.

3. *Organization of inner structure.*
Metaphors suggest the existence of an inner structure. In case of a City metaphor this structure is dictated by the metaphor itself, and it is defined rather rigidly – there are buildings, quarters, streets, districts. In Landscape metaphor a structure choice is nondedicated. In this case one may say about landscape nesting.

4. *Key elements.*
Metaphors suggest a representation of large volume of information, and in most cases this information is rather homogeneous in visual sense. Users need in key elements (*anchors*) to interpret this information. If we want to use a metaphor for revealing of specific features and/or exceptions (for example bugs in programs), these elements have to depict by easy distinguished images-*keys*.

5. *Influence of City metaphor on resultant picture.*
Unlike in the case of Landscape metaphor, the choice of City metaphor strongly limits the set of possible views..

6. *Resistance to scaling.*
These metaphors are stable in the case of increase of information volumes. Moreover, applications of City and Landscape metaphors are reasonable only in cases of large information volumes.
In fact, one can say about Urban Space metaphor as a special subtype of the Landscape metaphor, but with its own set of specific properties, such as specific internal structure, the effect on the map.

"Industrial Landscape" metaphor may be considered as a separate subtype of Landscape metaphor. Its properties are similar to properties of City metaphor, but there are no key elements. Also one can speak about partial restriction of the context (that unites it with Room metaphor). Furthermore, it is possible to "load" its elements of meanings, related, for example, with developing of a program "products".
In the cases of City and Industrial Landscape metaphor of the an, existence of *transport corridors* helps to project software visualization systems. Transport corridors may be used as means to represent *control flows*, *data flows*, and other relations between program constructions or parts of program complex.

8. Context, Interpreter and Interpretant

According to semiosis a metaphor defines techniques of designation and an imagery of visualization. Also a metaphor defines a *context of interpretation*. Interpretation of visualization (and also interactive manipulations) based on given metaphor reconstructs (or creates anew) a set of user's cognitive structures in which the picture of the phenomena is represented. A process of interpretation is exactly the generation of representative cognitive structures on base of visual images. This process is inverse or more exactly dual to visualizations.
Process of visualization, in turn, is considered as construction of visual (geometrical) images on the basis of abstract representations of objects. These abstract representations are the model of objects under researches, the phenomenon, or the process, somehow connected with the user's cognitive structures that describe these entities.
The context is defined as a metaphor, and an individual of the *interpreter*. The interpreting context defined by the metaphor is revealed in the individual of the user of visual systems – the interpreter of the sign visualization process. The answer to a question "who is the interpreter of visual texts?" defines that part of a context which depends on the interpreter. Against this background user modeling is very important. One can consider user models of various levels, for example, the general model of visual perception, or by contrast the concrete model of user manipulations with the concrete input device.
Now the research domain of User Modeling is "under construction". For obvious reasons, researches related to modeling of users of mass interfaces (such as educational or informational systems, e-shopping, social network sites) are carried out most actively. Also there are interesting researches on modeling users of specialized visualization systems, for example, systems based on virtual reality environments.

As already noted, the meaning of “visual texts” implied by a developer of the visualization system (an author of the text) can be significantly different from the meaning obtained by an user of visualization systems (an *interpreter* of the text). Thus, in many cases it is impossible to determine accurately the content of *interpretant* in computer visualization systems.

For the design of visualization systems it is necessary to consider possibility of meaning distortion, appearance of “descriptive artifacts”, partial or full misunderstanding of senses implied in visual texts. Development of the user model and its analysis have to help with an explanation of similar negative occurrences, or (better) have to prevent them.

On the other hand there is possibility of some positive occurrences connected with partial determinancy of *interpretant.* These situations are frequent at the first stage of development of some specialized visualization systems when there are not understood fully the algorithms and methods to implement them, and often there are not clearly defined the mathematical models themselves.

The successful metaphor, well designed and developed views of one or another scientific abstractions often allow the user who really understands an essence of the phenomena under researching, to find more valuable meanings, more than interpreted information in the resulted picture, than the designer of visualization supposes.

Thus, indeterminacy or partial determinancy of interpretant (if to consider it from the designer point of view) can occur in those cases of computer modeling, when a new, hitherto unknown knowledge about a given application domain are gained.

9. Design of Visualization

In summary let’s describe our approach to the semiotics design of visualization systems.

Design of visualization itself is the part of the process of the development of specialized visualization systems. This process includes among other such stages as search/choice/designing of visualization metaphors. The next stage is the design *views*, based on these metaphors. (We define a *view* as the abstraction of a graphic display, containing specification of visual objects, their attributes, their interpositions, possible dynamics and ways of interaction.)

After determination “*who is who*” in visualization in terms of semiosis let's translate resulting scheme of semiotics analysis into the language of visualization design for specialized visualization systems.

The first point of our scheme concerns the recognition of denotatum (designatum) in semiosis. For the scheme of design of visualization systems this point corresponds to such questions as “*what is the goals of visualization?*” and “*what is the subject of visualization?*”. Thus, the definition of denotatum is related in the process of visualization to the definition of the objects of special interest, their states, features and specifications, as well as moments of transition from one state to another. Note that the same set of model objects can be visualized in a few views by different methods.

The next point is associated with the search for methods of signification for the denotatum, that is, with the choice of sign.

For the design of visualization systems it is important to understand that whole graphical display (a picture) rarely appears as a sign. It is necessary to determine which elements of the image should (and can!) be recognized, understood and interpreted by the user specifically as such.

It is known that the choice of imagery for the view is primarily dependent on the visualization metaphor. Moreover, the metaphor sets the context of interpretation. The context does not exist by itself. In principle it is subjective, as it bases on the senses of the interpreter. In this regard, let’s make one more remark. Signs (or more exactly the text) are interpreted only by those who can do it, who has the necessary knowledge. (For example, a hunter “reads” animal tracks in the snow forest clearing and reconstructs exactly the events what happened there. And an inexperienced person can not do it.) Hence another important question in the design of visualization stage is the following – “*Who is the interpreter of visual texts”, what experiences and what knowledge he has?*”.

As already mentioned, there is another important (if not the most important) actor of the design process - the author of visual text (that is, the designer of visualization). She/he should have knowledge of the application domain, allowing precise identification of the main objects of interest to be visualized, and understand what type they are. However there is an example of the visualization environment which may independently choose by certain criteria a way of visual representation from a set of the available ones. This environment should be belonging to the class of cognitive visualization systems. Here the current author of the visual text is the computer program therefore it is difficult to say about the presence of some primary, pre-embedded sense put in the visual text. In the meantime a user of this system does successfully the analysis and interpretation of pictures, getting new (hitherto unknown information) from presenting graphical displays. Note once again, that the problem of the source of the interpretant in the visualization process is still not fully explored.

Due to the projection on the process of visualization design the scheme of semiotic analysis is a useful tool for the design of visualization systems of various types. It was successfully demonstrated their ability to create new visualization techniques.

10. Conclusion

Semiotics approach to the description of visualization doesn't isolate us from other approaches. On the contrary, the fact that signs have to be recognized, understood and interpreted, requires the researches of the perception of signs and their recognition among the other elements of the pictures. These issues are studied in the framework of Gestalt psychology. There are the well-known publications on Gestalt design of human-computer interaction and visualization. However, their results are not always taken into consideration by system designers.

Consideration of computer visualization and visual human-computer interface in terms of visual communications is another source of analysis techniques and experience. The analysis of visual communication may be also performed from a perspective of semiotics.

It is very significant the problem of formalizing the visualization theory. There are different approaches to the formalization basing as on semiotic as mathematical analysis methods. This is a one of further directions of our researches.

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