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Searching and Analysis of Interface and Visualization Metaphors

Vladimir L. Averbukh, Mihkail O. Bakhterev, Aleksandr Yu. Baydalin
Institute of Mathematics and Mechanics, Inst. of Math. and Mech., Inst. of Math. and Mech.
Dmitriy Yu. Gorbashevskiy, Damir R. Ismagilov, Alexey Yu. Kazantsev
Inst. of Math. and Mech., Ural State Univercity, Inst. of Math. and Mech.
Polina V. Nebogatikova, Anna V. Popova, Pavel A. Vasev
Ural State Univercity, Ural State Univercity, Inst. of Math. and Mech.
Russia (all)

1. Introduction

This chapter is devoted to problems of interface and visualization metaphors. Really the subject-matter of metaphor is popular in modern literature on HCI and visualization. One can find hundreds interesting articles, books, technical reports and thesises on metaphors in computing. The metaphor matter is discussed regularly at workshops and seminars. The success of metaphors is apparent, all the more a well-known Desktop metaphor, which is widely used on millions and millions computers all over the world. One source of the theory of computer metaphors is classical theory of metaphor, especially the cognitive approach advanced by G. Lakoff and his colleagues. Also the sign nature of the human-computer interface and visualization allows using semiotics in the theory of computer metaphor.

Our interest in theoretical problems of a metaphor is connected with our main goal - to design specialized interactive visual systems as well as quickly. The goals of our researches are to draw up design criteria for “good” human-computer interface and “effective” visualization on the one hand and recommendations for developers of visual systems on the other hand. Our approaches are connected with our experience of design and development of specialized visualization systems including systems of scientific, informational and software visualization. The specialized systems support the decision of certain class of problems by the certain class of users (mathematicians, physicians, sociologists, etc.). Specificity of such systems frequently demands new methods of visualization and interaction that are adequate to the given task and concrete (possibly narrow) user or class of users. The practice of design and development of specialized visualization systems shows necessity of specific metaphors, and a stage of metaphor searching and designing is a part of development process. During design and development process of such systems the following aspects are distinguished:

- Computer Graphics means and means of Human-Computer Interface organization;
- Software Engineering;

- Cognitive aspects.

We consider cognitive aspects of system engineering. Cognitive aspects are the most independent from technology. There are a lot of examples, when failures with “cognitive” components of projects bring to nothing all successes and achievements in computer graphics and software engineering of projects. In connection with this we are interested in language aspects of visualization and human-computer interaction. Metaphor is considered as the source of this language, a basis of representation of visual and dialogue objects and methods of interaction with these objects. We need to search and choose “good” metaphors for specialized systems. We aim to understand how metaphors are constructed, how they work and how users interpret them. The theory of computer metaphor serves to evaluate existing visual interactive systems and to predict properties of new systems at designing stage. However in practice, there are problems both with concrete metaphor searching and with evaluation of their suitability for the given problem and user group.

Below some points of the metaphor theory are considered in connection with computer metaphors. The theory of interface and visualization metaphor is supplemented and defined more exactly. The structural analysis of concrete metaphors is carried out. Bases of the analysis are the concepts of “metaphor action” and “metaphor formula”, as well as realizing the logic of metaphor choices and generations. This analysis is necessary to understand the reasons of successes of one and failures of other visualization and visual interface metaphors. In turn, it allows formulating criteria of evaluating of cognitive components of visual systems.

2. Metaphors in HCI

Above we have noted, that the theory of interface and visualization metaphor is based both on the theory of a classical metaphor on semiotics. A lot of researches are devoted to the formal description of the computer metaphor theory and to studying of interface metaphors from these positions. Now concept of metaphor is widely used for the description of concrete decisions in interactive visual systems. We have gathered near two hundreds books, articles, dissertations and technical reports on problematic of computer metaphor. Our literature sources (of course not full) can be subdivided as follows:

- general works on metaphor and semiotics;
- works on theory of interface metaphor;
- works describing the concrete systems but containing issues on metaphor theory;
- works describing the concrete systems and using the elements of metaphor theory;
- works describing the concrete systems where only the concept of metaphor is used;
- works containing the criticism of computer metaphors.

Among these works there are our researches on visualization metaphor theory as well as our specialized visualization systems where the concept of visualization metaphor using for design and development.

Studying of this literature on problems of a computer metaphor allows drawing some conclusions. One of them - the certain consensus on the computer metaphor theory takes place. First of all this consensus consists of the recognition in *cognitive* ***approach*** to metaphor theory as the base of theory of interface metaphor. (This approach is linked with names G. Lakoff and his colleagues (Lakoff & Johnson, 1980), (Lakoff, 1993)).) The cognitive approach to a metaphor considers a metaphor as the basic mental operation, as a way of cognition, structuring and explanation of the world. 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.

Secondly, Peircean semiotics is applied to user-interface metaphor (Barr et al, 2004). (Note in this connection the researches on visual semiotics and semiotics of HCI such authors as P. Andersen, J. Goguen, M. Nadin, C. de Souza (Andersen, 2001), (Goguen, 2004.), (Nadin, 1997), (de Souza, 2005.)

Some other approaches to forming of interface metaphor theory are mentioned. Among them - M. Black's *interactive* model (see, for example, (Gardenfors 1996) and (Blackwell, 2006)) and T. Kuhn's theory of scientific metaphor (see, for example, (Harrison et al 2007), (Travers, 1996)). There is also the consideration of games as a metaphor for interface systems (Stathis & Sergot, 1996). But just Lakoff's and Peirce's approaches are prevailed in forming of interface metaphor theory. The other approaches to describing of interface metaphors are less common.

Now let's copy out the main (or may be more typical and popular) positions of existing interface metaphor theory:

1) A metaphor is a rhetoric figure, whose essence is understanding and experiencing one kind of things in terms of another (Lakoff&Johnson, 1980).

2) M. Johnson defined metaphor as a pervasive mode of understanding by which we project patterns from one domain of experience in order to structure another domain of a different kind. (Johnson,1987).

3) The two domains are commonly called the source and target domains of a metaphor and the metaphorical projection is a mapping from source to target. The target consists of the concepts the words are actually referring to (also said the original idea). The source refers to the concepts in terms of which the intended target concepts are being viewed (the borrowed idea). Conventional metaphors are represented as sets of associations, or relations, between source and target concepts. Source and target concepts usually belong to different domains, and the familiarity with the source domain is exploited to understand the target concepts. The metaphor specifies how the source concepts reflected in the surface language correspond to the various target concepts. It establishes an isomorphism between the target and source domains. Interface metaphors, in this projective view, go beyond explaining unfamiliar domains to novices. They determine how labor is distributed between a user and a system, what concepts a user has to deal with, and in what terms user and system communicate. In short, they structure application domains and organize tasks. (Kuhn W. & Frank A.U., 1991), (Catarci et al, 1996).

4) A metaphor is a device for explaining some concept or thing, ***x***, by asserting its similarity to another concept or thing, ***y***, in the form ***X IS Y***.

The concept being explained is often referred to as the tenor of the metaphor, while the concept doing the explaining is called the vehicle. (Barr et al., 2004)

A typical definition of metaphors might run like this:

Given two domains A and B, taking A as metaphor for B is equivalent to providing a formal mapping from the primitives defining A into the primitives defining B.

Such definition makes the metaphor question a question about representational formats, structural primitives, and the properties of formal mappings. From the standpoint of cognitive “process” these analyses reduce metaphor to primitive pattern matching operations defined over the elements and relations of structural descriptions (Carroll J. & Mack R., 1985) Structure-mapping analysis of metaphor interprets metaphor as mapping between two (graph theoretical expressed) domains, pairing the nodes of each. The relations of these two domains are constrained to be identical (Gentner, D. 1983).

User-interface metaphor is intuitively the application of this device to the user-interface. Thus, a user-interface metaphor is a device for explaining some system functionality or structure (the tenor) by asserting its similarity to another concept or thing already familiar to the user (the vehicle). The key here is that the chosen vehicle is something already familiar to the user and so the intention is to provide a base level of comfort and knowledge without necessarily understanding the underlying system (Barr et al., 2004).

5) For Peirce the sign is a genuine triadic relationship among the elements: the representamen, the object and the interpretant. The representamen refers to the material aspect of the sign and represents the object under certain aspects or “capacities”. The sign only means so because the representamen can represent another thing: the object. The interpretant doesn't refer to the interpreter of the sign but it refers to a relational process occurring in the interpreter's mind, associating representamen and object (de Oliveira & Baranauskas 1998).

The interface is defined as a collection of computer-based signs, i.e., the software parts which can be seen or heard, used and interpreted by a community of users (Andersen, P. B. 1997).

The use of semiotics will help to resolve how the metaphor functions or what the metaphor really means.

A metaphor sign involves the interaction in some way of two signs, which are the tenor and the vehicle of the metaphor. The stance we take in this paper is that a metaphor may well be composed of two signs, but can plausibly be treated as a sign in itself as well. Essentially, the meaning of the metaphor intended by its author comprises the object, while the expression of the metaphor itself, usually in language, forms the representamen. An encounter with the representamen leads a reader to form an interpretant, which is what the metaphor is taken to mean by them. (Barr et al, 2004)

5) A metaphor gives the possibility to understand new and complex concepts by means of more familiar (i.e. well-known) ones. This feature has been exploited in the interfaces of several computer systems (Marcello L'Abbate & Matthias Hemmje, 1998)

6) The process of applying our experiences on things that are new to us is called “mapping”. Analogy is the most obvious kind of mapping… Metaphors are mappings from source to target domains… Metaphor is the most complex kind of mapping, where the two structures - or concepts - being compared actually explains each other. (Kuhn W. & Frank A.U., 1991), (Olle Torgny 1997) A conceptual metaphor is a set of mappings from a relatively concrete domain to a more abstract domain. Through these mappings, the more abstract domain is more readily understood. (David G. Hendry, 2006). When the domains are specified algebraically, it is natural to use morphisms, which are mappings between algebras, to define metaphorical mappings . (Kuhn W. & Frank A.U., 1991)

7) 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 interface metaphors. This assumption agrees with Lakoff's invariance hypothesis which claims that image-schemas remain invariant under metaphorical mappings (Kuhn W. & Frank A.U., 1991), (Benyon & Imaz, 1999).

8) The best known formal theory of metaphor and analogy is Gentner's structure mapping theory (Gentner, D. 1983), (Gentner, D. 1989). It describes analogies as mappings between source and target domains, each represented by semantic networks. It does not formalize the mappings themselves, however, and rests on a syntactical distinction of different kinds of relations. While Gentner's theory deals with structural aspects, it neglects the role of tasks in metaphor use. Our formalization addresses these problems by formalizing mappings as morphisms and expressing tasks and actions through algebraic operators and their effects. Describing domains algebraically rather than relationally may only be a syntactic difference; it does, however, allow for relating metaphors to task mappings .

If an image-schema is invariant in a metaphorical mapping, it must be a common part of the source and target domains. It is therefore possible to obtain the algebraic specifications of these domains by extending a common core specification which formalizes an image-schema. Such a process of adding operators to algebraic specifications is called an enrichment. Thus, a formal version of Lakoff's invariance hypothesis is:

For any metaphor, there is an algebraic specification which describes an image-schema or a combination of image-schemas and which can be enriched toward specifications of the source and target domains.

Since an algebraic specification describes a class of algebras or category, image-schemas are formalized as categories. These categories contain the algebras of the source and target domains as well as the morphisms between them . (Kuhn W. & Frank A.U., 1991).

The common perception of the word "formalization" is connected with the derivation of some formulas and equations that describe the phenomenon in analytical form. In this case, formalization is used to describe a series of steps that ensure the correctness of the development of the representation of the metaphor. Metaphor formalization in the design of semantic visualization schemes includes the following basic steps:

- *Identification of the source and target spaces of the metaphor* - the class of forms and the class of features or functions that these forms will represent;

- *Conceptual decomposition of the source and target spaces* produces the set of concepts that describe both sides of the metaphor mapping. As a rule, metaphorical mappings do not occur isolated from one another. They are sometimes organized in hierarchical structures, in which `lower' mappings in the hierarchy inherit the structures of the `higher' mappings. In other words, this means that visualization schemes, which use metaphor are expected to preserve the hierarchical structures of the data that they display. …these are the geometric characteristics of the forms from the source space, and other form attributes like colors, line thickness, shading, etc. and the set of functions and features in the target space associated with these attributes and variations;

- *Identifying the dimensions of the metaphor* along which the metaphor operates. These dimensions constitute the common semantics. …this can be for instance key properties of the form, like symmetry and balance with respect to the center of gravity, that transfer semantics to the corresponding functional elements in the target domain;
- *Establishing semantic links, relations and transformations* between the concepts in both spaces, creating a resemblance between the forms in the source domain and the functions in the target domain. (Simoff 2001)

Formalization by itself, however, is not enough to arrive at useful theories. Concentrating on the mathematical aspects of a theory underlying an implementation can lead designers to neglect usability aspects of the resulting system and can produce undesirable effects at the user interface. Theoretical refinements sometimes burden the users with an additional load of concepts they have to master if they want to use a system effectively. Depending on the tasks and users, some concepts of a formal theory may be completely irrelevant or even unintelligible to users mappings (Werner Kuhn, 1993).

9) The structural formulation of what metaphor is allows us to define many further concepts regarding metaphor relations. [It is defined] a variety of such relations: base specificity, clarity, richness, abstractness, systematicity, validity, exhaustiveness, transparency, and scope.

"Base specificity" is defined as the extent to which the structure of the metaphor base, or source, is understood.

"Clarity" refers to the precision of the node correspondences across the mapping.

"Richness" is the density of predicates carried across the mapping.

"Abstractness" refers to the level at which the relations carried across the mapping are defined. If they are the individual predicates of the base, the mapping is less abstract than if they are relations among predicates in the base.

"Systematicity". Metaphors are "systematic" to the extent that the mapped relations are mutually constrained by membership in some structure of relations.

"Validity". Metaphors are "valid" to the extent that the base relations carry their truth values across the mapping.

"Exhaustiveness. "Base exhaustive" metaphor map each of their relations into target ("target exhaustive" metaphor are defined analogously).

"Transparency". Metaphors are "transparent" to the extent that it is obvious which relations in the base are able to be carried into the target.

"Scope" refers to the extensibility of the mapping.

(Carroll J. & Mack R., 1985)

10) The success of a metaphor depends on having a familiar domain to analogize from and on recognizing enough in the new domain so that some correspondence can be established.

Structural descriptions of corresponding domains in a comparison relation provide only an abstract set of possible mappings. The actual relevance of any of these mappings to a real and usable metaphor depends fundamentally on the needs and goals of the [user]. Put another way, we need to understand the pragmatics of the [given] situation. (Carroll J. & Mack R., 1985)

11) How can we Find Metaphor Candidates? Everybody asks this question and only few researchers or designers have proposed generalizable methods to come up with useful interface metaphors. Can there be systematic approaches to generating metaphors at all? Isn't a good metaphor the result of a strike of creative thought which cannot be planned?

Clearly, much more can be done in a systematic way than what has been done in this area so far. Metaphors do not fall out of the blue sky. If they should be appropriate for a certain user community in a certain application area, they must have source domains which are meaningful to these people in their work environment. Such meaningful concepts are certain to appear in the language of prospective users, in their work regulations, documentation of existing technology, and many other manifestations of how these people think and act when they do their work. Finding metaphor candidates, therefore, means listening to users, observing their work and behavior, and reading their instructions and regulations. We have all become skeptical, with good reason, about clever ideas of interface designers for fancy metaphors, commands, and icons which are generated late at night while playing around with the latest interface design tool kit. They tend to disappear as fast as they were created. Useful metaphors are the work of design teams which have studied the work flow, tools, language and general culture of users over months or years. Seen in this way, finding metaphor candidates is a central part of task analysis. It can indeed be argued that the selection of metaphors constitutes the essence of task analysis, explaining why there is often much more synthesis than analysis involved in this process. Choosing a metaphor means deciding on the ontology of the user interface, i.e., on the concepts which users will have to master, the objects and operations they get to see, and the work distribution between them and the system. The more complex an application area is, the more time this process will take. A good example is, again, the much discussed desktop metaphor. It took years of very careful analysis and synthesis of work processes, based on detailed observations in actual office work environments, until the design of the Star interface was completed. Then, it took another couple of iterations to make it usable in practice (Kuhn W., 1995).

12) An account of the mechanisms of metaphorical understanding would tell us why one or more metaphors are useful and how they are generated and then used to support [interface]. What Makes a Metaphor Good or Bad? Once metaphor candidates have been found, an engineering design approach requires some kind of evaluation method to be able to select the best candidate among them. In practice, there often seems to be an "obvious" choice and a designer may feel compelled to use it without investigating alternatives. There are some plausible criteria to separate better from worse metaphors in a given context. Starting with qualities which make a metaphor "good" for an application, the first and decisive feature has to be its understandability. If a metaphor is not understandable to the users, it is really no metaphor at all, as its source domain should by definition be familiar. Understandability is not only a matter of the source concepts, however, but also of how these are presented to the users. A second, more subtle criterion is that a metaphor should create a useful ontology for the user's tasks. The ontology of a user interface is the collection of concepts which a user has to master in order to use the system productively. Another way to evaluate interface metaphors is by the suitability of the work distribution that they impose. If a metaphor satisfies these three criteria, it may still be "bad" for a user interface, if it has some undesirable properties. Among them are incomplete mappings from source to target domains. This means that there are either salient source concepts which the user expects to find, but are missing from the interface, or there are abstract user interface concepts not matched to appropriate parts of the source domain. The latter problem is fairly common in practice, confronting the user with a bewildering mix of metaphorical concepts and computer jargon. A second slippery slope is mixing metaphors. From our use of natural

language, we have a fairly good intuition about the possibilities and limitations of mixing metaphors. Simply applying this common sense to the evaluation of metaphor combinations in a user interface would already take care of many problems in existing interfaces. (Werner Kuhn 1995).

Also there are some important and concepts used in the theory of interface (and visualization) metaphor. Among them there are concepts of mental spaces and a mental model.

Mental spaces

Mental spaces provide a medium in which cognitive activities can take place. Cognitive models created through imaginative processes structure those spaces. We think by connecting different mental spaces. So for example, we may have a space that structures our experienced reality, another that is structuring future situations, another fictional situations and so on.

The concept of mental space refers to the partial cognitive structures that emerge when we think and talk. It is in these mental spaces that domains are defined, altered and merged. There is a source mental space, a target mental space and connectors that map elements from both spaces. However, the concepts of mental spaces and connectors apply to more general situations, involving more than two spaces (Benyon & Imaz, 1999).

A mental model

A mental model is a cognitive construct that describes a person's understanding of a particular content domain in the world. This contrasts sharply with much other work in cognitive psychology, which attempts to be domain-independent (Plantings, 1987).

There are three elements that work together in the interface. Two mental models: the user's model, the designer's model and finally the system image. One of the paramount interests next to usability testing of HCI is to improve the design of interfaces in first place. Therefore it is a proven good idea to use prescriptive mental models, so called conceptual models, throughout the design. The design goal is to reach as much as possible congruence of all the mental models (Weidmann, 2004).

The visual metaphor is seen as a transformation between abstract and visual information. In that case, the abstract information is the database schema. Therefore, the main elements of the formalisms are:

1) A data model that captures schemata,
2) A visual model that captures visualizations, and
3) A visual metaphor that is a mapping between data and visual models (Catarci et al, 1996).

Thus, the harmonious enough theory of the interface metaphor takes place, including (alongside with other elements) definitions of basic concepts, the description of metaphor formalization on base of semiotics and algebraic approaches, criterion of "good" metaphors and principles of their choice.

For the practice of applications of the interface and of visualization metaphors there is the following situation. The metaphor is considered in less strict manner, as some basic idea of bridging the gap between different areas (even if strict definitions also take place). Instead of precise metaphor evaluation criteria heuristic approaches are used. Here are rather typical examples of using the metaphor conception in papers on HCI and/or visualization:

i) The mapping from a program model (lower level of abstraction) to an image (higher level of abstraction) is defined through a metaphor, specifying the type of visualization. Most

visualization techniques and tools are based on the graph metaphor (including the extensive research on graph layout algorithms). Other initiatives are the representation of programs as 3D city notations, solar systems, video games, nested boxes, 3D Space, Software World, etc. (Panas et al, 2003a), (Knight & Munro 2000). With the help of the metaphor, different views on the program representations are provided. These views are finally illustrated as one picture and can be interactively (Panas et al, 2003b).
ii) The Magic Mirror is a user interface technique that mimics a hand mirror. In addition to providing the optical effect of a real mirror, several non-physical extensions are also proposed. As a metaphor, the Magic Mirror is an intuitive and easy to learn interaction technique (Grosjean & Coquillart 1999).
iii) Our classification distinguishes between two basic structural metaphors differing in terms of the mental model being generated. First the theater metaphor, where the user has a static position and viewpoint and the world around changes. Second the locomotion metaphor, where the user has a dynamic position and will be moved through a structure.
Theater Metaphor
This metaphor resembles typical WIMP interfaces, since the user's viewpoint remains constant. In analogy to a stage portal this is symbolized through a static frame of reference. The 3Ddocument mainly stays in the center of interest. It does not necessarily have to remain in the field of view, but can also exit and reappear like a real actor. Whenever changing action spaces the "set" (i.e. 3D-widgets, displays, decorative elements...) changes, too.
Locomotion Metaphor
The user's viewpoint changes with this metaphor, made visible by a dynamic visual frame of reference (e.g. different rooms or floors). The rooms or action spaces are completely changed along with their interface elements. In some cases 3D-widgets can be shared with other action spaces. 3D-document of the application might remain in the last visited action space or can be taken to the next space. The locomotion metaphor is most suitable for applications consisting of various action spaces with simpler associated sub-tasks (Dachselt 2000).
iv) Roles of variables, which describe stereotypic usages of variables, can be exploited to facilitate teaching introductory programming. This paper describes the evaluation of visual metaphors for roles used in a role-based program animator. The evaluation is based on several criteria: properties of the images, metaphor recognition and grading, and effects on learning. The study demonstrates that as a whole the role metaphors facilitate learning. The results also identify ideas for further elaboration of the individual metaphors. Furthermore, the study suggests that the evaluation of animated metaphors may require special measures (Stutzle & Sajaniemi, 2005).
v) We interpret the rules governing an interactive system as the rules specifying a game. Under this metaphor, interactions made by the participants of an interactive system are interpreted as moves selected by the players of a game (Stathis & Sergot, 1996)
vi) We present WeatherTank, a tangible interface that looks like a vivarium or a diorama, and uses everyday weather metaphors to present information from a variety of domains, e.g., "a storm is brewing" for increasingly stormy weather, indicating upcoming hectic activities in the stock exchange market. WeatherTank represents such wellknown weather metaphors with real wind, clouds, waves, and rain, allowing users to not only see, but also feel information, taking advantage of our skills developed through our lifetimes of physical

world interaction. Metaphors-concrete images that illuminate abstract ideas - are common in user interface design. We propose to use the rich and well-understood natural phenomena of weather as metaphors to represent abstract information from other domains. Many people, irrespective of educational level, literacy, and profession, understand weather metaphors intuitively (Marti et al 2001).

Here are only the small part of hundreds works where the concept of metaphor is used. In our list we can't embrace all cases of computer metaphor using. Beyond our theme there is such interesting application of computer metaphor as system metaphor (or design metaphor) in software projects (especially in "Extreme Programming") (Khaled et al, 2004), (Stubblefield, 1998).

One can recognize that the certain discrepancy between theory and practice takes place. For example, in practice there are no distinctions between metaphors and metonymies (and even between analogies and metaphors) when using in HCI and visualization. Instead of the criteria of metaphor "goodness" designers use the insight when find and/or choose metaphors for their systems. Note, by the way, that some of positions in the interface metaphor theory are based on the general theory of analogy and some of criteria are applicable to every type of mapping but not just to metaphors much less to interface and/or visualization metaphors. On our opinion that is why some of criteria such as precision or completeness of metaphor are redundant. We need to study these metaphors as original phenomenon and to reveal their original characteristics. As in beginning of 90-th we again need to answer such questions as "what are user interface metaphors", "how can we find metaphor candidates", "what makes a metaphor good or bad", etc. (Kuhn, W., 1995). It means we need to supplement the theory of interface and visualization metaphor and to define it more exactly.

Below we'll describe our approach to the of computer metaphor theory.

3. The Theory of Computer Metaphor

In this section our approach to Computer Metaphors (mainly interface metaphors and visualization metaphors) are considered. We try to increase existing approaches and to construct new bases for criteria of metaphor choice and search.

Our main goal is to design "good" interaction visual systems and in this connection we are interested in the problems of a representation of model objects as well as recognition of visual objects and manipulations them.

As it has been noted above, the semiotics is one of the bases of both HCI theory and computer visualization theory (Andersen, 2001), (Goguen, 2004.), (Nadin, 1997). It is obvious that human-computer interface and visualization have the sign and language nature. Each interface and visualization system contains the language as its core. The language 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 is built upon some basic idea of similarities between application domain entities with visual and dialog objects, i.e., upon a *computer metaphor*. (We use the broad meaning of "metaphor" concept, not dividing it onto analogy or metonymy as it is usually used in practice of interface and visualization design.)

One can consider *mapping* a computer model of the entity under study into some visual representation based on the *mental model* of this entity in the mind of the user and/or the developer of this visualization system. Also let us consider the conception of *model entity*, i.e., an object of the computer model to be studied, an object whose state and behavior, characteristics, attributes, and features are of interest to the researcher and, hence, are to be mapped (visualized).

The sign nature of the human-computer interface and visualization allows reveal sign systems, determining interactions, visualization and communications. (A *sign system* can be defined as a set of signs together with internal relationships among signs corresponding, in one way or another, to the relationships among denotations.) In these cases relations between object of representation (denotate) and visual sign are easily separated. Defining some context the user or the observer (interpreter) recognizes the idea caused by visualization that is the interpreting idea (interpretant). There are all relations described of *semiosis* (the process of interpreting signs or *sign process*).

The visual interface uses regularly the language based on one or other sign system. 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. Interpretation of an individual visual situation, which is outside of some context (as it has been made in some works, for example (Roberts, 2000), (Barr et al., 2004)), is problematic. It is more productive to consider interfaces and visualizations as sign systems. That is to choose a metaphor means to choose a sign system that will be used to define the dialog language of interaction and/or visualization.

Let's 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. It is possible to consider a view as standard or ad hoc techniques of visual data presentation, some kind of, visual procedures, which after realization in concrete visual environments and, after substitution of the real data is output on some graphic devices. In such "procedure" (that is the view) possible changes of images, including animation, and allowable ways of interactions with a picture can be provided. Changes of significant and meaning pictures during possible interaction with the image are here the external side of visualization. These pictures (concrete graphical displays) are a realization of an abstract concept of a view. For example, Cartesian ("precomputer") data visualization metaphor generates a function graph as the view. In turn after substitution of the data (x and y coordinates) the real curves on a plane are displayed.

The set of the given system views can be considered as a vocabulary of some visual (or visualization in case of computer visualization systems) language, whereas as grammar it is possible to consider rules of formation the concrete displays and specifying a sequence of image changes. Thus, it is realized with reasonable facility a separation of language elements. Semiotics analysis of the visual (visualization) language requires correct revealing of its spatial syntax and semantics. But it is especially important the description of true visualization languages pragmatics. The problem of pragmatics is tightly related to the fact that perception of the visual text is subjective and is dependent on cultural, psychological, and even physiological factors.

Interface metaphor is considered as the basic idea of likening between interactive objects and model objects of the application domain. Its role is to promote the best understanding of semantics of interaction, and also to determine the visual representation of dialog objects and a set of user manipulations with them.

Specificity of visualization, as independent discipline in frameworks of Computer Sciences, demands the distinction between visualization metaphors and interface metaphors. The concept of visualization metaphor is defined for generalization of metaphor using cases in all domains of Computer Visualization.

Visualization metaphor is considered as a map establishing the correspondence between concepts and objects of the application domain under modeling and a system of some similarities and analogies. This map generates a set of views and a set of methods for communication with visual objects. We consider the metaphoricalness of any visualization. *(In our opinion there are no "metaphorless" visualizations of computer models and program entities (*Averbukh 2001)
Thus, one can define a computer metaphor as a mapping 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.

In terms of semiotics the metaphor is something dynamic, in contrast to a stable sign. We can describe a metaphor as the act or the process of a designation of one concept by means of a sign, traditionally connected to other concept.
Another function of a metaphor is to determine the context for a correct interpretation of language elements, and to reveal the sense of *visual texts*. Thus, interface and visualization metaphors provide understanding represented entities of the application domain, and also metaphors help to create new entities based on the internal metaphor logic.
The conception of metaphor dominating at the moment is based on representing phenomena that are new or rather untypical for the user by means of phenomena familiar from everyday life; the latter phenomena must possess the same main properties as the phenomena they explain (Tscheligi & Musil 1994). Thereby constraints of metaphor habitualness and completeness are brought forth (Richards et al, 1994). Certainly, the appeal to ordinary human experience and interest activization while using habitual analogies facilitates understanding and learning of basic moments of the source phenomenon or process. But practice of the use of visual interface metaphors gives examples of habitual and full metaphors in which designer has achieved scrupulous conformity between entities of source and target domains and excellent recognition of almost all metaphorical objects. However, these metaphors may appear practically useless because of their bulkiness or occurrences additional and undesirable analogies connected to ordinary things. On the other hand there is a set of examples obviously incomplete, but fruitful metaphors.
So when does the metaphor work well? Examples show, that not only in that case when familiar concepts and images are used. Here it is possible the occurrence of additional, "parasitic" senses. Users may connect these senses with real concepts and images harmful to interpretation. Requirement of completeness of mapping from source domain onto target domain also may not always be suitable. Metaphors are successful, when their usages reduce the complete abstractiveness of computer modeling, including the abstractiveness of user interface with the system. Interpretation of visualization and the interactive manipulations constructed on the basis of the given metaphor, reconstructs (or creates anew) for users some mental structures in which the picture of the phenomena is represented. As a matter of fact a metaphor designs for the user some world frequently by means of objects, concepts or operations, not existing in a reality, creating as though "magic" opportunities for the user. Logics of new reality on the one hand reflect user ideas about the interface and objects of the modeled domain, and on the other - should coincide

(or to be close) with logic of development of processes and changes of objects in source domain, including logics of user activity.
We propose the approach to the understanding of metaphor as a main principle of mapping an application domain to visual universe. The understanding of metaphors as mapping from source to target domains is incomplete at least in case of interface and visualization metaphors. We offer more complex mechanism, which underlies functioning of metaphors. Our approach differs from traditional ones that in its frameworks the metaphor generates some independent metaphor domain at the expense of correspondence that puts to objects of target domain some objects from the source domain. And more exactly, structures and/or characteristics of objects from target domain are put in the correspondence structures and characteristics of objects from source domain. 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. Similarly in other classical metaphor RICHARD - THE LION some lion qualities (for example, courage, but not tail, fangs, and claws) are transferred on a human being, who now becomes in frameworks of the metaphor domain.
An action of visualization metaphor consists of extractions of structures from target domain on the base of certain structures from source domain and transfers them in metaphor domain, which in this case has a visual nature. (Metaphorically speaking, it is possible to compare the action of a metaphor with the action of messenger RNA in molecular biology.) The visualization metaphor is mapping (more exactly operator) to certain visualization world, where unshaped objects get its visual presentations.
(There are the similar approaches to metaphor understanding, see for example (Old & Priss, 2001) or (Turner & Fauconnier, 1995). Note also that our approach is based on initial understanding of metaphorical processes. Compare with Lakoff's point of view: "*A metaphor consists of the projection of one schema (the source domain of the metaphor) onto another schema (the target domain of the metaphor). What is projected is the cognitive topology of the source domain, that is the slots in the source domain as well as their relation with each other*." (Lakoff & Johnson 1980), (Lakoff, 1993).
As we noted above 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 a dialog visualization language in its turn. User formulates the problem with the help of this language and achieves its solving from the computer. The metaphor helps to describe abstraction, structures understanding of new applied area, but also assigns dialog [visual] language objects.
The use of metaphors should increase expressiveness of objects under investigation. To achieve it objects of target domain (with a set of structures, properties) are selected. As this takes place not all objects are chosen (and even not all their characteristic or structure elements), but only that, which are under interest most of all. Analogues for these objects (by way of structures, qualitative properties) are searched in source domain. Further the following operation takes place. Object of target domain together with object from source domain are located in *metaphorical domain*, or more exact in doing so the 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. There is a new logic of development metaphorical domain. 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. In that specific case of visualization metaphors mapping to some world of visualization, where imageless objects obtain their visual representations, takes place.

There are the questions - what are nature and structure of metaphorical domain; how its generation is produced? The natural answer to them is connected to understanding of that the consideration of a metaphor as a sign or as a pair of signs is not fruitful. First of all the metaphor generates some sign system, that is 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. (Barr et al., 2004).)

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.

The analysis of the use of visual interaction systems reveals that the metaphor has a "focus" making the greatest impact on the user of the visual language generated by this metaphor. Sometimes, the metaphor focus is founded upon dissimilarity between metaphoric and model entities. In other cases, the metaphor affects the user by placing an object of the metaphor to a semantic context unusual to this object. Note possibilities of presence several foci in metaphors and absences focus in the concrete metaphor. Also note that focus of the metaphor is always perceived subjectively and can be missed by some particular user.

The computer metaphor can be specified as a set consisting of the following parts:

· imagery of the metaphor;

· operations directed by metaphor both animation operations and user's manipulations (in degenerated case the observation may be considered as these operations);

· the set of similarities between model and metaphoric entities or elements of semantic discrepancy;

· the focus of the metaphor responsible for the greatest part of the impact the metaphor makes on the user.

Now when our extended approach to metaphor meaning was described, in the next section we'll consider our approach to metaphor generation.

4. Metaphors Generation

In this section the scheme of metaphors generation is considered. Note that this scheme is suitable both for computer, and for literary and rhetorical metaphors. It is necessary to determine relation between metaphor and target system of meanings, for which metaphor was formed. This relation might be expressed in the terms of "meanmarks".
Let's start with an example of a well-known metaphor "RICHARD - the LION". In this case notion "RICHARD" is the object of methaphorization. Some his qualities, in particular, bravery, nobleness, force, etc. are well known. There is some image of Richard [king] in our mind, along with insights about bravery, nobleness, force etc. Connections between Richard's image and these notions take place, so one can write down:
Richard - brave;
Richard - noble;
Richard - strong.
Note, that Richard is only simple name, which may be turned off the real world, and actually, is really free label (as, for example, "true" in classical logic). In the same time the label "brave" means an opportunity to attach the other labels or labels to a subject, or (may be) vice versa their obligatory absence. That's mean, that "brave" is the true conceptual label having the tree of implications, and as well as the tree of preconditions. If to say from the theory aspect side, one can consider it as the target domain of a metaphor. The goal here is to define a relation between the metaphor and the target system of meanings, for which the metaphor was formed. This relation might be expressed in the terms of "meanmarks". To define what meanmark is, let us consider the word "brave". The meaning of that word may be established through ***if-then*** (implication) relation of it to other words. The implication is important because it is a base for reasoning, and metaphors assist the process of reasoning. For the word "brave" one may define outgoing implications. For instance, if ***A*** is "brave" then ***A*** is "not timid". This relation is denoted with →, in the following form as *"brave" → "not timid"*. Besides outgoing arrows every word has incoming ones. So the following object emerges. ***{I}*** → "brave" → ***{O}***, where ***{I}*** is set of words implying "brave" and ***{O}*** is set of those which are implied by "brave" itself. Now the graph of such implications can be considered, and it is assumed here that the topology of graph's paths passing through node defines mean of that node. Meanmark is simple the label for node in such oriented graph. The graph may not be the graph of implication relations of words; it may depict any such relation.
We use a symbol arrow (→) to describe concepts sequence in this case. This symbol, against formal logic, designates what concepts entail the following concepts, which may be attached to the object under consideration. For example:
Richard → brave, strong; king;
or
there are red and dark blue and green → there is motley.
Concept under metaphorization is considered here as a way of meanmarks ascription to various entities, as interrelation of this meanmarks set. It's revealed - what meanmarks with what are connected in our cogitative metaphorization concepts model. Also it's detected following levels of arrows (the second, the third, the fourth etc.) that stand up for each of meanmarks in the given conceptual system. It turns out the graph consisting of meanmarks. This graph may be covered on a graph consisting of meanmarks from source domain of metaphor. It is obvious, that the sets of meanmarks in these graphs are differing, but their

general structures are similar. Both metaphorical system of meanings and target system have such graphs which show how meanings are connected within them. According to that representation the correspondence between meanings at target system and meanings at metaphor can be established through homomorphism from target system meanmarks graph onto meanmarks graph of metaphor.

If we want to illustrate the target system "King Richard is brave", firstly we must define meanmarks graph of that system. It is simple enough: "Richard → king, brave". But the meanmarks "king" and "brave" mean nothing without their language contexts: incoming and outgoing implications in the system of meanings of English. It is very difficult to find meanmarks in some graphs which will have the same topology of implications as "king": and "brave" in that system. So the required metaphor should include both these meanmarks. We are looking now for "somebody" → king, brave. And, of course "somebody" is "Lion".

So the following object appears in the general case:

$\{I\} \rightarrow M \rightarrow \{O\}$,

where M - considered concept; $\{I\}$ - set of concepts, implying M; and $\{O\}$ - set of concepts, generated by M.

When methaphorization proceed, the graph of meanmarks for a source domain is determined. Searching of a metaphor - is searching of the structure of interrelations which are similar to structure of interrelations in the target domain. On covering (*not exact, not one to one*) it may become, that it will be necessary to remove some bottom levels. But the additional level absent in target domain may appear. Exactly this second meanmark system with its interrelations is our metaphor to the object considered originally. It may be much more interrelations between concepts in the metaphorical system than in the source. Note that some interrelations may correspond to those arrows which are present also in the first set, but just wasn't noticed up before the metaphor construction. And here they can be seen obviously. In a considered example the required structure is "LION", with traditionally implied bravery, nobleness, force. (Here we should notice that all these properties basically differ from similar, inherent to Richard).

The suggested model may also help to describe how metaphor allows establishing new properties of target system. One can consider implication dependence graphs not only for words, but also for other similar dependences in the same way.

Let's assume that we have certain time sequence of values $\{X\}$. That is $\{X\}$ is a set of elements with one linear discrete coordinate and some value. Problem of presentation of this sequence is raised. For example, let's transform these values into music notes with certain melody. It is possible because notes may be interpreted as values, and duration of music notes is always discrete. Then:

Melody → time sequence of notes → a set of elements with one linear discrete coordinate and a certain value.

Recognition $\{X\}$ through a similar metaphor may lead to interesting conclusions. The sequence of notes has the special property - notes may compose (or not) beautiful melodies. And if our way of formal transformation values $\{X\}$ to notes may generate melody, that, probably, $\{X\}$ has interesting properties, which may be found out by means of a metaphor. (One can consider sonification as a special form of visualization see, for example, (Reed et al, 1995), (Osawa, 1998). There are examples of cognitive visualization with music in (Zenkin1991)..)

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.)

The person distinguishes any general logic in a picture, breaking it on the set (perhaps enclosed) of fragments, abstracting from minor elements. One can consider the structures of user's internal mental model. In these structures (so called "representative cognitive structures") images of external world phenomena and inward habit are presented (Chuprikova, 2003). Thus, there is the set of structures including cognitive structures, structures of entities under analysis and structures of visual objects and images. It is necessary to support conformity between these three types of visualization structures.

"Visualizeness" (in a broad sense) of source domain provides the interpretation. 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. Similarly to visualization principles the interpretation principles should exist. So, the metaphor's quality is connected with an opportunity of easy interpretation of the [visual] language, which is generated by this metaphor. Also the visualizeness requirement is connected with the known for a long time criterion of "good" metaphorization - habitualness, recognition of source domain objects. (The concept of habitualness and recognition in the specialized systems of the human-computer interface should be connected mostly not with everyday realities, but with potential user activity in that sphere for which the interactive system is created).

The analysis of a source domain is carried out at the next stage of methaphorization process. On the basis of the interrelations analysis and dependences in the context of a source domain, as well as on the basis of analogies with them, both the methaphorization the analysis of the object and its properties is carried out. Objects dependences in the context of target domain are revealed. It is necessary for a source domain to have the deeper structure of interrelations than target domain in order to search for new dependences in the target domain. It's one of the factors of a "successful" metaphor. (See also the examples of metaphors in (Barbosa & de Souza 2000).) It's clear, that the metaphor's success is connected first of all with interrelations concepts structure of a source domain and with a possibility to obtain on its base the new understanding of dependences in the target domain that was of interest to us initially.

The duality of interpretation and visualization processes (or any other form of representation) is shown here through a metaphor. Sign process in visual interactive systems (or more exact part of this process connected with the interface interpretation) is supported through metaphor action. Metaphor action and, in particular, the user reaction to