

# The Role of Subjective Perception in Visualization, Controllability Hypothesis and Abstract Visualization

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## **Abstract**

Visual analytics tools are used when interpreting and analyzing weakly formalized or non-formalized data. The paper considers the problem of the influence of subjective factors on efficiency of the visualization tools. Based on the previously proposed and developed semiotic visualization model, a system of initiating factors is formulated that have a significant impact on the effectiveness of visualization tools. A controllability hypothesis is formulated, on the basis of which an assumption is made about limitations of visualization systems. It is proposed to take these limitations into consideration when designing new visual analytics tools. Approbation of the assertions presented in the work was carried out on the example of social data.

**Keywords:** Visualization, data analysis, semiotic model, interpretation, perception, abstract space, visual metaphor.

## **1. Introduction**

The variety of solutions to the visualization problem is a consequence of subjectivity of visualization techniques and a lack of justification for their efficient application. The subjectivity reflects a long historical path of visual art development and an unformed apparatus for the formal description of its capabilities in solving visual communication problems.

Justification of application efficiency can be achieved as a result of analysis of numerous options for solving visualization problems, however, most attempts stop at the stage of generalizing the existing experience. Difficulties are associated with the need to systematize visualization problems and visual communication features that require activation in accordance with the goals of visualization.

A classification of visualization problems was proposed earlier in [1], [2]. The semiotic model, which complements the proposed classification, has created conditions for convergence of both difficulties. This manifests itself in the fact that visual representation of information and its interpretation, i.e. processes corresponding to the specified difficulties, have become elements of a linguistic space [3].

In this space, it is possible to correctly represent most of the concepts and definitions used in visualization. This combination of heterogeneous entities is necessary to search for and determine the factors that can be considered the reason for emergence of new hypotheses corresponding to visualized data, as well as new knowledge [4]. In other words, a detailed consideration of internal processes of visualization, which are the basis for its development as a cognitive tool, should be considered a relevant area of research.

Creation of a theoretical model of such processes will fully or partially answer a number of important questions: how to adapt visualization parameters to characteristics of a particular user or their group; what the prospects for visualization are in terms of creating a univer-

sal means of information communication; whether it is possible to create efficient subsystems in visualization tools that allow levelling or using productively interpretation subjectivity of visual images, etc. One of the expected results when answering these questions will be the use of a visual representation of both the initial data and the knowledge corresponding to them, in a generalized form. In other words, visualization, as a way of information communication, will get an opportunity to become a knowledge formalization tool initiating processes of transferring knowledge between subject areas, both at the level of hypotheses and in the form of verified models and systems.

## **2. Visualization of data and/or knowledge**

Known patterns of visual perception largely confirm the assumption of a high degree of persuasiveness of any visual images. This is both a serious disadvantage and the most important advantage of visualization. Moreover, the boundary between these qualities is very blurred. What is the point?

Visual representation of any information is perceived by the observer as an object with properties of completeness, constancy, integrity, etc. If time for interpreting an image is short, then, according to the linguistic model, it remains a symbol that reflects an indisputable fact. The same result can be obtained using a number of expressive techniques, so the impact of such visualization on the viewer belongs to the category of “informing”. Consistency of the received new information with the user’s own knowledge system in this case becomes a signal to complete the interaction with visual information.

Knowledge, as information with a higher degree of formalization, involves supplementing the initial data with information about their significance in a particular subject area, reliability and generalization. However, when solving the problem of knowledge representation, it is difficult to point out differences between data and knowledge because, in most existing solutions, these differences are presented as additional data using known syntactic rules. An experimental assessment [5] carried out as part of the study of the semiotic model suggests that a conceptual interpretation of visualized data occurs only as a result of creating special conditions for the observer [6], [7].

At the level of organizing the researcher’s interaction with information, such conditions can be obtained in various ways, both known and completely new. However, in the development of visual communication tools, the same goal is pursued with more or less success in each case: provoking the user, initializing the activity aspect in the course of visual communication. If this goal cannot be achieved, then the visualized knowledge remains data that has no practical value for the researcher at the current time.

## **3. Initiating effect**

Studying existing approaches to organization of initiating effect on the user and examining the problem of increasing its effectiveness cause the emergence of new visualization tools as well as the development of a specialized visualization tool classifier, that complements the semiotic model. The need to separate the means of visual analytics depending on mechanisms of initiation of cognitive processes is associated with the obvious desire of visualization system developers to increase efficiency. The correspondence between the toolkit and the problem solved with its help is one of the most important directions in data interpretation techniques. The classifier under consideration can be a simple and convenient method for achieving this correspondence [8], [9], [10].

### **3.1. Direct question**

In a more complete formulation, it is an external indication or subordination to a request. It is the most common way of organizing interaction between a researcher and a visual analytics tool. It can be organized in several ways including preliminary informing about the search goal, a demonstrative analogue or a sign indication. In each such case, a mental per-

ception pattern is formed which reduces the time spent by the researcher on interpretation and analysis of visualized data. Feedback responsible for comparing the results of the analysis and its goal plays a significant role in dynamic analysis. Hence, in this case, substitution of the dynamic analysis for a quick comparison with a mental template and deciding about the degree of closeness between the template and the current result of visual perception should be considered a negative cognitive effect.

### **3.2. Incompleteness**

In other words, it is subjective proneness to conflict. It is a variant of interaction with a visual image that naturally occurs in situations where both the direction of the analysis and verification of its results are determined by the researcher himself. In other words, if there is not enough data for the search of and making the only correct solution to the problem, then visualization tools should not form a false sense of accuracy of interpretation and associated problem-solving hypothesis. Application of some features of the researcher's perception for correcting his actions can become a more useful variant of communication between the user and initial data, aimed at collecting and involving new data in the solution and generating additional hypotheses. For example, in a situation of inconsistency with the user's own current expectations, the incompleteness of data emphasized by means of visualization (image incompleteness, gap, limited representation, unreasonable movement, etc.) gives rise to a subjective conflict and forces to take actions necessary to eliminate it. Thus, cognitive search is initiated allowing to supplement the available information.

### **3.3. Perceptible controllability**

It is compliance with an achievable goal. It is a broader statement of the problem of the researcher's interaction with the initial data. It is assumed that a potential opportunity is created to correct both available knowledge and data study goals simultaneously with initial data interpretation. In the "data – visualization – user" system, a dynamic component arises, that is the user's knowledge that changes system behavior. In this formulation of visualization problem, the most ambiguous is the user's behavior. Therefore, the key issue that arises at the visual analytics system design stage is a choice of possible methods and corresponding means of influencing the user [11]. The purpose of such influence is to switch the researcher's activity between the "observation" – "search" – "understanding" states depending on the actual task [12].

## **4. Controllability hypothesis**

For a deeper understanding of many related cognitive and emotional factors responsible for the results of visual interpretation of data, an analysis of known solutions to a number of applied problems in the field of design – industrial and digital – has been carried out. As a result, a hypothesis has been formulated that explains a significant number of stable reactions of users of design objects – fears, sympathies, interest or apathy, – as well as the reasons for disappearance or transformation of these reactions. The meaning of the assumption made is as follows: the achievement of the necessary user reaction and control over it depends on the ability to influence the subject's own role in the system "user – space perceived by him". It is easy to give several examples illustrating the validity of the proposed hypothesis.

**Fear** and similar emotional reactions in terms of the hypothesis under discussion correspond to a situation where the user's activity or its planning is suppressed by external factors. In other words, if the perceived space dominates the analyzed system, then this deprives the user of the opportunity to understand and predict its development and, consequently, causes formation of various negative reactions. Within the framework of the semiotic visualization model, this is an analogue of the state of passive perception, i.e. visual informing.

**Curiosity and cunning.** From the point of view of the proposed hypothesis, in this case, elements of the system retain activity parity, i.e. have mutual influence on each other. The activity aspect in the user's behavior is aimed at obtaining new information about the perceived space and clarifying already existing knowledge. The user's emotional state is considered "conditionally positive", because the knowledge gained compensates for the effort to obtain it. In the semiotic model, these processes include two of its states at once – learning and research.

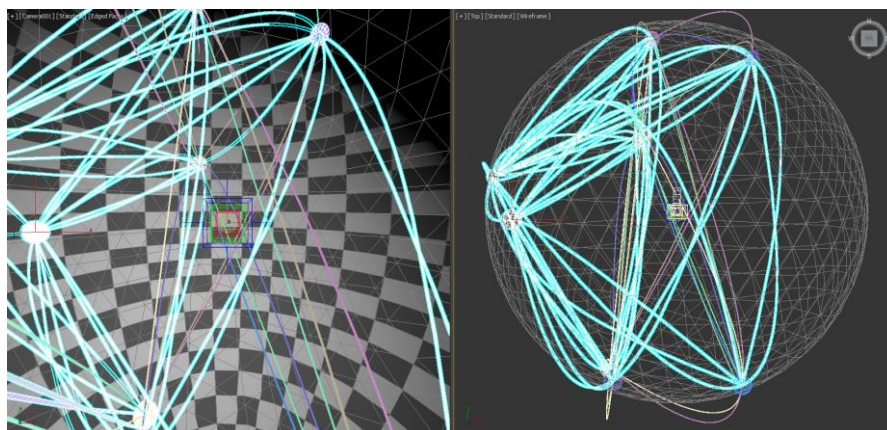
**Possession and manipulation.** This is the most productive situation for the user, because it correlates with the possibilities of full-fledged planning of activities and self-realization. The perceived space is considered a place for realizing one's own interests, forming hypotheses and receiving dividends from their practical verification. Thus, it should be considered that the emotional state is exclusively positive and constructive because it is defined as directed use of existing experience and achievement of new results. From the point of view of the semiotic model, this is the control task.

An important consequence of the hypothesis under consideration is another assumption that can be used in visual analytics systems. The main idea is that the emotional states described above can be primary in relation to visual analysis tasks. In other words, visualization tools, their perceived characteristics and control subsystems, can form necessary emotional factors for the user to control his activities. Thus, design of visualization tools is considered as a complex parameter for managing their purpose and efficiency.

## 5. Abstract visualization

### 5.1. Objectness or abstractness

When studying the applicability of the design of visual analytics tools, including correspondence of a visualization metaphor to its purpose, two extreme cases should be distinguished on the basis of the hypothesis under discussion: a specific object space image and its opposite – the most abstract environment. In the first case, interpretation of visualized data through the symbolism of the object metaphor becomes the most accurate and unambiguous. At the same time, the adequacy of interpretation is determined not by the metaphor but rather by its correspondence to the user's visual thinking. This situation is the most popular among developers of visualization systems, because it simplifies information communication and increases its speed.



**Figure 1** – Example of an abstract visual model

In the opposite situation, the initial data are compared with an image that does not have an associative connection with the user's subjective experience and, therefore, is considered abstract (Fig. 1). It is easy to assume that a cognitive effort aimed at interpreting such an image can lead to the emergence of a new subjective hypothesis and its subsequent verification. Designing a visualization tool oriented towards this kind of result is associated with several

complexities at the same time. Firstly, personal user experience in today's digital world is extremely extensive and diverse, so choosing a metaphor that does not use known associations is not an easy task. Secondly, the reverse side of the refusal to use stable associative links is the difficulty in developing controls for such visualization systems. And thirdly, as the results of experimental assessments show, construction of a cognitive model of visual information is quite fast, it is determined by characteristics of the user's perception, by the convenience of the controls and by information richness of visualization.

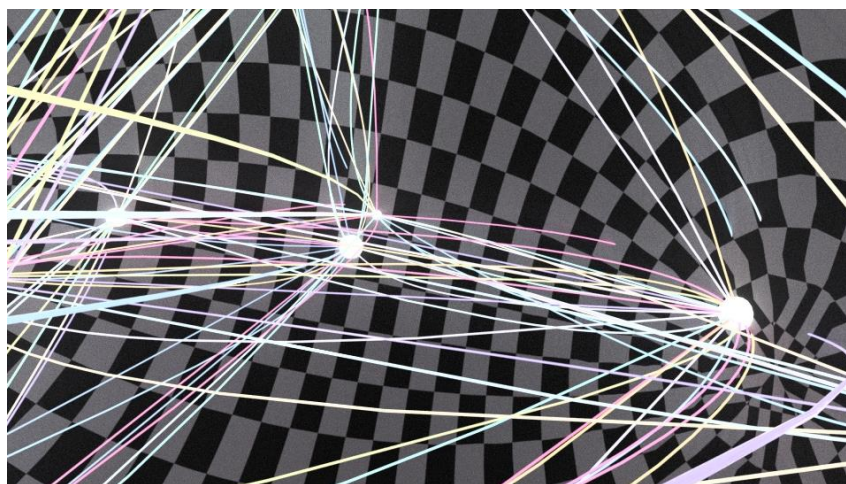
## 5.2. Ergonomics of visualization

Overcoming each of these difficulties is an independent direction of research into the future possibilities of visual analytics. In the generalized case, they can be defined as the development of a transformable visual communication language, the definition of its syntax and its own expressive means. A separate task is the study of ergonomics of visual space. This term refers, firstly, to the correspondence between the user's perception capabilities and visual space implementation, and secondly, to the consistency between the purpose of visual analytics tools, determined by the developer, and their use, depending on the user and his goals.

To determine the functional approach to the study of ergonomics of visual digital space, a number of experiments have been carried out using various versions of such a space. The purpose of the study was to identify factors which, when their values are changed, can change or significantly affect the perception or interpretation of visual information. To achieve this goal, an interactive visual environment has been designed that allows evaluating the observer's reaction and decision-making while interacting with the environment.

Among the results obtained, several factors should be noted that can be used to create a controlled influence on the user's perception:

**Direction.** In a visually perceived space limited, for example, by the plane of the screen, it is easy to distort the subjective sense of direction (Fig. 2). To do this, it is enough to violate the main spatial landmarks that characterize the view direction – top-bottom, left-right. In the simplest case, this is achieved by eliminating the horizon line or by building a homogeneous environment. It takes 3.0–5.0 seconds for a change in view direction to completely disorientate the user.

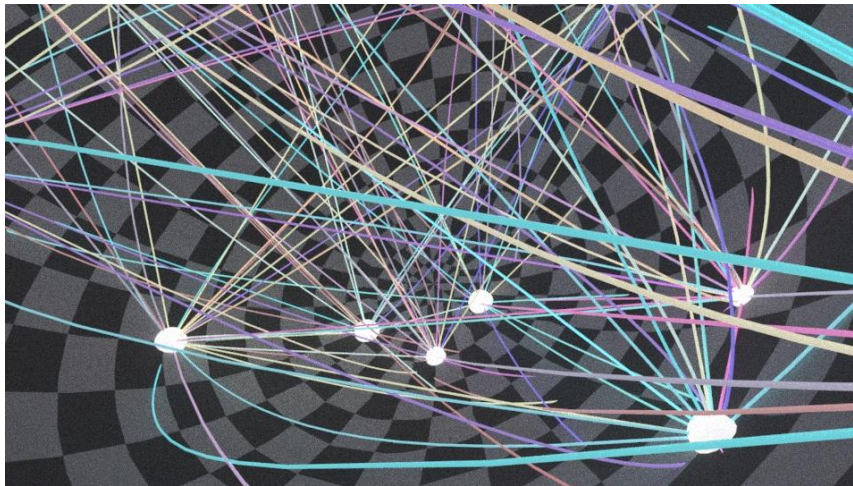


**Figure 2** – Space with direction distortion

**Time.** Focusing on details of an image or focusing on individual changes alters the idea of natural speed of these processes. As a result, changes can occur in the visual space simultaneously with different, also changeable, time scales. Meanwhile, time scale control becomes a convenient parameter for manipulating the visual image, i.e. creates conditions for increasing its cognitive significance.

**Structure (Rhythm).** Visually perceived space structure, as well as appearance of a rhythmic pattern that is not related to the initial data, can be a template that determines the

content of interpretation hypotheses (Fig. 3). Naturally, use of a template always reduces time for searching a solution, but only in those tasks where the template matches the task. In the event that a visualization tool is needed for cognitive search for non-standard answers, the imposed rhythm can become a tangible hindrance. For example, in a model of a connected system using the curvilinear relationship metaphor, the relationships between two nodes expressed as a straight line will look like an error and can be excluded.



**Figure 3** – Perceived visualization rhythm

**Perspective.** In three-dimensional space, perspective control and distortion become another way to influence the observer. The result of such an effect is a change in the information richness of the image (Fig. 4), establishment of the proportionality of the system visible elements, management of the viewer's expectations and preferences. Wide-angle distortions can change the significance of individual information elements and therefore become one of the reasons for the emergence of new hypotheses.



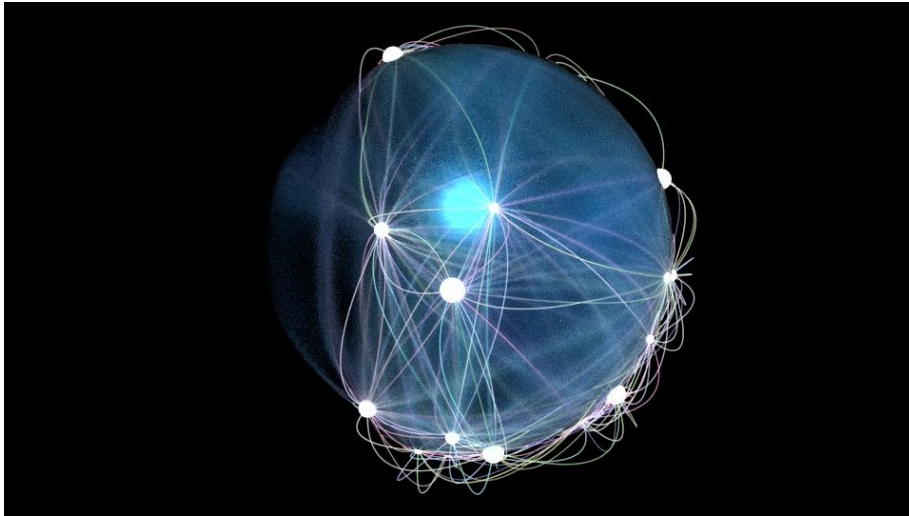
**Figure 4** – Adjustable information richness

### 5.3. Social data model

The task of developing visual analysis tools for the study of informal data can be exemplified by a system of visualizing social data. The primary difficulty preventing meaningful conclusions is a significant amount of data (10–200 people) that characterizes communication between members of a social group.

To analyze the initial data, an interactive visual model is proposed that combines data on several types of communication in one image. A spherical surface has been chosen as the

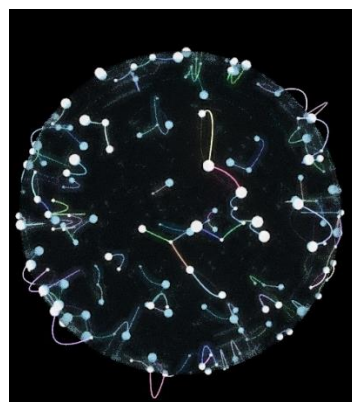
main object necessary for the formation of a common visual space. This has made it possible to place data without considering perceived proximity to boundaries or artificially selected points (poles). Thus, the researcher, having received the opportunity to observe data in a three-dimensional representation from an arbitrary perspective, actively uses the possibility of a subjective choice of the most informative direction (Fig. 5).



**Figure 5** – Visual model of social data. Informative perspective indicating heterogeneity of communication processes in a social group

The location of nodes, each of which symbolizes a member of the group under study, on the surface of the sphere is arbitrary and can be changed interactively. In one of visualization options, the nodes were placed at a distance from each other, corresponding to the activity of their face-to-face communication. Thus, an image was formed that allowed visualizing the internal division of the group under study. Then the model was supplemented with information about the interaction between the representatives of the group in work or educational projects. The final model made it possible to draw conclusions about the complementarity of various types of communication and to predict the dynamics of changes in interaction (Fig. 6).

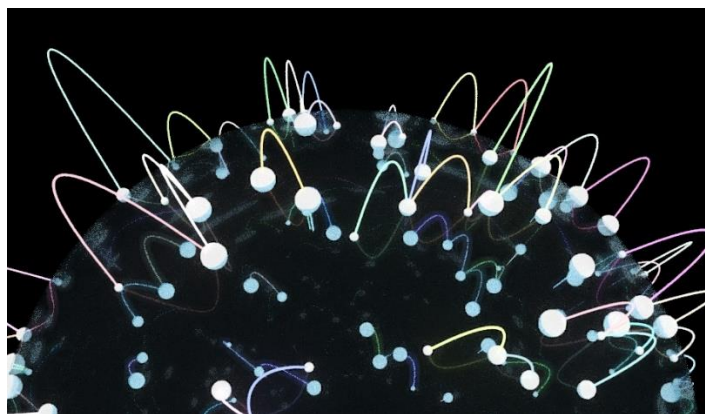
In different options for setting up the model, the researcher has the opportunity to form subjective preliminary conclusions about the connectedness or disunity of the tested group (Fig. 6a), the volume and complexity of working communication (Fig. 6b, the red line is the largest working group), the significance of connections that go beyond close interpersonal communication (Fig. 6c, curved lines correspond to distant connections).



a



b



c

**Figure 6** – Visualization of interpersonal and work communication in a group

The model makes it easy to imagine the relationship between face-to-face and work communications, as well as their possible mutual influence. From the point of view of studying the capabilities of visualization tools for their use in the study of systems similar to the test one, it should be noted that the instrument takes little time to master for an unprepared specialist, as well as provides the possibility to simulate new, modified system states that correspond, for example, to the optimality criteria for the parameters chosen by the researcher. An essential circumstance that determines results of visual research is the active involvement by the user of subjective experience that complements analyzed data.

All examples of visual models presented in the work, are built with the author's algorithms implemented in the languages MaxScript and Python in the three-dimensional modeling environment Autodesk 3ds Max, using internal visualization tools.

## 6. Conclusion

In the course of the study, there has been proposed a classification of visualization tools differing in the ways of influencing interpretation and cognitive search for an answer to the task assigned to the user. The developed classification is consistent with the semiotic visualization model and is its consequence. The use of visual models based on the abstract space metaphor is proposed as a means of visual analytics with the greatest functional flexibility. Examples of features of user interaction with such models and options for their useful application are given.

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