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Cognitive Clarity of Graph Models: an Approach to Understanding the Idea and a Way to Identify Influencing Factors Based on Visual Analysis

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Abstract

The article describes new authors' approach to understanding the idea of cognitive clarity of graph models. A scheme for structuring concepts related to cognitive clarity is given. In accordance with this scheme cognitive clarity forming factors are distinguished, cognitive clarity itself as a set of internal characteristics of a visual image of a model, as well as the effects of its presence revealed in the visual analysis of the model. Properties of various components of this scheme are discussed, and it is concluded that, due to their constructive nature, cognitive clarity forming factors are of the greatest interest. A detailed diagram of an approach to understanding cognitive clarity is described, based on two levels of a visualization metaphor, and individual components of this diagram are discussed. An approach is proposed to organize experimental studies aimed at studying and evaluating the influence of various factors on cognitive clarity of graph models by measuring various indicators that characterize the degree of manifestation of cognitive clarity presence effects. The idea of this approach is to form a hypothesis about the influence of certain factors, followed by an experiment in which the analyst solves a certain task of visual analysis with the participation of these factors. As a result of registering the given indicators, the achieved effect of changing the level of cognitive clarity is assessed and the nature of the dependence or its absence is revealed, which makes it possible to accept, reject or refine the initial hypothesis. A generalized algorithm for preparing and conducting an experiment within the framework of the described approach is proposed, and implementation features of its individual stages are considered. An example of setting up an experiment is given, the purpose of which is to study the dependence of efficiency indicators of graph model visual analysis on the volume of its visual image. Promising areas of research in this area are discussed in the conclusion.

Keywords: graph model, graph visualization, cognitive clarity, visualization metaphor, cognitive map, experiment, Hick's law.

1. Introduction

The language of graph theory is one of the most common means for describing problems of representing and processing information. The wide variety of both graph models themselves and their areas of application is due to the fact that, as noted in [1], graphs are "a natural means of explaining complex situations on an intuitive level". This circumstance also determines the fact that many models currently used in knowledge engineering and decision support also quite naturally allow a graph form of representation. Among such models, one can distinguish, for example, semantic networks, thesauri and ontologies [2], Bayesian networks and influence diagrams [3, 4], decision trees [5], hierarchical and network decision-making models [6], transport and flow models [7], cognitive models based on various types of cognitive maps [8].

Advantages of graph models are most often manifested in their visual processing, which makes the problem of visualizing such models relevant. The problem is characterized by multivariance of its solutions [9]. To describe a visualization problem in a general way, an approach can be used based on the concept of a visualization metaphor [10], which is understood as a set of principles for transferring characteristics of the object under study into the space of a visual model. The visualization metaphor has two components applied sequentially:

- a spatial metaphor that describes the general principles of constructing a visual model (type and dimension of visualization space, mutual arrangement of model elements in it);
- a representation metaphor responsible for clarifying characteristics of a visual image (as a rule, in order to visualize certain properties of an object under study, the most significant at the current stage of its analysis).

When working with any graph model, simplicity and convenience of visual perception of the model by the researcher is of particular importance. To describe this aspect, the concept of cognitive clarity is often used [11, 12], which refers to the ease of intuitive understanding and interpretation of a certain amount of information presented in a visual model. Insufficient cognitive clarity of a model is usually associated with difficulty in understanding information, omission of its significant part, inaccurate or erroneous interpretation of some of its elements, etc. On the contrary, providing a high level of cognitive clarity of the visual model allows the researcher to "cover at a glance" a greater number of important properties of the modeled object, increase the probability of detecting errors made when building the model, and also increase the speed of interpreting the results of its analysis.

The authors' research in the field of visualization of graph models, as well as the development of methods for assessing their cognitive clarity and ways to improve it, were published in [13-17]. In particular, in [13-15] the problems and tasks of visualization of a particular type of graph models – fuzzy cognitive maps – were studied in detail.

One of the results of a more general work [17] was the identification of a problem that was formulated as a contradiction between the volume of the graph model representation metaphor and its cognitive clarity, where the volume of the representation metaphor is understood as the number of different visual features in the resulting visual image of the model. At the same time, it was assumed that there is a relationship between this contradiction and Hick's law [18], which establishes a relationship between the number of elements contained in a certain user interface and the average time that the user spends on visual detection and selection of the element he needs. In this regard, it was noted that an experimental research of the discovered contradiction as well as its possible relationship with Hick's law is of interest.

In this paper, we propose a more general conceptual approach to conducting experimental research in the field of visual perception of graph models, potentially suitable for solving not only the above problem but also many other research problems that may arise in this area.

A significant part of the terminological apparatus used in this work was introduced and described in detail by the authors in the paper [17].

2. General approach to understanding the idea of cognitive clarity of graph models

Figure 1 shows a diagram illustrating the approach proposed by the authors to understanding the idea of cognitive clarity of graph models and related concepts and phenomena.

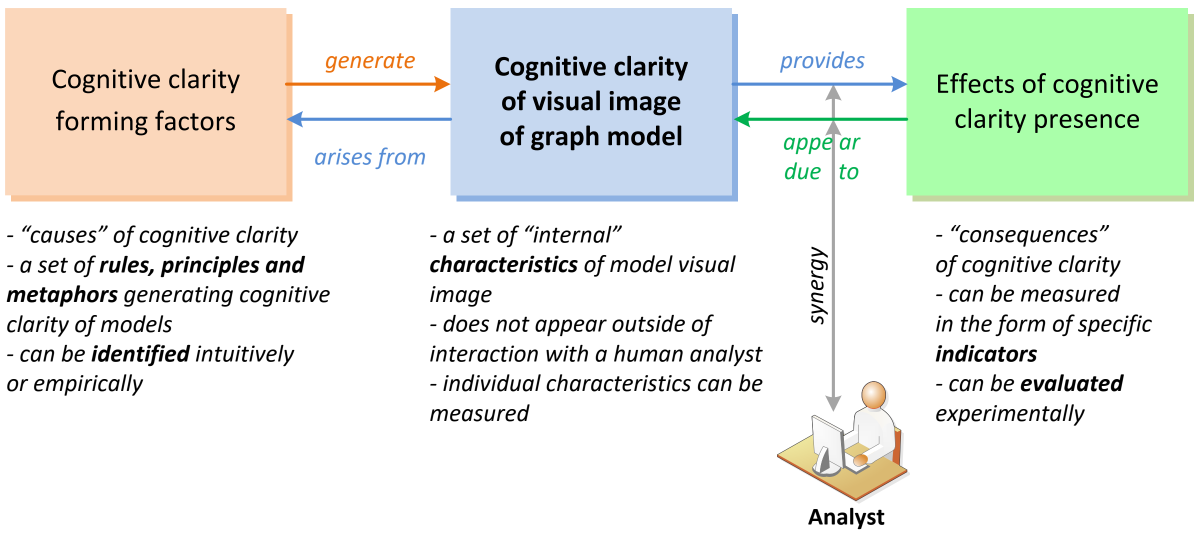

Figure 1 – Conceptual diagram of the proposed approach to understanding the idea of cognitive clarity of graph models

Based on the presented diagram, the concepts and phenomena associated with the idea of cognitive clarity are proposed to be structured into three categories.

Cognitive clarity forming factors, in a sense, can be interpreted as "causes" of its occurrence. This category includes everything that can contribute to the emergence of cognitive clarity of visual images of the studied graph models: the observed general visualization principles, the metaphors used, specific rules of thumb (up to highly specific ones) and algorithms.

Cognitive clarity forming factors have yet to be identified. The concept of the studies aimed at their identification is proposed in this paper. Theoretically, it is possible to say that identification and formalization of all factors-"causes" is tantamount to the construction of an "ideal visualization metaphor" (for a certain type of graph models and problems of their analysis). From a practical point of view, obviously, such a goal is completely unattainable, but it can serve as a good guideline.

Under *cognitive clarity "as such"* it is proposed to understand a certain set of characteristics and properties of a visual image which makes the corresponding graph model "cognitively understandable" for a human analyst. Here it is necessary to note the fact that this category is not constructive: even if you have already constructed visual images that have cognitive clarity to a "sufficient" degree, you may know nothing about the principles of obtaining them (i.e., not own the forming factors) and, accordingly, not be able to create new visual images with similar qualities. Thus, constructiveness is typical for the category of cognitive clarity forming factors.

In addition, although cognitive clarity in its proposed understanding exists objectively (properties of a visual image do not depend on whether the analyst perceives it at the moment), it is actualized only "at the junction" between the visual image and the cognitive functions of the human analyst. Through these functions, a synergetic combination of a set of individual properties into a certain integral result (the appearance of which is well described by the term "emergence" from systems theory [19]) takes place, due to which the observed effect arises.

It is important that at the level of this category it becomes possible to measure individual formal components of cognitive clarity (examples are graph tiling characteristics, such as the number of arc intersections, etc. [14], as well as parameters of the representation metaphor, such as its volume [17]). However, it remains impossible to measure the magnitude of the synergetic effect (because it does not occur at the level of this category itself) and its practical consequences.

Finally, it is the *effects of cognitive clarity presence* (which, within the framework of the presented approach, can be interpreted as its "consequences") that are the "ultimate goal" of interest in the very concept of "cognitive clarity" and research on this topic.

This category corresponds to the level of phenomena at which the efficiency indicators of the graph model visual analysis can be identified, available for evaluation and measurement. Examples include the speed of solving a certain problem of visual analysis or the number of errors made in this process.

The category of effects-"consequences" is also not constructive: a single knowledge that a certain visual image provides an efficient analysis does not give anything in terms of a general understanding of how to build such images. In terms of the scheme under discussion, it can be said that, in general, it is impossible to reconstruct the chain of cause-and-effect relationships in the opposite direction, from the effects of cognitive clarity presence to the factors that form it. The method proposed below for solving this problem is to create a closed loop with feedback by introducing an experiment.

3. Cognitive clarity of graph models in terms of two levels of visualization metaphor

Considering the fact that the visualization metaphor includes two components, it seems appropriate to consider a detailed version of a diagram of the outlined approach (Figure 2). This version involves allocation of two levels of the visualization metaphor on the diagram – the spatial metaphor and the representation metaphor, with the subsequent specification of the semantic content of the intersections of these levels with each of the three categories introduced above.

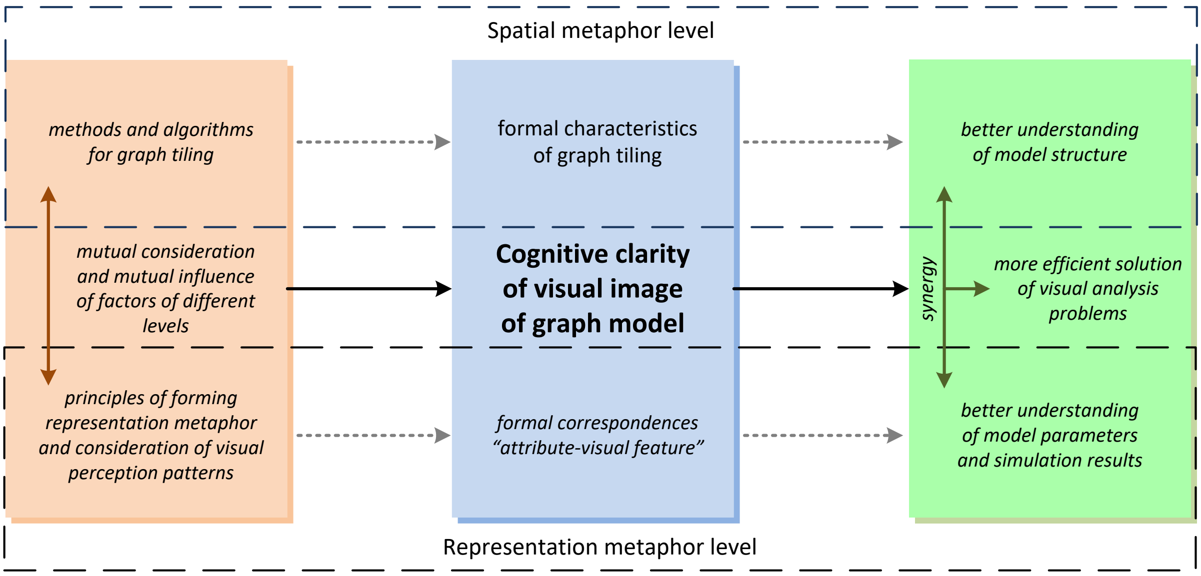

Figure 2 – A detailed diagram of the proposed approach to understanding the idea of cognitive clarity of graph models, considering two levels of visualization metaphor

Thus, the main cognitive clarity forming factors of graph models at the level of spatial metaphor are algorithms for graph tiling. It is assumed that an algorithm chosen optimally from the point of view of a given type of a graph model and correctly configured taking into account specifics of the problem being solved will ensure a graph tiling with the highest degree of cognitive clarity possible. Such graph tiling will have formal characteristics that are most conducive to simplifying the analyst's visual perception of this particular graph model. For example, it can be characterized by the absence of arc intersections, well-pronounced symmetry, arc directions that are convenient for quickly viewing the graph, etc. [14]. Depending on the type and specific features of a graph model, other, more complex and less obvious characteristics may contribute to the improvement of perception.

In any case, the analyst's perception of a graph model visual image that has a set of such characteristics should lead to a more efficient (compared to other situations) understanding of the model structure. The increase in this efficiency can be registered by measuring the analyst's performance when solving visual analysis problems directly focused on understanding model structure.

At the representation metaphor level, cognitive clarity forming factors can, firstly, be based on the principles of constructing representation metaphors for graph models outlined in [17]. These principles set very general and intuitive rules for the formation of correspondences between model attributes and visual features, and their observance contributes to the creation of metaphors with a sufficient level of cognitive clarity and the absence of "gross" violations. Secondly, it is of interest to formalize and consider visual perception patterns, both related to the perception of graph models in general and related to their certain types. Such regularities include, for example, the already mentioned contradiction between the volume of the representation metaphor and its cognitive clarity, as well as the hypothesis about its connection with Hick's law.

The optimal (under the conditions of a specific visual analysis problem) distribution of correspondences between attributes and visual features creates the basis for the most efficient understanding by the analyst of a set of visualized attributes, which can reflect both the initial parameters of the model and the results of modeling. At the same time, in order to evaluate the efficiency, it is required to measure the analyst's performance in the conditions of solving visual analysis problems focused on understanding not structural, but parametric components of the model.

Of considerable interest, both in research and practical terms, is the content of the middle level of the scheme, which corresponds to the junction between the two levels of a visualization metaphor in each of the categories. Thus, in the category of cognitive clarity forming factors, the main semantic content of this junction is the possible mutual influence and mutual conditioning of factors related to different levels of metaphor. In particular, the following questions are useful to ensure efficient visualization:

- How much influence does the choice of factors at the level of spatial metaphor have on cognitive clarity of the representation metaphor level? In particular, whether a bad choice of such factors (for example, an obviously erroneous choice of graph tiling method) can negate the positive effects of even a very well-constructed representation metaphor.
- How meaningful is the feedback? In particular, whether the choice of cognitive clarity forming factors at the level of spatial metaphor will depend on the representation metaphor and the research problem as a whole. An example of such dependence can be the expediency of changing graph tiling when moving to another visual analysis problem of the same model.
- What are the possibilities and limits of acceptable compensation for errors made at one level by successful solutions at another level? For example, to what extent is the correct selection of graph tiling capable of compensating for an insufficiently qualitative representation metaphor (in the context of solving a specific visual analysis problem), and vice versa.

Finally, in the category of cognitive clarity effects at the "junction" between the levels of the visualization metaphor, there is a synergetic combination of effects from both levels of the metaphor that occurs when the analyst perceives a visual image. In other words, the analyst's clear understanding of the graph model structure, combined with understanding of its parameters and modeling results, as a rule, leads to a much more efficient solution of the visual analysis problem than in the absence of any of these components. A detailed study of the mechanisms of such synergy and the search for methods for quantifying its impact on the analysts' work efficiency can be very useful for the development of the proposed approach.

4. Approach to organization of experimental research to assess the influence of factors on the cognitive clarity of graph models

The diagram shown in Figure 3, on the one hand, can be considered as an addition to the conceptual diagram in Figure 1, and on the other hand, it demonstrates the "role and place" of the authors' concept of cognitive clarity within the framework of the proposed approach to organization of experimental research.

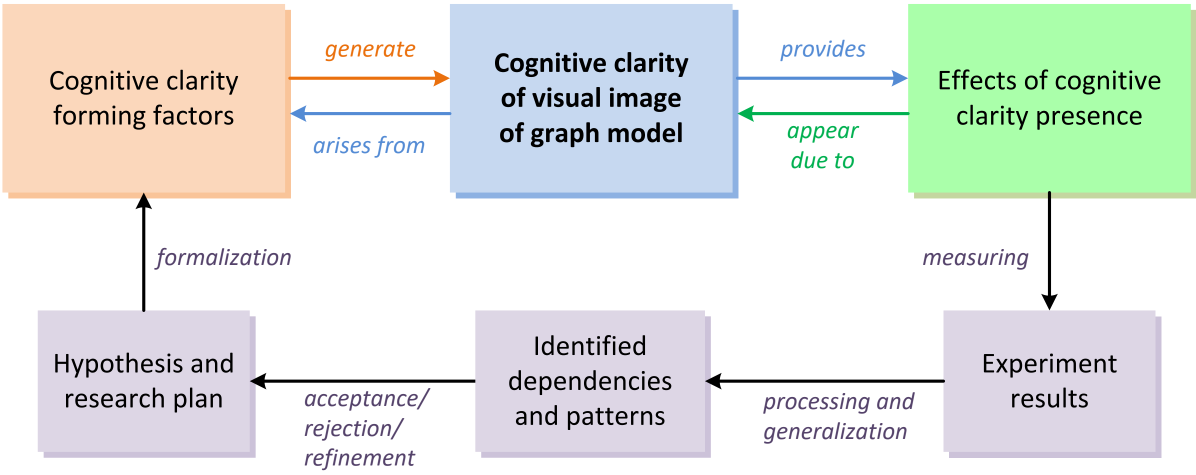

Figure 3 – Diagram of the proposed approach to organization of experimental research to study the influence of various factors on cognitive clarity of graph models

The proposed approach is aimed at solving the problem of experimentally identifying the factors that contribute most to the formation of cognitive clarity, i.e. provide the greatest effect. At the same time, the idea of the approach proceeds, as mentioned above, from the practical impossibility of "directly" detecting cognitive clarity forming factors based on the observed effects of its presence.

It is assumed that the cycle presented in the diagram should begin with a hypothesis about the influence (or, conversely, the absence of influence) of a certain factor (or their combination) on cognitive clarity of the resulting visual image of the graph model, which should manifest itself in specific effects, the magnitude of which is estimated by measuring relevant indicators.

Based on the formulated hypothesis, an appropriate experiment plan is built, in accordance with which the experiment is conducted. It consists in analyst's solving the task of graph model visual analysis. During the experiment, the necessary indicators are measured, and then they are processed, which, among other things, may include matching and combining the results with those obtained earlier. Based on the results of processing, the identified dependencies are formulated, which serve as the basis for confirming, rejecting or refining the hypothesis.

Note that execution of each iteration of this cycle should take place in the context of a specific type of graph model and a selected problem of visual analysis.

Thus, the approach involves identification of cognitive clarity forming factors not in the sense of their detection, but in the sense of an iterative process of putting forward and testing hypotheses about the influence (or lack of influence) of certain factors. The task of hypothesis formation is assigned to the researcher. In other words, the approach generally does not provide support for the formation of hypotheses, acting primarily as a methodological and technological basis for their verification. In the future, however, it is possible to develop an approach towards the automatic formation of new hypotheses based on the results of testing a number of previously proposed ones.

5. Generalized algorithm for setting up and conducting an experiment

As for experimental studies of the impact of graph models on cognitive clarity, it is of considerable interest to ensure reproducibility of the results of studies of this type as well as sufficient transparency of the study itself. In this regard, it seems appropriate to develop some methodological foundations for preparation and conduct of such studies as well as processing their results. It is possible to form a certain general set of recommendations, the implementation of which will help expand the possibilities of conducting experiments, as well as increase the generality and reliability of the results obtained.

First, it is advisable to provide for the possibility of conducting an experiment not only on specific, known types of graph models (such as, for example, fuzzy cognitive maps), but also on "abstract" types designed specifically for a particular experiment, taking into account its hypothesis and conduct specifics. This will allow more flexible adjustment of experiment parameters to efficiently refine the dependence of interest to the researcher.

Secondly, the possibility of varying the complexity of the model should be implemented, i.e. the number of elements in its composition (in this case, the best option is to implement a separate variation in the number of vertices and the number of edges of the graph). This will contribute to the formation of a more general picture of the desired dependence, without linking it to a model of a certain complexity, and, accordingly, will allow testing more complex and abstract hypotheses.

Thirdly, it must be taken into account that with a single solution by an analyst of any problem of visual analysis, the measured indicators will inevitably be influenced by the random factor. A natural way to reduce the degree of influence of this factor is to re-solve similar problems of visual analysis with registering the average values of the indicators.

Fourthly, it is necessary to introduce a mechanism to counteract the analyst's habituation to the same graph model, especially in combination with the same spatial arrangement. The essence of this effect is that with each subsequent presentation of the same model, even when using different representation metaphors, the analyst will navigate it faster and better than with previous presentations. The difference in the degree of the analyst's habituation to the model at different stages of the experiment can lead to a distortion of the real dependence of the analyst's performance on the considered cognitive clarity forming factors. Accordingly, considering the described effect is most relevant when these factors relate to the representation metaphor used. The desired mechanism can be implemented in two ways. The first method involves a constant change in the graph spatial arrangement or, in general, replacing the model with another one that has identical (from the point of view of the current visual analysis task) characteristics. The second way is to provide the analyst with the possibility of a preliminary study of the model (primarily its structure) for subjectively sufficient time.

One of the key concepts of the considered approach is the type of experiment. We will understand it as the result of formalization of the visual analysis task from the point of view of its formal goal. The type of experiment acts as a very general class that combines many real tasks of visual analysis of various graph models characterized by a similar shape.

We can distinguish the following main types of experiments, which reflect the nature of typical situations that arise in the visual analysis of real graph models, and at the same time are quite simple in terms of implementation:

1. Selection on the entire set of elements of a subset that satisfies the specified restrictions on attribute values (attributes refer to any characteristics of graph model elements related to certain data types [17]). A special case of this type of experiment is detection of any one element that fits the specified restrictions.
2. Ranking elements (or some subset of them, also visually distinguished based on values of other attributes) in ascending or descending order of the value of some target attribute. A special case is finding an element with the optimal value of the target attribute (with possible consideration of restrictions on the values of other attributes). For example, when analyz-

ing cognitive models of semi-structured systems, this type of experiment corresponds to the problem of identifying concepts that are of the greatest interest from the point of view of controlling the system being simulated [20].

Other types of experiment are also possible, reflecting more complex or, conversely, specific tasks of analyzing graph models and visual models in general [21, 22].

Taking into account the above, it is possible to propose a generalized algorithm for setting up and conducting an experiment, which includes the following steps (Figure 4):

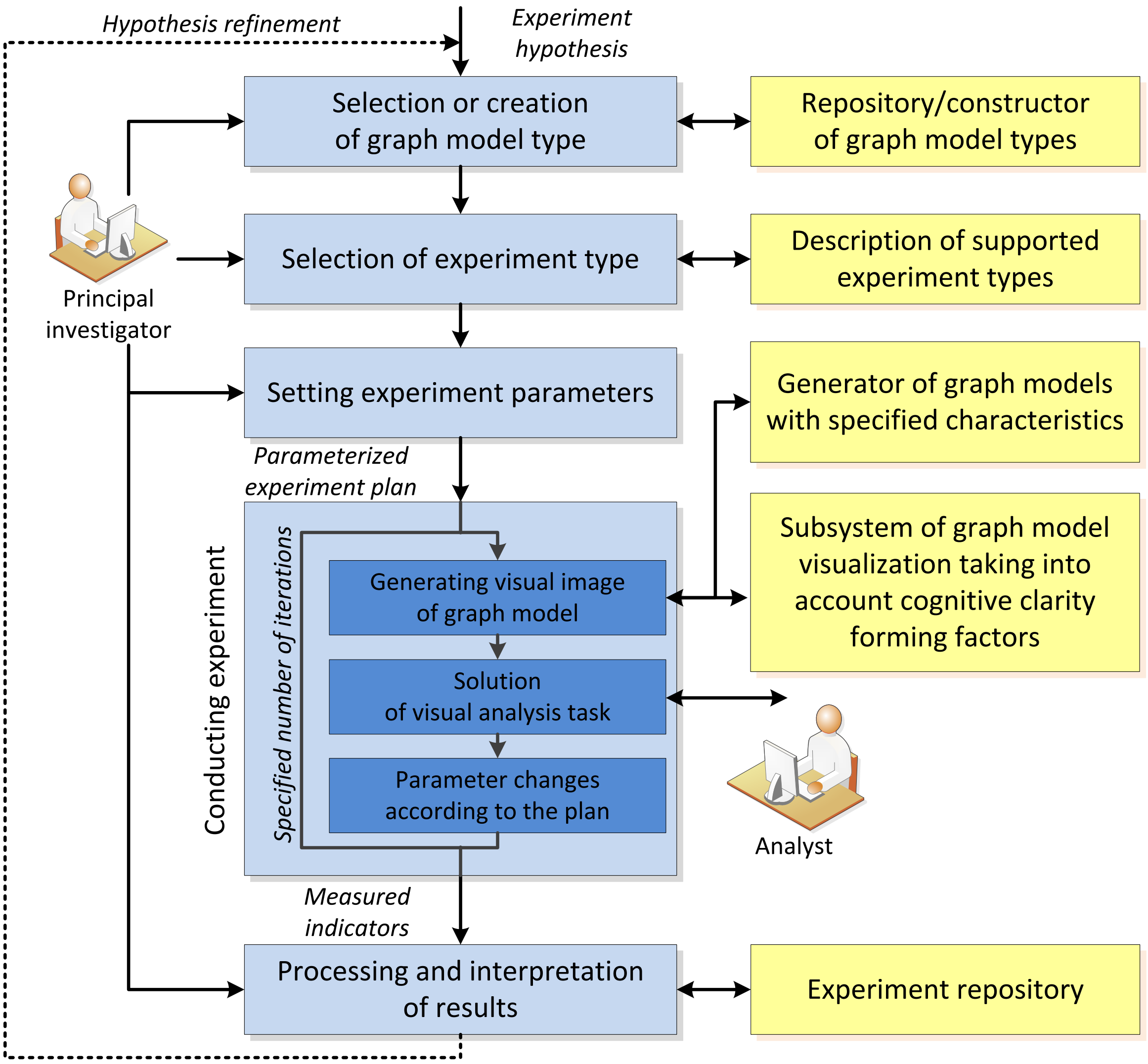

Figure 4 – Generalized algorithm diagram for setting up and conducting an experiment

1. Selecting a graph model type or creating an “abstract” type on which the experiment will be conducted.

2. Selecting experiment type, i.e. defining what exactly is meant by solving a visual analysis problem from a formal point of view.

3. Setting experiment parameters. There are several groups of parameters depending on various factors.

a) Parameters depending on the model type. Here, for example, a subset of model attributes participating in the experiment is indicated, and also a range of model sizes is specified, within which the number of its elements should vary (a special case involves conducting an experiment on models of one specific size).

b) Parameters depending on the type of experiment. This group formulates in detail conditions for solving a visual analysis problem (restrictions on attribute values, the attribute to be optimized and the direction of its optimization, etc.).

c) Parameters determined by the hypothesis. Here cognitive clarity forming factors and variation ranges of their values are set, as well as the measured indicator of visual analysis efficiency (or a set of them).

d) General parameters. These include, for example, the number of repetitions of solving the same visual analysis problems in order to eliminate the influence of the random factor.

4. Conducting an experiment with the parameters set at the previous stage. Each iteration of the experiment involves presenting the analyst with a visual image of the graph model (which, as a rule, is pre-generated randomly and visualized taking into account cognitive clarity forming factors under study). After that, the analyst is required to quickly solve the task of visual analysis and register the achieved result (at the same time the specified indicators are registered). The task re-execution mechanism itself is used both to eliminate the influence of the randomness factor (in accordance with the above requirement) and to vary the parameter values, the change of which is provided for by the experiment plan (model dimensions, values of cognitive clarity forming factors, etc.).

5. Processing of the results, as well as, if necessary and possible, their coordination and combination with previously obtained results of similar experiments in order to identify the desired patterns and dependencies more reliably and more accurately evaluate the initial hypothesis.

Depending on the type of experiment, the process of solving a visual analysis problem can be considered completed when one of the following conditions is met:

1. The analyst received a completely correct answer to the question of the problem. In the event that the recorded answer does not meet the specified correctness criteria, the analyst can be notified of this using a visual signal, with a possible hint pointing to specific elements associated with the errors made.

2. The analyst received an answer close enough to the correct one, taking into account a predetermined error margin.

3. The analyst, in principle, registered some answer.

4. The time allotted for solving the problem has expired.

Indicators of visual analysis efficiency (characterizing the effects of cognitive clarity presence), depending on the hypothesis, can include time for the analyst to achieve the correct or close to the correct answer, the completeness of the visual analysis problem solution (i.e., percentage of its completion in the allotted time), the number of errors made, etc.

6. An example of setting up an experiment within the framework of the proposed approach

As mentioned above, it was noted in [17] that it is of interest to experimentally verify the discovered contradiction between the volume of the graph model representation metaphor and its cognitive clarity, as well as the possible relationship of this contradiction with Hick's law. With this in mind, one of the possible ways to use the proposed experimental approach can be to study the dependence of the efficiency indicators of graph model visual analysis on the volume of the visual image of this model, i.e. the number of different visual features it contains. A priori, it is assumed that from the point of view of the time indicator for solving the problem, this dependence should obey a pattern that is similar in structure to Hick's law.

Thus, the following experimental setup can be proposed.

- The time taken to complete the visual analysis task is used as the target for cognitive clarity.
- The volume of the representation metaphor is a variable factor in the formation of cognitive clarity, the influence of which needs to be investigated.

- The following relationship between the factor and the target indicator is considered as a hypothesis: an increase in the volume of the representation metaphor (which entails complication of the visual image) leads to a decrease in the cognitive clarity of the model visual image (which is expressed in an increase in the time for solving the visual analysis problem).

A possible way to conduct an experiment is to conduct it in the context of visual analysis of Silov's fuzzy cognitive maps [8, 20]. At the same time, one of the most relevant problems can be chosen for this type of model as a specific task of visual analysis – the problem of identifying concepts that are most preferable from the point of view of providing control actions on the system under study. This task refers to the second type of experiments described in section 4: ranking concepts by the value of the selected target attribute. In this case, this attribute is a systemic indicator of the concept's influence on the system [8].

In accordance with the recommendations given in section 4, the complexity of the cognitive model itself (the number of concepts in its composition) should vary, as well as the repetition of solving problems of the same complexity a given number of times (in order to counteract the influence of randomness) should be provided.

Examples of visual images of a fuzzy cognitive model that have different volumes of the representation metaphor that can be presented to the analyst during the experiment are shown in Figure 5 (the difference in volumes of the representation metaphor for these visual images was discussed in [17]). Let us also note that randomly generated abstract cognitive models with the required characteristics can be used in the experiment in addition to cognitive models of real tasks.

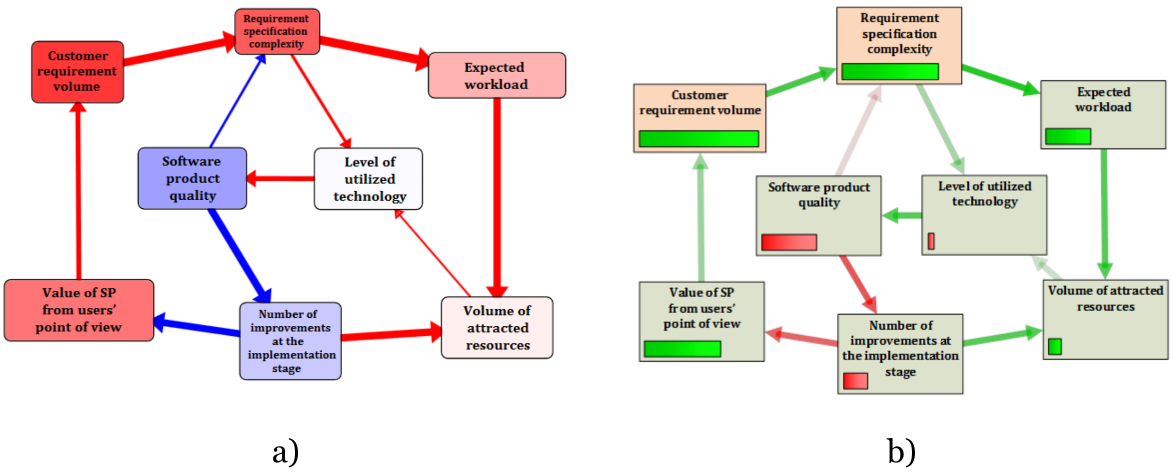

Figure 5 – Examples of visual images presented to the analyst during the experiment: a) smaller volume of representation metaphor; b) bigger volume of representation metaphor (source: [17])

Based on the results of the experiment, it is necessary to assess the degree of similarity of the revealed pattern with Hick's law. The technique for assessing such similarity belongs to the statistical analysis field.

Obviously, in addition to an increase in the time spent by the analyst on solving the visual analysis problem, a decrease in the cognitive clarity of the model visual image can manifest itself in deterioration of values and other indicators. So, in the context of the described problem, other relevant indicators to be measured may be the following:

- The degree of solution correctness (without limiting solution time). This indicator, in fact, will determine the correctness degree of ranking concepts by the analyst according to the value of their influence on the system. Violation of the ranking correctness, generally speaking, can also arise due to the analyst's insufficient attentiveness, especially in situations where some two concepts affect the system with approximately the same force. However, it seems very plausible to assume that high complexity of a visual image will contribute to the distraction of the analyst's attention, which will increase the probability of human error. A specific nature of such a dependence is not clear a priori and, apparently, can only be established experimentally.

- The degree of solution completeness (for limited time). This indicator is generally "symmetrical" to the indicator of time spent on the complete solution of the problem. However, an important point, leading to less predictable results, may be additional discomfort for the analyst associated with the requirement to meet a limited time period. Let us note here that this aspect of stress effect on the results should be studied separately. In any case, it is assumed that more complex and information-saturated visual images will slow down perception and reduce the value of the indicator under consideration.

Identification of dependency nature for all of the above indicators will provide an opportunity to form a more comprehensive and reasonable idea of how the complication of a graph model visual image leads to deterioration in its perception by a person, and in what particular negative consequences this manifests itself. All this will become a theoretical basis for developing practical recommendations for optimizing the complexity of visual images of models in various applied problems.

The results of the experiment carried out in the described setting are planned to be presented in one of the future works. Let us also note that, in the future, it will be necessary to conduct similar experiments with other types of graph models and visual analysis problems, followed by generalization and systematization of the results for a more complete assessment of the patterns under study.

7. Conclusion

The article proposes the authors' interpretation of the idea of cognitive clarity of graph models and related concepts and phenomena. On its basis, an approach is proposed to organize experimental research aimed at studying the influence of certain factors on the cognitive clarity of graph models by measuring various indicators characterizing the degree of manifestation of the effects of cognitive clarity presence. An example of setting up an experiment is given, the purpose of which is to study the dependence of efficiency indicators of visual analysis of a graph model on its visual image volume.

The concepts considered in the paper and the proposed experimental approach provide an extensive basis for promising research aimed at their refinement, generalization, improvement and application. According to the authors, the following areas of research seem to be the most relevant:

1. Approbation of the proposed approach to organizing and conducting experimental research when testing specific hypotheses about the influence of certain factors on forming cognitive clarity of various graph model types.
2. Studying possible mutual influence and mutual conditioning of the factors that generate cognitive clarity and relate to different levels of metaphor (primarily in the aspect of the questions formulated in section 3 of this article). In addition, an important subject of research may be the synergetic effect that occurs when the analyst perceives a visual image due to the combination of cognitive clarity effects from both levels of metaphor.
3. Development of methods for adaptive planning and experiment control, including methods for combining and coordinating the results obtained at different stages of its implementation, dynamic adjustment of parameters, etc. It seems that such methods will help optimize the volume and content of visual analysis problems presented to the analyst during an experiment, taking into account the requirements of reliability and statistical significance of the results. These methods can be based on the approach described in [23].

In addition to the above areas, it is of considerable interest to study the degree and limits of applicability of the concepts outlined not only for graph visualization problems but for other classes of visual models and also, in the long term, for any problems of visualization and visual information perception of various nature.

Finally, a separate large area of research to be considered is the role and place of the subjective factor of a human analyst in the described concepts. This refers mainly to the influence of analyst's individual perception and other psycho-emotional characteristics on the course of solving various problems of visual analysis and the indicators recorded in this case. The degree of generality and universality of theoretical and practical conclusions that can be obtained on the basis of the above approach in the future depends on the completeness of the study of this topic.

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