Visualization of Mental Map Representation Patterns

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Abstract
The paper is devoted to the automation of visual analytics of digital mental map representation sets. Digital mental map representations are digital drawings of some certain spaces made by humans, reflecting their spatial experience and distinctive thoughts they have about the considered spatial places. The subjectivity behind mental maps fundamentally distinguishes them from the geographical maps and makes them a very fruitful material for Digital Humanities research. To unveil the potential of this research, in the previous works we developed the Creative Maps Studio vector graphics editor to enable informants intuitively draw their mental maps. In the present work, we enrich Creative Maps Studio with ontology-driven analytical subsystem to enable in-place handling of mental map representations. The proposed subsystem provides visual tools to describe the processing pipeline of mental map representations using a data flow programming paradigm wherein each processing step is described by ontology. This approach proved its flexibility and efficiency in solving different visual analytics tasks. The implemented analytical modules allow automatically render a set of mental maps representations in the graphical form and to view statistical characteristics of individual objects from these representations. The process of data preparation and visualization is described. The suggestions are proposed on the interpretation of the result. The pros and cons of using the proposed method are discussed along with the possible directions for its further development.

Keywords
Mental Map, Digital Mental Map Representation, Mental Map Aggregation, Mental Map Visualization.

1. Introduction

The methods of studying mental maps have changed due to the development of digital technologies. It became clear that the study of mental maps using digital technologies has some advantages [1, 2, 3, 4]. Some digital systems for working with representations of mental maps have appeared [2, 5, 6], including the Creative Maps Studio application (https://creativemaps.studio), which has been developed to allow creating digital representations of mental maps. More than 800 maps from 9 regions of Russia were collected by using this application. In order to analyze the general perception of the country by the residents of each region, an analytics component was developed within Creative Maps Studio. One of the modules of this analytics component is a pattern visualization module (PVM). Pattern consists of a set of maps drawn by the residents of a certain region. PVM is the subject of this paper.

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In addition to describing the operation of the PVM itself, its input and output data are also discussed. Several interpretations of the output data are proposed along with the discussion of pros and cons of using the PVM rendering results. Some assumptions are made about possible future works.

It is worth noting that the terms 'representation of a mental map' and 'mental map' are not well-established yet, so other authors may use different terms to denote these concepts, for example 'mental map' (to refer to what is here called a 'mental map representation') [7, 8], 'cognitive map' [9], 'sketch map' [10]. As a rule, it depends on the specifics of the scientific field and the preferences of the researchers.

For the sake of clarity and disambiguation, let us define the terminology to use hereafter. **Mental map** – a representation of a certain space in someone's mind, possibly in conjunction with some subjective representations of a non-spatial nature (if a person's map is being considered). **Mental map representation** – a reflection of a mental map on some material storage (for example, paper or computer memory). **Mental map representation pattern (or just pattern)** – a data structure that stores information about the objects in mental maps representations from a certain set. In the present work, only settlements are considered as objects included in patterns. **Mental map representation pattern visualization (or just pattern visualization)** – an interactive graphical representation of the pattern in the form of a two-dimensional chart.

2. Key Contributions

The distinctive new features proposed are the following:

1. The ability to automatically visualize a set of mental maps representations in the graphical form (pattern rendering).
2. The ability to view the coordinates dispersion of settlements within the pattern and compare the frequencies of occurrence of any settlements on maps (it is possible to choose which settlements will be displayed).

3. Related Works

Hypotheses about the existence of mental maps are suggested not only in relation to people, but also in relation to animals. Since there are no known cases of animals drawing representations of mental maps, as a rule, their mental maps are studied indirectly. Only assumptions can be made about how mental maps are arranged (if their existence is taken for granted) based on how animals act in space. A pioneering work in this field is [9] followed by [11, 12]. In these works, statistics are usually collected on the actions of animals and the frequency of actions that more or less contribute to the achievement of the estimated goal (usually, the foraging).

As for people, here a wider range of research tools is available. A person can be asked to draw something or fill out a survey. In the present work we concentrate on the map drawings, as a natural way to represent mental maps.

Informants can draw on ready-made maps, marking features, which are important for them [3]. They can draw maps on their own from scratch, both on paper [13, 14, 10] and on digital devices [4]. Accordingly, generalized analysis can also be carried out in traditional form [13, 15] or in digital form [2, 4]. In the latter case, as a rule, the researcher manually draws up a pattern visualization. In other words, a qualitative assessment takes place [13, 14]. Quantitative assessment is also used, but it usually involves some expert steps [2].

At the same time, it is important to note that mental map representations are sustained reflections of information from the real world, albeit this information is modified [10, 16]. So, the study of representations of mental maps is considered relevant to Digital Humanities research.

4. Background

The mental map representations used in this work as a data source are collected in digital format using the Creative Maps Studio application developed earlier [6]. The analytics component (the PVM is a part of) is built using the ontology engineering principles and data flow programming paradigm. This approach was first introduced in the SciVi ontology-driven visual analytics platform and proved its efficiency in solving real-world visual analytics tasks from different application domains [17]. The analytical pipeline is being described as a data flow diagram – a chain of operators linked by data. Each operator has its certain typed inputs, outputs, settings, and implementation described by a lightweight ontology using predefined concepts like 'Operator', 'Input', 'Output', 'Setting', 'Worker', etc., and paradigmal relations 'is_a', 'a_part_of', 'has', and 'is_instance'. This allows defining the analytical capabilities in a knowledge base, and thereby easily extending the module's palette of operators without manual changes of its source code.

The idea of generalized visualization of mental map representations was already discussed in [18]. In this work, maps were collected in the traditional form, and the visualization of the generalized pattern was built manually. To do this, the researcher looked at maps, selected the most frequently drawn settlements, calculated the dispersion and median values and drew these data in the form of a diagram (an example of a diagram from [18] is shown in Figure 1). However, with the advent of digital technology, it became clear that the process of calculating the patterns can be automated. Moreover, more information can be extracted from digital maps. Therefore, it was decided to develop an analytical component in the Creative Maps Studio, in which it would be possible, among other things, to visualize map patterns.

5. Analytical Module of Creative Maps Studio

At the moment, an analytical module is being implemented in Creative Maps Studio, based on the visual data flow programming concept. Generally speaking, this analytical module contains not only the visualization algorithm presented below, but also other algorithms, however they are not considered here laying beyond the scope of the present work.

The point of creating a visual programming system directly in the Creative Maps Studio is that it allows you not to send large input data over the network to the third-party software (for example, to the SciVi platform), and also allows you to use algorithms and software components, which are implemented using the React framework.

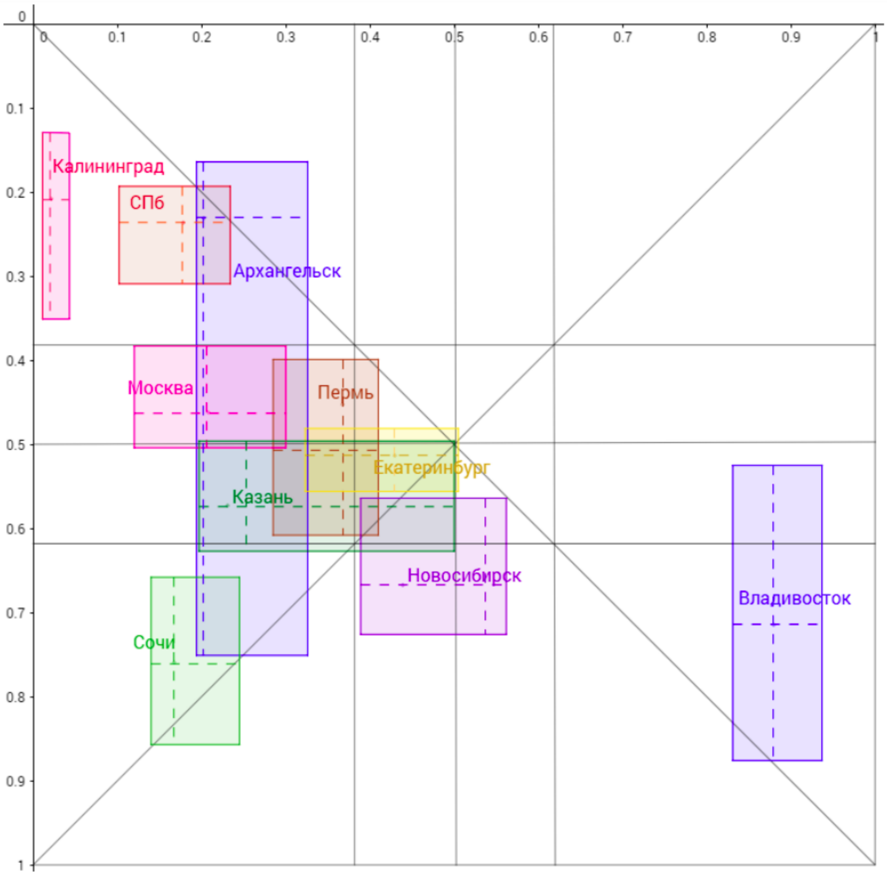

Figure 1: Mental maps pattern visualization diagram from [18].

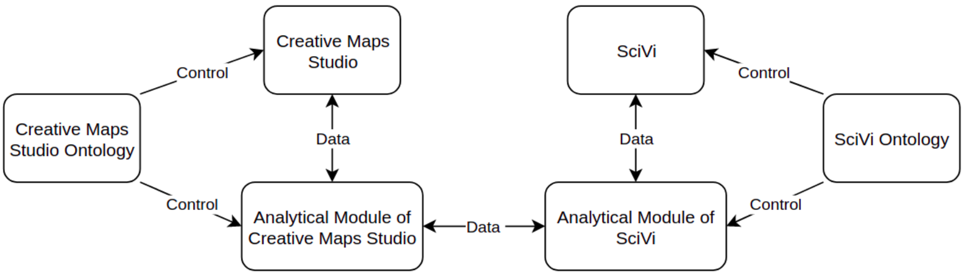

Figure 2: The scheme of the proposed interaction based on the API of the Creative Maps Studio and SciVi.

As a future work, we plan to set up the interaction of the SciVi and Creative Maps Studio systems in terms of data exchange via API (remote procedure call). This will allow using the data processing and visualization algorithms of both systems together without duplicating the code (see the diagram in Figure 2). The pattern visualization algorithm is implemented as one

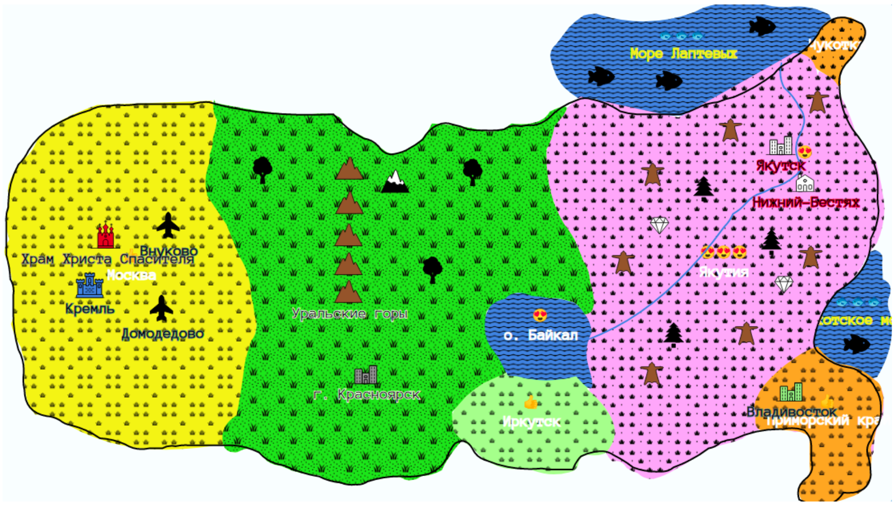

Figure 3: An example of a digital mental map representation.

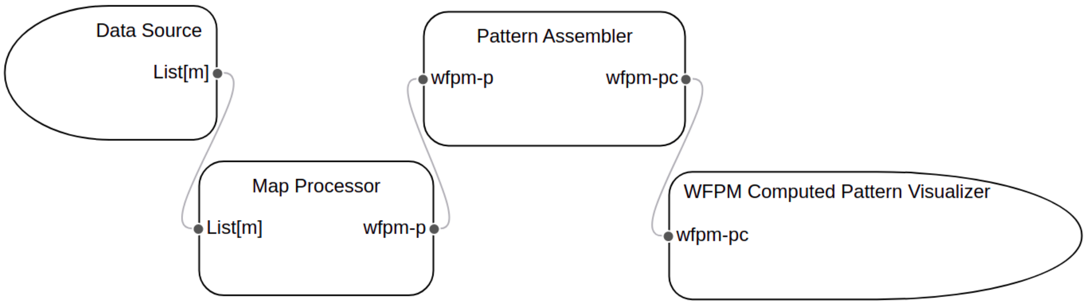

Figure 4: Data flow diagram for pattern visualization.

of the software modules inside the analytical component and is executed on the studio client.

6. Data Preparation

To begin with, for visualization, it is needed to create a pattern from the maps. Figure 3 shows an example of such a map. Figure 4 shows a data flow diagram that describes a step-by-step transformation of a set of source maps into a pattern and visualization of this pattern. Each module performs some data transformation algorithm. The inputs and outputs indicate the types of data that must be submitted to the input and which will be returned as a result of the algorithm. The “Data Source” module has no inputs and is designed to download data from a server or local computer. As it can be seen in the diagram, the processing is as follows. First, a list of maps is loaded (the data format List[m] denotes a list of maps). After that, the maps are processed using the Map Processor module. This module removes data from maps that are not relevant to the visualization (for example, the history of editing objects, the objects not recognized as settlements, etc.) and performs some other transformations (for example, decomposes color codes into three numerical channels, normalizes the settlements' coordinates, etc.). As a result of the work of this module, a file of the wfpm-p format (Weighted Fuzzy Pattern Matching - Pattern) is obtained. This format was used to classify the maps relying on the WFPM algorithm (see [19]). The output file contains a dictionary of maps, each of which is a dictionary of settlements, each of which is a dictionary of parameters with values that characterize this settlement. A simplified format of this file is shown in Listing 1.

Listing 1: Simplified wfpm-p format example.

```
{
    "100-162-2": {
        "Moscow": {
            "colorB": 140,
            "colorG": 120,
            "colorR": 100,
            "fontSize": 10,
            "creationTime": 4,
            "volume": 40,
            "x": 270,
            "y": 100,
            ... //other parameters
        },
        ... //other settlements
    },
    ... // other maps
}
```

Further, the maps from the file are combined into one aggregated map using the "Pattern Assembler" module. As a result of its work, a file of the "wfpm-cp" ('c' means 'computed') format is obtained, containing the occurrence frequency distributions of parameters for all settlements (normalized by the maximum frequency) and the frequencies of settlements. The simplified format of this file is shown in Listing 2.

Listing 2: Simplified wfpm-pc format example.

```
{
    "Moscow": {
        "colorB": {
            ...
            "140": 0.7,
            "150": 0.5,
            "200": 1,
            ... //other values
        },
        ... //other parameters
    },
    ... //other settlements
}
```

7. Pattern Visualization

When visualizing objects on the map using the "WFPM Computed Pattern Visualizer" module, the weighted average of the distribution is taken as the parameter value for the settlement (counting the frequency as the weight). At the same time, to display the color, the weighted average values of color channels are simply combined into one RGB color. We can say that in fact the values of the parameters that are displayed on the map may not exist in the maps themselves. After all, the values of the parameters are averaged. In other words, suppose that the distribution of values for any parameter has more than one occurrence frequency concentration center. Then the visualization will give an average result, which is not really the most frequent on the maps.

However, the occurrence of a situation in which the distribution has several peaks in different places rather indicates that the informants were incorrectly grouped. Perhaps the group is too large and it should be further divided according to some attribute. Therefore, this shortcoming was rated as having little effect.

Another reason for the large spread of values in a distribution may be the existence of settlements with the same names in different places. In this case, an expert review is needed. This usually applies to small settlements, such as villages.

Let's move on to the consideration of the pattern visualization itself. An example is shown in Figure 5. The pattern displays the average values of various parameters of settlements that were found on the maps of this pattern. The circles represent the settlements themselves. The size of the circle reflects the weighted average size of the settlement on the maps. The color of the circle (except for the alpha channel) reflects the weighted average color of the settlement. The color and size of the locality label reflects the weighted average of the map labels. The number after the caption in brackets shows the order in which the object is drawn on the map. That is, for example, in the illustration below, the informants draw the settlement 'Москва' (Moscow) on average earlier than 'Санкт-Петербург' (St. Petersburg), but later than 'Бийск' (Biysk). The alpha channel reflects the frequency of occurrence of the settlement on the map

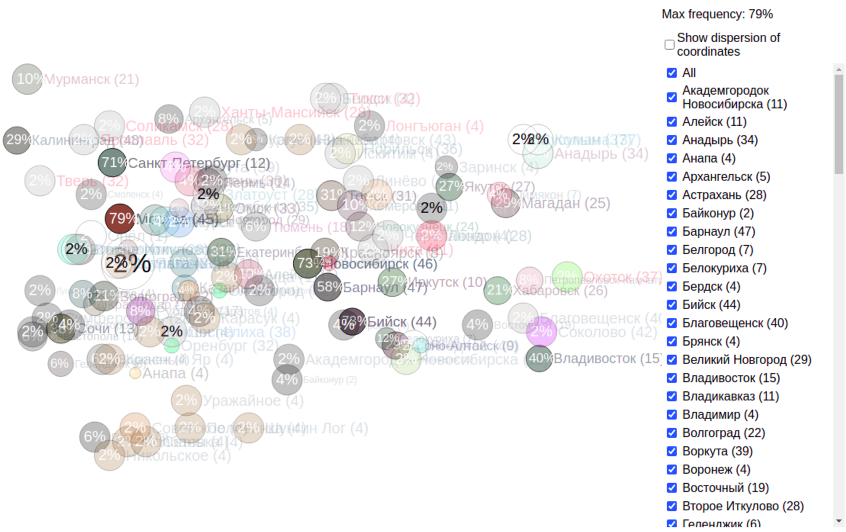

Figure 5: An example of a visualization of a pattern assembled from maps drawn by informants from the Altai region of Russia.

(in addition, the quantitative value of the frequency is indicated as a percentage in circles). The greater the transparency, the rarer the object occurs, and vice versa (at a minimum frequency, transparency takes on a value of 20%). In this case, the frequency of the most opaque object at the moment is displayed in the upper right corner (in Figure 5 it is 74%).

It is also possible to display coordinate spreads for settlements. However, it is more convenient to do this when there are few settlements on the pattern visualization. Figure 6 shows an example of manual filtering of objects on the map with display of coordinate spreads (the 'Show dispersion of coordinates' option is set). It can be noticed that the maximum frequency among the displayed objects is 79%, while the most frequent object displayed is 'Москва' (Moscow). And it can be seen how accurately the informants imagine the positions of the settlements (the most accurate result here is for the settlement 'Казань' (Kazan), because it has the smallest spread).

8. Results Interpretation

The visualization of the map pattern makes it possible to obtain some generalized information about the informants' collective ideas about the object of study. In particular, firstly, looking at the pattern, we can find out which settlements are in the center of attention of the informants and how they approximately appear (although the visualization of the pattern provides much more scarce information regarding the image of the settlement (color, size, etc.) than if the text layer of the maps were analyzed). Secondly, we can compare the frequency of drawing an arbitrary group of settlements on the maps (marking them in the column on the right in both Figures 5 and 6). Thirdly, it is possible to obtain information about the positioning of settlements: how uniform is the opinion of informants about the location of a certain settlement.

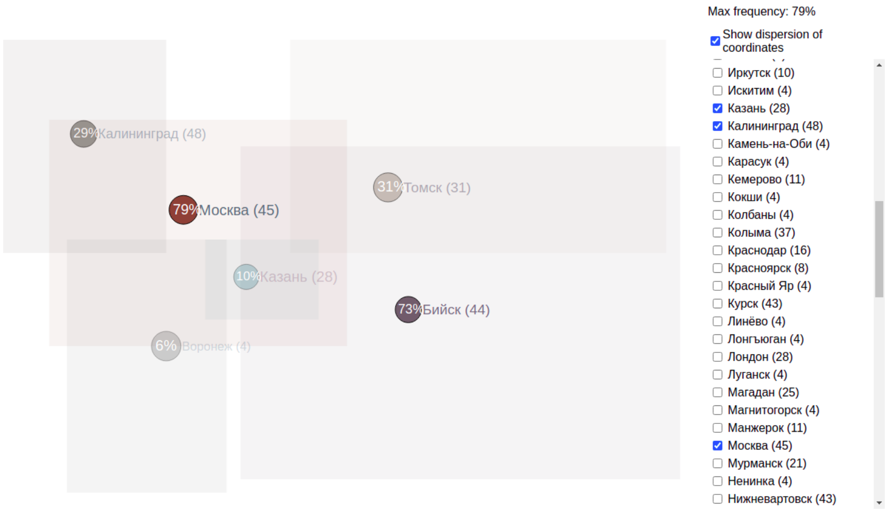

Figure 6: An example of manual filtering of objects on the map.

Fourth, you can get information about the approximate order in which cities are drawn on maps.

Also, in some cases, it is possible to determine the settlement of residence of the majority of informants from the sample. This is possible due to the fact that informants more often mark the capital and other settlements from their own region, that from the foreign regions. The exceptions are the cities of 'Москва' (Moscow) and 'Санкт-Петербург' (St. Petersburg), which are often marked on the map, regardless of the region of residence of the informants, since they are the largest and most valuable Russian cities in terms of culture, politics, and economy. However, according to our experience, this exception does not significantly affect the definition of the informants' region of residence.

9. Conclusion

In conclusion, it can be said that automating the processing of map data (in this case, pattern rendering) has some advantages. First, in terms of visualization, graphical display of a pattern can help to generate or test hypotheses faster than having only a set of maps, which can be viewed separately from each other, or some textual data, which describes this pattern. Secondly, it allows us not to waste time on routine operations with maps. For example, some quantitative calculations and comparisons of maps can be done automatically, since maps have a well-defined format.

Of course, the proposed approach also has its drawbacks. First, expert input is needed in the early stages of preparing patterns. The researcher needs to determine how to recognize whether an object is a populated area or not. To do this, it is necessary to compile a dictionary of settlements, including in it, in addition to the official names of settlements, also informal names, which informants may use to designate these settlements. Of course, the more maps, the less such participation is required in the future (new maps will contain less and less new settlement names), since for any settlement the set of its possible names is quite limited. Secondly, as mentioned earlier, there is an ambiguity problem for many small settlements, such as villages, and a few large ones, for example, the cities of 'Ростов' (Rostov) and 'Ростов-на-Дону' (Rostov-on-Don) (both can be called 'Ростов'), 'Великий Новгород' (Veliky Novgorod) and 'Нижний Новгород' (Nizhny Novgorod) (both can be called 'Новгород'), etc.

Nevertheless, the visualization of the patterns seems to be appropriate and quite informative. Moreover, this visualization can be improved.

10. Future Work

There are several directions for further research development. First, it can be tried to compare the visualized pattern with the real geographic objects (in different projections). So it can be possible to get information about the accuracy of the positioning of the settlement relative to its real position. It is likely that for many localities there will be a regular shift. Saarinen mentioned this phenomenon in [14]. Moreover, there are quite a lot of works in the field of comparing representations of mental maps with GIS (for example, you can see a review of similar works in [1]).

Secondly, it is possible to expand the set of objects for visualization by including, in addition to human settlements, other anthropogenic and natural objects. Although different categories of objects may have some features related to their recognition and positioning, which will also need to be taken into account.

Perhaps pattern visualization can be useful not only for the analysis of mental map representations. Despite the fact that it is not yet known whether there are data of a similar format in other scientific fields, it is considered appropriate to organize API interaction with the SciVi visualization system so that, if necessary, it would be possible to use the created visualization module in other application domains.

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