DE GRUYTER
OPEN

DOI: 10.1515/pjap-2015-0065

Polish Journal of Applied Psychology
2016, vol. 14 (4), 9–34

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CogMap Analyst – a quantitative analysis of the structure and content characteristics of sketch drawings of cognitive maps of urbanized spaces

Abstract

The paper presents the specification of the CogMap Analyst program, which has been created for the purpose of conducting an analysis of the structure and content of sketch drawings of cognitive maps of urbanized spaces. Assumptions for this analytic tool come from the neobehavioral understanding of the concept of cognitive maps, which has its source in the works of Tolman, and from the criteria of analyzing their contents and structure, which were developed by Lynch (1960). The program serves the purpose of collecting numerical data on the quantity, size, as well as placement and distortion of objects on drawings by participants in relation to the actual layout of the terrain, which was selected by the researcher, and to the sketch's scale. This data may be used not only to determine the measurements on drawings, but also to determine possible connections with other variables, such as personal traits of participants and formal traits of the space, according to the research goals of particular scientific studies for which the CogMap Analyst program shall be used. In this article we present the theoretical basis for the tool that we have created, we compare its characteristics with

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other similar methods of quantitative analysis of sketch drawings of cognitive maps, and we present in detail the mode of operation and of data analysis employed by CogMap Analyst.

Keywords

cognitive maps, sketch maps, LabView, quantitative analysis

Streszczenie

Niniejszy artykuł przedstawia charakterystykę programu CogMapAnalyst stworzonego na potrzeby dokonywania strukturalnej i treściowej analizy rysunków szkicowych map poznawczych przestrzeni zurbanizowanych. Założenia tego narzędzia analitycznego opierają się na neobehawiorystycznym rozumieniu konceptu map poznawczych wywodzącym się z prac Tolmana (1948) oraz kryteriach ich analizy treściowej i strukturalnej wypracowanych przez Lyncha (1960). Program umożliwia zebranie danych liczbowych odnoście liczby, rozmiaru oraz rozmieszczenia i zniekształceń obiektów na rysunkach badanych w odniesieniu do rzeczywistego planu terenu, a także zastosowanej przez badanego skali jego szkicu. Dane te mogą zostać wykorzystane nie tylko do określenia charakterystyk metrycznych rysunków, ale także do porównań z innymi zmiennymi, np. podmiotowymi badanych i formalnymi przestrzeni, w zależności od celów badawczych konkretnych studiów naukowych, do których program CogMap Analyst będzie wykorzystywany. W tym artykule prezentujemy podstawy teoretyczne stworzonego przez nas narzędzia, porównujemy jego charakterystykę z innymi podobnymi metodami analizy ilościowej rysunków szkicowych map poznawczych oraz przedstawiamy dokładnie sposób działania i analizy danych wykorzystywany przez CogMap Analyst.

Słowa kluczowe

Mapy poznawcze, mapy szkicowe, LabView, analiza ilościowa

1. Introduction

One of the main areas of research in environmental psychology, since the beginning of this scientific discipline's existence, has been the search for the mode by which people perceive and memorize space (Stokolos, 1978). These inquiries are part of the analysis of perception and cognition (Rovine and Weisman, 1989), and they categorize the mental representation of space created in a human mind as a so-called cognitive map. This type of cognitive representations is characterized by a strong variability in different groups and types of people (this matter has been more widely discussed by pioneers in the field, Downs and Stea (1973)). Thus the question of measuring and analysing cognitive maps is a topic not only for geography or urban planning, but also for psychology (cognitive and environmental psychology, as well as neuropsychology).

1.1. Characteristics of cognitive maps

In the broadest terms, a cognitive map can be defined as a personal representation of space and the objects within it, including all internal processes that enable: the acquisition and manipulation of information about the nature of the spatial environment (Kara, 2013), as well as the coding of symbolic aspects of the environment (Pinheiro, 1998). In other words: it is an individual, personalized reflection of what and how is perceived by a person, as well as what is used for planning and taking certain action in a particular spatial situation. Thus, as logically follows from the above definition, a cognitive map is not a map as understood in geography. Its purpose is not to precisely represent the measures of distance or angles according to Euclidean geometry (which is the main purpose of cartographical maps) (Buttenfield, 1986; Tversy, 1993). Cognitive maps are full of errors, deviations from actual measurements, omissions of many objects, and are linked to simplifications of meanings of objects (Pinheiro, 1998), combining them into patterns and configurations, which are meant to lighten the load on working memory and limit the use of cognitive resources. A simplified, incomplete, and imprecise scheme is meant only to provide data that are necessary for effective navigation, according to the preferences of the individual (Montello, 1992). Cognitive structuring enables organizing the world in a recognizable and manageable manner.

Unfortunately, cognitive representations cannot be analysed explicitly. We do not know what elements comprise a memorized image (verbal, numerical, or pictographic), and it cannot be precisely verified (Buttenfield, 1986). Thus, "third-hand products" are analysed – indirect expressions of knowledge about a space. In over seventy years of research into cognitive maps, numerous, diverse, and often innovative methodologies were developed, meant to enable the analysis of representations of varied areas in different groups and types of people (Downs and Stea, 1973). For the purposes of scientific studies of different aspects of cognitive maps, scientists have created a wide variety of tools designed to measure mental representations, differing as a consequence of the adopted research problems. The most common research tasks include analysing sketch maps of certain areas drawn by people, locating points on a base map, estimating the distance or direction between series of locations, and many more, in relation to real as well as virtual spaces, familiar or previously unknown to the research participants (e.g. Kitchin, 1996; Bors and Vigneau, 2011; Chaney, 2010; Foo, Warren, Duchon and Tarr, 2005; Tu Huynh and Doherty, 2007; Appleyard, 1970). Analysing yielded results was difficult, however, due to the specific nature of the gathered data, especially as regards sketch cognitive maps. In order to compare individual sketch drawings, to categorize them, certain methods are required that give a chance of making the data objective. And so the original sketch map analysis program, CogMap Analyst, was created, which shall be described in the further subsections of this paper.

1.2. Sketch drawing as a method of analysing cognitive maps

One of the classic methods of analysing cognitive maps is the sketch drawing method. Drawing is a natural way of expressing, sharing, storing, and creating knowledge (Eppler and Pfister, 2011). It is one of the most primal forms of representing mental images (Tversky, 2002). Drawing was a widely used method of communication long before the emergence of formal types of writing, as evidenced by, for instance, cave paintings. Furthermore, drawing a map of terrain is one of the most widely spread and most often used methods of representing space in most cultures (Hurtowicz and Adler, 1911). When we draw a simplified sketch map of a given area, we are able to convey not only spatial relations between individual objects, but also convey semantic meanings, which are based in the cultural and personal conditions of the drawer (this topic will be discussed more widely in further sections of the article).

1.2.1. Methodology of analysing the structure and content of sketch drawings

Despite its naturalness, this method of investigating cognitive maps through analysing sketch drawings creates considerable difficulties in conducting reliable analysis. This is because the mode of representing spaces is very much individualized, hard to study in a quantitative manner, as opposed to purely qualitative approaches. Through the decades of research into cognitive maps many different methodologies of analysing sketch maps have been developed (Downs and Stea, 1973). When investigating differences in cognitive maps in different groups and types of people it is important to assume that the structure of a sketch drawing of a cognitive map is connected to the process of reproducing the effects of memorizing information about a space on a sheet of paper, and that it is not formed randomly in the reporting phase (Buttenfield, 1986).

In 1960 one of the most important books on the matter of sketch drawings of cognitive maps has been published, Kevin Lynch's "The Image of the City". It put forth an innovative method of analysing sketch drawings of cognitive maps of urbanized spaces. It became the starting point for an analysis of sketch drawings in most of future studies (e.g. Banerjee et al., 1977; Cadwallader, 1976, 1979; Day, 1976; Lloyd and Heivly, 1987; Wong, 1979). The characteristics of sketch maps distinguished by Lynch are related to elements of their content – objects that appear on the map, and to elements of their structure, related to themetric properties of the objects (size and location in a given area).

1.2.1.1. Components of (the content of) a sketch map

Lynch distinguished five basic types of objects appearing on maps – landmarks, paths, edges, nodes, and districts.

Paths are just roads that, at least potentially, enable movement. They include streets, sidewalks, passages, canals and transit lines. Edges are linear elements of the landscape, which are not considered paths by users. They are boundaries of a sort, separating or connecting parts of the city. Their essence is the breaking of some kind of continuity. They can include river banks, sea or lake shores, moats and walls. The next element is districts, meaning medium-sized parts of cities which have some recognizable characteristic traits, which distinguish them from others. This gives the observer a mental sense of entering a district. The next kind of elements of cognitive maps is nodes. On the city scale these can be intersections, railway or communication nodes, squares, street corners. These places often gather large number of people and/or functions, and are characterized by their outward traits or by the functions that they fulfil. Landmarks are orientation points. Most of the time they are physical objects that are easily recognizable because of their outward characteristics (Lynch, 1960). They can be large objects (skyscrapers, mountains), distant or proximal, standing out in the surrounding space (monuments, memorials, fountains), adding expressiveness to the space (signs, shop signboards, atypical building facades). Landmarks are, therefore, objects with characteristic, easily spottable, and distinctive traits. Thus, objects in space that are related to decision making points in navigation (e.g. when to make a turn) become landmarks for the user (Arnold et al., 2013).

1.2.1.2. Structural elements of a sketch map

Based on the analysis of drawings of sketch maps yielded by study participants, Lynch distinguished categories of errors that occur most often. These errors are not related to the structure of the cognitive map. Rather, they spring from the specific nature of human cognitive processes, or are related to the personal conditions of the specific person, or to the formal characteristics of the space (for a review see: Stryjewska and Janda-Dębek, 2013), and they will be analysed further as such. The most often occurring types of errors described by Lynch (1960) include: *incompleteness*, *distortions*, and *expansions*.

Errors of incompleteness are omissions of certain elements of the environment – from small details, up to large and significant fragments. They may appear for different reasons, and may be related to ignorance of a given space, to ignoring elements that are unimportant to the observer or just disliked by him (Lewicka and Bańka, 2008). Errors of distortion of the actual image are related to the distances between elements and their relative, erroneous, placement in space. The third group of errors is expansions. As understood by Lynch, these are added elements, which do not appear in a given space in reality. This is caused by interference from earlier experiences and the contents of existing cognitive schema. Elements that are characteristic to a given schema are included in the image even if they do not appear in a particular exemplification of it. This phenomenon is called *default structuring*, and may often facilitate spatial orientation (Bell et al., 2004).

The errors described above are not accidental nor are they are purely a result of observer's ignorance. Rather, they appear to emerge as a consequence of the nature of human perceptual an cognitive processes. The number of errors that inevitably appear due to this nature may be reduced by local specific sensorimotor feedback (performing a specific action), as well as by local environmental cues (Tversky, 2003). Mechanisms that cause the errors are multicausal, and undoubtedly very beneficial for adaptation. Navigation based on schema of cognitive representation is, in most cases, adequate and effective (Tversky, 2003), as well as parsimonious with the use of cognitive resources.

1.3. Other characteristics of sketch drawings of cognitive maps of urbanized spaces

As we have mentioned before, the image of cognitive maps of urbanized spaces is formed subjectively in the mind of every human as a result of interaction between perceived external environment with the individual conditions of a given person. According to Appleyard (1970), the creation of a cognitive representation (including a cognitive map) is related to the domination of one of the modes of perception, distinguished by the functions they fulfil: (a) *operational* – related to carrying out concrete tasks; (b) *communicational* – related to passive reception of signals and symbols; or (c) *interferential* – related to analysing and comparing perceived objects with prototypes that were seen earlier.

Based on this division, Huynh et al. (2008) distinguished three types of organization and structuring of elements of cognitive maps: *sequential*, *spatial*, and *hybrid*. The distinguished types of cognitive maps are related to the differentiation in the process of prioritization and grouping of elements of space. Each level of organization reflects a subjectively felt level of significance of particular elements (Banai, 1999; per: Huynh et al., 2008). The sequential model emphasizes the importance of elements related to the communication network (roads-links) and the borders that it created between each area, as well as the framework for placement of other objects. The spatial model is based on the priority of the identification of points in space that are important for the observer (landmarks), the third model combines the features of both (Stryjewska and Janda-Dębek, 2013).

Like with other structures of knowledge, attitudes affect the way of processing information about objects to which they pertain (Wojciszke, 2002), and are related to (a) selectiveness in seeking information (we seek information concordant with our attitude (Frey, 1986)), (b) tendentiousness of perceptions and conclusions (data and information from the environment are interpreted, and conclusions concordant with our attitude towards an object are drawn based on that (Wojciszke, 1980)), and (c) selectiveness of memory (we remember facts concordant with our attitude, and we remember more information about objects toward which we have a positive attitude).

Attitudes and personal engagement (e.g. emotional engagement) affect the image of cognitive maps in relation to estimations of distance and size between particular objects, among other things. Eckman and Bratfisch (1965) were the first to present results pointing to a link between emotional disposition and subjective distance to an object. This was confirmed by later research, showing that attitudes may be linked to selective deformations (e.g. distances to countries towards which the participants held negative attitudes were overestimated in studies (Carbon and Hesslinger, 2013)).

Some landmarks, like a person's home or workplace, also become anchoring points for individual images of cognitive maps. Each user of a space uses some objects as subjective landmarks. These may be places that are important due to personal experiences or are related to the values of a social group of which a given person is a member. Their influence on learning and recalling spatial locations is just as strong as that of physical landmarks. Some traits of the physical environment are more important to a particular person or stand out in some other way, and thus are more likely to be remembered (Bell et al., 2004). People also remember more objects that have characteristics that interest them, e.g. restaurants or shops with particular stock in offer (Lynch, 1960), according to their interests. This is why, in the course of analyses of content and structure of cognitive maps of urbanized spaces, it is important to determine the affective component of the participant's attitude towards a particular area, as it is a significant information about a potential reason for the appearance of a given kind of distortions.

Apart from the properties of sketch maps flowing from personal traits of the participants, it is also important to realize that formal qualities of the space have a significant effect on the remembered image of a given environment. Legibility is one of the most important qualities of this kind. According to Lynch's (1960) definition, legibility is a quality of an environment that causes its parts to be easily recognized and organized by the user into a coherent pattern. A legible environment implies that it is easy to learn and memorize its structure, which in turn facilitates navigation. Legibility may also affect emotional reactions, and make the space seem more aesthetic and attractive (Bell et al., 2003). In other words: a city is legible when it is easy to create a cognitive representation of it, and to find one's way around it (Lewicka and Bańka, 2008). According to Lynch, a legible space (or a well-designed space, from the perspective of an urban planner) is easy to remember thanks to well-known objects (symbols) in it, as well as widely known and available roads (Hauziński, 1998). This is why, when constructing the CogMap Analyst program, we have thought it important to include the possibility to gather data on legibility or illegibility of given areas among its functions.

1.4. Methods of analysing of sketch maps

In the last years scientists have developed different, analogue and computerized, methods of objectively measuring characteristics of sketch drawings of cognitive maps. Below we shall mention a few of them, whose theoretical assumptions and scope of analysed data is closest to our approach.

Montello and Ishikawa (2006) have compared the sketch drawings yielded by participants in their research to a cartographical map of the analysed area based on six points chosen by them (4 landmarks and 2 nodes). After doing the necessary scaling and rotation of sketches, they superimposed their image on a cartographical underlay in such a way as to make the marked objects overlap as much as possible. Next they used bidimenstional co-eYcient correlation, which yields information about the level of similarity between two maps on a scale of 0 to 1 (the higher the number, the stronger the similarity). To analyse the correlation of distances they have used Fisher's r-to-z transformation.

Imani and Tabaeian (2012) have used a very classic procedure in their research, which consisted of: (a) counting the landmarks, paths, and nodes presented on the sketches (contents of map); (b) counting the correct reproductions of connections between paths (analysis of map complexity); (c) analysis of correctness of placement of 8 landmarks on the sketch in relation to a cartographic map.

The CogSketch program, developed by Forbus' research team (Forbus et al., 2003; Forbus et al., 2008) is a system that is meant to analyse the structure of sketch drawings. It can be used for modelling spatial inference. Spatial abilities and learning spaces by participants are tested by analysing drawings with respect to different aspects, such as: the employed spatial language, spatial representations, and analogies. CogSketch uses qualitative topological and orientation relations presented on a sketch drawing to describe relations between the drawn elements.

Spatial Scene Similarity authored by Nedas (2006) and Nedas and Egenhofer (2008) offers using measurements of similarity between two images (e.g. maps) to compare them. Analyses are conducted for (a) similarity between objects on two images, (b) similarity between binary relations between objects marked on two images, (c) proportions of the total number of objects on both images to the number of objects that were matched on both images, and those that remained unmatched. Determination of the degree to which the images (maps) match is reached by searching for all possible associations between images and choosing the set of associations that gives the highest similarity.

In contrast to the methods described above, the CogMap Analyst program created by us enables a complex analysis of sketch cognitive maps. It makes it possible to count elements placed on a map independently from analysing numerical data, so it yields additional information from the same map. Acquisition of data on the placement and size of objects in relation to both the underlying map (a cartographic map of the studied area), and in relation to the particular distortions of regions on the sketch drawing allows for a wider view on the subject of the structure of mental maps.

The program, due to its method of detecting elements, also enables the analysis of those that were marked in an abstract manner (e.g. by placing a three-dimensional presentation of a building on the sketch). Additionally, due to the researcher's participation in the acquisition of data, it is possible to determine the location of erroneously sketched areas, even in a situation where objects' places are switched or where their orientation or shapes are changed. Systems of automatic acquisition of data simplify the researcher's work, however we must note that they require an adequate amount of information in order to conduct analysis. In other words: systems that automatically analyse sketches or that are based only on algorithms of relations between arbitrarily defined objects make it necessary to acquire drawings from the participants that have a predefined level of accuracy and detail; other sketches must be rejected due to insufficient data. Because we approach each sketch map individually, we can omit this problem and extract full information about the entire studied group, and not only relatively standardized maps. Moreover, CogMap Analyst enables the collection of data about any type of elements appearing on sketches, including when the entire space on the drawing is distorted. Analysing each object separately, and grouping them according to their position in areas, allows for a detailed look at each fragment of the sketch map and detecting distortions related to a single element, and not only determining the similarity of a sketch to the original plan as a whole.

2. Description of the CogMap Analyst program

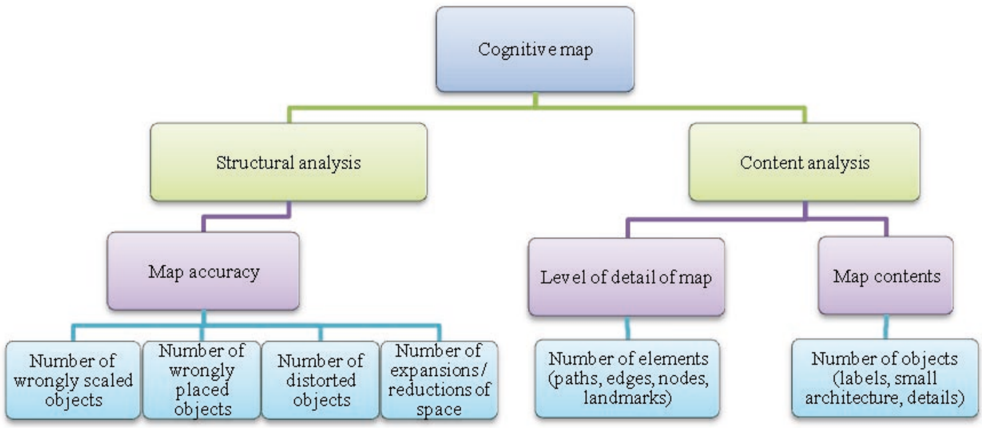
2.1. Theoretical assumptions

Because among the available research methods we have not found a tool that enabled easy and objective analysis of complex sketch maps of large areas, which would let us gather data about the content and structure characteristics of the drawings, and to make comparisons not only on the level of the entire map, but also in particular areas (districts), we have created the CogMap Analyst program.

Based on the knowledge and tools proposed by other researchers, we have developed a computer program that allows for a precise analysis of sketch drawings of cognitive maps of any area. Starting with Lynch's theory about types of elements and types of errors appearing on sketch drawings, we wanted to create a tool that would let us determine various characteristics of drawings of maps in an objective and measurable manner. Objective data gathered in this way could then be used for further analysis, including for studying relations between the characteristics of cognitive maps and the personal traits and/or formal traits of space.

The CogMap Analyst program is built on Tolman's neobehavioral conception, which assumes that organisms, in the course of exploring their environment, develop expectations as to the effects of their actions in the space through analysing the results of their earlier experiences (Tolman, Ritchie, and Kalish, 1946). Expectations that have formed in the process of learning a space create a cognitive map, understood as a set of patterns of behaviour in a concrete situation and the basis for searching for alternative behavioural choices in the event of unexpected changes in the environment.

Sketch drawings can be analysed with respect to their (a) structure and (b) content in order to determine their substance (components) and distortions (understood as errors described above according to Lynch's (1960) types). Based on the subject literature, we have constructed a model of analysing the drawings of cognitive maps in the form of a sketch drawing. The criteria of analysing sketch maps are shown on the graph below.



Graph1. Chart of analysing sketch maps.

By structural differentiation we mean the differentiation of cognitive maps expressed on a sketch drawing in relation to their accuracy. By map accuracy we mean the number of correctly reproduced objects appearing in the real environment on the map. Empirical indicators of map accuracy include: (a) number of wrongly scaled elements on map (paths, nodes, landmarks, and districts), (b) number of distorted elements (paths, nodes, landmarks, and districts), (c) number of reductions and expansions with elements that do not exist in a given area (paths, nodes, landmarks, and districts), and (d) number of wrongly placed elements (paths, nodes, landmarks, districts). Elements are considered wrongly placed if their numerical parameters (size, spatial placement in relation to other objects) exceed the confidence interval of one standard deviation determined based on all research results. The variable of accuracy takes the numerical value of the sum of numbers in the above categories of errors on cognitive maps. This way it is possible to distinguish between accurate and inaccurate maps.

By content differentiation we mean the differentiation of maps in relation to their level of detail and to their content. By level of detail we mean the number of objects on the map which also appear in the real environment. The empirical indicator of a map's level of detail will be the number of elements marked on the map (paths, nodes, landmarks, and districts). The variable of level of detail is the sum total number of these objects. This way it is possible to distinguish detailed and not detailed map categories. By content of maps we mean the abundance or scarcity of elements related to contents, which also appear in the real world. The empirical indicator of abundance/scarcity on maps is a variable consisting of the number of (a) architectural details, (b) labels, and (c) small architecture objects. Thus maps can be divided into abundant/scarce.

The above scheme does not take into account the analysis of elements which Lynch has dubbed "edges", because they are necessary to divide an urbanized area into districts. So the analysis of districts by itself includes the analysis of the placement and metric characteristics of edges.

2.2. Description of the operating principles of the CogMap analyst program

The CogMap Analyst program prepared by us allows analysing the structure and contents of sketch maps of any space (especially urbanized spaces) by:

(1). Determining the number of objects of different types (landmarks, paths, nodes, and districts) on a sketch map;

(2). Determining the dimensions and placement of the objects in space;

(3). Analysing the accuracy of the size and placement of a given object in relation to a cartographical map and to the scale and general distortion of the sketch map;

(4). Determining parameters of the analysed space such as (a) legibility – illegibility, (b) preferences (liked – disliked), and the parameter of the type of the sketch drawing (sequential – spatial – hybrid).

In order to determine the way a sketch map was drawn in a quantitative (metrological) manner, we have designed and developed the CogMap Analyst program, written in the LabVIEW environment. It allows us to precisely locate the studied areas and objects in a coordinate system superimposed on sketch maps, and to use analytical geometry to determine the parameters of each object. In order to obtain a unified format of results for different types of objects, e.g. for landmarks as well as paths, we have used the geometrical centres of figures (centroids (fig. 1)). Determining a numerically expressed position of objects on sketch maps is necessary to obtain the knowledge which lets us compare them, because a lack of measurable results would yield unproductive and disappointing information.

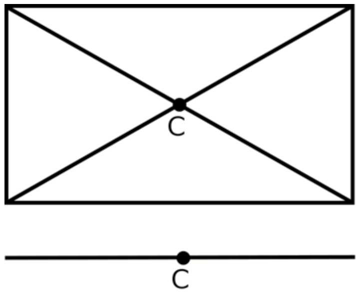


Figure1:Geometric centers of figures marked on a rectangle (district or landmark) and on a segment (path).

In order to analyse sketch maps drawn by study participants, we must firstly create a set of reference data, determined on the basis of the original plan of a given place. This method is necessary, because it enables an objective comparison of the sketch with reality. The data that are taken from the objects marked on the map, are coordinates of edges and rotation of the figure in relation to the geometric centre (regarding districts and landmarks), coordinates of the starting and ending points (regarding paths), and coordinates of a point (regarding nodes) (fig. 2).

Dividing the studied area into smaller fragments enables a comparison of objects not only in relation with their real size (appearing on the original cartographic plan), but also in relation to distortions of the areas in which they lie. We have included a possibility of making any desired division by areas and a possibility to analyse nodes as independent objects (i.e. without calculating distortion in relation to regions).

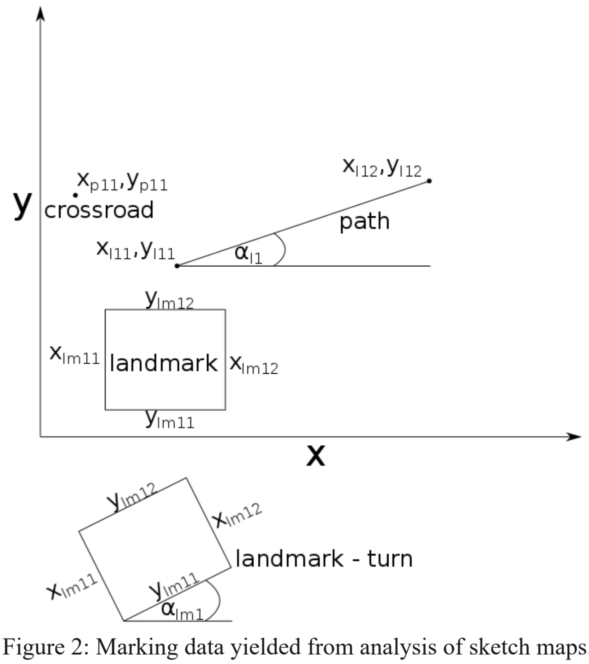


Figure 2: Marking data yielded from analysis of sketch maps.

Two basic forms of distortion taken into account in the analysis of objects on the map include scale and displacement. Depending on the type of the object they were applied in different configurations, which we have presented in table 1. We are using this divisionbecause it is an objective method of analysing distortions which is possible to use on a small number of participants, meaning a situation where it is impossible to use a neural network to compare sketches.

Type of object	Analysed distortions
District	Displacement, Scale.
Landmark	Displacement, Relative displacement, Absolute scale, Relative scale, Rotation.
Path	Displacement, Relative displacement, Absolute elongation, Relative elongation, Rotation.
Node	Displacement.

Table1: Analysing distortion depending on the object.

For each map it is possible to determine additional characteristics, beyond Lynch's typology, i.e. its type (per: Appleyard, 1970 and Hunay et al. 2008), total number of objects, number of details, number of labels, surplus objects (expansions), legibility and preference (affective component of attitude). The next required step in the analysis is marking districts in order to determine if and how they are distorted. Displacement and change of scale of districts are information necessary for analysing relative distortions of the rest of the objects, disregarding nodes which lie outside of districts (fig. 3).

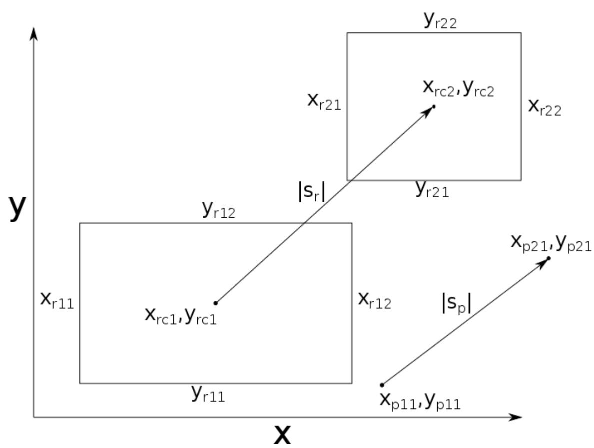


Figure3: Displacement and change of scale of district, and displacement of a node

Distortions of objects presented on figure 3 are calculated by using the following formulae for:

– displacement of district $|s_r|$:

$$x_{rc1} = \frac{x_{r11} + x_{r12}}{2}$$
$$y_{rc1} = \frac{y_{r11} + y_{r12}}{2}$$
$$x_{rc2} = \frac{x_{r21} + x_{r22}}{2}$$
$$y_{rc2} = \frac{y_{r21} + y_{r22}}{2}$$
$$|s_{rx}| = x_{rc2} - x_{rc1}$$
$$|s_{ry}| = y_{rc2} - y_{rc1}$$
$$|s_r| = \sqrt{(x_{rc1} - x_{rc2})^2 + (y_{rc1} - y_{rc2})^2}$$

– change of scale of district dP_r:

$$w_{r1} = x_{r12} - x_{r11}$$
$$h_{r1} = y_{r12} - y_{r11}$$
$$w_{r2} = x_{r22} - x_{r21}$$
$$h_{r2} = y_{r22} - y_{r21}$$
$$dw_r = \frac{w_{r2}}{w_{r1}}$$
$$dh_r = \frac{h_{r2}}{h_{r1}}$$
$$P_{r1} = (x_{r12} - x_{r11}) \cdot (y_{r12} - y_{r11})$$
$$P_{r2} = (x_{r22} - x_{r21}) \cdot (y_{r22} - y_{r21})$$
$$dP_r = \frac{P_{r2}}{P_{r1}}$$

displacement of node $|s_p|$:

$$|s_p| = \sqrt{(x_{p1} - x_{p2})^2 + (y_{p1} - y_{p2})^2}$$

Analysing distortions of landmarks and paths requires making calculations for the two cases mentioned before: relative and absolute. In the absolute case, displacement and change of scale or length of an object on a sketch is calculated without taking into account the position of the rest of the elements on the drawing. In the relative case, first and foremost, based on the placement and size of the district containing the considered object on the sketch, the coordinates are calculated where a given element should be, together with its size, if it was displaced and rescaled in exactly the same way as the district was. Next, based on these "predicted" values, relative values of distortion are calculated. Absolute displacement was shown on the coordinate system on figure 4 – it is the ideal case when there is no relative displacement or relative change of scale (objects are ideally reproduced in the displaced district), both of which were presented on the second system of coordinates.

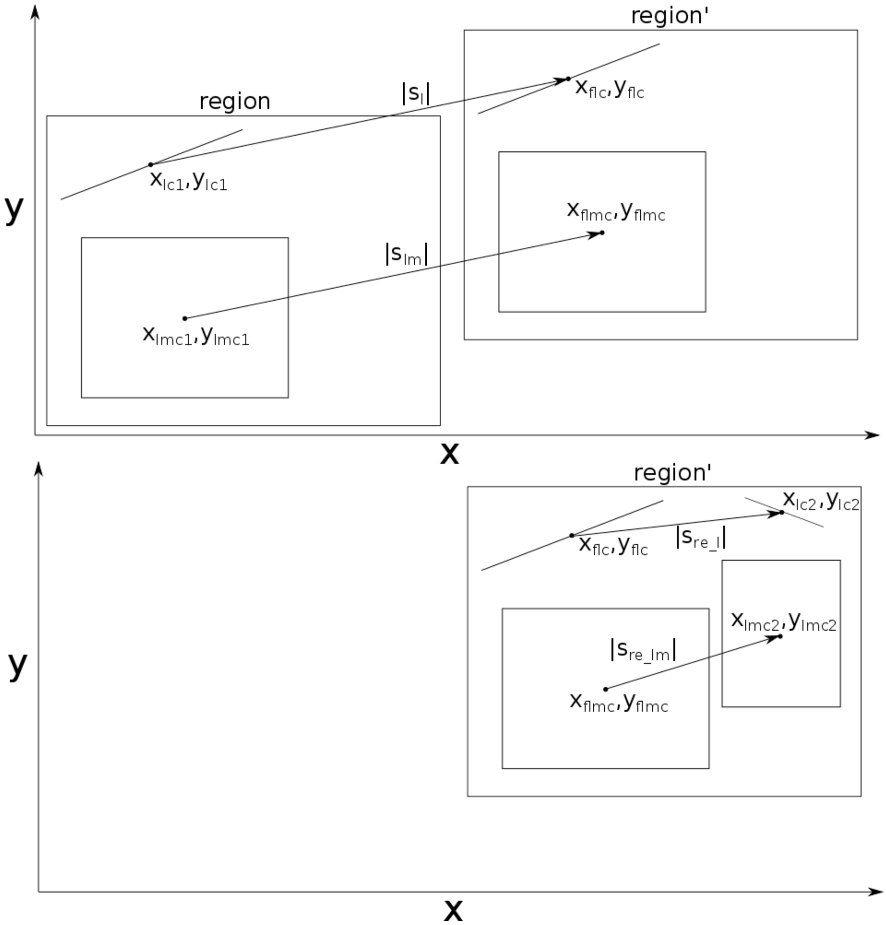


Figure 4: Displacement and change of length of a path and displacement and change of scale of a landmark. Absolute displacement is shown on the first coordinate system (while keeping the same length of the path and scale of landmark), presenting an arrangement of objects correctly placed in the displaced district (so that the "predicted" placement of objects is kept). The second system of coordinates contains a presentation of the method of determining the displacement of objects in relation to the change of placement of the district.

Distortions of objects presented on figure 4 were calculated by using the following formulae for:

– displacement of a path $|s_l|$:

$$x_{lc1} = \frac{x_{l11} + x_{l12}}{2}$$

$$y_{lc1} = \frac{y_{l11} + y_{l12}}{2}$$

$$x_{lc2} = \frac{x_{l21} + x_{l22}}{2}$$

$$y_{lc2} = \frac{y_{l21} + y_{l22}}{2}$$

$$|s_l| = \sqrt{(x_{lc1} - x_{lc2})^2 + (y_{lc1} - y_{lc2})^2}$$

– change of length of a path dl:

$$l_{l1} = \sqrt{(x_{l11} - x_{l12})^2 + (y_{l11} - y_{l12})^2}$$
$$l_{l2} = \sqrt{(x_{l21} - x_{l22})^2 + (y_{l21} - y_{l22})^2}$$
$$dl = \frac{l_{l2}}{l_{l1}}$$

– change of angle of alignment of a path $d\alpha_l$:

$$\alpha_{l1} = arctg\frac{|y_{l11} - y_{l12}|}{|x_{l11} - x_{l12}|}$$
$$\alpha_{l2} = arctg\frac{|y_{l21} - y_{l22}|}{|x_{l21} - x_{l22}|}$$
$$d\alpha_l = \alpha_{l1} - \alpha_{l2}$$

– predicted placement of a path x_{fcl}, y_{fcl}:

$$x_{flc} = x_{r21} + dw \cdot (x_{lc1} - x_{r11})$$
$$y_{flc} = y_{r21} + dh \cdot (y_{lc1} - y_{r11})$$

– relative displacement of a path $|s_{re\_l}|$:

$$|s_{re\_l}| = \sqrt{(x_{flc} - x_{lc2})^2 + (y_{flc} - y_{lc2})^2}$$

– predicted length of a path l_f:

$$l_f = \sqrt{[(x_{l11} - x_{l12}) \cdot dw]^2 + [(y_{l11} - y_{l12}) \cdot dh]^2}$$

– relative change of length of a path $|dl_{re}|$:

$$|dl_{re}| = \frac{l_{l1}}{l_f}$$

– displacement of a landmark $|s_{lm}|$:

$$x_{lmc1} = \frac{x_{lm11} + x_{lm12}}{2}$$
$$y_{lmc1} = \frac{y_{lm11} + y_{lm12}}{2}$$
$$x_{lmc2} = \frac{x_{lm21} + x_{lm22}}{2}$$
$$y_{lmc2} = \frac{y_{lm21} + y_{lm22}}{2}$$
$$|S_{lm}| = \sqrt{(x_{lmc1} - x_{lmc2})^2 + (y_{lmc1} - y_{lmc2})^2}$$

– change of scale of a landmarkdP_{lm}:

$$P_{lm1} = (x_{lm12} - x_{lm11}) \cdot (y_{lm12} - y_{lm11})$$
$$P_{lm2} = (x_{lm22} - x_{lm21}) \cdot (y_{lm22} - y_{lm21})$$
$$dP_{lm} = \frac{P_{lm2}}{P_{lm1}}$$

– rotation of a landmark $d\alpha_{lm}$:

$$d\alpha_{lm} = \alpha_{lm1} - \alpha_{lm2}$$

- predicted placement of a landmarkx_{flmc}, y_{flmc}:
  $$x_{flmc} = x_{r21} + dw \cdot (x_{lmc1} - x_{r11})$$
  $$y_{flmc} = y_{r21} + dh \cdot (y_{lmc1} - y_{r11})$$
- relative displacement of a landmark $|s_{re\_lm}|$:
  $$|s_{re\_lm}| = \sqrt{(x_{flmc} - x_{lmc2})^2 + (y_{flmc} - y_{lmc2})^2}$$
- predicted size of a landmarkP_{flm}:
  $$P_{flm} = P_{lm1} \cdot dP_r$$
- relative scale of landmarkdP_{re_lm}:
  $$dP_{re\_lm} = \frac{P_{lm2}}{P_{flm}}$$

Using the above algorithms, we can obtain objective results, which can be subjected to further analysis (i.e. statistical analysis). The method allows for comparing the results of other research to sketches not only in a qualitative manner, but also in a quantitative manner, which is an approach which has not been heretofore employed on a large scale.

2.3. Description of the functions of the program

The program consists of functions responsible for two basic tasks: preparing the research area and data analysis (fig. 5). Preparing the research area consists of creating a list of districts (fig. 6), and then assigning elements to each of them (it is worth it to keep the name of each element unique, in order to avoid mistakes when they are marked later), and dividing the elements into types. Further, the base map must be analysed, meaning a map that will correspond to the area where the research will be conducted. The program automatically scales all images to 500 pixels in width, and 700 pixels in height, which corresponds to the proportions of an A4 sheet of paper with a 1% confidence interval, but it is still recommended to make scans of drawings obtained from participants in one resolution and on automatic devices, because we have noticed during tests that scans tend to be displaced in relation to one another when different devices or scanning by hand is used. A constant width and height of image also allows the program window to fit in whole on most standard monitors.

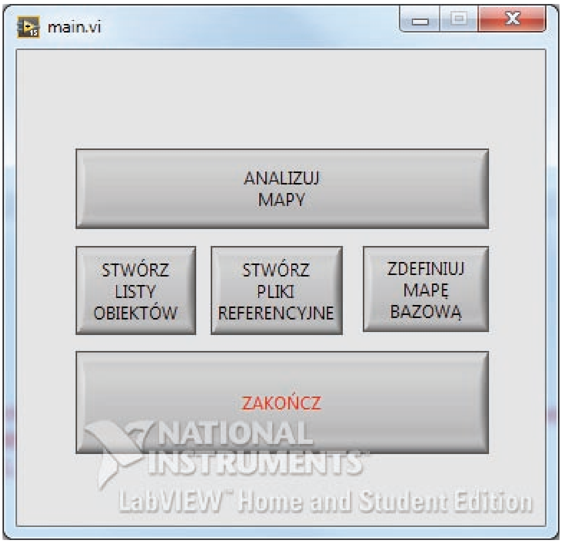


Figure 5: Main window of the CogMap Analyst program

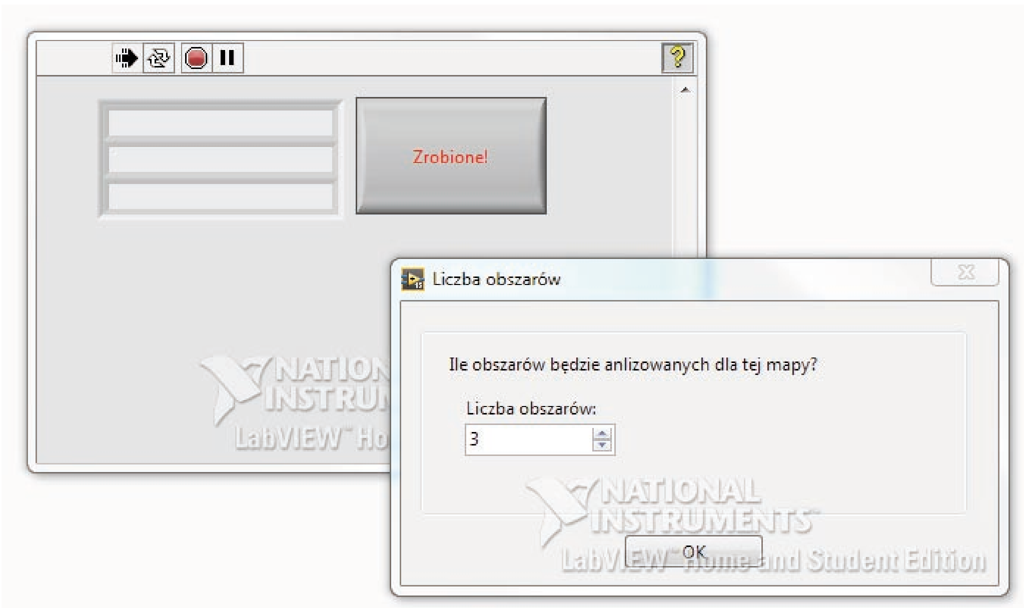


Figure 6: Interface for making lists of districts and objects.

In order to analyse data, it is also necessary to create the mentioned files with reference data, with which further results will be compared. This part of the configuration of the program is similar to conducting the proper analysis of maps, but it only requires marking all districts and objects on the base map (fig. 7), meaning those that will be used in the study and will be mentioned on the discussed lists.

The above steps are done once, and their effects are saved in .txt files for lists of objects, which allows for easy modification, and in .xml for reference files, so that it is possible to read them outside of the program as well. Until the configuration procedure is repeated, analysis will be carried out each time according to the prepared scheme.

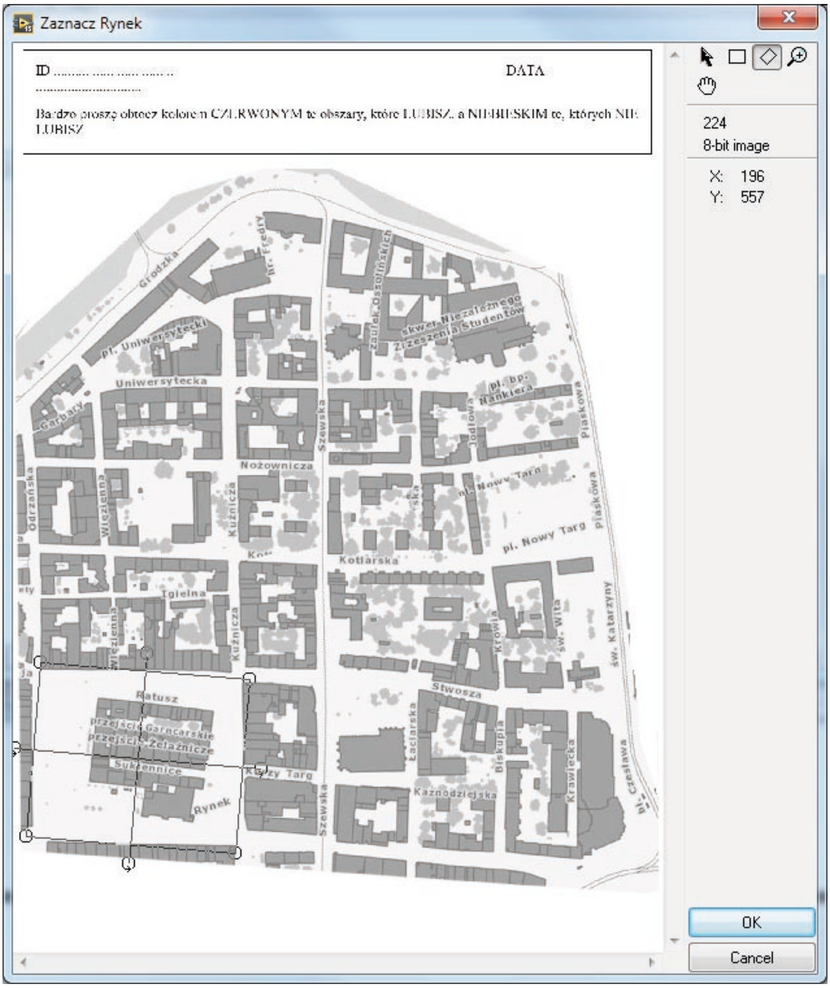


Figure 7: Fragment of the interface responsible for marking particular elements on maps, created using the NI-IMAQ library, which is used for handling cameras.

To use the program correctly, it is also necessary for the participants to receive an underlying map, which contains a fragment of the cartographical map of the places adjacent to the researched area (whose map is to be drawn), so that they are able to use the proper scale. Without this assumption it is impossible to obtain correct data about the appearing distortions of size of objects and areas.

Data analysis is similar to preparing reference files (in the context of acquiring data about the shape and placement of objects), but this stage is preceded by determining other parameters characterizing the studied area according to the participant (fig. 8). Type of map must be determined, then elements, labels, and details appearing in the districts must be counted, and the number of surplus objects, which obviously do not appear on the map (e.g. the Sphinx drawn in the centre of Cairo), must also be counted. Additionally, the participant's attitude towards the studied area and whether it is considered legible (as understood by Lynch (1960)) is measured. Gathering this data is optional, and dependent on the researcher's approach. If gathering information on any of the above characteristics is redundant in a given study, the rubric should be omitted.

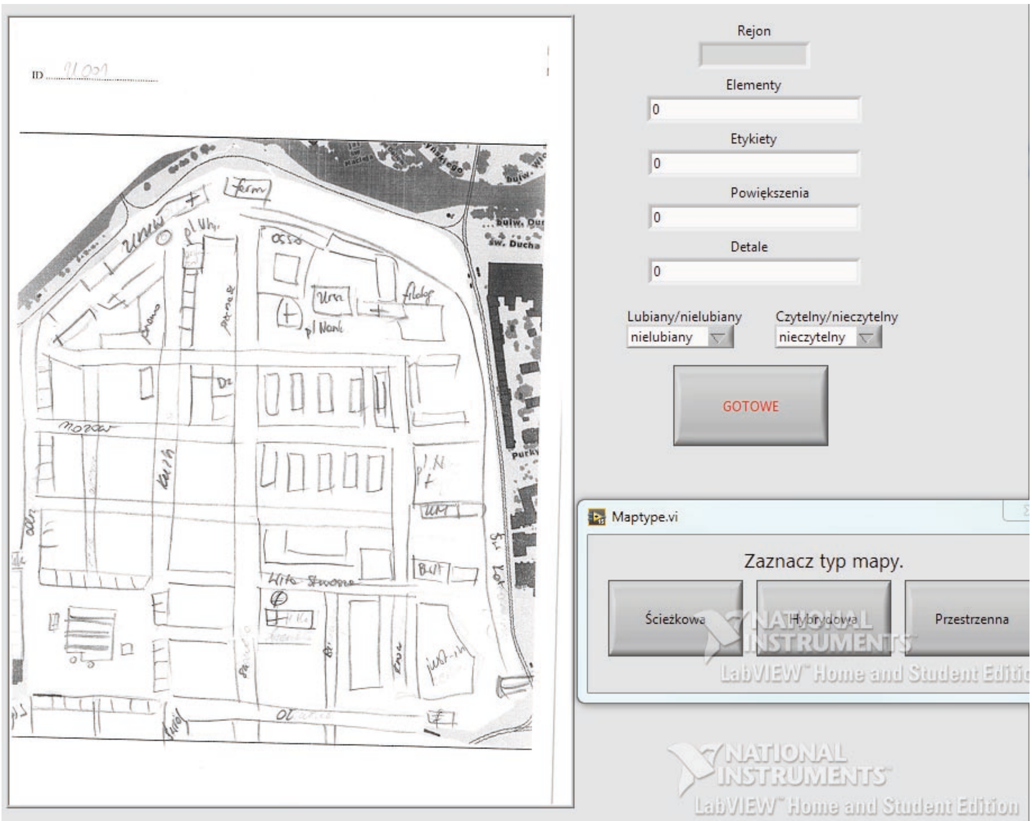


Figure 8: Interface used for entering data about the sketch.

Calculations are done when necessary for each marked object, but results are only saved after the entire analysis of the sketch is finished. In order to simplify further treatment of data, they are saved in the form of a simple text file with a delimiter in the form of spaces, and results from subsequent sketches written in a new line. The heading for results is saved a separate file, and is constructed so as to facilitate reading the data by hand, should the need arise.

3. Discussion

The CogMap Analyst program put forward by us enables gathering numeric data regarding the structure and content characteristics of cognitive maps of urbanized spaces in the form of sketch maps. Scientific research into this subject has been continued by psychologists for a few decades, and many aspects of construction and differentiation of maps still remain unexplained (Tu Huynh and Doherty, 2007). In order to make it possible to analyse differences in cognitive maps of spaces when using the method of sketch drawing, it is necessary to develop a reliable tool for measuring differences in the yielded research material (sketches). As we have presented in the theoretical part of this article, psychologists have developed many methodologies of analysing drawings. However, in order to enable comparison of results, it is important to create a coherent method of scientific investigation. Thus, with psychologists who study the reasons for differentiation of cognitive maps of urbanized spaces in minds, we have created the CogMap Analyst program, which is an easy to use and precise tool, which enables quantitative measurement of numerous parameters of elements appearing on sketches. The data obtained in this way are parameters of dependent variables, which can then be compared with values of the analysed independent variables (e.g. demographic variables such as age, sex, place of origin, or attitudes, cognitive process characteristics, and formal traits of the studied environment).

Thanks to this tool, maps may be analysed very precisely and objectively, and concrete information about the changes in size and placement of particular objects in relation to actual shapes or in relation to the given drawing can be obtained. The method allows for rejecting the objection stated by many researchers regarding the subjectivity of evaluation of obtained results and low reliability of the sketch method (Schmeicka and Thurston, 2007). Moreover, results obtained with CogMap Analyst give a wide view of the way in which urbanized space in a given area is perceived by a particular person. Importantly, we gain independent data about types of objects which appear on maps, which is an important information for qualitative analysis of a given drawing. What type of objects and in what quantity does a given person present on their mental map may be an important indicator of their preference or other personal traits (Lynch, 1960).

The theoretical assumptions made, including the joint but also independent analysis of the structure as well as contents of a sketch drawing give a comprehensive view of the characteristics of cognitive maps. The program allows for gathering data in a relatively quick manner, and for obtaining objective, metric data. Moreover, the analysis of results is carried out automatically.

Because the LabVIEW environment was used to create the program, and because the application itself is written in a modular way, it is relatively easy to continue to develop and modify CogMap Analyst depending on the needs and requirements of a particular study. At this stage, the program only yields raw data, which must then be imported to appropriate statistical software in order to carry out further analysis.

It should be considered if, when the next version of the program is created, it would be a beneficial solution to add the possibility to analyse the placement of objects in relation to other objects nearby. This solution was used by, among others, Rovine and Weisman (1989). It would enable a deeper look in to the structure of the image of a cognitive map in the memory of the participant, and give the researchers information allowing for a wider understanding of the structure of spatial cognitive maps stored in human memory.

Rovine and Weisman (1989) put forward a method of analysing sketch maps which consisted of gathering four measures: (1) counting the frequency of marking landmarks, segments of streets, and nodes; (2) determining the type of map as spatial or sequential according to Appleyard's (1970) developed division (spatial maps show the existence of interrelations between paths on the map; sequential maps are representations of sequences of objects encountered one after another, as if on route from point A to point B); (3) accuracy of a cognitive map was determined based on a correct topological reproduction on a drawing of each of 20 landmarks marked by the researchers in a given area. A building was considered correctly reproduced if it (a) was drawn in the appropriate place between the two closest buildings in the area, and (b) was placed by the appropriate path. Accuracy of placement of a building on a cognitive map was therefore determined based on its correct placement in relation to other objects on the map.

Rovine's and Weisman's assumptions seem correct, however such a methodology creates difficulties when drawings of cognitive maps lack so many analysed objects (landmarks and paths) that it is impossible to control the fulfilment of criteria of accuracy of the cognitive map. A universal tool for quantitative analysis of cognitive maps of spaces should be based on data coming from drawings by participants, and not an outside criterion of relations between objects appearing in real space (because these other reference points may not be marked on a map, which may produce an erroneous categorization of an object as wrongly placed). This question must be considered in depth and it must be found out if it is possible to include the analysis of placement of objects in relation to one another.

According to our knowledge, CogMap Analyst is, at this time, the most comprehensive available tool for analysing the characteristics of sketch maps. It is easy to use and flexible, it is possible to use it to analyse areas of any size, with varied spatial layouts or containing varied architectural objects. The quantity and variability of obtained data allows for conducting very different and complex statistical analyses in relation to the adopted research goals. We hope that it will be used by many researchers to gain empirical knowledge related to the characteristics of sketch maps of different environments in different groups and types of people.

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