Spatial Distortions in Cognitive Maps – a Chance and Challenge to Enrich the Principles of Map Design

Räumliche Verzerrungen in kognitiven Karten – Eine Chance und Herausforderung zur Erweiterung der Prinzipien der Kartenkonstruktion

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Cognitive maps have been dealt with in a remarkable number of studies. By today, it has been shown that spatial judgements based on information learned from maps are systematically distorted. These findings of cognitive psychology, however, have not been taken on board in the theory of map design. The aim of a current interdisciplinary DFG-funded project is to identify and optimise the design of specific map features in order to reduce the perception-based distortion errors people learn from cartographic maps and store in their cognitive maps. This paper presents the approach of this project after giving a brief overview of the most relevant spatial distortions identified by today. In addition, the results of a first empirical study are shared and discussed.

Keywords: cognitive maps, spatial distortion errors, empirical cartography, information transfer, map communication


Schlüsselwörter: Kognitive Karten, räumliche Distanzverzerrungen, empirische Kartographie, Informationsvermittlung, kartographische Kommunikation
1 Introduction

The term cognitive map¹ has been used in a diverse and interdisciplinary portfolio of publications since it was first introduced by the psychologist Eduard C. Tolman (1948). The term is useful and confusing at the same time. It misleads people to emphasising the convenient word “map” and, thus, to regarding the term in a strictly cartographic sense – a cognitive map, however, is not to be seen as a coherent whole designed according to cartographic principles, it is a metaphorical term and rather refers to a “collage” (Tversky, 1993, p. 14) including the “awareness, impressions, information, images, and beliefs that people have about environments” (Moore & Golledge, 1976, p. xii). A cognitive map is the result of the (re-)processed experiences individuals have made with the geospatial reality. It concerns information about places, their spatial relations and the presence or absence of specific objects (Barkovsky, 2002; Mark et al., 1999). This spatial knowledge is based on the experiences in the environment itself (direct experience) or on information learned from cartographic visualisations (indirect experience) (Dickmann, 2012; Schnaitte, 2003; Bitter, 1999). These experiences are not restricted to information taken up visually. In a cognitive map, perceptions of all human senses are merged together (Downs & Stea, 1977).

Visualisations coming out of these experiences are not necessarily neutral “organized representation[s] of a part of the spatial environment” (Downs & Stea, 1977, p. 51) – space may also be represented as “maps of emotions” (Griffin & McQuoid, 2012, p. 292). In a quite remarkable number of projects, topography is characterized and evaluated according to feelings and internal judgements⁶. In some of these projects, the terms cognitive map and/or cognitive mapping have the wide ranging scope indicated before and cover these examples of humanistic cartography (Griffin & McQuoid, 2012, p. 297; Edler, 2011, p. 176).

Apart from the more recent development to visualise emotionally evaluated space, most of the research into cognitive maps, by today, has concerned how individuals acquire, encode, store, recall and decode spatial information. As such, there have been quite some important studies that identified spatial distortions as consequences of normal processing.

2 Spatial distortions in cognitive maps

Many intrinsic and extrinsic factors determine the structure of cognitive maps. For example, it has become evident that the size and position of objects in maps, as well as the distances between them, are not just by chance – memorised in a distorted way. By today, the results of cognition and cartographic research have rather pointed out that spatial judgements based on information learned from maps are distorted in a systematic way.

One of the most important distortion errors refers to a hierarchical (re-)organisation of space, i.e. a top-down influence of existing knowledge on the processing of spatial information: a pioneering series of experiments was carried out by Stevens & Coupe (1978). In one of their studies, participants were asked to use their memory in order to set, on a circle, the geographical direction from one U.S. city to another. Most of the subjects – although it was clearly wrong – thought that, for instance, Reno was situated to the northeast of San Diego. According to the authors, people did neither memorise the exact location of each city nor the relative locations of all cities. People, though, tended to store the relative locations of the states and, in a further step, the locations of the cities within the state. So, when recalling the city locations (subordinate unit), the answers were distorted according to the locations of the states to another (superordinate unit). Nevada is east of California – all cities in Nevada (incl. Reno) are east of all cities in California (incl. San Diego). Evidence for the effect that barriers cause a hierarchical “spatial chunking” (Eastman 1985, p. 2) and, thus, increase the estimates of distances between places was also given in Newcombe & Liben (1982), McNamara (1986) and Newcombe (1998). The idea that a subsequent hierarchy from global to local would influence spatial judgements was earlier suggested by Cox & Zannahras (1973), Navon (1977) and Bartram (1978).

In addition, Wilton (1979) measured the time people needed to verify or falsify a directional statement about two American cities. It took people longer to answer when the two cities were in the same state than when the two cities were in different states. In quite a similar study, Maki (1981) found out that the closer together the cities were within one state, the more time people needed to give an answer. However, for cities in different states, the answers were constantly fast.

Another experiment concerning hierarchical effects in cognitive maps was conducted by Hirtle & Jonides (1985). Their study went along with the idea of organising spatial information based on anchor points (Golledge et al., 1985). The subjects were shown a map-like sketch of Ann Arbor including 32 familiar landmarks they were to memorise. In the recall of the landmarks, grouping effects occurred partly by actual proximity but also by functional similarity⁷. When dealing with the distances between specific landmarks, the participants generally tended to estimate smaller distances for the landmarks of the same subjective group and larger distances for the landmarks across the groups. In a related study, McNamara et al. (1989) ended up with similar results. They found out that distance estimates for locations between the groups were higher than the estimates for inter-cluster locations.

¹ The term is, to a large extent, interchangeable with other terms, such as abstract maps (Hernandez, 1991), cognitive representations (Golledge, 1977), cognitive images (Lloyd, 1982), cognitive representations (Downs & Stea, 1973), cognitive schemata (Lee, 1968), cognitive space (Montello, 1989), cognitive models (MacEachren, 1995), conceptual representations (Stea, 1969), configurational representations (Krasin, 1991), environmental images (Lynch, 1960), mental images (Pocrn, 1973), mental maps (Stea, 1969; Gould & White, 1974), mental representations (Gae, 1982; Tversky, 1992), mental models (MacEachren, 1995), internal representations (Tversky, 1993) and spatial representations (Allen et al., 1978), for further reading: see Kitchin & Blades (2002, pp. 1-3).


⁷ An interesting example of ‘functional’ grouping is also given in Tversky & Schiano (1989, p. 39B): Over several years people were asked which they thought was located further east, Japan or the Philippines. In their answers, the respondents reported the Philippines – presumably due to their closer political association with the USA at that time.
Many of the studies dealing with distortions caused by hierarchical coding are based on abstract map material representing areas the participants are familiar with. In these studies, people rather recall information from spatial facts acquired through experience and education. However, this does not mean that all distortions in cognitive maps are generally dependent on background knowledge. In quite some experiments, evidence has been provided that distortions may have perceptual fundamentals. These studies are based on the idea that the way map information is perceived and perceptually organized may shape the cognitive map – even before the actual processes of memory encoding begin (Klippel et al., 2004; Hommel et al., 2000; Montello, 1998; Tversky, 1981).

Canter & Tagg (1975) assumed that humans were naturally equipped with systematic simplifying mechanisms that would facilitate the recall and use of spatial information. Tversky (1981) has demonstrated in a series of experiments that whenever map information is tricky to remember, the human brain may use two “heuristics” to simplify the information. One of these heuristics is alignment. Alignment is related to the Gestalt law of grouping objects by proximity. People do not learn the absolute locations of spatial objects but their relative locations towards each other. In case objects are grouped together by their proximity and have an offset in one spatial dimension, people remember the objects more aligned than they are in reality (Tversky, 1992). In other words, the human brain tends to store spatial objects in cognitive maps as if they gravitated toward each other.

To give evidence of alignment, Tversky (1981) altered a selection of world maps in the direction of alignment. She defined eight critical pairs of well-known cities (5 east-west, 3 north-south). Then subjects were asked to choose from their knowledge whether the original map or the aligned map showed the real locations of the city pairs. The result was that more than 60% of the participants selected the aligned map in preference to the original map, in the horizontal and vertical planes. Not only did Tversky obtain alignment errors when operating with world maps but also for artificial maps, map-like sketches of familiar local environments and meaningless shapes.

The second heuristic introduced by Tversky (1981) is rotation. Rotation is related to the Gestalt law of grouping objects by common fate. People do not learn the actual orientation of objects; their orientation is shifted and corresponds with the orientation of the frame of reference. In other words, the human brain tends to store spatial objects in cognitive maps as if they were located along the same axis.

To give evidence of rotation, Tversky (1981) created, amongst other things, map-like displays of the San Francisco Bay Area including four critical pairs of Bay Area cities and another four filler pairs. In this area, the northern cities are far west of the southern cities. The critical pairs were selected so that, under rotation, the west city would seem to be east. In addition, the map was featured with a rectangular grid providing the orientation of the reference frame. Taking up the method used by Stevens & Coupe (1978), subjects were asked to indicate the compass directions between each pair of cities. The significant result was that the majority of people committed rotation errors. Similar results were achieved by Howard & Kerst (1981), for familiar locations and studied maps.

Additionally, Tversky & Schiano (1989) carried out a series of six experiments identifying systematic errors caused by the Gestalt law of grouping objects by symmetry. In two of their experiments, the subjects remembered rivers in maps as more symmetric than they really were. Concluded from their results, Tversky & Schiano (1989, p. 396) characterized symmetry as an “excellent cue to ‘figureness’” and as a “powerful factor” in the perceptual organization of map information.

Hommel et al. (2000) showed that grouping of objects in map-like displays can be influenced by colour and shape, going along with the Gestalt law of grouping objects by similarity. In their experiments, colour and shape similarities influenced the reaction times but not the accuracy spatial judgements were made with.

Klippel et al. (2004) took up a study conducted by McNamara et al. (1984). Their study was built on the Gestalt law of grouping objects by connectedness. They designed a map-like display including 16 black square symbols connected via different lines ("routes"). In their results, they identified the significant effect that the participants estimated the distances between directly connected location pairs shorter than between pairs that were unconnected. Furthermore, the answers were given faster for connected pairs than for unconnected pairs. The results of both estimates and time back up the findings of McNamara et al. (1984) and, accordingly, demonstrate the robustness of the so-called route effect.

Hurts (2005), moreover, investigated three conditions of perceptual grouping: by common region (using black boundary lines to shape adjacent artificial ‘countries’), by adjacent colour (colouring city symbols that belong to the same ‘country’ in the same way), by colour only (using colour to create non-contiguous, overlapping clusters). He generally confirmed that grouping effects in cognitive maps may be based on perception. He showed that boundary lines (common region) tend to affect spatial judgements; they are made faster when objects are located in the same region. However, neither the combination of colour similarity and spatial proximity (adjacent colour) nor colour similarity in the absence of other grouping effects (colour only) had an impact on spatial judgements. Fabrikant (2003), however, found out that colour, in comparison to monochrome displays, had a positive effect on the accuracy and speed of distance estimates.

3 New approach

The results compiled before refer to just a selection of relevant empirical studies on memory-based and, mainly, perception-based distortion errors in cognitive maps that have been carried out by today. They demonstrate that spatial information is structured and systematically distorted. Although empirical studies in cartography have verified that map graphics have complex effects on map communication, the findings on distortions in cognitive maps, however, have not been exploited to enhance the theory of map design. This is the point of departure for a current
research project funded by the German Research Foundation (DFG).

Traditionally, psychological research into (cognitive) maps has concerned the identification of cognitive structures. This project, however, is based on reversing this approach. Involving both the Geography and Psychology Department of the Ruhr-University Bochum (RUB), the aim of the project is to exploit the findings on the structures of spatial memory in order to optimise the principles of map design. The improvement of design principles especially relies on the idea that the construction of cognitive maps may be controlled by the map graphics. It has so far not been explored which specific elements of the map graphics are the key features affecting the accuracy when recalling and recognising objects learned from maps (indirect experience). After qualifying these map features, they are supposed to be quantified. In other words, their design shall be altered and examined in order to counteract and reduce the spatial distortions people get from maps and erroneously carry around in their heads. The ideal result of the project would be a catalogue of qualified and quantified map features that help to store map information more accurately: cartographers shall be provided with reliable statements how to outsmart perception-based distortion errors and, consequently, how to design a map to make map communication a bit more efficiently.

Going beyond previous perception research, the graphic elements to be investigated here are not extremely reduced cartographic sketches (i.e. isolated symbols on a blank map base) but those forming visual frameworks within more appropriate and practically relevant cartographic visualisations. These frameworks are firstly based on the graphic interaction of map symbols that represent linear topographic features (river courses, roads, border lines, relief contours). In alignment with the cartographic concept of chorèmes (Brunet, 1980; Brunet, 1987, pp. 190-192; Klippel, 2003), these linear features chunk the map surface into regions and, thus, evolve visual structures that may influence and guide the map user’s perception in a subliminal way. This spatial chunking caused by – more or less eye-catching – linear map structures, presumably going along with perception-based grouping effects (Gestalt laws), may increase or decrease distortion errors in cognitive maps.

Secondly and in addition to linear features, artificial map elements providing an additional visual structure (geometric grids) will be thoroughly considered in the study. Geometric grids, in contrast to linear map features and their rather arbitrary order, make up a clear system of identical frames. Hence, their presence in the map, traditionally due to functional reasons, may also support and guide the user’s way to perceive and, consequently, to store map information. To meet the objectives, a series of empirical studies is required.

In order to deduce statements for a wide range of users, authentic and practically relevant maps will be used as study materials. However, before jumping off with more complex map material derived from official data sets, a first study was planned to explore whether a generic topographic base layer – as a whole, not in its possible single elements – has a bearing on the accuracy of cognitive maps. A short graphic summary of the project’s approach is given in figure 1.

4 First empirical study

As mentioned before, most of the studies presented in chapter 2 operated with map-like displays in which real or fictional space was represented via simple points, lines and areas on a blank base. This study material, on the one hand, represented spatial information but, on the other hand, was far away from modern visualisations of topographic or thematic cartography. In a first empirical study, the assumption that the perception of explicitly drawn boundary lines chunking the map surface into ‘spatial pieces’ may have an effect on spatial judgements (Hurts, 2005; McNamara, 1986; Eastman 1985, Newcombe & Liben, 1982) is taken up and extended. This extension refers to using a layer of boundary lines and, in addition, a layer of coloured topography as within factors. The topography layer is characterised by a higher visual complexity than the usual base layers used before and intends to make a (study) map a bit more authentic and practically relevant. The assumption behind this first study is that a generic and coloured topographic base layer as well as a layer of chunking boundary lines would generally help to reduce distortion errors in cognitive maps. This study is to be seen as a first experiment examining whether already such a ‘coloured topographic whole’ (that in further research will be investigated in its single features) impacts the recall performance of map information.

1 e.g. Dickmann & Diekmann-Boubaker (2010); Uttal (2000); Bollmann et al. (1999); Bollmann (1981); MacEachren (1979).
2 See also: Besigeh et al. (2013); Griffin & Fabrikant (2012); Daum (2012); Fabrikant et al. (2010); Fabrikant & Lobben (2009); Veranoula et al. (2009); Klippel et al. (2005); Dransch (2003); Klippel (2003); Kitchin & Bades (2002); Montello (2002); Paulet (2002); Fairbain et al. (2001); MacEachren & Kraak (2001); Slocum et al. (2001); Kitchin & Freudenthal (2000); Bitter (1999).
Participants

Thirty-eight subjects (16 male, 22 female) aged between 19 and 34 (M = 23.7; SD = 4.2) voluntarily participated in the study. All subjects were RUB students of Psychology (B.Sc.). They were unaware of the purpose of the study and signed a written informed consent before being included in the study.

Materials

Four different digital maps (680 px x 510 px) were created as study material (fig. 2). Each map contained seven red circular symbols representing the locations of fictional cities. The symbols were pseudo-randomly distributed over the map surface. Each of them was labelled with a fictional German name consisting of eight letters, such as Edenhorn, Kahlendorf, Moorholm, Reithude, Salzroda, Vielhaus and Wallsund. In terms of further map information, the first ‘map’ included no additional objects. The second map comprised red lines representing fictional administrative boundaries and splitting up the area into nine regions. The third map included an additional topography layer whereas the boundary layer was dropped. The topographic layer comprised the physical continuum height information represented in contoured hypsometric layers (six classes) that were coloured in a range from green (flat) to brown (high). The fourth map was featured with both boundaries and topography. The arrangement of the boundary lines and topography, if any, as well as the distribution of the city symbols, incl. their labels, were different in all four maps. In general, no eye-catching landmarks were included in the topographic base layers.

Design

All participants were confronted with four trials imbedded into an Adobe® Flash® application. In each trial, they were shown one of the four maps in random order. They were asked to memorise the seven cities, in terms of their exact location on the map surface and their names (study phase). This study phase was limited to 120 seconds. It was followed by another 120 seconds interval including filler tasks. After that, the participants were given another 180 seconds to recall the cities on the trial map that now contained all information layers apart from the cities and their names (recall phase). Here, the participants were instructed to use the cursor to place the recalled cities onto the map screen. They were then asked to type in the name of the cities (re-)located before. Generally, the participants were encouraged to complete the recall task as accurate but also as fast as possible. Prior to beginning with the actual trials, the participants were given a practice trial to make them familiar with the software, maps, tasks and the general test procedure.

Statistics

The recall performance was assessed by measuring the Euclidian distance between the coordinates of the recalled city and the coordinates of its original location. The distance was measured in pixels. The location of a recalled city was accepted as correct if it differed between 0 and 28.4 px (0–1 cm) from the original location (see Okabayashi & Glynn, 1984, p. 274).

Results

The repeated measures ANOVA for distortion errors considering the within factors topography and boundaries revealed a significant main effect for topography \(F(1, 37) = 21.099, p = 0.000, \eta^2 = .363\) (fig. 3); no significant main effect was found on boundaries \(p = .96\). Furthermore, there was no significant interaction between topography and boundaries \(p = .16\) – for means and standard deviations, see Table 1.

Discussion

The results of this study show that both a coloured physical base layer and boundary lines have an impact on the recall performance of exact locations in maps. A significant main effect was found for the topographic base layer. When it was included in the map, the distortion error significantly decreased. The inclusion of

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<td>62.8 (3.7)</td>
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<td>boundaries</td>
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boundaries, however, had no effect. As can be seen in Table 1, their existence in the map seemed to produce a slightly negative effect on the recall performance when the topographic base was displayed as well. On the opposite, when combined with a blank base, boundary lines tended to have a slightly positive effect on the recall performance—however, these effects were far from significance.

The fact that a layer of colored topographic information has a convincing positive impact on spatial judgements generally shows the potential of the research approach presented in chapter 3. It becomes obvious that a topographic base has an impact on the perception and helps to increase the accuracy when the locations of pseudo-randomly distributed objects are recalled from cognitive maps. This is a first starting point for future research. Having found out that the inclusion of topographic information increases the accuracy of spatial memory, the chance and challenge remains to empirically qualify and quantify the map elements responsible for this improvement.

Although the boundary lines or rather the spatial chunks they bring out did not seem to act as significant perception guides, their presence in the map changed the results to a certain small extent. Still, their relevance for the perception of map information should not be underestimated. An additional analysis and evaluation of the chronological order in which the city locations were recalled showed that quite some participants dealt with the given task by systematically processing the city locations and their names from chunk to chunk. Despite this systematic chunk-wise procedure by some participants, it did not necessarily result in a good recall performance. It is well possible that the bold and red design of the lines was too dominant and deterrent to be used by all subjects. Thus, it seems likely that people generally tend not to store and recall map locations along clustering chunks that appear rather patchy than identical in size and in a uniform arrangement. This is where geometric grids should come into play.

![Fig. 3: Distortion errors of the recalled cities in maps with topography and no topography. (A city was considered correct if the recalled location fell within a maximum distance of 28.4 px (1 cm) to the original location.) *** = p < .001](image)

5 Outlook

The discussion of the results has already pointed out that the qualification and quantification of those map features that help to counteract perception-based distortion errors are the key topics of this project. The map elements of particular interest are linear map features that may cause a spatial chunking effect guiding the map reader’s perception. The inclusion of geometric grids, not in their role as tool to define locations and coordinates but as systematic perception guides, should be considered in future research. First results showing the impact of grids on cognitive maps will soon be available (Bestgen et al., 2013).

After identifying the key features and their design, it is necessary to investigate and to underline the results via eye movement registration. It can be assumed that map objects directly fixed with the eyes are processed at the very same moment. This corresponds to the fact that eye movement data are regarded as indicators of cognitive processes (Rayner, 1998; Bollmann et al., 1997; Just & Carpenter, 1976). Systematically evaluated eye movement data could exactly show which features of the map graphics were focussed or were outside the map user’s foveal vision. The chronological tracking of eye movement would help to understand which elements are looked at first and which elements follow each other. Specific map viewing behaviours could be observed, and the impact of particular line features and grids could be determined. Such results could not only give impor-

tant hints to detect causal connections between map elements and perception, but they could also improve the placing and design of map objects.

Furthermore, it must be considered that, depending on the area a cartographer wants to represent, topographic features vary and, as a result of this, the visual complexity of the map graphics changes. Therefore and in order to derive statements for a wide range of users, future experiments should operate with study maps derived from official (vector) data sets, such as ATKIS®-Basis-DLM data, and take account of different levels of visual complexity.

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References


Training Paths in Cartography and Geomatics in Germany, Austria, and Switzerland

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The traditionally demanding training of specialists of cartography and geomatics is gaining importance worldwide. Training content is now dominated by digital methods for cartographic information processing, the findings of information and communication theory, and by innovative products and user requirements. Training in cartography has a long tradition and similar structures in Germany, Austria and Switzerland. One must distinguish three training paths. As basis training, there are vocational training for geomatics in Germany and Switzerland. In Austria there is presently no real possibility for vocational training. Furthermore, courses are available at universities of applied sciences and academic universities (Bachelor and Master). The current situation is presented and reviewed.

Keywords: Cartography, geomatics, training, education, Bachelor, Master


Schlüsselwörter: Kartographie, Geomatik, Berufsausbildung, Studium, Bachelor, Master

1 International development

Training as a systematic teaching and acquisition of knowledge, skills, abilities and competencies as a requirement for skilled employment in a profession or area of expertise is essential to the existence and development of that profession or area of expertise. This is also true for cartography and areas of expertise with which it has interdisciplinary associations, and especially for geoinformatics (Bill and Naumann 2013) and geomatics, which have grown significantly in recent decades. Cartography – the science and technology of the communication and representation of spatiotemporal information – is an important field both nationally and internationally. The traditionally demanding training of specialists in this field of activity is gaining importance worldwide. The structure and level of education is different for each country, yet the development trends are largely the same. Training content is now dominated by