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Journey to the End of the World Map – How Edges of World Maps Shape the Spatial Mind

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Abstract

World maps are among the most widely used geomedia products for visualizing global phenomena. Since there are, theoretically, infinite ways to portray Earth's spherical surface on a plane, the question of the most appropriate world map design has been widely discussed in recent decades. However, this discussion has focused mainly on different projections, while another basic characteristic of any map, i.e. the presence of map edges, has been largely ignored so far. In view of this gap in cartographic research, this article examines empirically whether spatial relations are memorized differently by learners when these are presented on maps that have differently positioned edges. Distance estimations between locations learnt on Eurocentric and Americentric world maps are compared for this purpose. In line with previous spatial cognition research on barrier effects, our results indicate that distances are memorized more exactly when relevant inter-object relations are not being cut by map edges. Hence, designing an appropriate world map does not seem to be a problem purely of map projection; the position of the map's edges shapes the knowledge that users may acquire when reading a map.

Keywords:

world maps, map projections, map edges, distance estimation, barrier effects

1 Mapping the world: distortions, discussions and disputes

When Gerard Mercator published his conformally projected world map in 1569, he had a clear objective in mind, namely preserving angles in a way that allowed portraying loxodromes (also called rhumb lines) as straight lines – at that time a quality of particular usefulness for compass-based navigation and seafaring. Given that no map projection (i.e. transformation of spherical coordinates into positions on a plane) is free from distortions, Mercator achieved conformality only at the cost of increasing distortion of area towards the poles (see Figure 1). However, at the time this downside was of little relevance for marine navigation.

Originally designed for a very particular scenario, the application range of the Mercator projection changed and widened during the following centuries, when mapmakers started to use it for visualizing any kind of global phenomenon. As Monmonier (2004, pp. 122–23) states, "[T]he equatorial Mercator projection became the standard world map for nineteenth-century atlases and wall maps." Consequently, the distortions inherent in the Mercator projection became more relevant, and increasingly discussed and criticized by cartographers, resulting in a multitude of alternative ways to picture the surface of the Earth on a plane map (see Robinson, 1990). A detailed review of the scholarly debate and the history of map projections in general are beyond the scope of this paper; the interested reader is referred to e.g. Monmonier (2004) and Snyder (1997). However, a brief outline of some of the main arguments regarding the most appropriate projection(s) for world maps can be revealing. For this purpose, the Peters (or Gall-Peters)[1] projection will serve us, for two reasons. First, it is probably "the best-known map in the world, excepting only the Mercator" (Crampton, 1994, p. 22). Second, the Peters projection allows us to summarize the current state of research, but also to shed light on the blind spots of the world map projection debate.

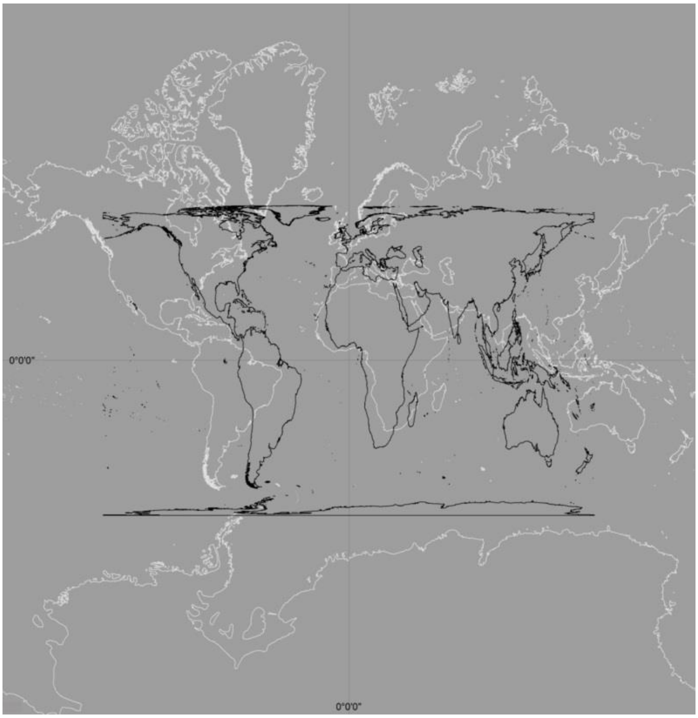

Figure 1. Mercator projection (white) and Gall-Peters projection (black), aligned at the equator and the Greenwich meridian (0°/0°); the former conserves shapes and angles at the cost of areal distortion, while the latter conserves areas and distorts shape.

1 James Gall, as early as 1855, described an orthographic projection with identical characteristics to the one presented by Peters in 1973. Apparently, Peters had not deliberately copied Gall's work, and the projection is currently also known as the "Gall-Peters" projection (Snyder, 1997).

When Arno Peters presented "his" world map and map projection to a wider public in 1973, he referred extensively to the Mercator projection and its successors to illustrate the supposed advantages of his own proposal: since Mercator's 1569 map covers latitudes from 80° N to 66° S, the northern hemisphere occupies the greater part of the map space available and, consequently, is shifted towards the horizontal map centre. These two details, together with the aforementioned areal distortions, are the main pillars of Peters' argumentation, who criticized the Mercator projection for being a child of European imperialism and its ongoing use as an expression of a Eurocentric world view.
Following this argumentation, "Arno Peters' project concentrated on two main points. First, arguing for the complicity of mainstream cartography in European imperialism (Peters, 1983), and secondly, in promoting his own, supposedly egalitarian and objective 'new cartography'" (Vujakovic, 2003, p. 62). The centrepiece of the "new cartography" was a world map with a cylindrical equal-area projection secant at 45° North and South, promoted as one of the most important innovations in map-making in over 400 years (see Vujakovic, 2003).

Cartographers, in turn, questioned both Peters' argumentation and the projection: the former for ignoring a number of map projections that were already known (including the equal-area projection), the latter for its distortions of landmasses, which are, according to Robinson (1985, p. 104), "somewhat reminiscent of wet, ragged, long, winter underwear hung out to dry on the Arctic circle". Moreover, it has been argued that any kind of rectangular world map would be inappropriate for visualizing global data (Robinson, 1990).

Peters' mapping project and his criticism of academic cartography prompted a long-lasting debate, whose after-effects on cartographic research are still noticeable. Vujakovic (2003) and Monmonier (2004) provide comprehensive reviews on these "map wars" from a cartographic perspective, while Barney (2014) also focuses on the iconicity of the Peters projection from a rhetorical viewpoint.

The discussion on how to portray the Earth certainly advanced our understanding of map projections and the (also political and social) meaning of world maps. However, the central question behind this debate has not been answered yet: we still lack a comprehensive understanding of how to represent global phenomena most appropriately. Concretely, the following shortcomings can be mentioned: (1) Neither Peters' criticism of the Mercator projection, nor cartographers' criticism of the Peters projection were underpinned with empirical evidence regarding the spatial knowledge generated by users of a particular map type. (2) The potential of undistorted visualizations on globes has not been discussed systematically. (3) All popular map projections (including the Mercator and Peters) can be criticized as being Eurocentric if the map is aligned and centred vertically on the Greenwich meridian (as in Figure 1).

These three points will be discussed in greater detail below. In section 2, we will review empirical studies on spatial knowledge acquired from world maps and globes. This will allow us to formulate a hypothesis for the last-mentioned issue, that of Eurocentrism, and, consequently, also regarding the function of map edges.

2 Empirical research on world maps and globes

Studies on map projections

A study that is very close to the issues outlined in section 1 above was carried out by Battersby & Montello (2009) on area estimations of different regions of the Earth. The authors began their study "believing that any distortions in areas on the global-scale cognitive map would come primarily from visual representations (i.e. maps) that the participants in our studies were familiar with previously, and that Mercator may be one of these familiar visual representations" (p. 288). However, this assumption proved not to be justified since participants estimated areas relatively well: "Thus, we found no evidence for a Mercator Effect in our studies, which would lead to increasing estimates of area as landmasses become more distant from the equator" (ibid.).

Another series of tests, focusing on positional rather than areal estimates, was conducted by Friedman & Brown (2000). In four experiments, they asked participants to estimate the latitude or longitude of cities in Europe, Africa and the Americas. Their results indicate that map users, when asked to make spatial estimates, do not rely on a single world map stored mentally. Rather, general knowledge (accessed e.g. via plausible-reasoning processes) is combined with multiple representations that are organized in a hierarchical manner (cf. also Battersby & Montello, 2009): "For example, a person attempting to estimate the latitude of Athens, Greece might know that Greece has a warm climate and that countries with warm climates tend to be close to the equator. This implies that Greece, and hence Athens, is relatively close to the equator. Moreover, because Greece is in Europe and Europe is north of the equator, Athens must also be north of the equator. However, because Greece has a warm climate, it cannot be too far north. Thus, an estimate of 15° north might seem reasonable, although it is incorrect (the actual latitude of Athens is 38° north)" (Friedman & Brown, 2000, p. 195). Europe, Greece and Athens are instances of hierarchical spatial categories in the example quoted above. Friedman & Montello (2006) showed in another experiment that such categories also affect the estimation of distances. Concretely, results obtained by these authors reveal that distances between locations from the same category (e.g. distances between Mexican cities) tend to be underestimated, while inter-category distances (e.g. distances between Mexican and southern U.S. cities) are, rather, being overestimated.

Hruby & Riedl (2013) confirmed the importance of spatial categories within a comparative test on world maps and globes. In this study they showed, on the one hand, that "distances are memorized more exactly when presented without distortions" (p. 206), i.e. when learned on a globe; this finding indicates that the potential of (analogue and digital) globes for the communication of global phenomena is still underestimated. On the other hand, they noticed that map edges affect the quality of distance estimates, i.e. whenever the shortest path between two locations crosses the right- or left-hand map edge, "Since map borders are reproduced in the structure of spatial memory they also can be understood as psychological borders, causing barrier effects like the estimation errors observed" (ibid., p. 209).

Studies on map edges

Summarizing the aforementioned studies we can deduce the hypothesis that designing an appropriate world map is not only a problem of map projection. The positions of the map edges also influence the knowledge that users may acquire when reading the map.

The importance of world map edges has received only limited attention in the scholarly literature. Using sketch maps, Saarinen (1987) concludes from a global study that Eurocentric world maps are the most commonly used map type for a large part of the world, with the exception of East Asia and Oceania, where Sinocentric maps dominate. While Saarinen focuses on the centre of world maps, thus addressing the position and function of map edges only indirectly, Hennerdal (2015) explicitly refers to the user's understanding of world map edges. Testing both children and adults, Hennerdal examines to what extent map users understand peripheral continuation at map edges. His test design is built on the scenario of airplanes passing beyond the edge of a world map. Using five different map projections, he asks participants to highlight where an airplane will reappear on the map after crossing the map edge: "The results clearly verify the hypothesis that people answer according to the idea of linear peripheral continuity, even in those cases in which such continuity does not apply" (ibid., p. 785). This means that, with regard to cylindrical projections like the Peters or Mercator, for example, most users – wrongly – expect an airplane passing over the south-western map corner to reappear at the north-eastern corner, while it would actually do so at the south-eastern edge. Hence, Hennerdal's study indicates a serious misunderstanding of map edges regarding peripheral continuity. So far, little research has been done concerning possible distance-estimation errors and effects of barriers (see also section 4) in connection with world map edges. Hruby & Riedl (2013), for example, indicate effects of map edges on distance estimates but deduce this assumption from a single abstract map design. Whether distances on world maps are learned and estimated differently when the position of the map edge is shifted systematically (e.g. on Americentric vs. Eurocentric maps) has not – to the best of our knowledge – so far been tested. The prototype study presented below will help close this research gap.

3 The current study

Test design and materials

The study presented here was designed for Mexican participants. According to Saarinen (1987), but also in concert with our own experience of national school atlases, Eurocentric maps are the most common type of world maps in Mexico, showing the country on the left-hand (western) side. Given that, in the Eurocentric case, Mexico's Pacific connections with East Asia and Oceania are cut by the left-hand map edge, we considered Americentric world maps to be of particular interest for a Mexican (and American in general) audience, since the country's relations with both Europe and Asia could be visually preserved. Hence, we decided to compare Eurocentric vs. Americentric maps (see Figure 2).

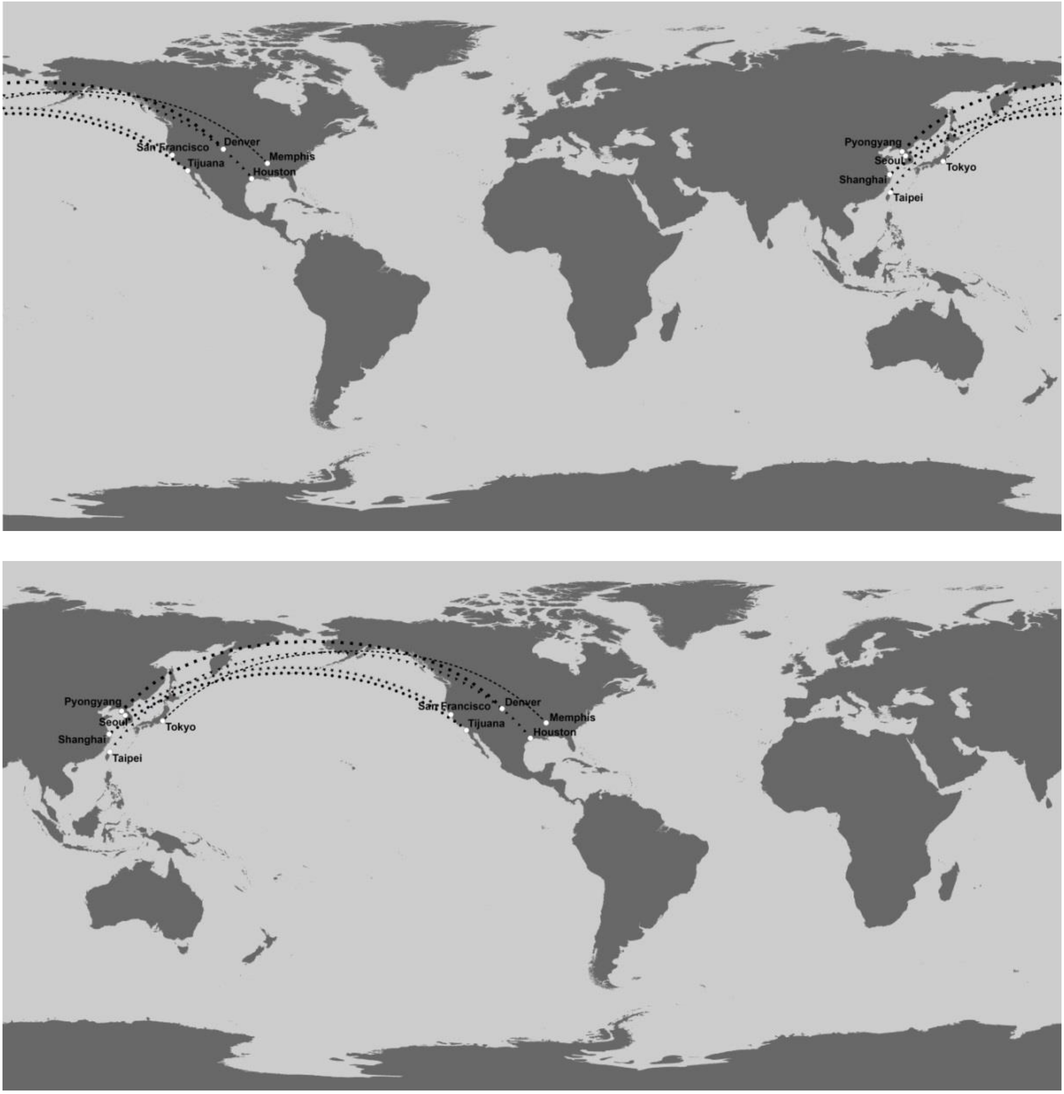

Figure 2: Eurocentric (above) and Americentric (below) test maps using a plate carrée projection, showing the 10 locations learnt and estimated (see Table 1); the shortest-path (great circle) connections indicated here for illustration purposes were not included in the maps used during the experiments; Spanish toponyms were used for the original test maps

From among the different map projections available, we decided to use an equi-rectangular projection (plate carrée), for the following reasons: (1) In the case of rectangular world maps like the plate carrée, the visual distance between left and right map edges is constant, thus introducing no additional complexity into the test design (compared to projections with rounded corners). (2) In a recent study on user preferences for different world map projections, Šavrič et al. (2015) observed that the plate carrée is a popular projection for rectangular world maps: "General map-readers most often selected the Robinson and Plate

Carrée projections over the other projections" (p. 404). (3) This projection is "commonly used for exchanging and visualizing geospatial data" (ibid., p. 400). (4) Hruby & Riedl (2013) also tested a plate carrée projected layout. Hence, by including the same projection in our test design, we expected to more closely tie our results to existing research.

To compare Eurocentric vs. Americentric world maps, pairs of locations A and B were defined against the following criteria: (1) As we are interested in possible differences regarding left and right (i.e. vertical) map edges, and given the increasing poleward distortions of the plate carrée projection, A and B should have a similar latitude. This also reduces the peripheral continuity issues observed by Hennerdal (2015). (2) Since Eurocentric world maps are the standard design for Mexican participants, we are particularly interested in pairs of locations where AB is being cut by an edge on a Eurocentric but not on an Americentric world map (see Figure 2).

The prototype study presented here is based upon five pairs of locations. Given the Mexican context of our test, we focused on locations in North America. These five North American locations were linked with five Asian locations according to the criteria above (see also Table 1). The resulting ten locations were mapped on both Eurocentric and Americentric world maps (see Figure 2).

Participants and test procedure

Fifty-four students from two undergraduate courses on Geographic Information Systems (GIS) took part in the study (24 Guadalajara University students, and 30 participants from the National Autonomous University of Mexico), 26 of whom took the test using the Eurocentric layout, while 28 used the Americentric map. They received a small number of course credits for their participation. Of these 54 subjects, we eliminated one person's data from further consideration since the estimation values they gave indicated a fundamental misunderstanding of the task.

All participants were tested individually, sitting in front of a standard 19-inch computer flat screen. In the first stage, they were asked to memorize the locations of all 10 names shown on each map; they were not informed about the distance-estimation task requested subsequently. Once participants thought they had memorized the 10 locations, the names were removed and participants were asked to label each location on a blank map using the computer keyboard. This knowledge test was repeated until subjects could name all locations correctly.

Immediately upon completing the knowledge test, participants estimated the distances of all 5 pairs of locations (see Figure 2 and Table 1). To facilitate this task which was cognitively demanding both in terms of estimating the distances and in terms of the evaluation and comparability of the results obtained, a relative measure of distance was introduced (cf. Hruby & Riedl, 2013): participants were instructed to start the distance-estimation test by selecting the pair of locations which were closest to each other and to assign a distance value of 1 to this pair. Having chosen the nearest neighbours, they were asked to estimate the distances of all the other pairs in relation to the closest pair. If a participant estimated, for instance, the distance between the members of a given object pair as 50% greater than the closest pair, a value of 1.5 was assigned. Participants were told explicitly that the map used a plate carrée projection.

Furthermore, they were reminded that understanding the test map as a plate carrée implied considering the relationships between the left- and right-hand edges of the map (e.g. the shortest path between Hawaii and Japan on a Eurocentric world map). Finally, participants were also asked to keep in mind the growing horizontal distortions towards the upper and lower edges of the world map. The estimation task had to be done from memory: the map memorized before could no longer been seen during this part of the experiment. No time limit was given for any task in the test.

Results

The majority of participants overestimated the five distances requested, both in the Euro- and in the Americentric test groups (see Table 1). On average, participants produced estimation errors of 1.74 (Eurocentric map) and 0.71 (Americentric map) respectively. Estimation error is defined here as the difference between real and estimated value, and expressed in relation to the closest object pair (as described in 3.2 above). This difference was statistically significant at the 0.05 level using an unpaired t-test ($t = 3.3618$, $df = 51$).

Table 1: Inter-location relations tested, showing estimated and actual distances, and averaged errors observed for the Eurocentric and Americentric world maps; numbers of inter-location relations under- and overestimated are shown in %; bold fonts indicate statistically significant differences at the 0.05 level

location pairs estimated	*distance in km*	*distance in relation to the closest pair*	*averaged estimate error on the Eurocentric map (under-/ overestimated pairs in %)*	*averaged estimate error on the Americentric map (under-/ overestimated pairs in %)*	*unpaired t-test results (df = 51)*
Denver - Pyongyang	9,850	1.09	1.79 (0% / 100%)	0.94 (4% / 96 %)	**t = 2.9698**
Memphis - Tokyo	10,600	1.17	1.67 (11% / 89%)	0.85 (4% / 96%)	**t = 2.0913**
San Francisco - Seoul	9,050	1.00	1.65 (8% / 92%)	0.51 (14% / 86%)	**t = 3.9875**
Houston - Taipei	12,800	1.41	1.61 (8% / 92%)	0.59 (7% / 93%)	**t = 2.8940**
Tijuana - Shanghai	10,650	1.18	1.70 (12% / 88%)	0.55 (14% / 86%)	**t = 3.8732**

In order to analyse the distance estimation errors in even greater detail, we also compared the data on the level of location pairs. Again, the difference was statistically reliable at the 0.05 level for all 5 pairs tested (using unpaired t-tests; see Table 1). Both sets of results presented show clearly that participants in our study estimated distances significantly better when object-memorization was done on an Americentric world map. All statistical tests were done using GraphPad Prism software (GraphPad Software Inc., La Jolla, CA, USA).

4 Discussion and Conclusion

In this paper, we have tried to shed light on the question of how the position of a map's edges influences the knowledge that users acquire. For this purpose, using both Euro- and Americentric maps, estimations of distances between 5 North American and 5 Asian cities were analysed. Our findings indicate that distances are memorized more accurately when learned from an Americentric map. This is particularly remarkable since the majority of our participants are more familiar with Euro- than Americentric world maps.

The data we have collected so far fits in with previous findings of spatial cognition research that "the general effect of barriers is that distances across barriers are overestimated in contrast to comparable distances that do not cross a barrier" (Hirtle & Jonides, 1985, p. 209; cf. also McNamara et al., 1989). Our results confirm this observation and show that a map's edges can be understood in terms of barriers according to Hirtle & Jonides (1985): distances between pairs of locations whose shortest connection path crosses the right- or left-hand edge of the map are overestimated in relation to comparable distances that do not cross a map edge. To better understand the patterns observed, findings from basic visual perception research should also be considered, e.g. regarding grouping phenomena and their possible effects on distance estimates (cf. Palmer et al., 2003). Cross-checking the test design applied here would also be desirable to further substantiate our results – e.g. to compare the results for other pairs of distances that (conversely) are cut on Americentric but not on Eurocentric world maps, or comparing the performance of European and North American map users on the same test location-pairs and maps. The data presented here could therefore be useful for future comparative studies.

Finally, the experiments presented are significant also with regard to discussion of how to map global phenomena most appropriately. As we showed in sections 1 and 2, this discussion has so far been limited to the question of the optimal map projection(s). However, our results indicate that users memorize identical spatial information differently depending on whether it is presented on a Eurocentric map or an Americentric one. How world maps shape the spatial mind is, thus, a matter not only of projection but also of the alignment of the map and of its edges.

Although a map's edges might work as psychological barriers when spatial distributions are being learnt, they are an essential characteristic of any world map. Hence, barrier effects will occur as a matter of course whenever a world map is being used. Familiarizing pupils with differently-centred (e.g. Ameri-, Euro- and Sinocentric) world maps (so using a multi-representational approach to cartography (cf. MacEachren, 2004)) could help to counter and compensate for the effects of map edges. Given such familiarization we could, then, start to align maps not only on historically agreed references, but according to user-specific requirements, for example for the needs of a particular topic. With this in mind, the findings presented in this paper should be of particular interest not only for a Mexican and American audience, but also for map users and mapmakers globally.

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