Cognition and Perception of Map Projections: A Review Fritz

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Introduction

We believe that map projections are poorly understood by many who work with spatial data, and that map readers and creators are often confused as to the role that projections play throughout the mapping process. For instance, the projection selected may be inappropriate for the spatial analyses or map purpose. This may be due to the lack of options provided for selecting a projection (e.g., working in an online web Mercator-based system), lack of understanding of distortion in map projections, or just due to simple aesthetic preference without concern, or knowledge, of distortion in map projections (e.g., "My boss says we need to use the *rounded-looking projection*"). Mismatches between projection choice and map purpose lead to errors in analysis and faulty interpretation of spatial patterns. In this paper, we explore the challenges in how people understand map projections from both perceptual and cognitive perspectives. Through a review of the literature, we will explore map readers' mental models, spatial thinking, and understanding of projections to better understand how we can help users of spatial data, and designers of the spatial tools that these users rely upon, more accurately and confidently evaluate spatial data.

We discuss a subset of our topics in this extended abstract, and are preparing a full-length paper to provide additional detail and insights.

Perceptual and Cognitive Research in Cartography

Maps provide assistance to us in making sense of the world around us; scaled maps are the only way we can synthesize the world into a view small enough to comprehend in its entirety. In order for maps to work effectively, they need to follow good cartographic design principles, grounded in what we understand of the processes of human *perception* and *cognition*. This is particularly important when considering the role of map projection in visualization and analysis of spatial data, where the inherent distortion introduced by the projection process can alter both how people perceive patterns when visually inspecting a map, and how they form cognitive representations of the world around them that are mentally recalled as needed to help us make sense of the world.

In cartography, as a whole, cognitive and perceptual methods to guide research is a relatively modern addition to the field (Montello, 2002). While there is some notable early cognitive research in cartography (e.g., Eckert 1921 & 1925; Miller 1931), the field research seemed to blossom more after Robinson's (1952) "The Look of Maps."

For studying perceptual and cognitive issues in cartography and general cognition of the environment, a variety of methods have been adopted and employed, from classic paper and pencil studies in spatial abilities (Eliot and Smith 1983), physical activities such as pointing (Kirasic et al. 1984) or wayfinding (Golledge et al. 1999), to recognizing patterns from shadows (Downs & Liben 1991), drawing sketches (e.g., Saarinen et al. 1996), approximating paths (Anderson & Leinhardt 2002), or estimating specific properties of projections from memory (Battersby & Montello 2009; Montello & Battersby 2022) or while directly interacting with maps (e.g., Battersby 2009; Battersby & Kessler 2012), or brain scanning using fMRI (Lobben et al. 2009) to name a few. Though these are not all directly relevant for evaluating cognition and perception of map projections, they lay an important foundation for the range of research to understand and mitigate the impact of map projections.

In addition to cognitive and perceptual studies designed to elucidate our understanding of map projections specifically, there are also interesting, and highly relevant, bodies of work tied to a more general focus on stages of intellectual development (Piaget 1965), as well as specific development in understanding maps (e.g., understanding childrens' mental models of Earth (Vosniadou and Brewer 1992)). For instance, considering development of interrelated mathematical and spatial thinking skills and abilities (e.g., Goodchild & Janelle 2010), and how that relates to the process of understanding the transformations that occur with map projection (e.g., Jo et al. 2012).

Why is this important to understand? Because, at their core, map projections are rather difficult for many people. As Snyder (1993, p.276) has noted, "working with projections still strikes fear in the hearts of many trained cartographers and geographers..." We explore this problem in the next section.

Map Projections are Hard

Map projections are challenging for both the map maker and the map reader. This difficulty is driven by the mathematical transformation from spherical Earth to a 2-D representation; this topological transformation necessarily introduces distortion across the 2-D map. There have been long-standing debates in cartography about the impact of projection distortion and its impact on both the map reader's perception and cognition of the map.

There are many nuanced and confusing *rules* (or, perhaps, guidelines) for addressing the impact of distortion in map projections, the reflection of this distortion in subsequent analyses, and in ensuring that the map correctly conveys the desired spatial information. We summarize these rules into three basic arguments - each of which helps emphasize why projections are hard for many people.

Rule one is focused on correct understanding of map projection properties and how they can be preserved or distorted. Basic projection properties preserve Earth's spatial relationships such as angles, areas, and distance while there are other special projection properties, e.g., preserving loxodromes as straight lines on a map, that focus on other metrics. Limited understanding of a specific property and what it preserves can lead to erroneous assumptions about what information the map presents. For instance, we have noted inaccurate statements such as "conformal projections preserve shapes" repeatedly in GIS texts. Conformal projections preserve local angles for infinitely small extents, so technically they also *do* preserve shape, but only for those same infinitely small extents. If, as has been (incorrectly) suggested in some texts, conformal projections truly preserved shape, and this is true for large geographic areas like continents, then we would have to assume that all conformal projections would show identical shapes for these continents and, thus, look the same. Clearly this is not the case, as there are numerous conformal projections that do not look alike. We see this as a demonstration of a common misconception about what preserving properties may mean for different projection types.

Rule two speaks to the mechanics of using a specific projection property to carry out a measurement task and how distortion affects the outcome of that measurement task. For example, despite their name, equidistant projections do not offer the ability to accurately measure any distance on a map, just selected distances (e.g., only along meridians). Here, even though a projection property implies one thing (equidistance), the nuance of this rule means there are limitations on how this property can meet a specific map purpose.

Rule three relates to how distortion influences the appearance of landmasses and spatial patterns in the data. Distortion leads to landmasses being stretched or compressed in one or more directions. The preservation of one property and inherent distortion of other properties necessarily impacts the overall appearance of landmasses and spatial patterns in datasets, altering how a reader may interpret the data.

Ultimately, the map maker's understanding of the map reader's task, as well as the type, amount, and distribution of distortion across the mapped area, should influence the selection of a map projection. While there are always tradeoffs in selecting any specific projection, the map maker is expected to have at least some minimal knowledge of map projections, and interest and desire to make an appropriate choice, to help guide a reasonable projection selection. On the other hand, the map reader cannot be expected to have had any formal training on map projections. Thus, when the map reader examines a map, what knowledge can they apply to make sense of what they see? Given this, in order to select an appropriate projection in designing a map, it is especially important for map makers to understand what map readers might be expected to know about map projections (the rules), the potential perceptual challenges readers may face in interpretation, and the misconceptions about how maps / map projections work that might be perpetuated in map reading. Cognitive and perceptual research studies help shed light on what map readers know about map projections and how that knowledge is brought to bear when examining projections.

Cognitive Map Projection Studies

Compared to other research avenues in cartography, cognitive and perceptual studies specifically focused on map projections are more limited. In our in-progress paper, we will evaluate this body of literature with respect to its situation in the broader body of cognitive and perceptual research areas in cartography and related disciplines. In general, we focus on works related to perception or cognitive estimation of properties such as area, size, and shape, understanding and interpretation of distances and directions, the influence of map projections on alignment in cognitive maps, aesthetics and user preferences, and how familiar map projections may, or may not, alter our overall understanding of the world. We also will address relevant work in map projection education and the role of cognition and perception in the design of map projection selection / guidance tools.

In our presentation at the AutoCarto conference, and in the subsequent full paper, we will provide a review of these and other relevant avenues of work. Our intent is to document and synthesize what is known about map projections and the challenges of human perception and cognition of projections to help shape future work in map design, as well guide future developments in software and other tools supporting geospatial work so that they better align with human understanding of distortion in map projections.

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