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The Polysemy of Map Signs

An Exploration of the Connotative Meanings of Cartographic Point Symbols

DISSERTATION

zur Erlangung des akademischen Grades

Doktorin der Naturwissenschaften (Dr. rer. nat.)

eingereicht von

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Wien, 12. April 2021

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submitted in partial fulfillment of the requirements for the degree of

Doctor of Natural Sciences (Dr. rer. nat.)

by

Mag. rer. nat. Silvia Klettner, BA

Registration Number 00002857

to the Faculty of Mathematics and Geoinformation

at TU Wien

Advisor: Univ. Prof. Dr. rer. nat. Georg Gartner

Reviewer: Prof. Michael P. Peterson, PhD, University of Nebraska Omaha, USA

Reviewer: Dr. Amy Griffin, RMIT University, Australia

Georg Gartner | Michael P. Peterson | Amy Griffin

Vienna, April 12, 2021

Silvia Klettner

Declaration of Authorship

I hereby declare that I have written this Doctoral Thesis independently, that I have completely specified the utilized sources and resources, and that I have definitely marked all parts of the work - including tables, maps, and figures - which belong to other works or to the internet, literally or extracted, by referencing the source as borrowed.

Silvia Klettner

Vienna, April 12, 2021

Acknowledgments

As I conclude this dissertation, I would like to express my gratitude to everyone who contributed to this project.

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— Ich danke allen, die mich ein Stück begleitet
und mir diesen Weg ermöglicht haben.

Abstract

Maps are a means of communication. Through the use of signs and symbols, maps communicate about the geographic world. As such, they enable us to relate to spatial phenomena from viewpoints beyond direct experience.

Cartography is, therefore, deeply concerned with the use of map signs and their meanings. Semiotic theory generally emphasizes two meaning dimensions of any sign, i.e., the dimension of reference and the dimension of sense (Nöth, 1995). These two dimensions are also referred to as explicit and implicit meanings, as denotation and connotation, as meanings *in* maps and meanings *of* maps (MacEachren, 1995). So far, cartographic semiotics has mainly focused on the explicit, denotative meanings in maps. The implicit, connotative meanings of maps and their effects on map users have, yet, largely been disregarded.

This dissertation was, thus, devoted to exploring the dimension of connotation in cartographic communication. Four empirical user studies were carried out to examine the implicit, connotative meanings of abstract cartographic point symbols. The studies revealed that cartographic signs connote on multiple levels, i.e., visually, associatively, and affectively. The findings further disclosed the cognitive relatedness of cartographic point symbols, revealed their affective qualities, identified symbol-content congruences, and demonstrated that the connotative meanings associated with abstract shapes influence how people judge geospatial events.

With these findings combined, this dissertation contributes a diverse empirical basis of the potential connotative meanings of cartographic point symbols. It demonstrates the significance of the visual sign in cartographic communication. It also emphasizes the polysemy of cartographic signs and the need to consider their connotative meanings with more attention in cartographic research and practice.

Kurzfassung

Karten sind ein Mittel der Kommunikation. Durch den Einsatz von Zeichen und Symbolen geben Karten Aufschluss über die geografische Welt. Sie ermöglichen uns damit einen Zugang zu räumlichen Phänomenen, der weit über die unmittelbare menschliche Wahrnehmung hinausgeht.

Die Kartographie befasst sich daher insbesondere mit der Verwendung und der Bedeutungen kartographischer Zeichen. Semiotische Theorien betonen dabei zwei zentrale, allen Zeichen inhärente Bedeutungsdimensionen: die referenzbezogene Bedeutung und die sinnbezogene Bedeutung (Nöth, 1995). Diese beiden semiotischen Dimensionen werden auch als explizite bzw. implizite Bedeutungen bezeichnet, als denotativ bzw. konnotativ, als Bedeutungen *in* Karten bzw. *von* Karten (MacEachren, 1995). Kartografische Semiotik beschäftigte sich bislang vor allem mit den denotativen, referenzbezogenen Wirkweisen von Kartenzeichen. Die konnotativen Bedeutungen von Karten und Kartenzeichen sind jedoch kaum erforscht.

Um zu einem ganzheitlicheren Verständnis über die Wirkweisen von Karten beizutragen, widmete sich diese Dissertation der Konnotation kartographischer Zeichen. In vier empirischen Studien wurden daher die konnotativen Bedeutungspotentiale abstrakter Punktsignaturen und deren Wirkungen auf Kartennutzer*innen erforscht. Dabei zeigte sich, dass Kartenzeichen auf vielfältigen Ebenen wirken, nämlich: visuell, assoziativ und affektiv. Die Studien veranschaulichten ferner die kognitiven Ähnlichkeiten und Hierarchien abstrakter Symbole, legten deren detaillierte affektive Qualitäten dar, identifizierten konkrete inhaltsspezifische Kongruenzen von Kartensymbolen und verdeutlichten überdies, dass die schiere Form kartografischer Punktsymbole die Beurteilung geografische Ereignisse signifikant beeinflussen kann.

Mit diesen Ergebnissen legt diese Dissertation eine vielfältige empirische Grundlage der unterschiedlichen konnotativen Bedeutungspotentiale kartografischer Punktsignaturen dar. Die Ergebnisse der empirischen Studien unterstreichen damit die Polysemie kartografischer Zeichen und verdeutlichen die Notwendigkeit, diese in kartografischer Forschung und Praxis stärker zu berücksichtigen.

Content

Part I

Introductory Chapters

CHAPTER 1

Introduction

Background

Maps are a means of communication. They evolved from early drawings rooted in the human desire to capture the environment's spatial structures (Robinson et al., 1995) and to communicate about "our place in the world long before the development of written language" (Kent, 2018, p. 96). Maps have enabled us to relate to spatial phenomena from viewpoints beyond direct experience. As such, they are recognized as powerful means of "conceiving, articulating, and structuring the human world" (Harley, 2009/1988, p. 129).

Cartographic communication is, yet, a complex process. Maps are based on a myriad of choices concerning *what* and *how* to communicate. They are the result of a series of decisions, influenced by the cartographers' conceptions of reality, knowledge, skills, interests, socio-cultural context, and the like (Harley, 1989; Koláčný, 1969; Leeuwen, 2005; Tversky, 2000; Wood & Fels, 2008). Cartographic communication is, thus, recognized as an interrelated and multifaceted process in which not only information but also values, viewpoints, and meanings are shared. Hence, maps are never neutral or value-free.

As a discipline of geospatial communication, cartography is deeply concerned with the study of map signs and the meanings they induce. Semioticians have proposed two dimensions of meanings inherent in any sign, i.e., the denotative meaning *dimension of reference* and the connotative meaning *dimension of sense* (Nöth, 1995).

From a cartographic perspective, all cartographic signs communicate on the dimension of reference, as they are used as identifiers to indicate and locate geospatial information (MacEachren, 1995). At the same time, cartographic signs give rise to meanings on the dimension of sense. They stimulate ideas and express values. In doing so, they implicitly influence the meaning of maps (Keates, 1996; MacEachren, 1995). These two meaning dimensions of signs are also known as denotation and connotation (Nöth, 1995), as explicit and implicit meanings (Nöth, 1995), as the meanings *in* maps and the meanings *of* maps (MacEachren, 1995).

While semiotic theory has long emphasized the two meaning dimensions present in any sign, the study of connotative meanings has, yet, largely been disregarded in cartographic research. Critical approaches to cartosemiotics have, therefore, stressed for advancing the conception of maps beyond a neutral, referential representation (Harley, 1989; MacEachren, 1995; Petchenik, 1977; Wood & Fels, 1986). Such critical approaches emphasize the polysemy of maps and map signs, i.e., that signs denote *and* connote inseparably (Aiello, 2020a; Kress, 2001; Leeuwen, 2005).

Meanwhile, the rise of new and well-accessible technologies has shifted the dominant cartographic medium from paper to digital. This development transformed the way maps are made, used, and shared (Kent, 2018). Web maps have become smaller and simpler, many of single purpose and single-themed (Field, 2014; Kraak & Ormeling, 2011). At times, they are as simple as to represent a single incident by a single cartographic symbol. Such maps are not designed to be processed deliberately with high cognitive effort. Instead, they allow for intuitive judgments based on associations and connotations (Evans, 2008; Kahneman, 2002, 2003).

Yet, little is known about the connotations and associations triggered by such simple maps. Research, however, emphasizes that the cartographic design influences how maps – or more aptly, the phenomena represented in maps – are interpreted, imagined, and acted upon (Monmonier, 1996).

The missing knowledge about the connotative effects of maps and map signs, together with the ever more ubiquity of simple web maps, motivated this research on visual semiotics. This dissertation was devoted to exploring the connotative meanings of cartographic point symbols and to examining their effects in simple, monothematic maps. This research aimed to contribute to a more holistic understanding of the polysemy of cartographic signs.

Contribution

This dissertation studied the dimension of connotation in cartographic communication. Four empirical studies were carried out to disclose some of the connotative meanings of abstract cartographic point symbols. The studies revealed the symbols' cognitive relatedness, their affective qualities, symbol-content congruences, and their effects on map-related intuitive judgments. As such, this research demonstrated that cartographic point symbols connote on multiple levels. The findings of this dissertation, thus, contribute new and empirically grounded knowledge to the field of cartographic semiotics.

This dissertation's research questions, main findings, and contributions can be summarized as follows:

RQ1: *Which geometric shapes are experienced to be (dis)similar and why?*

Study 1 – Cognitive Proximity of Point Symbols – examined the similarity of abstract geometric shapes (Chapter 5). To answer if – and if so, how – geometric symbols differ, the empirical study used the concept of similarity (or sense of sameness) to disclose their cognitive relatedness.

The study applied a card sorting method where study participants grouped a set of twelve geometric shapes according to their similarities. Through cluster analysis and multidimensional scaling, the study quantified the shapes' cognitive proximities and hierarchies. Three homogeneous clusters were found: a cluster of round shapes, one of polygonal shapes, and one of spiked shapes. Findings further suggest a cognitive meta-concept between round shapes and polygonal shapes. Qualitative content analysis revealed three strategies underlying the participants' similarity judgments, i.e., visual, associative, and affective processes.

The proximity space and the strategies uncovered set the theoretical basis for the three subsequent studies. These studies were designed to explore the connotative meanings of abstract point symbols in cartographic contexts. In particular, they focused on examining their associative and affective connotations.

RQ2: *Which affective responses do (carto)graphic point symbols involve?*

Affect is a "neurophysiological state that is consciously accessible as a simple, nonreflective feeling" (Russell, 2003, p. 147). It can also be experienced as *affective qualities* (i.e., attributes) associated with stimuli or objects (Bakker et al., 2014; Russell, 1980). Affect influences human thinking and decision-making (Izard et al., 1984) and is a sub-dimension of connotation.

Study 2 – Affective Potential of Point Symbols – examined the affective connotations of cartographic point symbols (Chapter 6). The study used eight abstract point symbols in three stimulus conditions, i.e., one non-cartographic and two cartographic conditions. The symbols comprised six symmetric shapes and two asymmetric star shapes. Study participants rated the point symbols' affective qualities in each of the three study conditions through a semantic differential technique.

The Semantic Differential revealed detailed affective profiles for each shape stimulus along the affect dimensions of valence and dominance. The study further identified affective similarities between the shapes in each of the three stimulus conditions through multiple pairwise comparisons and multidimensional scaling. The findings revealed that asymmetric star symbols triggered the most potent negative affective responses, while symmetric symbols generally led to more positive responses. This difference prevailed across all three stimulus conditions.

This research demonstrated that abstract point symbols connote affectively. As such, the findings infer that some map symbols must not be treated as neutral symbols in cartographic communication.

RQ3: *Which cartographic point symbols are (in)congruent to which type of content?*

Study 3 – Contextual Congruence of Point Symbols – examined the cognitive correspondence between map symbols and positive, neutral, and negative map topics (Chapter 7). Twelve map topics were selected for the study (four positive, four neutral, and four negative topics). Each topic was depicted by six point symbols (five symmetric symbols and one asymmetric star symbol). This resulted in a stimulus set of 72 monothematic maps. The congruence of each map topic and map symbol was rated on a 6-point Likert scale, ranging from 0 (not at all congruent) to 6 (very congruent).

The findings suggest distinct correspondences between the type of cartographic point symbol and map topic. In particular, the findings showed that symmetric shapes were highly congruent for depicting positive map topics. Circular symbols were most congruent with neutral topics. Asymmetric stars, on the other hand, were regarded as most congruent for representing negative map topics.

This study demonstrated that the meaning of cartographic point symbols is susceptible to context. This, in turn, implies that cartographic design may be enhanced by following principles of contextual congruence.

RQ4: *Do cartographic point symbols influence how geospatial events are judged?*

Study 4 – Point Symbols and Intuitive Judgments – examined how abstract cartographic point symbols influence how map users perceive the severity of negative geospatial events (Chapter 8). The study comprised twelve negatively connoted map topics (e.g., traffic accident, floods, wildfires). Each topic was depicted by six point symbols (five symmetric symbols and one asymmetric star symbol). This resulted in 72 monothematic maps. Study participants rated the perceived severity of the depicted events on an 11-point Likert scale, from 0 (very low) to 10 (very high).

The results showed that star symbols generally led to significantly higher ratings. Across all map topics, asymmetric star symbols led to the highest estimates about the severity of the depicted geospatial events, followed by symmetric star symbols. In contrast, triangle and rhomb triggered the lowest ratings. Circle and square, on the other hand, led to the most variant results, i.e., high and low, depending on map topic. This finding suggests that circles and squares imbue the most variable meaning potential among the tested cartographic point symbols.

This study showed that map symbols influence – and even amplify – how geospatial events are judged. In other words, the connotative meanings of cartographic point symbols can have a significant impact on how map users imagine and interpret geospatial events.

Publications

Parts of this dissertation research have been published elsewhere in the form of journal articles and conference papers. Some sections of these publications are directly included or reworked as chapters in this thesis.

Journal publications:

- Klettner, S. (2021). The Significance of the Cartographic Sign: Influences of Symbol Shape on Intuitive Judgments. *Manuscript submitted for publication.*
- Klettner, S. (2020). Form Follows Content: An Empirical Study on Symbol-Content (In)Congruences in Thematic Maps. *ISPRS International Journal of Geo-Information, 9(12), 719.*
- Klettner, S. (2020). Über die semiotischen Wirkebenen kartographischer Punktsignaturen [About the semiotic dimensions of cartographic point symbols]. *VGI – Österreichische Zeitschrift für Vermessung und Geoinformation, 3, 105-112.*

- Klettner, S. (2020). Affective Communication of Map Symbols: A Semantic Differential Analysis. *ISPRS International Journal of Geo-Information, 9(5), 289.*
- Klettner, S. (2019). Why Shape Matters — On the Inherent Qualities of Geometric Shapes for Cartographic Representations. *ISPRS International Journal of Geo-Information, 8(5), 217.* [1, 2]

Peer-reviewed conference proceedings:

- Klettner, S. (2020). More Than Identifiers: Map Symbols and Their Connotative Meaning. *EuroCarto - Central European Cartographic Conference.*
- Klettner, S. (2019). Small Symbols With Big Effect? A Cognitive-Affective Perspective on Map Symbolization on Small-Sized Displays. In *15th International Conference on Location-Based Services (p.13).*
- Klettner, S. (2019). The Significance of Shape in Cartographic Communication. *Abstracts of the ICA, 1.*

Terminology

Based on the theoretical discourse as laid out in Part I of this dissertation, this research defines its core concepts as follows:

Cartographic communication: Cartographic communication is defined as a complex process between the map maker and map user. Communication in this research is regarded as the *act of sharing ideas* to make them common. Through maps and map signs, both denotative and connotative meanings are shared. Both dimensions of meaning are conceived as constructions by the map maker and the map user alike, embedded in socio-cultural contexts (Harley, 1989; Petchenik, 1977).

Maps: Maps are recognized as symbolized, multifaceted representations of geographic space (MacEachren, 1995), as inherently selective and subjective (Wood, 2010), as depictions which "reflect conceptions of reality, not reality" (Tversky, 2000, p. 78). As such, maps are acknowledged to be never neutral nor value-free, but the result of both individual cognitive and socio-cultural constructions (Harley, 1989; Wood & Fels, 2008).

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[1] Winner of the *Karl-Rinner Award 2019* for outstanding international scientific publications of young researchers. Awarded by the Austrian Geodetic Commission (ÖGK).
[2] Winner of TU Wien's *Best Paper Award 2019.* Awarded by the Department of Geodesy and Geoinformation of TU Wien.

Map signs: Cartographic signs and symbols are acknowledged as more than their constituent sign-vehicles or signifiers (Nöth, 1995). This research recognizes the sign's triadic structure, such as proposed by Peirce (1986, 1990). It comprises the *sign-vehicle,* which acts as a physical sign, *the referent,* which is the phenomenon or object of reference the sign-vehicle refers to, and *the interpretant,* which is the sign's effect on the interpreter. This research focuses on the map sign as a sign-vehicle meditating between referent and interpretant. As such, map signs are studied from an interrelated triadic semiotic perspective.

Meaning: Meaning is recognized as a manifold concept. As theorists have decomposed the "many meanings of 'meaning'"(Osgood et al., 1957, p. 2), two core dimensions have widely been agreed on: the dimension of reference and the dimension of sense (Nöth, 1995). This research studied the dimension of sense. More specifically, it focuses on exploring the connotative meanings of cartographic point symbols.

Map users: Map users are acknowledged as active interpreters (as opposed to passive receivers). They actively process the explicit, denotative meanings in maps as well as the implicit, connotative meanings of maps (MacEachren, 1995). This research studies the connotation meanings of map signs from an individual's cognitive-affective perspective.

Affect: Human affect is defined as a "neurophysiological state that is consciously accessible as a simple, nonreflective feeling" (Russell, 2003, p. 147). It can be neutral, moderate, or extreme (Russell, 2003). When affect is moderate or extreme, it can be consciously experienced as a feeling or emotion (Feldman Barrett et al., 2007; Russell, 2003). When affect is neutral, it is experienced as *affective quality* and referred to as attributes or properties of the surrounding stimuli, objects, or environment (Bakker et al., 2014; Russell, 1980). Whether mildly or extreme, affect influences human thinking and decision-making (Izard et al., 1984). The study of affective qualities of cartographic point symbols is part of this research.

Cognition: Cartographic information may activate three types of cognitive processes (Kahneman, 2003). One process refers to human perception. The second process refers to low-level cognitive processing (Type 1 intuitive processing). The third process refers to high-level cognitive processing (Type 2 reflective reasoning). This dissertation focuses on low-level cognitive cartographic tasks, which involve intuitive, associative, and affective judgments. As such, it focuses on *Type 1 intuitive processing*.

Methodology

This dissertation combined qualitative and quantitative research methods to explore the connotative meanings of cartographic signs. It used this triangulation approach to study connotation from different methodological perspectives (Denzin, 1970). Quantitative methods were used to identify significant differences between cartographic point symbols. The collected qualitative data, on the other hand, were used to complement and clarify quantitative findings.

This dissertation further encompassed a controlled research approach, where variables of interest were isolated and confounding variables controlled. The stimulus material's visual complexity was stepwise increased, from studying abstract symbols isolatedly (Study 1) towards stepwise mimicking realistic map scenarios (Study 2 – 4). In doing so, this dissertation research explored the overarching research theme from a fundamental and an applied research perspective, aiming to derive conclusions systematically (Kosara & Haroz, 2018).

Figure 1 illustrates the methodological approaches of the four empirical studies of this dissertation research.

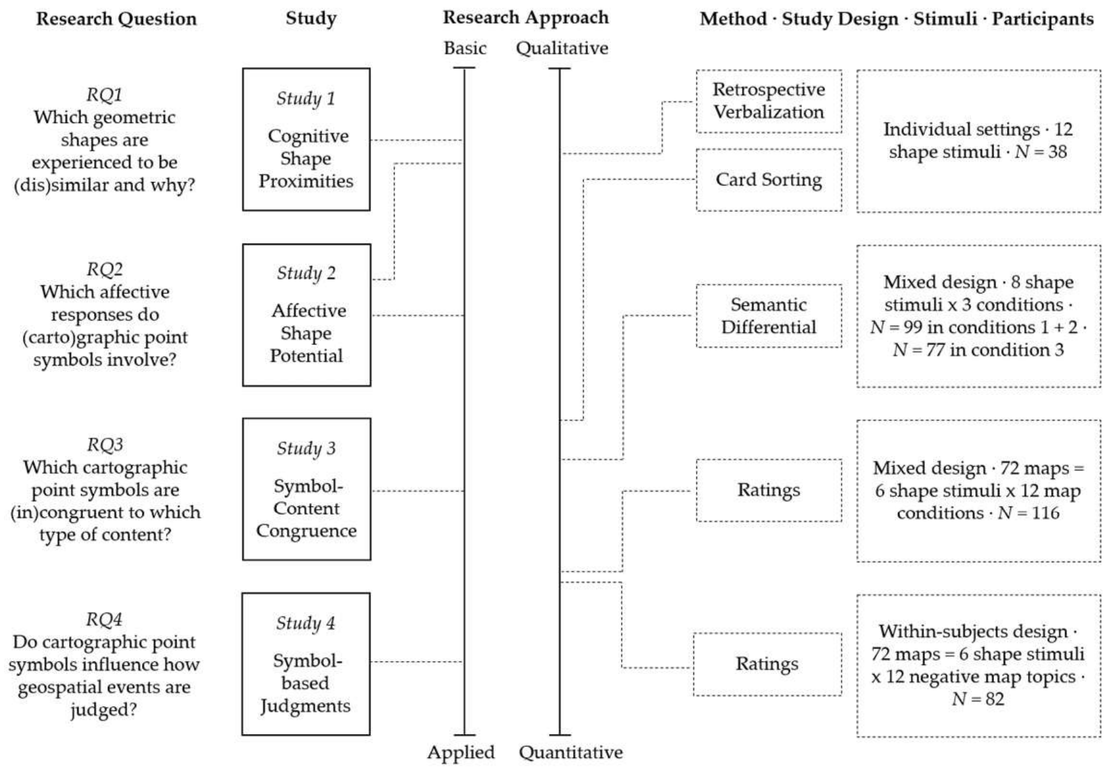

Figure 1. Overview of empirical studies and methodological approaches.

The following research methods were used in the empirical studies of this dissertation:

Card sorting: Cart sorting methods have a long tradition in psychology (Berg, 1948; Creque & Kolakowsky-Hayner, 2018). They have more recently been established as a common method in usability studies (Wood & Wood, 2008). Card sorting is a method used to disclose cognitive structures, such as revealing how people categorize information. A card sorting approach was applied in Study 1 to identify perceived similarities between geometric symbols. Participants sorted cards depicting geometric symbols freely and intuitively into groups. Afterward, they were instructed to explain their decisions by retrospective verbalizations.

Retrospective Verbalization: Verbalization methods are used to uncover processes and concepts underlying decision-making. Through verbalizations, "a direct trace is obtained of the heeded information, and hence, an indirect one of the internal stages of the cognitive process" (Ericsson & Simon, 1993, p. 220). Verbalizations can either be concurrent, i.e., undertaken during decision-making, or retrospective, i.e., after a decision task. Concurrent verbalizations are used when the decision-making steps are of particular interest. They provide more insights into the decision-making process than retrospective verbalizations, while the latter provide more statements about the final decisions (Kuusela & Paul, 2000). Study 1 of this research used a retrospective verbalization method, as it was explicitly interested in intuitive decisions rather than the decision-making process. Verbalizing retrospectively, thus, allowed study participants to respond intuitively before reasoning about their decisions.

Semantic Differential: The semantic differential technique (or *Semantic Differential*) is based on the premise that any concept (be it a painting, a person, a word, an abstraction, etc.) can be defined or described by its connotative meaning (Osgood et al., 1957). It is based on the attempt to subject meaning to quantitative measurement. The technique combines association and scaling procedures, designed to "give an objective measure of the connotative meaning of concepts" (Osgood & Luria, 1954, p. 579). The Semantic Differential uses scales of bipolar opposites as anchors or reference points, such as bad – good, unpleasant – pleasant, passive – active. It allows comparing different stimuli in the same semantic space. A semantic differential technique was applied in Study 2 to explore the affective meanings of cartographic point symbols.

Rating Scales: Rating scales are instruments of closed-ended survey questions used to assign scores to items along some numerical dimension (American Psychological Association, n.d.). Rating scales are classified according to the number of points along a dimension that is being assessed. Study 3 used a 6-point rating scale to assess symbol-content congruences. Study 4 used an 11-point rating scale to examine how geospatial events are judged based on the type of cartographic point symbol.

Thesis Structure

Part I of this dissertation comprises the theoretical chapters. It provides a theoretical grounding for this dissertation's overarching theme, i.e., the connotation of cartographic signs. It complements and extends the more specific theoretical discussions of the empirical scientific articles of Part II. As this dissertation is concerned with the connotative meanings of cartographic point symbols and their effects on human cognition and affect, it bridges the domains of cartography, semiotics, and psychology.

Chapter 1 comprises the introductory sections of this thesis. It summarizes this dissertation's background and motivation, describes its methodological approaches and terminology, lists the scientific publications of this thesis, and summarizes its main contributions.

Chapter 2 is the first theoretical chapter and concerned with communication. This chapter outlines the development of cartography as a communication science and discusses pivotal influences and perspectives on cartography as a communication discipline.

Chapter 3 draws attention to the cartographic sign. It discusses main semiotic traditions and relates them to the field of cartographic semiotics. It further lays out different perspectives on sign-relations and discusses the dimensions of meanings.

Chapter 4 provides an overview of human information processing. It defines the most relevant human concepts related to information processing, such as perception, cognition, and affect, and introduces theoretical perspectives on visual information processing.

Part II discusses four empirical studies.

Chapter 5 draws attention to cognitive proximities between abstract shapes. The empirical study examined the cognitive relatedness of geometric shapes and further explored strategies and processes underlying the similarity judgments. This chapter addresses the first research question: *Which geometric shapes are experienced to be (dis)similar and why?*

Chapter 6 comprises an empirical study on the affective meanings of abstract cartographic point symbols. The study aimed to identify shape clusters of similar affective qualities. As such, it addresses the second research question: *Which affective responses do (carto)graphic point symbols involve?*

Chapter 7 discusses an empirical study concerned with the concept of congruence. The study examined symbol-content correspondences in monothematic maps. As such, it addresses research question three: *Which cartographic point symbols are (in)congruent to which type of content?*

Chapter 8 comprises empirical research on symbol-referent judgments. The study explored how negatively-connoted geospatial events are judged based on the cartographic point symbol used for their representation. This chapter addresses this dissertation's fourth and final research question: *Do cartographic point symbols influence how geospatial events are judged?*

Part III of this dissertation is dedicated to the reflection and discussion of this research.

Chapter 9 first provides a summary of the main empirical findings. It proceeds with a critical reflection on the findings' strengths and shortcomings. It discusses practical and theoretical implications before laying out possible future directions for research.

Chapter 10 finalizes this dissertation with concluding remarks.

CHAPTER 2

Maps and Communication

What a map offers is a possibility, not a message.

– John S. Keates

Communication

Human communication involves the use of signs to share and express information (Keates, 1996). Although all species communicate, human communication is notable for its precision and flexibility, allowing "to formulate an unlimited number of meaningful novel messages that are not tied to the immediate present"(Krauss, 2002, p. 1).

The term *communication* originates from Latin *commūnis* and *commūnicāre*, which translates to "common" or "public", respectively, "to make common" or "to share" (Partridge, 2006, p. 576). Communication, as defined today, encompasses the exchange of thoughts and feelings (Sternberg, 2009), the process of sharing and understanding meaning (Pearson et al., 2017), as much as the articulation and negotiation of shared meanings (Slack, 2006). And at the same time, communication "is not *in essence* any of these, and it is not any of these *exclusively*"(Slack, 2006, p. 223).

Communication is a "richly meaningful concept" with many meanings (Craig, 1999, p. 130). Different scientific disciplines approach communication from different perspectives, which leads to varying conceptions of what communication is (Craig, 1999). As there is no single definition that could adequately explain the concept of communication (Craig, 1999; Littlejohn & Foss, 2008; Slack, 2006), Littlejohn and Foss (2008) propose to discuss the concept of communication along three commonly shared dimensions:

- The first dimension used to distinguish the definitions of communication involves the *level of abstractness*. Abstractness refers to the concept's description as a broad and inclusive process instead of a restrictive system, such as one designed to transmit information.
- The second dimension refers to the distinction of communication in terms of its *intentionality*. In this respect, some definitions refer to communication as transmitting a purposeful message with conscious intent. Other definitions do not impose this limitation but conceive communication as a process that makes something common without claiming its effect or outcome.
- The third dimension involves the notion of *judgment*. Some definitions include a statement about the outcome of communication, such as its success, effectiveness, or accuracy. Other definitions refrain from such judgments.

Liberated from the idea that communication is any one thing, it allows acknowledging that there is no right or wrong perspective of what communication is. Yet, "different definitions have different functions and enable the theorist to do different things" (Littlejohn & Foss, 2008, p. 10).

In cartography, two prevalent conceptions of communication emerge. One regards communication as *acts of sharing ideas to make them common*. The other one refers to communication as a directional process of transmitting information. The latter perspective is based on the analogy of physical structures (e.g., roads, canals, and railways) used to convey and exchange goods. By adopting this analogy, the meaning of communication as *to convey* was established, which later stimulated the idea of communication as a process of transmission (Keates, 1996). Both perspectives are used in cartography. And while there is no one correct approach, such perspectives are hardly distinguished in cartographic research. Often it remains unexplained what cartographic communication refers to (Keates, 1996).

The following sections, thus, discuss different perspectives and theoretical discourses on communication in cartography's recent history.

Perspectives on Cartographic Communication

Maps have been used to communicate about "our place in the world long before the development of written language" (Kent, 2018, p. 96). Maps are representations of geographic space that "permit the exploration, analysis, understanding, and communication of information about that space" (ICA, 2003, p. 17). As such, maps are regarded as vehicles of thought and communication (Robinson et al., 1995).

Maps evolved from early drawings, sketches, and graphics, rooted in the human desire to capture the environment's spatial structures and to communicate their relationships (Robinson et al., 1995). Cartography started with the basic idea of representation in the form of figurative maps. Thenceforth, it has devised a variety of different map types and mapping methods in a "repeated cycle of revolution and evolution", stimulated by technological advancements and developments in society (Robinson et al., 1995, p. 21). From such a historical perspective, maps reflect technological advancements, general thinking, and socio-cultural relations of power (Crampton, 2001; Harley, 1989; Wood & Fels, 1992). As such, maps are regarded witnesses of their times, and their developments are referred to as branching courses as opposed to a linear sequence (see Figure 2).

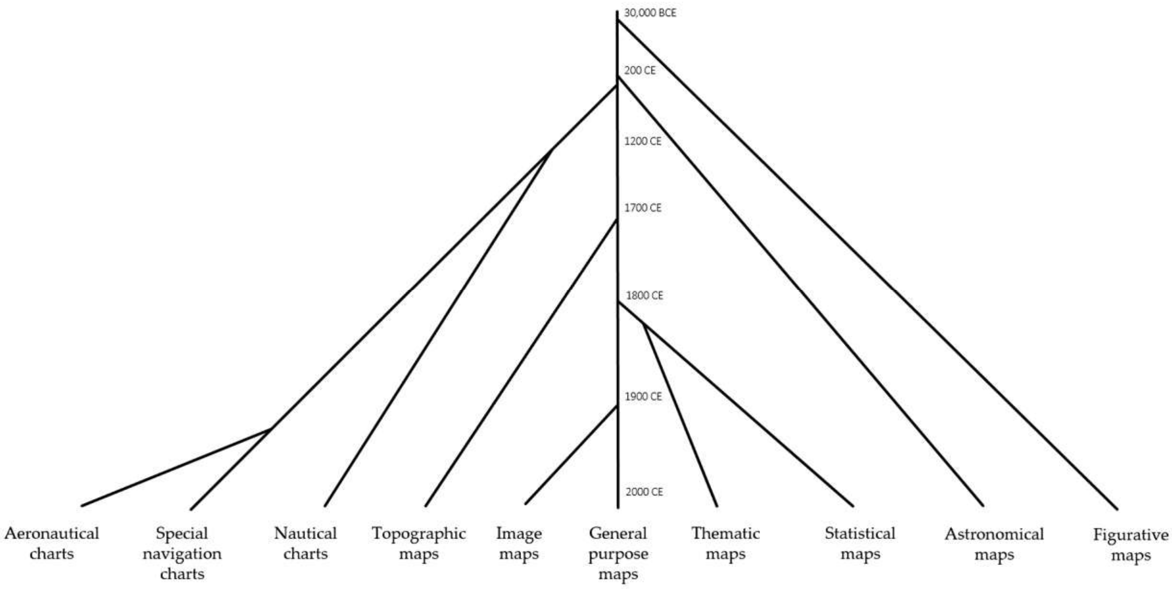

Figure 2. Map types throughout history (own illustration; adapted from Robinson et al., 1995, p. 22).

From a present perspective, the notion of cartography as a communication discipline may appear evident or even tautologous. "Are not all maps expected to communicate geographical information in one way or another?" (Board, 2011/1972, p. 37). The conception of cartography as a research field concerned with communication, however, arose not before the middle of the 20th century. Two developments played a crucial role in establishing cartography as a scientific discipline (MacEachren, 1995): a call for objective research in the 1950s (Robinson, 1952), followed by cartographic communication models in the 1960s and 1970s (e.g., Board, 2011/1972; Koláčný, 1969).

From that time on, ever new theoretical perspectives and critical discourses began to redefine what communication in cartography means. Understanding maps as objective mirrors of nature shifted to acknowledging their subjective, selective, and socio-cultural construction. This, in turn, initiated new possibilities for exploring and discovering the meanings in and the meanings of maps.

The following sections discuss these influences in greater detail. They lay out some of the most important traditions and transition points in cartography's recent history and discuss cartography from a communication perspective.

From Artistic Maps to Functional Maps

The idea of cartography as a communication process was first put forward in the 20th century. Through his seminal work, *The Look of Maps* in 1952, the American geographer and cartographer Arthur H. Robinson is recognized as one of the first to regard communication as the primary function of maps (Montello, 2002). Robinson claimed that a "revolution appears long overdue in cartography", a cartographic revolution where "function provides the basis of the design" (Robinson, 1952, p. 13).

Throughout the centuries of cartographic history, the use of maps had been limited to particular groups of distinct professions, such as navigators, surveyors, military planners, and the like. As those professions were primarily concerned with spatial data of precise and numerical nature, cartographers at the time aspired to create "truth documents … [which] represent the world as it really is with a known degree of precision" (Martin Dodge et al., 2011, p. 4).

The aspiration of precision, accuracy, and truth had been the preoccupation for Western cartographers since the late Middle Ages (Martin Dodge et al., 2011). Geographic space was viewed from an absolutist perspective, where "space exists in addition to any material bodies situated within it" (Dasgupta, 2015, p. 601). As such, geographic space was regarded as "a container with an explicit geometry that was filled with people and things, and cartography sought to represent that geometry" (Martin Dodge et al., 2011, p. 5). Maps, thus, became ever more precise, and it was assumed that "everything could be known and mapped within a Cartesian framework" (Martin Dodge et al., 2011, p. 5).

While Robinson acknowledged the aspiration for cartographic accuracy as "the first objective of any scientific activity", he further argued that "when presentations of factual materials become widely used, the manner of presentation becomes of primary significance"(Robinson, 1952, pp. 7–8). Until that time, neither cartographic techniques nor cartographic presentation media had been of particular concern in cartography (Robinson, 1952). Functional evaluations by geographers and cartographers focused on the geographic content itself, not concerning the cartographic methods employed to convey it. For Robinson, however, "these graphic methods, together with the logic which binds them to their function and sets the limits of their utilization, constitute the cartographic technique" (Robinson, 1952, p. 15).

Robinson resonated with earlier considerations from the German cartographer Max Eckert, who had claimed that one of the most important topics of scientific cartography was that of *map logic*, i.e., "the laws which underlie the creation of maps and which govern cartographic perception" (Eckert, 1908, p. 348).

Eckert also stressed that cartography was more than a technical art, but "for the greater part an applied art, an art governed and determined by scientific laws" (Eckert, 1908, p. 346). For Eckert, the crucial point that made cartography a scientific discipline was that of generalization: "In generalization lies the difficulty of scientific map-making, for it no longer allows the cartographer to rely merely on objective facts but requires him to interpret them subjectively" (Eckert, 1908, p. 347). He argued that the map maker's interpretations needed a scientific basis to ensure the maps' objective character despite the cartographers' subjective impulses. Eckert claimed that ideal maps as those that unify "the scientific spirit with artistic execution", that are "products of art clarified by science" (Eckert, 1908, p. 347).

Eckert (1908) and Robinson (1952) argued for pursuing research on the physiological and psychological effects of cartographic variables, such as their perceptibility and readability. In doing so, one could develop design principles based on "experience, experimental research, or logic which would govern the employment of the various structural materials" (Robinson, 1952, p. 13). As a consequence and by reference to these principles, Robinson (1952) inferred that one could arrive at reasonably accurate evaluations of their effectiveness.

Such design principles were still missing in the domain of cartography. Despite steadily evolving techniques for collecting and mapping data, cartography had pursued its profession as a practical and applied craft. It was a discipline of drafting and drawing with arbitrary results based on the map makers' decisions and skills (Robinson, 1952).

Robinson, thus, emphasized shifting the focus from cartographic art and map-production efficiency to studying map functionality and cartographic design principles (Robinson, 1952). Robinson proposed that the best way to understand how maps function was through rational thought and rigorous, systematic research (Montello, 2002). As such, Robinson's *The Look of Maps* set a seminal foundation for establishing cartography as a scientific communication discipline, as one that was guided by formalization and systematization.

Maps as Transmitters of Information

Stimulated by Robinson's work, the first cartographic communication models emerged in cartography in the following decades. As cartographers became more concerned with symbolization and design (MacEachren, 1995), these models aimed to help designing better maps that were "capable of recreating in the mind of the reader, so far as possible, precisely the intended intellectual meanings and interpretations of the author"(Robinson, 1952, p. 8).

In the 1960s and 1970s, the paradigm of communication had become the first to gain widespread acceptance amongst the international cartographic community (Kent, 2018). By this, cartography had begun to redefine itself as a graphic communication discipline.

This new paradigm brought forth various map communication models that aimed to formalize, systematize, and eventually improve cartographic communication (for a synopsis, see Board, 2011/1972; or Lechthaler, 2004). These models introduced *cartography as an information communication system*, as a coding and decoding process of information. In these communication systems, information from a more or less shared reality is translated by the map-maker into cartographic language and transmitted to the map user through the map as a medium. The cartographer, as the sender, determines what information is communicated and how it is depicted. The map users, as recipients, decode the map and relate the map information to their prior knowledge and develop some understanding from it (MacEachren, 1995). In these models, the communication of information became the primary function of cartography. The map became its vehicle, a vehicle that was believed would just need to be optimized to enhance map effectiveness (Kent, 2018; Robinson, 1952).

The British cartographer Christopher Board appeared to be the first to propose such a formal cartographic communication model in 1967. His model attempted to portray the complex, cyclic cartographic information flow while pointing to the progressive loss of information in the map-making and map analysis processes (Board, 2011/1972).

The most influential cartographic communication model, however, was put forward in 1969 by the Czechoslovakian cartographer Antonín Koláčný (see Figure 3). In his model, Koláčný treated map making and map use as inseparable, in the sense that "cartographers should be concerned with the use of maps as well as their construction" (Keates, 1996, p. 112). Koláčný's model further emphasized the cartographer's selective observation of reality, who transforms his/her "'multi-dimensional intellectual model' … into cartographic information, objectified and expressed by map symbols" (Keates, 1996, p. 113). Through the map-making process, the cartographer's intellectual model becomes perceptually available to others and "produces an informative effect on the map user, transforming the user's opinion about reality, so that the map user creates in his mind a 'multi-dimensional model of reality' and experiences this reality" (Keates, 1996, p. 113). Koláčný further highlighted the difference between the cartographer's reality and the map user's reality. He also emphasized several factors on the map makers' and the map users' sides that influence the cartographic communication process and its outcomes, such as interests, aims, knowledge, experience, abilities, psychological processes, and external conditions.

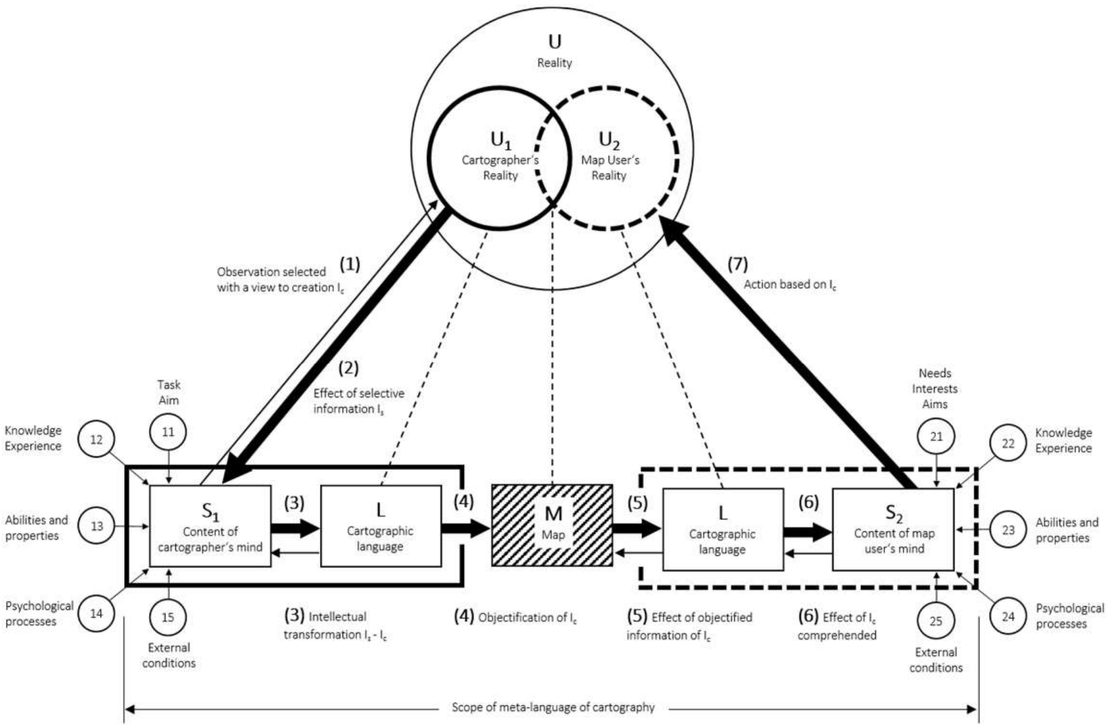

Figure 3. Koláčný's cartographic communication model from 1969 (redrawn from Kent, 2018, p. 100). Note: I_c in the model refers to cartographic information, I_s refers to selected information.

Various cartographic communication models emerged in the following years with varying details (Keates, 1996; Lechthaler, 2004). Despite their differences, they followed a similar understanding of cartography as an information communication process, one that was believed could be improved towards an error-free information transmission.

The Polish cartographer Lech Ratajski, for instance, proposed such a model (see Figure 4). Ratajski proposed several processes and relations between reality as a source of information (R), the cartographer as the sender of a message (K), the map as a communication medium (M), the map user as a receiver (O), and the imagination of reality (R^1). The model aimed to exhaustively portray *all* possible sequences involved in cartographic communication (Keates, 1996).

In contrast to Koláčný, who had refrained from concepts of information communication theory, Ratajski adopted its concepts and terminology. Ratajski was particularly concerned with enhancing communication efficiency and overcoming information loss, which he indicated to occur throughout the communication process (see arrows in Figure 4). As such, Ratajski's model reflected the zeitgeist of that time. Many authors conceived the fundamental challenge of communication as "that of reproducing at one point either exactly or approximately a message selected at another point" (Shannon, 1948, p. 379).

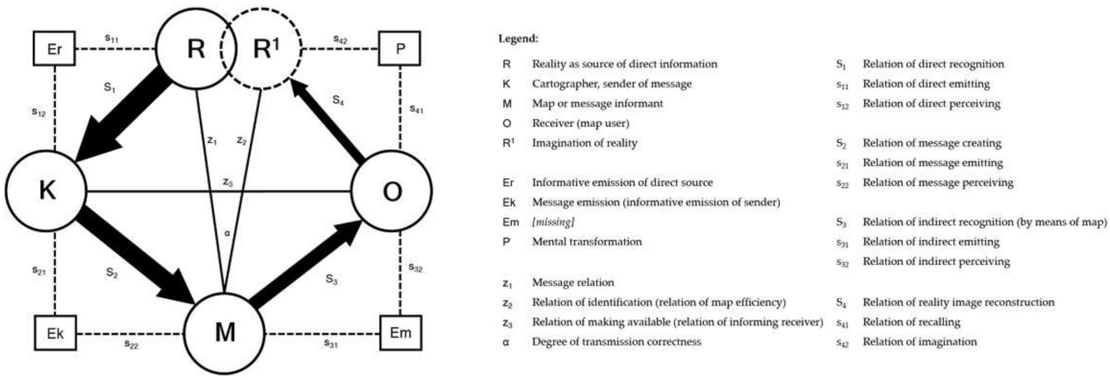

Figure 4. Cartographic communication model proposed by Ratajski in 1978 (redrawn from Lechthaler, 2004, p. 22).

The understanding of cartographic communication as a closed and controllable system was strongly influenced by two empiricist schools, i.e., information theory and behaviorism. Both aimed for a formalization and optimization of human processes:

Information Theory defines communication as a closed system and its task to analyze that system (Ash, 1965). The very beginnings of information theory date back to 1948, when the mathematician Claude E. Shannon introduced *A Mathematical Theory of Communication*. Shannon (1948) argued that the fundamental challenge of communication was to achieve an error-free transmission of information or data over imperfect or noisy communication channels. Shannon envisioned communication in abstract, mathematical terms and aspired to a theory of communication irrespective of the type of information signal (e.g., voice, image, text) and type of transmission medium (Guizzo, 2003). Shannon proposed a definition of "what the once fuzzy concept of information meant for communication engineers" (Guizzo, 2003, p. 8) and defined five components involved in the process of communication (Shannon, 1948). By his definition, communication involves an *information source* that produces a message; a *transmitter* that creates a signal which can be transmitted over a channel; a *channel*, which is the medium used to send signals from a transmitter to a receiver; a *receiver*, which reconstructs the message from the signal; and a *destination* for whom (i.e., a person) or which (i.e., a receiver) the message is intended. Based on this formalization, Shannon (1948) successfully demonstrated that by applying mathematical theory, information can be coded, transmitted, and decoded across a noisy channel without information loss. The successes of information theory and the prospect of unbiased and error-free communication inspired cartographers at the time to adopt the information theory metaphor to cartographic theory.

Behaviorism was the second school of thought that inspired cartographic scholars of that time. Behaviorism was an influential academic school that dominated psychological theory from the 1920s onwards. It developed as a countercurrent to introspective psychology, which focused on exploring human consciousness and inner processes (such as emotions, motivations, intentions). Behaviorists regarded consciousness as unscientific, unprovable, and unapproachable "intangible something" (Watson, 2017/1924, p. 5). They, therefore, claimed to "make what we can *observe*" the focus of science (Watson, 2017/1924, p. 6). They suggested to refrain from the concept of human consciousness as it "is neither a definable nor a usable concept; that it is merely another word for the 'soul' of more ancient times" (Watson, 2017/1924, p. 3). Behaviorists, thus, focused on measurable and observable data. Behaviorism "sought 'laws' that relate behavioral responses to stimuli available to our senses" (MacEachren, 1995, p. 7). It attempted to explain behavior in terms of external physical stimuli and responses, aiming to predict how behavior changes as the environment and its stimuli change (Graham, 2000).

> The scientific 'system', like the law, is designed to enable us to handle a subject matter more efficiently … When we have discovered the laws which govern a part of the world about us, and when we have organized these laws into a system, we are then ready to deal effectively with that part of the world. By predicting the occurrence of an event, we are able to prepare for it. By arranging conditions in ways specified by the laws of a system, we not only predict, we control: we 'cause' an event to occur or to assume certain characteristics. (Skinner, 1965, p. 14)

Focusing on human behavior and treating humans like a controllable, stimulus-response-systems suggested several benefits for cartography. Most notably, they provided the prospect of establishing laws to control and predict human responses.

Maps as Cognitive Constructions

Empiricist approaches dominated the scientific landscape until the 1970s, when a new critical, interdisciplinary movement began to emphasize the complexity and interrelatedness of human processes, known as the *Cognitive Revolution*. Its scholars strongly criticized the sciences' dismissal of mental processes:

> Empiricism insists that the brain is a tabula rasa, empty, unstructured, uniform at least as far as cognitive structure is concerned. I don't see any reason to believe that; I don't see any reason to believe that the little finger is a more complex organ than those parts of the human brain involved in the higher mental faculties. (Chomsky, 1977, p. 1)

Cognitivism argued that there is "no direct, *im*mediate access to the world, nor any of its properties" but that all we know "has been *mediated* … by complex systems which interpret and reinterpret sensory information" (Neisser, 2014, p. 3). Cognitive perspectives rejected the body-mind dualism and called for a holistic understanding of human nature (Chomsky, 1977; Pinker, 2002). They emphasized focusing on "the diverse cognitive structures … and their relation to the physical and social environment, seeking to determine, as best we can, the principles which govern these cognitive structures" (Chomsky, 1977, p. 1). Hence, by the 1970s, the empiricist doctrine of mind-body dualism began to re-center around critical and more inclusive perspectives on human-related sciences.

These critical perspectives also challenged the prevailing conception of cartographic communication as a formal, controllable, and law-like system:

- Empiricist perspectives were criticized for reducing cartographic communication to a series of supposedly manageable areas (Keates, 1996; Sless, 1986). Cartographic communication was treated as a "well-behaved physical system", one that was believed could be manipulated to prevent information loss (MacEachren, 1995, p. 9). Approaching cartographic communication as a law-like system suggested that intended responses could be evoked by following stimulus-response laws and creating appropriate conditions. Such positivist perspectives reflected the belief in general rules that operate regardless of context (Keates, 1996). Yet, it excluded a large part of human processes that are "purposive and choice-oriented and, therefore, poorly suited to law-like explanation" (Cappella, 1972, p. 232).

- The adoption of the information communication paradigm was regarded as too restrictive as it constrained the functions of maps to one of communicating a predefined message (MacEachren, 1995). Map effectiveness and communication efficiency had become the central themes in cartography. This conception overlooked the vast majority of maps that do not seek an intended response or communicate a predetermined message (MacEachren, 1995). It also limited the cartographer's role to one that was about designing optimal maps to elicit a specific response. The information communication metaphor, thus, failed to reflect the diversity of map-use scenarios.
- Empiricist approaches further limited the role of map users to passive receivers. Yet, cartography differs from other forms of communication (Robinson & Petchenik, 1975). Its communication is based on signs, not signals. Signs require active interpretations, not passive responses. Different map users will process information differently and find information in maps differently meaningful – if meaningful at all (Robinson & Petchenik, 1975). Critical scholars, thus, rejected the information communication paradigm as a false analogy for the field of cartography (Robinson & Petchenik, 1975). They stressed that "the map itself is passive", not the map user, and that "communication takes place only when a map user actively directs attention to it"(Keates, 1996, p. 128).

By the 1970s, critical perspectives had surmounted the conception that stimulus-response laws could sufficiently explain human processes. They shifted the scientific focus from predicting behavior to exploring human mental processes also in cartography. Inspired by the new theoretical perspectives of that time, cartographic scholars, such as Barbara Petchenik (1977), envisioned a similar path for cartography. In *Cognition in Cartography*, she called for redirecting the focus of cartographic communication away from stimulus-response relations to studying cognitive processes:

> This new approach conceives of communication as the process wherein thought originating in one human mind is converted by that mind into physical forms according to rules developed by the culture in which he lives. These symbols are then apprehended through eye or ear by the person for whom the message was intended, and from them he constructs in his own mind the meaning originally formulated in the message sender's mind. In this view, the physical means of communication such as language and maps, do not carry meaning, but rather, they trigger or release it. (Petchenik, 1977, p. 184)

This new understanding of cartography emphasized the maps as a cognitive construction. As such, maps were regarded not to contain or transmit messages but to stimulate hypotheses and offer possibilities (Keates, 1996; MacEachren, 1995; Petchenik, 1977). Critical scholars stressed that cartography was about the *construction of meaning* and that the core focus of cartographic research must, therefore, be human cognition (Petchenik, 1977; Wood & Fels, 2008).

Cognitive perspectives understand the "human organism as an active seeker of knowledge and processor of information" (Peterson, 1985, p. 41). Cognition goes beyond the level of seeing and refers to how people perceive, learn, remember, and think about information (Sternberg, 2009). According to Wood and Fels (2008), cartography must go exactly beyond that level of seeing, beyond the question of how the elements of maps are arranged for the eye, beyond the presentation of information. Instead, they must be concerned with "how the design promotes and constraints, how it directs the construction of meaning" as a basis for action (Wood & Fels, 2008, p. 194).

Stimulated by these perspectives, a new research strand started to evolve, emphasizing the human mind and related processes through which meaning is constructed – known as *Cognitive Cartography*. Cognitive perspectives had long been an implicit part of cartography as maps recognizing that maps have contributed to inner mental worlds ever since (Montello, 2002). Human processes had, however, not been studied explicitly in cartographic research. By the developments of the late 1970s, however, scholars recognized that map design was about human cognition and emphasized cognitive processes as an integral part of cartographic communication research. Since then, cognitive cartography has become a flourishing research field, and today encompasses both "the application of cognitive theories and methods to understanding maps and mapping" as well as "the application of maps to understanding cognition" (Montello, 2002, p. 283).

Maps as Social Constructions

About the time cognitive perspectives had established in cartography, another critical school of thought began to overturn one of the most fundamental cartographic certainties, i.e., that of maps as reflections of nature.

In the late 1980s, critical cartographers, such as J. Brian Harley, Denis Wood, and John Fels stressed that cartographers had created an "epistemological myth" (Harley, 1989, p. 15). In that myth, maps claimed to be "passive reflections of the world of objects" (Harley, 2009/1988, p. 129), "a window through which we view the world …, [and as] a servant of the eye that sees things as they really are"(Wood & Fels, 1986, p. 64). In that myth, cartography was presented as "an objective science" (Harley, 1989, p. 15).

These critical scholars strongly rejected the narrative of map objectiveness and its conception as a mirror of nature. Instead, they argued that maps were inherently selective products, graphic artifacts that make propositions and arguments, artifacts that do not represent nature but represent power (Harley, 1989; Wood, 2010). They argued:

> There is nothing natural about a map. It's a cultural artifact, an accumulation of choices made among choices every one of which reveals a value: not the world, but a slice of a piece of the world; not nature but a slant on it; not innocent, but loaded with intentions and purposes; not directly, but through a glass; not straight, but mediated by words and other signs. (Wood, 2010, p. 78)

From such a social constructionist perspective, the cartographers become "selective creators of a world—not *the* world, but *a* world—whose features they bring into being with a map" (Wood, 2010, p. 51). Maps were, thus, understood not to reproduce but to construct the world (Wood & Fels, 1992), to be "culturally determined and ethnocentric in origin" (Axelsen & Jones, 1987, p. 447). As such, maps were not what cartographers said they were: not fact but symbol (Harley, 1989).

> Maps are never value-free images. Both in the selectivity of their content and in their signs and styles of representation maps are a way of conceiving, articulating, and structuring the human world which is biased towards, promoted by, and exerts influence upon particular sets of social relations. (Harley, 2009/1988, p. 129)

Harley, Wood, and Fels were among the first who stressed that maps were inherently social products. They called for a new research agenda "concerned with the roles maps play in different societies" (Kitchin et al., 2011, p. 9). In that agenda, maps were to be discussed as cultural artifacts, as the result of accumulated choices, each of which reveals particular values (Wood, 2010). Harley (2009/1988) argued that by accepting the premises that maps are never neutral but "value-laden images" (p. 129), it would become easier to see how maps are used as manipulations by the powerful in society. Harley further stressed that we could only understand the nature of maps when interrogating the historical and social context and forces in which mapping occurs (Kitchin et al., 2011). In his seminal work *Deconstructing the Map*, Harley, thus, called for a radical epistemological shift; a shift towards deconstructing the nature of maps:

> Deconstruction urges us to read between the lines of the map … to discover the silences and contradictions that challenge the apparent honesty of the image. We begin to learn that cartographic facts are only facts within a specific cultural perspective. (Harley, 1989, p. 3)

Maps as Multifaceted Representations

Throughout history, critical approaches had stimulated the theoretical discourse in cartography. Each perspective unfolded new possibilities and new approaches for research. The beginnings of cartography as communication science were strongly inspired by positivist approaches that aspired to elevate cartography to a more formal science. Cartography evolved from a purely artistic craft to a scientific discipline. Postpositivist thinking redirected the scientific focus of cartography away from its strive towards universal rules that operate regardless of context and towards studying human mental processes. Postmodern perspectives, on the other hand, initiated a critical discourse by reminding cartographers "of the social implications of the products they produce" (MacEachren, 1995, p. 10) and renewed the understanding of maps as socioculturally constructed artifacts. Each of those perspectives contributed to a more holistic understanding of maps and laid the foundations for new possibilities for exploring and discovering their meanings.

Yet, none of these approaches alone could fully satisfy cartography as a multifaceted discipline. No single communication model could encompass the diverse and complex processes involved in map communication, nor could deconstructionist perspectives be employed to renew cartographic practices (Keates, 1996). MacEachren (1995), therefore, argued that "if we accept the premise that maps can 'work' (i.e., that they are a useful way of obtaining spatial information), we have an obligation to facilitate their use as information sources" (p. 11). At the same time, "the fact that maps seem to work does not absolve us of the responsibility to consider the kind of work they do, whether explicitly or implicitly" nor to "ignore the practical consequences of our decisions in designing that artifact"(MacEachren, 1995, p. 11).

Today, cartography is recognized as a multifaceted discipline, as "the art, science and technology of making and using maps" (ICA, 2003, p. 17). As such a diverse domain, cartography benefits from contemplating different perspectives and explanations, each of which can contribute to a more cohesive understanding of maps (MacEachren, 1995). Such an integrative perspective acknowledges maps as "multifaceted representations", as "tools of rhetorical discourse", shaped by "social processes by which maps and map symbols acquire their meaning" (MacEachren, 1995, p. 11). It recognizes maps as reflections and portrayals of socio-cultural aspects, as selective and symbolized representations of geographic space. And, it takes into account the roles of semiotics, perception, and cognition in the process of constructing and deconstructing the meanings *in* maps and the meaning *of* maps (MacEachren, 1995).

This dissertation research adopts such an integrative perspective to cartographic communication. It acknowledges cartographic communication as a complex, interrelated process of both explicit meanings *in* maps and implicit meanings *of* maps and map signs. Maps are recognized as multifaceted representations, as depictions which “reflect conceptions of reality, not reality”(Tversky, 2000, p. 78). Maps are further recognized as the result of a myriad of decisions concerning *what* to communicate and *how* to communicate information through cartographic signs. As such, maps are conceived to be never neutral nor value-free but influenced by individual conceptions of reality and socio-cultural context (Harley, 1989; Wood & Fels, 2008). Hence, this research acknowledges both the socio-cultural and cognitive construction of maps as it proceeds to discuss the relations between Maps and Signs (see Chapter 3) and Maps and Humans (see Chapter 4).

CHAPTER 3

Maps and Signs

Every map is at once a synthesis of signs and a sign in itself:
an instrument of depiction … and an instrument of persuasion.

– Denis Wood & John Fels

Semiotics and Cartography

As a discipline of geospatial communication, cartography is deeply concerned with the study of signs and semiotic rules. *Semiotics* (from Greek σημεῖον sēmeĩon = sign or signal) refers to the study of signs, of what they mean, and how they are used (Cambridge English Dictionary, n.d.). As the science of signs, the fundamental concern of semiotics is "to discover how human beings are able to communicate with one another, and in this sense how meaning is conveyed through the use of language or any other sign system" (Keates, 1996, p. 68). It focuses "formal and empirical research on signs, signification, meaning and communication"(Bouissac, 2004, p. 240).

> [Semiotic analysis] aims to make the hidden structures, underlying cultural codes, and dominant meanings … both visible and intelligible. In doing so, semiotics is also a powerful instrument for a systematic study and critique of ideology in visual communication. (Aiello, 2020b, p. 368)

Cartographic semiotics is regarded as a branch of applied semiotics that consists of explicit and implicit studies (Nöth, 1998). Explicit semiotic research in cartography study map signs and sign structures with explicit reference to semiotic theory. Implicit semiotic research in cartography lacks such explicit reference (Nöth, 1998). Implicit approaches have, therefore, been criticized. Keates (1996), for instance, stresses that "despite a large number of papers dealing with communication in cartography, relatively few have pursued in detail the analysis of map symbols, and the relationships between map symbols and semiotic theory" (p. 179). As a consequence, "the difference of what a map sign means and what it represents has become blurred" (MacEachren, 1995, p. 245).

This chapter aims to provide such "a proper appreciation of how signs function" (Keates, 1996, p. 128) by grounding this dissertation research in semiotic theory. The following sections are, therefore, dedicated to semiotic traditions, cartographic semiotic frameworks, and the meaning dimensions of signs.

Semiotic Theories

Semiotic theories generally differentiate between two classes of signs, i.e., between *symbols* and *signals*. Symbols refer to those types of signs that represent and/or characterize a referent. They may also be referred to as intentional or representational signs as they refer to something other than themselves (Meyers, 2011). Signals, on the other hand, refer to signs that require "a single, predetermined response", "not open to various interpretations", nor do they "represent the characteristics of an object"(Keates, 1996, p. 73). Semioticians are concerned with the first: the representational sign.

Semiotic traditions theorize communication as *intersubjective mediation by signs* and target questions of "(re)presentations and the transmission of meaning, of gaps between subjectivities that can be bridged, if only imperfectly, by the use of shared systems of signs" (Craig, 1999, pp. 136–137). Semiotics is, however, not a unified scientific discipline, but one with "many schools and branches of both theoretical and applied semiotics" (Nöth, 1995, p. 3).

In the history of modern semiotics, two main traditions have evolved, which study signs either as dyadic or triadic systems. Both approaches emphasize that "the sign is more than its constituent sign vehicle" (Nöth, 1995, p. 79). Both traditions are discussed in the following.

Dyadic Semiotic Theory

Dyadic semiotic theories originated from the field of linguistics. They define the sign as a two-sided entity, composed of an expression *(a signifier)* and the concept the expression refers to *(a signified)* (see Nöth, 1995, p. 88 for a synopsis). The dualistic conception of signs was first introduced by the Swiss linguist and semiotician Ferdinand de Saussure[3]:

> The linguistic sign unites, not a thing and a name, but a concept and a sound-image. The latter is not the material sound, a purely physical thing, but the psychological imprint of the sound, the impression that it makes on our senses. (Saussure, 1959, p. 66)

Saussure (1959) argued that the link between signifier and signified is wholly arbitrary in the sense that the signifier "has no natural connection with the signified" (p. 69). He explicitly omitted any external referents from his theory. Saussure regarded both signifiers and signified as entirely mental entities, as independent of any referential object or real-world entity (MacEachren, 1995; Nöth, 1995). As such, Saussure's perspective is also referred to as a *mentalistic conception* of signs (Nöth, 1995).

Saussure's dyadic semiotic theory (or *semiology* as referred to) was regarded as the fundamental analytic paradigm for all sign systems (MacEachren, 1995). It was applied in linguistic and nonlinguistic disciplines to study the relation between signifier and signified (Keates, 1996; Nöth, 1995).

Also, cartography adopted the dualistic conception of signs at first. Despite the parallels, it discovered significant differences between linguistic and cartographic sign systems (Ljungberg, 2015; Nöth, 1998). MacEachren (1995) argues that conceiving maps as entirely psychological entities without relation to external referents is counterintuitive from a cartographic perspective: some relation to real-world referents is the essence of any map.

Due to the fundamental difference between map signs and linguistic signs, dyadic approaches became gradually discarded in cartography. Instead, triadic perspectives have superseded dyadic sign approaches as they recognize external referents as core components of all human signs (see next section for a discussion on triadic semiotic theory).

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[3] Ferdinand de Saussure (1857-1913) was a Swiss linguist and semiotician. He is considered one of the founders of modern linguistics and one of the two main initiators – together with Charles S. Peirce – of modern semiotics.

Triadic Semiotic Theory

Triadic theorists, such as Plato, Aristotle, or later Charles Peirce[4] and Charles Morris[5], emphasize three semiotic correlates: the *sign-vehicle* which acts as a physical sign (i.e., expression or carrier of meaning, such as a sound, mark, or movement), *the referent* (i.e., the phenomenon or object of reference the sign-vehicle refers to), and *the interpretant* (i.e., the sign's effect on the interpreter, such as the concept the sign-vehicle refers to for the interpreter) (see Nöth, 1995, p. 90 for a synopsis). Triadic semiotic theories claim that "something is a sign only because it is interpreted as a sign of something by some interpreter" (Morris, 1938, p. 4). This triadic sign conception is also referred to as a *semiotic triangle* (Ogden & Richards, 1923); see Figure 5.

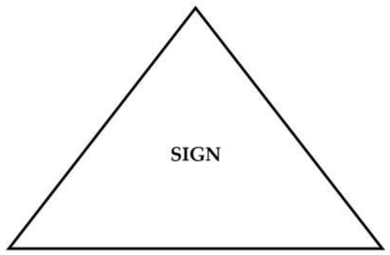

Figure 5. The semiotic triangle. Illustration based on Ogden and Richards (1923).

The conception of signs as triadic entities enabled theorists to discuss signs from various different perspectives. For instance, it inspired scholars to study its dyadic semiotic relations, such as between sign-vehicle and interpretant (known as *pragmatics*), between sign-vehicle and referent (known as *semantics*), and between sign-vehicle and other sign-vehicles (known as *syntactics*), as proposed by Morris (1938). The triadic model further prompted semioticians to study each of the three triads as mediators within the triadic semiotic structure, as proposed by Peirce (1986, 1990). Both approaches are discussed in the following sections.

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[4] Charles Sanders Peirce (1839-1914) was an American philosopher, mathematician, and semiotician. He is regarded as one of the two main initiators – together with Saussure – of modern semiotics. His triadic elaboration of signs is one of the most complex semiotic theories, due to its attempt to provide a universal theory of signs.

[5] Charles William Morris (1901-1979) was an American philosopher and semiotician. He built on Peirce' triadic model and claimed three sign-dimensions, known as *semantics*, *pragmatics*, and *syntactics*.

Semiotic Triangle: Diadic Relations

Morris (1938) proposed to approach semiotics from the three dimensions of *semiosis*, which he referred to as "the process in which something functions as a sign" (p. 3). The three dyadic relations of the triadic sign structures that he proposed comprise the dimensions of *pragmatics, syntactics,* and *semantics* (see Figure 6).

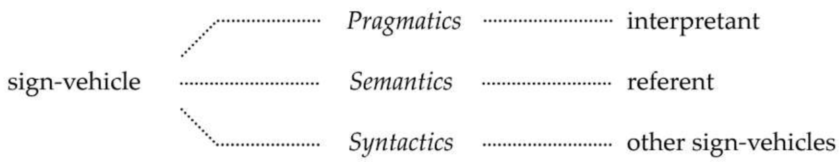


Figure 6. The three dimensions of semiosis and their relational structure (Morris, 1938); own illustration based on Nöth (1995).

Pragmatics is a branch of semiotics which "studies the origin, the uses, and the effects of signs" (Morris, 1946, p. 352). As such, it is concerned with the relation between sign-vehicle and interpretant or concept. In the field of cartography, pragmatics study the relationships between the uses and effects of map symbols (Board, 2011/1972).

Semantics, on the other hand, studies the signification of signs, i.e., the relation between sign-vehicles and their referents (Morris, 1946). According to Sternberg (2009), semantics is concerned with denotation, i.e., "the strict dictionary definition of a word", as opposed to connotation, which refers to "a word's emotional overtones, presuppositions, and other nonexplicit meanings" (p. 335). Similarly, semantics in cartography is concerned with the explicit relations between map symbols and their referents, i.e., what is represented by signs (Board, 2011/1972). This involves studying the meanings of map symbols "in terms of geographical and other concepts about the real world" (Board, 2011/1972, p. 41).

Syntactics is the third branch of Morris' semiosis. It "studies the way in which signs of various classes are combined to form compound signs" (Morris, 1946, p. 355). It abstracts from a sign's uses and effects and focuses on rule-based relations between signs (Morris, 1946). Applied to cartography, the dimension of syntactics studies the relations between sign-vehicles and "concerns rules abstracted from users of signs and real world environments" (Board, 2011/1972, pp. 41–42).

Morris' three dimensions of semiosis significantly impacted cartographic theory as they provided a needed framework to understand map representations (MacEachren, 1995). The three dimensions of pragmatics, semiotics, and syntactics, thus, became the predominant approach in cartographic semiotic research (MacEachren, 1995; Nöth, 1998).

Semiotic Triangle: Triangular Relations

Despite studying dyadic relations, the triadic structure of signs further incited theorists to draw attention to the sign as a triadic entity and its triadic interrelations (Peirce, 1986, 1990). This approach considers each of the three sign components as mediators between the other two (Nöth, 1995). This theoretical perspective to semiotics is less prevalent in cartographic research (Nöth, 1998). It is, yet, one that enables approaching map signs from its complex, triadic interrelations (MacEachren, 1995).

Peirce's philosophical foundation of semiotics refers to his phenomenology of three universal categories, i.e., that of *firstness*, *secondness*, and *thirdness* (Peirce, 1986, 1990). *Firstness* refers to "the mode of being of that which is such as it is" without reference to anything else (Nöth, 1995, p. 41). It is the category "of unreflected feeling" and of "undifferentiated quality" (Nöth, 1995, p. 41). *Secondness* is the category of comparison between something "of a first to a second" (Nöth, 1995, p. 41). It is "action, reality, and experience in time and space" (Nöth, 1995, p. 41). *Thirdness*, on the other hand, "brings a second in relation to a third" (Nöth, 1995, p. 41). As such, it is "the category of mediation, … communication (semiosis), representation, and signs" (Nöth, 1995, p. 41).

On the level between secondness and thirdness, Peirce's semiotic theory distinguishes three possible mediations within the triadic sign structure (Peirce, 1986, 1990), i.e., *the interpretant as a mediator*, *the referent as a mediator*, and *the sign-vehicle as a mediator* (see Figure 7).

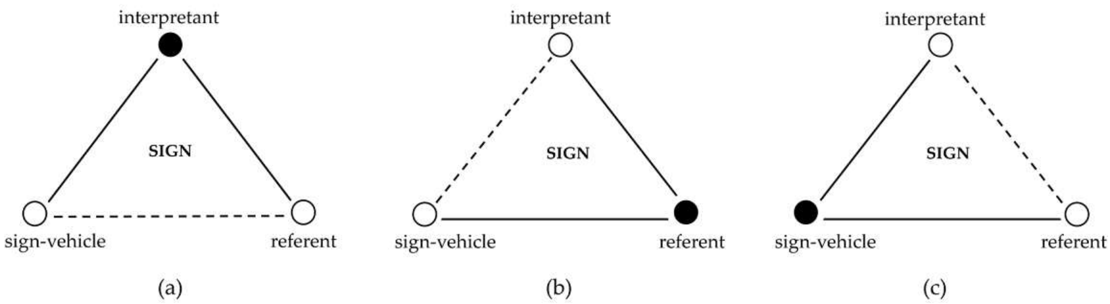


Figure 7. The semiotic triangle illustrating the triadic sign relation with (a) the interpretant as a mediator, (b) the referent as a mediator, and (c) the sign-vehicle as mediator; own illustration based on MacEachren (1995).

The interpretant as a mediator: The interpretant as a mediator is an approach to semiotics that stems from "Aristotle's definition of words as signs of the soul, and the latter as likenesses of actual things"(Nöth, 1995, p. 89). In this understanding, sign-vehicle and referent are mediated by their interpretant (see Figure 7a). A thing or object (i.e., referent) may evoke an idea (i.e., interpretant) that leads to creating a word or symbol (i.e., sign-vehicle). Cartographic semiotic research, which focuses on the interpretant as a mediator, emphasizes a shared understanding between the cartographer and the map user (MacEachren, 1995). The sign-vehicle, such as the map or map sign, represents a referent by an agreed code, linking the sign-vehicle with that referent. It is, thus, concerned with establishing syntactic relationships between cartographic variables and referents.

The referent as a mediator: From the perspective of *the referent as a med*iator (see Figure 7b), the referent as a real-world entity "is a phenomenon of secondness, and the interpretant is one of thirdness" (Nöth, 1995, p. 89). In cartography, this perspective acknowledges that there are many possible representations for a given real-world object (or referent). As such, attention is drawn to the categorizations of referents that cartographic sign-vehicles may refer to (MacEachren, 1995). This, for instance, comprises the differentiation of geographic versus nongeographic information, spatial versus spatiotemporal dimensionalities, discrete versus continuous phenomena, and the like.

The sign-vehicle as a mediator: The third perspective considers *the sign-vehicle as a mediator* (see Figure 7c) as a "link between thing and meaning" (MacEachren, 1995, p. 246). Nöth (1995) refers to this process as "meaning endowing act" (p. 90), where sense (i.e., the interpretant) leads to sign production (i.e., sign-vehicle) with reference to an object (i.e., referent). This semiotic perspective directs attention to the aspects of referents that sign-vehicles represent and to the dimensions of meanings that sign-vehicles trigger (MacEachren, 1995). From a cartographic point of view, map symbols act as such sign-vehicles. They mediate between referent and the associated concept or meaning of that referent (MacEachren, 1995).

Maps and Meaning

As mediators between things and meaning, sign-vehicles give rise to ideas or thoughts related to a referent. While both sign-vehicle and referent may be of a physical nature, meanings are mental events and, therefore, difficult to precisely define and measure. Many scholars have acknowledged this challenge. Nöth (1995), for example, referred to the many possible meanings of meaning as a "semiotic labyrinth both on theoretical and on terminological grounds" (p. 92). Morris (1946), on the other hand, did not include the concept of meaning in his semiotic theory due to its imprecision. Instead, he proposed "to introduce special terms for the various factors which 'meaning' fails to discriminate"(Morris, 1946, p. 19).

Meanwhile, theorists have decomposed the "many meanings of 'meaning'"(Osgood et al., 1957, p. 2), suggesting two dimensions that together form the meaning of signs (Sternberg, 2009): *the dimension of reference* and *the dimension of sense* (see Nöth, 1995, p. 94, for a terminological synopsis).

The dimension of reference refers to the explicit meanings of sign relations (Keates, 1996; MacEachren, 1995). Map signs, for instance, are used to refer to and inform about particular places. As such, maps use *codes of intrasignification* to denote (Wood & Fels, 1986). Intrasignificant codes are those that operate *within* the map and "which the map exploits"(Wood & Fels, 1986, p. 68). From a cartographic perspective, the main aim of maps is to neutrally communicate and inform about geospatial events or entities (MacEachren, 1995). Cartographic research has, thus, primarily focused on this denotative, referential dimension of meaning *in* maps (MacEachren, 1995).

The dimension of sense comprises the implicit meanings of signs (Nöth, 1995). Maps and map signs stimulate ideas beyond the explicit meanings of maps (Keates, 1996; MacEachren, 1995). They express values, goals, and status (Wood & Fels, 1986). As such, maps and map signs connote, giving rise to meanings on the dimension of sense (MacEachren, 1995; Nöth, 1995). They do so through *codes of extrasignification*. Extrasignificant codes are "those by virtue of which the map is exploited" (Wood & Fels, 1986, p. 68). They operate *outside* the map and refer to the connotative meanings of map signs, i.e., to what maps and map signs implicitly stand for (MacEachren, 1995). In that sense, these connotative meanings are also referred to as meanings *of* maps (MacEachren, 1995).

Semioticians have long emphasized the two dimensions of meanings as crucial factors in human communication (Nöth, 1995). As this semiotic differentiation has largely been neglected in cartographic research (Keates, 1996; MacEachren, 1995), the following sections discuss the perspectives of 'meanings *in* maps' and the 'meanings *of* maps' in greater detail.

Meanings *in* maps

The meanings *in* maps comprise all explicit, literal, and denotative meanings in maps. As such, they refer to the meaning dimension of reference. Such meanings are those that are either "specified precisely in a map legend or assumed to be part of the normal reader's general map schema" (MacEachren, 1995, p. 311). These denotative meanings relate to what a map claims to be about and are often regarded as the primary dimension of meaning (MacEachren, 1995).

When making maps, cartographers generally strive for *congruence*, where the schematization of the external representation corresponds to structures of the internal representation (Tversky et al., 2002). High congruence between external and internal representations is especially beneficial, enhancing cognitive processing and problem-solving (Tversky, 2000; Vessey, 1991; Winkielman, Schwarz, Reber, et al., 2003).

To create cognitively congruent maps, cartographers have put particular emphasis on establishing design principles and semiotic rules grounded in analytic thought and logical reasoning (Eckert, 1908; Robinson, 1952). They have focused on identifying logical relations between the characteristics of map signs and the characteristics of their referents (MacEachren, 1995). In doing so, cartographers put particular focus on the explicit, denotative meanings in maps.

The French cartographer Jacques Bertin appeared to be the first to propose such a semiotic framework. It was "based on ideas about consonance between data characteristics and map symbol characteristics" (Montello, 2002, p. 291). Bertin's seminal work *Sémiologie Graphique* was first published in 1967 (translated to German in 1974 and to English in 1983). His framework comprised six fundamental graphic variables (i.e., size, color value, texture, color hue, orientation, and shape) that can be implanted as points, lines, and areal symbols. With a set of syntactic rules, Bertin's semiology suggests guidelines for using these variables to represent quantitative, ordinal, or nominal data (see Figure 8). Bertin's semiotic framework aimed to cover the core "manipulable primitives of graphic sign vehicles from which any information graphic can be built" (MacEachren et al., 2012, p. 2497), which, in turn, aimed to serve as building blocks for designing thematic maps (MacEachren, 1995).

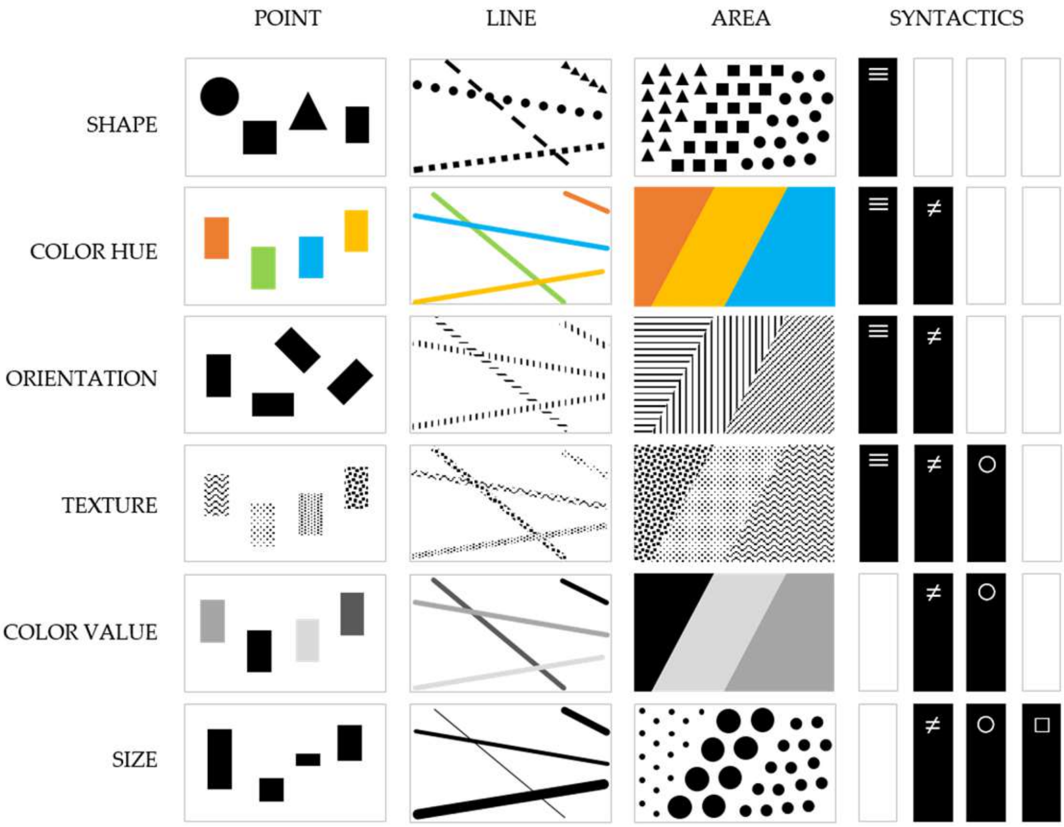


Figure 8. Graphic variables and their syntactics; own illustration based on Bertin (1974). Syntactic qualities of visual variables: ≡ associative, ≠ selective, ○ ordering, □ quantitative.

While Bertin's framework is widely accepted in cartography and information visualization until today, critical scholars have criticized it for being dogmatic, limitedly empirically verified, and incomplete (MacEachren, 1995; MacEachren et al., 2012; Montello, 2002). Researchers have, therefore, put particular emphasis on empirically testing his framework and on expanding Bertin's foundational work. As a result, ever more nuanced semiotic guidelines were established. Some are tailored to different map types, such as tactile maps, acoustic maps, or dynamic visual maps (e.g., see MacEachren, 1995). Others encompass different data characteristics, such as data uncertainty (MacEachren et al., 2012; McKenzie et al., 2016).

With these efforts, cartographic semiotic frameworks have followed the claim for establishing a shared set of signs and semiotic rules grounded in logic relations and analytic reasoning. Their syntactic rules are used to systematically relate cartographic variables to the characteristics of the information they represent. While the relevance for building such syntactic relations for sign-systems is undoubted, they address only the explicit, denotative referential dimension of meaning, i.e., the meanings *in* maps, while disregarding the implicit, connotative meanings *of* maps (MacEachren, 1995).

Meanings *of* maps

With the rise of critical cartographic perspectives, the conviction of maps as objective mirrors of nature began to fade (Harley, 1989). Critical approaches to cartosemiotics today argue beyond the meanings *in* maps but emphasize the implicit, connotative meanings *of* maps and map signs (MacEachren, 1995).

The connotative dimension of meaning has traditionally been treated as a secondary dimension of signs, as a dimension that may function in addition to a sign's primary, explicit, denotative meaning (Nöth, 1995). Yet, in the attempts to establish cartography as objective communication science, cartographic scholars excluded the study of connotation from their research (MacEachren, 1995). Critical perspectives, yet, stress that it is "impossible to determine which is the denotation and connotation, which is the primary meaning and which must be inferred from it" (MacEachren, 1995, p. 231).

Critical semioticians emphasize that the sign is polysemic, i.e., that it gives rise to both denotative *and* connotative meanings inseparably. Both dimensions of meaning are, thus, equally important. They are "an ensemble of semiotic modes brought together into an integrated whole" (Kress, 2001, p. 77). From such a critical semiotic perspective, the sign is more than a neutral, denoting identifier on a map, but "fully social" (Kress, 2001, p. 76), "regulated through social practices and guided by authority, expertise, or simple conformity in particular contexts" (Aiello, 2020a, p. 53). Visual signs, thus, express a "sense of the social world at a particular moment" (Kress, 2001, p. 76) and "invite a particular interpretation, that is formed by experience and social interaction" (Lechner, 2020, p. 333).

As signs are constructed in and by socio-cultural contexts and as people inevitably respond "culturally and engage emotionally with data and their visualizations" (Aiello, 2020a, p. 50), social semioticians emphasize an integrative perspective on semiotics. This perspective focuses on the "formal properties of visualizations together with their semiotic and social affordances" (Aiello, 2020a, p. 50). From such a contemporary semiotic point of view, visual signs do not have fixed meaning or predefined rules. Instead, they have *meaning potential*, which is based on past uses that have been introduced by society, and *affordances*, which are potential uses, that "lie … latent in the object, waiting to be discovered" (Leeuwen, 2005, p. 5).

Hence, maps are inherently ethnocentric and culturally determined in how they are constructed (Axelsen & Jones, 1987). As such, maps and map signs reflect individual and socio-cultural values. They "stimulate ideas and inferences by interacting with the prior beliefs of the users" (Montello, 2002, p. 296). Thus, our responses to maps and map signs are never based on "the physical qualities of things … but … according to what they mean to us" (Krippendorff, 1995, p. 9).

Research, thus, emphasizes the connotative meanings of signs as crucial factors in any form of human communication (Nöth, 1995; Sternberg, 2009). Empirical research, for instance, showed that connotative meanings are as powerful as to modulate affective responses and cognitive processes, influencing learning, memory, attention, and decision-making (Barrett & Bliss-Moreau, 2009; Loftus & Palmer, 1974; Sianipar et al., 2016).

Critical semiotic approaches to cartography are, yet, relatively recent and empirical studies scarce. Research has only begun to explore the potential meanings of cartographic signs. This dissertation, thus, aimed to contribute to this field of critical cartosemiotics by examining the *connotative meanings of cartographic point symbols* from a cognitive-affective research perspective (see Part II – Empirical Chapters).

CHAPTER 4

Maps and Humans

All perceiving is also thinking,
all reasoning is also intuition,
all observation is also invention.

– Rudolf Arnheim

Maps and Human Processes

When making maps, cartographers generally strive for *congruence.* Congruence is a quality or state of agreeing or coinciding (Merriam-Webster, n.d.), a condition of broadly corresponding to something or being in agreement with it in its essentials. Effective graphics are considered to follow the principle of congruence, where "the structure and content of the external representation … correspond to the desired structure and content of the internal representation" (Tversky et al., 2002, p. 249).

Maps are such external representations. They depict a particular selection of geographic space on a spatial scale smaller than 1:1 (Klippel et al., 2005). As maps are constraint by scale, they require cartographic generalization (Axelsen & Jones, 1987). Maps, therefore, simplify and regularize, reduce dimensionality, omit some information, and exaggerate others.

The way maps schematize information is considered comparable to how human minds schematize information (Tversky, 2000). High congruence between external representations and internal representations is beneficial as they enhance cognitive processing fluency (Tversky, 2000; Winkielman, Schwarz, Reber, et al., 2003) and problem-solving (Tversky, 2000; Vessey, 1991). High processing fluency is regarded as hedonically marked, i.e., eliciting positive affective responses (Winkielman, Schwarz, Fazendeiro, et al., 2003). In contrast, "visualizations that do not match the mental schema require cognitive transformations to make the visualization and mental representation align" (Padilla et al., 2018, pp. 3–4). The mental effort needed to correct mental mismatches and resolve cognitive discrepancies demands higher working memory and can increase the time to complete a task and can lead to more errors (Padilla et al., 2018; Vessey et al., 2006).

Thus, perception, cognition, and affect are core human concepts that influence information processing, as they mediate between sensory information and its interpretation (Barrett & Bliss-Moreau, 2009; Goldstein, 2014; Izard et al., 1984; Russell, 2003; Sternberg, 2009). The following sections introduce these psychological concepts.

Perception

Human perception is "conscious sensory experience" (Goldstein, 2014, p. 412). More specifically, perception is a complex psychological construct that encompasses processes by which humans "recognize, organize, and make sense of the sensations … from environmental stimuli" (Sternberg, 2009, p. 75). Perception can involve any sensory information, from visual, auditory, olfactory, gustatory, to haptic. Visual perception – as discussed in this section – is the most studied perceptual modality.

The term perception originally stems from Latin *percipere*, which means "to take (something) through (something else)" (Partridge, 2006, p. 7). Its original meaning describes what perception in its essentials is about: a *perceptual process* that begins with a physical stimulus (or, more precisely, light reflections from that stimulus) and ends with a conscious sensory experience. The perception process involves various physical transformations by the eye's optical system and the neural system (for details, see Goldstein, 2014). The final stage is "the most miraculous of all of the transformations in the perceptual process because the electrical signals … are transformed into conscious experience", i.e., the person perceives the object as such or even recognizes it (Goldstein, 2014, p. 8).

Perception, thus, refers to the conscious awareness of a stimulus or object, to the awareness of seeing something. Recognition, on the other hand, goes beyond perception and refers to being able to identify or even name what is perceived. It "is placing an object in a category … that gives it meaning" (Goldstein, 2014, p. 8). Both perception and recognition can lead to behavioral responses and actions, such as inspecting or walking towards the perceived stimulus or acting upon a recognized object.

Cognition

In contrast to the process of perception, which is tied to physical stimuli in the proximate environment, cognition is not (Downs & Stea, 2011/1972). The term cognition originally stems from Latin *cognōscere* and means "to know" or "to learn about" (Partridge, 2006, p. 557). Cognition is a broad concept and includes a wide range of processes, such as perception, thinking, reasoning, remembering, problem-solving, decision-making. It also refers to the organization of information and the structures of memory, concepts, and attitudes (Zimbardo & Gerrig, 1996).

From a cognitive perspective, individuals do not react to reality as it exists as an objectively describable material world, but as it appears to them as subjective reality, constructed by their interpretations (Zimbardo & Gerrig, 1996). Cognitive researchers are, thus, concerned with how people perceive, learn, remember, and think (Sternberg, 2009). Such cognitive processes are also referred to as *information processing* (Zimbardo & Gerrig, 1996).

As maps have been recognized to contribute to inner mental worlds, cognitive perspectives have implicitly been part of cartography ever since (Montello, 2002). Cognitive processes have, however, not been studied explicitly in cartographic research until the 1970s. Stimulated by the Cognitive Revolution, however, cartographic scholars began to emphasize that map design was about human cognition and the meanings constructed from them (e.g., Petchenik, 1977; Wood & Fels, 2008). Since then, cognitive cartography established as a flourishing research field. Today, it encompasses "the application of cognitive theories and methods to understanding maps and mapping" and "the application of maps to understanding cognition" (Montello, 2002, p. 283).

Affect

Affect is considered a human psychological primitive (Barrett & Bliss-Moreau, 2009; Wunth, 1902). It is a "neurophysiological state that is consciously accessible as a simple, nonreflective feeling" (Russell, 2003, p. 147). Some affect is always present within a person (Russell, 2003), influencing human thinking and decision-making (Izard et al., 1984). Affect can be neutral, moderate, or extreme (Russell, 2003). When affect is moderate or extreme, it can be consciously experienced as pleasant or unpleasant and form the basis of an *emotional experience* (Feldman Barrett et al., 2007; Russell, 2003). When affect is neutral, it influences conscious experience and behavior more mildly. It is then experienced as *affective quality*, i.e., as attributes or properties in the surroundings, stimuli, objects, or events (Bakker et al., 2014; Russell, 1980). Affective qualities are commonly described by affect-denoting adjectives such as pleasant, unpleasant, exciting, dull, safe, upsetting, soothing, and the like. Barrett and Bliss-Moreau (2009) argue that any human communication expresses some level of affective state. And as such, any form of communication, from verbal messages to human-made objects, imbue affective qualities (Russell, 2003).

Two possible sources for affective responses have been suggested to be involved in information processing, i.e., *feature-based affective responses* and *non-feature–based affective responses* (Winkielman, Schwarz, Fazendeiro, et al., 2003). Feature-based affective responses stem from declarative information, which are the features or attributes of a stimulus. Non-feature-based affective responses are based on experiential information, such as a "person's feelings or phenomenal experiences" (Winkielman, Schwarz, Fazendeiro, et al., 2003, p. 190). The latter may be caused by the experience of processing fluency, which can cause a subjective experience of ease (Winkielman, Schwarz, Reber, et al., 2003). Processing fluency is, therefore, regarded to be "hedonically marked" in the sense that "high fluency elicits positive affective reaction. […] This reaction, in turn, contributes to a more positive evaluation when a given stimulus can be processed with high rather than low fluency" (Winkielman et al., 2003, p. 191). Affect and cognition are, thus, closely related and influence each other (Izard et al., 1984).

Perceiving and evaluating the affective qualities of the human environment and the stimuli therein is considered a fundamental aspect of human information processing (Russell, 2003). And it has "psychological consequences that reach far beyond the boundaries of emotion" (Barrett & Bliss-Moreau, 2009, p. 167), influencing decision-making and human behavior (Izard et al., 1984).

Maps and Information Processing

Human information processing draws attention to understanding how humans perceive and conceptualize information. It stands in contrast to information theory (see Shannon, 1948), which focuses on measuring and controlling how much information is successfully transmitted, respectively lost (MacEachren, 1995).

Information processing encompasses a wide range of activities that are "interposed between that instant when one first fixates one's gaze upon a visual display and the point at which one has successfully extracted relevant information from it" (Kosslyn, 1989, p. 190). The main concepts of information processing are outlined in the following sections.

Bottom-up and Top-down Processing

Some information may be processed entirely stimulus-based, while others rely on prior knowledge and experiences (Goldstein, 2014; Sternberg, 2009; Zimbardo & Gerrig, 1996). They are referred to as *bottom-up processing* and *top-down processing*.

Bottom-up processing: Some perception can be direct and entirely stimulus-based (e.g., see Gestalt theory: Köhler, 1947; Wertheimer, 1923). This type of processing is also referred to as data-driven or bottom-up processing, where sensory information of stimuli is picked up by the perceptual system. Information is processed without involving cognitive processes that mediate between sensory stimulation and perception (Zimbardo & Gerrig, 1996). The term bottom-up processing refers to the starting point from where information is picked up to be processed, i.e., from the proximal, observable environment. It also refers to the direction of processing, i.e., converting concrete physical stimulus properties into abstract, mental representations (Zimbardo & Gerrig, 1996). In bottom-up processes, a stimulus is identified through comparisons between the percept and related knowledge (or schemas) stored in memory (Zimbardo & Gerrig, 1996). As such, bottom-up processing is also referred to as *precognitive* (MacEachren, 1995).

Top-down processing: Top-down information processing relies on knowledge, experiences, memories, motivations, expectations, and cultural background (Goldstein, 2014; Sternberg, 2009; Zimbardo & Gerrig, 1996). In many cases, the identification and classification of perceived objects can be enhanced by such pre-existing knowledge. The concepts stored in human memory lead to hypotheses about the perceived reality. They influence how humans perceive their environments and the stimuli therein. Top-down processing is, therefore, also referred to as concept-based or hypothesis-based processing (Zimbardo & Gerrig, 1996).

The great majority of human processing is determined by the interaction between bottom-up *and* top-down processes, each taking precedence some of the time (Goldstein, 2014; MacEachren, 1995; Sternberg, 2009). As such, human information processing is referred to as a process of *construction*, where the perceiver uses sensory information and other sources of information to build a cognitive understanding of the stimuli in her/his environment (Sternberg, 2009).

Dual-Processing Theory

Kahneman (2002, 2003) distinguishes perception from two types of human information processing, i.e., *intuition (Type 1)* and *reasoning (Type 2)*; see Figure 9. *Type 1 intuitive processing* refers to the type of thinking which is fast, unconscious, autonomous, experience-based, associative, and independent of cognitive ability (Evans, 2008; Evans & Stanovich, 2013; Kahneman, 2002, 2003). *Type 2 reflective processing*, on the other hand, refers to the mode of information processing that is conscious, deliberate, effortful, thus, typically slow, and of limited capacity (Evans, 2008; Evans & Stanovich, 2013; Kahneman, 2002, 2003).

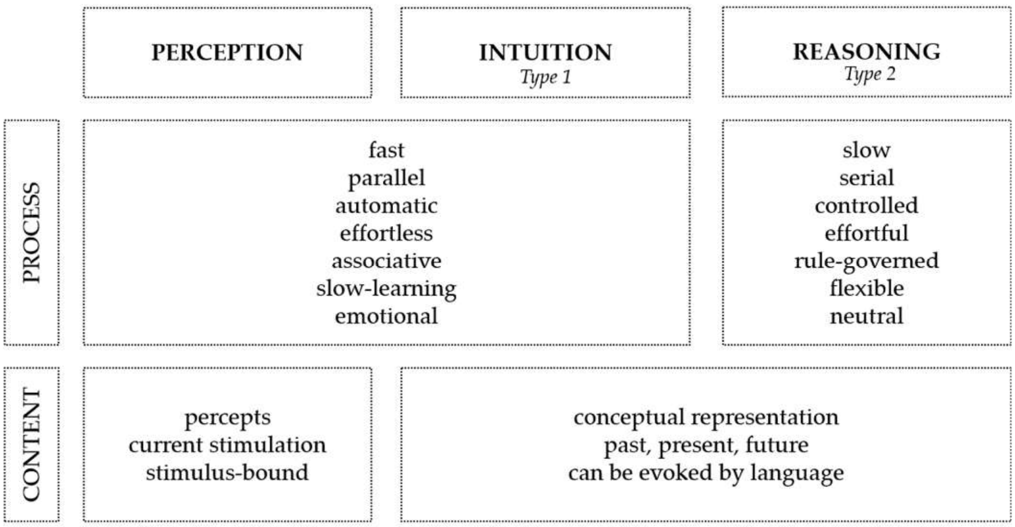


Figure 9. Two types of cognitive processing (Type 1: intuition, Type 2: reasoning) in contrast to perception (adapted from Kahneman, 2003).

The dual-processing framework is a well-accepted theoretical approach in cognitive sciences with considerable agreement on the characteristics that distinguish them (Evans, 2003; Evans & Stanovich, 2013). The two types of processing are also referred to as two distinct cognitive systems which developed evolutionary:

> System 1 is old in evolutionary terms and shared with other animals: it comprises a set of autonomous subsystems that include both innate input modules and domain-specific knowledge acquired by a domain-general learning mechanism. System 2 is evolutionarily recent and distinctively human: it permits abstract reasoning and hypothetical thinking but is constrained by working memory capacity and correlated with measures of general intelligence. (Evans, 2003, p. 454)

Information Processing and Cartography

The dual-processing framework has also been demonstrated as a useful framework for guiding cartographic research (Padilla et al., 2018). Kahneman's model (2003) provides a helpful approach for distinguishing the many different perceptual and cognitive processes involved in cartographic information processing, from direct perception, intuitive judgments to high-level reflective thinking.

Following this framework, cartographic research has strongly focused on processes related to map perception and reasoning. Map perception research, for instance, has put particular emphasis on identifying perceptual thresholds that help ensure the legibility of map symbols in cartographic visualizations (e.g., see Robinson et al., 1995, p. 325). Research on *Type 2 reflective processing*, on the other hand, focuses on more complex map-related decision-making based on reasoning. By definition, this involves any cartographic conscious and rule-based decisions where working memory is involved (Evans & Stanovich, 2013).

Cartographic research on *Type 1 intuitive processing* is, yet, scarce. In recent decades, maps have, however, changed profoundly. They have become smaller and simpler, designed for incidental engagement and intuitive processing.

The rise of new and well-accessible technologies has shifted the dominant cartographic medium from paper to digital. This development transformed the way maps are made, used, and shared (Kent, 2018). The web as a new medium has constrained the design of such maps to small physical display sizes. Well-designed web maps are, therefore, regarded to require extra attention and are considered "relatively empty" (Kraak & Ormeling, 2011, p. 79).

Such simple web maps have become ever more present yet, transient. Many are of single purpose and single-themed (Field, 2014). They do not require high cognitive effort to be processed but allow for incidental engagements and intuitive, associative processing in daily situations of quick use.

As little is known about the connotations and associations triggered by such simple maps, this research aimed to contribute to closing this research gap. It focused on *Type 1 intuitive processing* (Kahneman, 2003) and empirically assessed their connotative meanings and cognitive-affective responses when encountering such new forms of relatively simple and empty maps (see Part II Empirical Chapters).

Part II

Empirical Chapters

CHAPTER 5

STUDY 1

Cognitive Proximity of Point Symbols

This empirical research has been published in the ISPRS International Journal of Geoinformation. For the original and full version, see Klettner, S. (2019). Why Shape Matters – On the Inherent Qualities of Geometric Shapes for Cartographic Representations. *ISPRS International Journal of GeoInformation, 8*(5), 217. Supplementary materials are available online at http://www.mdpi.com/2220-9964/8/5/217/s1.

Abstract

All human communication involves the use of signs. By following a mutually shared set of signs and rules, meaning can be conveyed from one entity to another. Cartographic semiology provides such a theoretical framework, suggesting how to apply visual variables with respect to thematic content. However, semiotics does not address how the choice and composition of such visual variables may lead to different connotations, interpretations, or judgments. The research aimed to identify perceived

similarities between geometric symbols and the reasons underlying these similarity judgments. Based on a user study with 38 participants, the (dis)similarities of a set of 12 basic geometric shapes (e.g., circle, triangle, square) were examined. Findings from cluster analysis revealed a three-cluster configuration, while multidimensional scaling further quantified the proximities between the geometric shapes in a two-dimensional space. Qualitative content analysis identified three strategies underlying the participants' similarity judgments: visual, associative, and affective strategies. With the findings combined, this research provides a differentiated perspective on shape proximities, cognitive relations, and the processes involved.

Introduction

All human communication, in its widest sense, involves the use of signs to share information and to express oneself (Keates, 1996). Communication refers to the act of conveying intended meanings from one entity or group to another through the use of a mutually shared set of signs and semiotic rules. Although all species communicate, human communication is notable for its precision and flexibility, allowing one "to formulate an unlimited number of meaningful novel messages that are not tied to the immediate present" (Krauss, 2002, p. 1). Through language, people are able to refer to and think about concrete objects and abstractions, past events and experiences, and affairs remote both in space and time or those that exist only in the imagination (Keates, 1996).

To communicate, humans use signs (i.e., signifiers) which can take the form of words, images, speech sounds, objects, etc. When humans imbue signs with meaning, they become meaningful because they stand for something (i.e., the signified) (Chandler, 2007). Yet, the relation between signifier and signified may reflect a wholly arbitrary connection (Keates, 1996), constructed individually, socially, or culturally, based on experiences, knowledge, or shared norms. In other words, the physical means of communication, such as language and maps, do not carry meaning per se but rather trigger or release meaning (Petchenik, 1977). And yet, despite their similarities, maps are unlike language; their elements are unlike words. The elements of a map are independent, associative symbols with a reference fixed by convention but not by fixed associations or single, unequivocal references (Bertin, 1974; Langer, 1953). Maps are cultural artifacts based on an accumulation of choices, each of which reveals particular values (Wood, 2010).

In his famous work, *Semiology of Graphics*, Jacques Bertin stresses that visual variables (i.e., shape, color, hue, size, texture, and orientation) must be carefully selected to correspond with the information they represent (Bertin, 1974). With his semiotic theory, Bertin provided a theoretical framework for cartographic visualization, suggesting how to apply visual variables with respect to the thematic content, such as how to depict information that is selective, associative, ordinal, or quantitative (Bertin, 1974; MacEachren et al., 2012). Yet, the variety of methods available for representing information through cartographic representations allow for strikingly different results created from a single set of data (Thompson et al., 2015). While a map may be designed to convey a single focus of interest, it does not convey a single universal message (Thompson et al., 2015). The influence of cartographic representations on the perception and interpretation of maps is therefore significant (Monmonier, 1996). Chandler even claims that "changing the form of the signifier while keeping the same signified can generate different connotations. Changes of style or tone may involve different connotations, such as when using different typefaces for exactly the same text, or changing from sharp focus to soft focus when taking a photograph" (Chandler, 2007, p. 143).

Empirical research from related domains supports this notion. Loftus and Palmer, for example, showed that a simple change in the wording of a question could markedly and systematically affect individuals' associations and responses, like judgments of speed estimation and memory (Loftus & Palmer, 1974). Sianipar et al. argue that as constituents of language, words have abstract semantic or referential meanings and convey the emotional quality of their underlying concepts or references, i.e., they have connotative, affective meanings (Sianipar et al., 2016). A word's affective dimensions thus modulate cognitive processes, such as learning, memory, and attention. Such connotative, affective dimensions may not only refer to language alone but be present in any human-stimulus interaction (Barrett & Bliss-Moreau, 2009; Russell, 1980). The Gestalt psychologist Wolfgang Köhler claimed that objects and situations imbue a particular *"Anmutungsqualität"* ("appearance quality"), which refers to an object's or situation's vague effect on a viewer through perception (Köhler, 1947). Köhler tested this claim and found that in the majority of cases, participants assigned the soft-sounding word *maluma* to round shapes while assigning the word *takete* to angular-shaped figures. This intuitive, non-arbitrary correspondence between the different channels of human perception has been replicated in different contexts (Sapir, 1929; Spence, 2011) and cultures (Davis, 1961; Ramachandran & Hubbard, 2001).

Recent research in cartography has also begun to study the influence of design decisions on human responses. Findings support the notion that changes in visual map style influence the map readers' judgments, trust, liking, recall (Muehlenhaus, 2012, 2013a), and emotional responses (Christophe & Hoarau, 2013; Fabrikant et al., 2012). Likewise, the style of line shapes in origin-destination flow maps (e.g., curved versus straight flow lines) influences people's preferences and accuracy of judgments (Jenny et al., 2018). In recent years, the impact of cartographic representations has most profoundly been studied for the depiction of uncertain phenomena. Findings strongly imply a significant influence of the type of uncertainty visualization on intuitiveness, uncertainty judgments, and people's preferences (Cheong et al., 2016; Kinkeldey et al., 2014; MacEachren et al., 2012; Padilla et al., 2017). Research moreover emphasizes the importance of visual saliency in cartographic communication, which influences the effectiveness (e.g., detection time) and efficiency (e.g., accuracy) of map reading (Garlandini & Fabrikant, 2009). Salient information draws the attention of the reader, while visualizations of greater cognitive fit will produce faster and more effective decisions (Padilla et al., 2018). Such cognitive fit can already be found in school children, indicated by the associative and metaphorical use of signs and symbols even at an early age (Michaelidou et al., 2007; Voženílek et al., 2014).

Such empirical research in the field of cartography, however, is still scarce. There still remains the need for a differentiated perspective in terms of the "identification and articulation of the basic visual variables that can be manipulated to encode information"(MacEachren et al., 2012, p. 2496). As much as Jacques Bertin's Semiology of graphics provides a shared set of signs and rules (Bertin, 1974), cartographic semiotics does not address how the depiction of information through a particular graphic variable may lead to different associations, interpretations, or judgments. Semiotic rules provide a framework to adequately select *between* the types of visual variables in order to correspond with the particular information they aim to represent, such as when to depict information by shape, color, or size. These rules, however, do not further differentiate *within* each type of visual variables, such as regarding the effects of different shapes on people's associations and map interpretation.

Yet, shapes – in particular, geometric shapes – are considered as core visual variables over a wide range of disciplines (Arnheim, 1974; Bertin, 1974; Klee, 1920). In cartography, geometric shapes are prevalently applied as point symbols in thematic maps to represent nominal data and to locate spatiotemporal occurrences. To this day, the cartographer still faces the challenge of near-infinite variations of shapes to choose from. This challenging fact is acknowledged by Bertin's semiotic rules, which further help guide the selection process, such as by recommending to choose shapes that are associative to the content they represent (Bertin, 1974). While this provides helpful guidance in the cartographic communication process, the selection for an adequate visual signifier can still be a difficult task (Michaelidou et al., 2005). Besides following conventions, such decisions may be based on the map maker's individual associations, knowledge, and preferences. Hence, as much as cartographic semiology does provide a theoretical framework for geospatial communication, it does not further explain the effects of shape characteristics on the map reader's responses and judgments. And while empirical findings strongly support the notion that variations in visual representations can change the map reader's responses on multiple levels, it still remains obscure *why* some symbols emerge as more effective than others in conveying particular information.

This research will, therefore, explore the qualities assigned to two-dimensional, geometric shapes – such as triangle, point, or square – and examine their similarities. The concept of similarity (or sense of sameness) is pivotal to theories in cognitive sciences. By identifying similarities between two stimuli, part of the stimuli's cognitive structure and relatedness can be revealed. Shapes that are perceived as more similar can be regarded as more cognitively related. Besides studying perceived similarities, this study will further explore strategies and processes underlying the similarity judgments. With a better understanding of why some shapes are perceived as more similar, shapes can be more accurately be distinguished (Hout et al., 2013), allowing for more effective and associative visualization of information.

Empirical Study

Materials

The study's stimulus material comprised of 12 paper cards, each showing one two-dimensional geometric shape at a size of 1.7 x 1.7 cm, with the exception of the semicircular shape due to its semi-size nature. All shapes were displayed in black on a white paper background. Full shape filling in black aimed to control for responses towards the shape's qualities and to preclude similarity judgments based on color associations. Geometric shapes were systematically created by increasing complexity, i.e., by increasing the number of vertices of an initial point shape. As such an approach could result in an infinite number of shape variations, the number of stimuli was limited to a set of commonly used shapes (Bertin, 1974; Prange, 2001). As a result, a set of 12 geometric shapes was selected and further used in this research study (Figure 10).

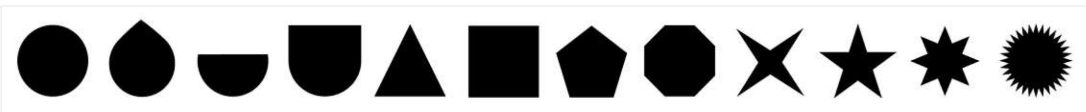


Figure 10. Stimulus material, comprising 12 geometric shapes.

Participants

In total, 38 Bachelor's students of Regional Planning and Geodesy from Vienna University of Technology, Austria, participated in the study (19 men, 19 women; mean age = 21.50 years, *SD* = 3.00). Students were recruited from a course on "Thematic Cartography in Regional Planning". Students participated voluntarily. For their participation, students received course credits in the form of bonus points, which counted towards their final grades. The study was conducted at the facilities of the Research Division Cartography at Vienna University of Technology in October 2018. In individual settings, all participants were tested by the same female instructor to control for experimenter effects. The study was conducted in German. Before participating in the study, each student gave their informed consent. The study was conducted in accordance with the Declaration of Helsinki.

Sociodemographic information was gathered at the end of the survey regarding the participant's affinity for graphic design (self-evaluation on a unipolar 4-point rating scale, from "not at all" to "very affine"), field of study, age, and sex. The majority of rated their affinity for graphic design to be moderate (18 individuals, approx. 47%) or high (15 individuals, approx. 40%). Five participants rated their affinity for design to be low (approx. 13%), and one individual reported having no interest in graphic design.

Study Design

After giving their informed consent, participants were given a short introduction about the aim of the study, i.e., to better understand how shapes are perceived (German introduction: *"Wir sind daran interessiert wie Formen auf Sie wirken und wie Sie diese wahrnehmen."* Translation: *"We are interested in how shapes affect you and how you perceive them."*). Each participant was asked for permission to audio record the responses.

The main study was structured using three tasks: a free-sorting task (task 1), a retrospective verbalization task (task 2), which aimed to identify strategies applied when grouping the geometric shapes, and a labeling task (task 3) in which the participants were instructed to label each group by its most prominent characteristic(s). Figure 11 illustrates the grouping procedure of task 1 and the free-labeling of task 3.

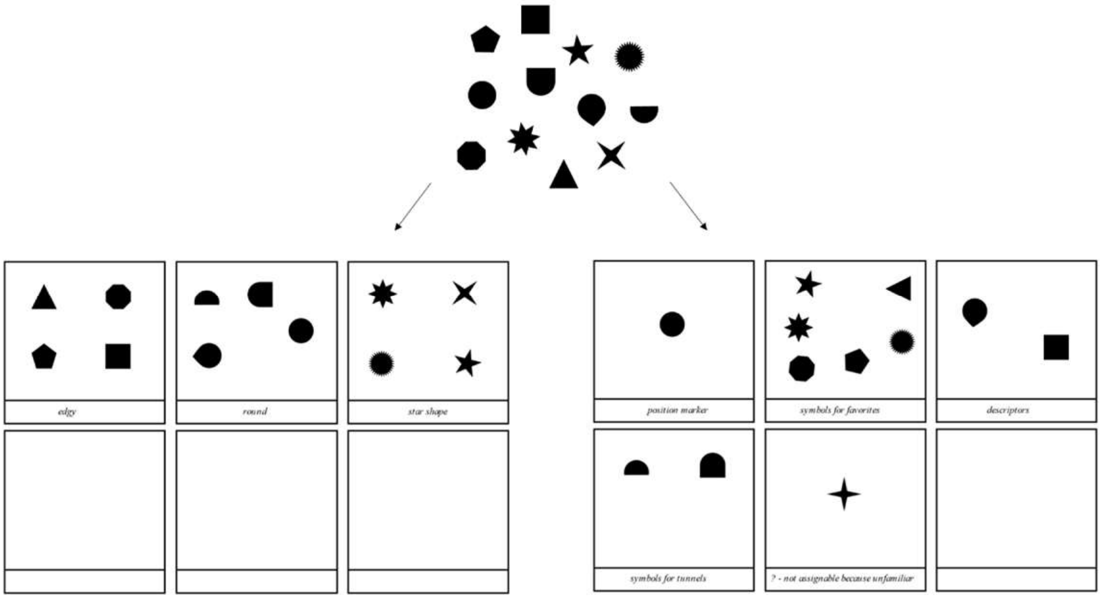


Figure 11. Illustration of two visual protocols from two participants after completing free-sorting task 1 and free-labeling task 3.

At the end of the three tasks, sociodemographic information was gathered from the participants regarding their affinity for graphic design, the field of study, age, and sex.

Task 1: Free-sorting

Task 1 aimed to identify perceived similarities of geometric shapes. Hence, each of the participants performed a free-sorting task based on their intuitive judgments. Each participant was handed a pile of paper cards comprising 12 geometric shapes in a randomized order. Subjects were instructed to first look at the shapes and then to freely sort them according to their intuition. Shapes, which were perceived to be similar, should be assigned to the same group, while shapes that did not match any other shape could be sorted as a single-item group. Subjects were free to create as many groups as needed without a time limit. Participants were further instructed to tape their grouping results onto DIN A3 papers, with each separate group of shapes placed into one of the fields on the papers (Figure 11 illustrates two visual protocols revealed from this task).

Task 2: Retrospective verbalization

After completing the free-sorting task, each participant was asked to explain their decisions through retrospective verbalization (Ericsson & Simon, 1993). With the retrospective verbalization method, "a direct trace is obtained of the heeded information, and hence, an indirect one of the internal stages of the cognitive process", which underlie the participants' grouping decisions (Ericsson & Simon, 1993, p. 220). The task aimed to uncover underlying processes and concepts that participants used for the groupings, such as associations or connotations. Instructions for this task were phrased as open-ended questions to allow for flexibility in explanation. In detail, participants were instructed to explain their decisions and describe which particular aspects contributed to their decisions (German instruction: *"Sie haben [Anzahl] Gruppen gebildet. Können Sie Ihre Entscheidungen nun erklären? Anhand welcher Aspekte haben Sie die Formen gruppiert?"* Translation: *"You have created [quantity] groups. Could you now explain your decisions? According to which aspects did you group the shapes?").* Participants verbalized their thoughts and decisions for each group of shapes successively. The experimenter audio recorded the participants' responses.

Task 3: Free-labeling

After the retrospective verbalization was completed, participants performed a labeling task. Participants were instructed to freely label each group according to what best described the group (German instruction: *"Können Sie nun jede Gruppe anhand des wichtigsten Gruppenmerkmals benennen?"* Translation: *"Could you now label each group according to its most significant group characteristic?"*). The free-labeling task aimed to provide another approach to explore relevant processes and strategies underlying the similarity judgments from task 1.

Results

Shape Similarities

The study aimed to identify perceived similarities between geometric shapes as well as strategies and processes underlying similarity judgments. In order to reveal shape similarities, participants freely sorted a set of 12 geometric shapes based on their intuitive judgments. In doing so, participants were free to create as many groups as needed. The free-sorting resulted in 177 groups in total. The participants frequently sorted the geometric shapes into five or six groups, *Min* = 3, *Max* = 7 (see Table 1).

Table 1. Frequency of grouping solutions for 12 geometric shapes, based on 38 participants.

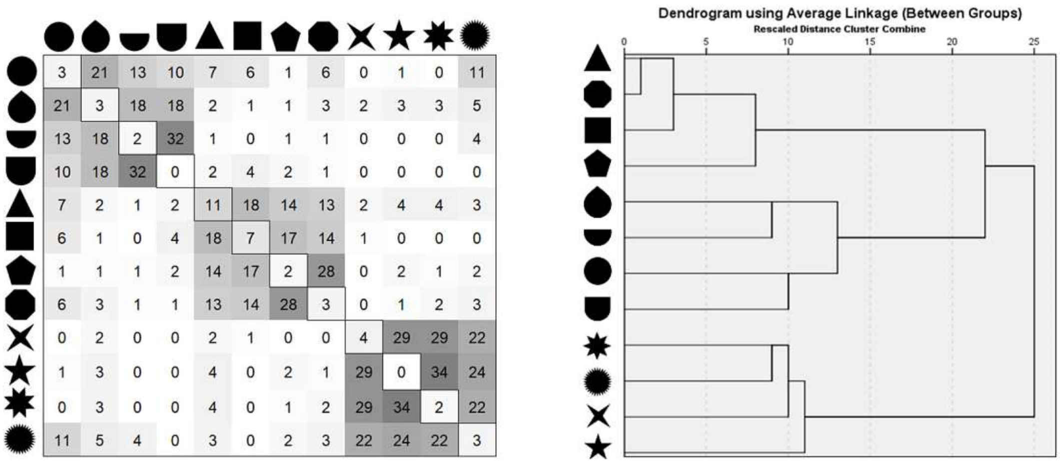
	Group Frequencies						
	1 Group	2 Groups	3 Groups	4 Groups	5 Groups	6 Groups	7 Groups
Frequency	·	·	8	9	10	20	1
Percentage	·	·	21%	24%	26%	26%	3%

In the next stage of analysis, results from free-sorting were statistically analyzed to identify shape similarities. First, co-occurrences of each pair of shapes were calculated. Second, cluster analysis was applied to reveal the proximities between shapes. Third, their distances were quantified and illustrated through the means of multidimensional scaling. These stages of analysis and their results are discussed in the following sections.

Co-occurrence matrix

First, the frequencies of co-occurring pairs of shapes were mapped into a co-occurrence matrix. Co-occurrence values represent the strength of association between objects by analyzing how often each pair of objects appears in the same group (Cox & Cox, 2001). In this study, co-occurrences represent the perceived similarity among the set of 12 geometric shapes. The co-occurrence matrix consists of a row and column for each of the geometric shapes, resulting in a 12x12 symmetric matrix. Each cell in the matrix represents the number of times a given pair of shapes was grouped across participants. The higher the number in a cell, the more frequently those two shapes were placed in the same group, and the higher the perceived association between those shapes (see Figure 12a).

Since the sorting task (task 1) also allowed participants to assign single items to a unique group, Figure 12a further illustrates the frequencies of single-item groups with respect to shape type. Most frequently, the triangular shape was assigned as a single-item class (11 times, 29%), followed by the quadratic shape (7 times, 18%). In most of the cases, however, triangle and square were paired into the same group.



(a) (b)

Figure 12. Co-occurrences of geometric shapes from free-sorting task 1, illustrated as (a) co-occurrence matrix: the values indicate the frequency counts of co-associations and those of single-item groups (see diagonal values) - higher values indicate higher similarity; and as (b) dendrogram based on agglomerative hierarchical cluster analysis.

Cluster analysis

In the next step, a hierarchical cluster analysis was performed based on the co-occurrence matrix to identify clusters of shapes with similar qualities statistically. The statistical software package SPSS was used to analyze the matrix (IBM, 2017). An agglomerative clustering approach was applied. It starts with each item as its own cluster and progressively links them based on their estimate of the distance to one another (for detailed results, see Supplementary Materials Table S1). A cluster distance measure of average linkage was employed that balances the limitations of single and complete linkage methods, i.e., using information about all pairs of distances to assign cluster membership, not just the nearest or the farthest item pairs. Results indicate a three-cluster solution (see dendrogram Figure 12b). The dendrogram revealed one cluster comprised of polygons, while round and partly round shapes fall into cluster two. Star-like shapes fall in cluster three. Moreover, the cluster analysis dendrogram indicates that round shapes (cluster one) and polygons (cluster two) belong to a shared meta-cluster (Figure 12b).

Multidimensional Scaling

Multidimensional scaling (MDS) was applied to reduce the complexity of the data set and permit a visual appreciation of the underlying relational structures. Through MDS, distances between items are quantified, and proximities and relations are revealed. The outcome of MDS is a dimensional space that conveys relationships among items, wherein similar items are located proximal to one another, while dissimilar items are located proportionately farther apart (Hout et al., 2013). Thus, proximities between the geometric shapes were calculated based on the 12x12 co-occurrence matrix composed previously, resulting in 66 similarity counts (k items, (k * (k − 1)) / 2). The co-occurrence matrix was subjected to a PROXSCAL scaling algorithm to disclose the spatial relationship between the geometric shapes, treated as ordinal data. A scree plot was computed to determine the appropriate number of dimensions, indicating a two-dimensional configuration (see Supplementary Materials Figure S1 and Table S2). Figure 13 illustrates the two-dimensional space and the relationships between the 12 geometric shapes used in this study (see Supplementary Material Table S3 for detailed coordinates of each shape). Similar shapes are located proximal and dissimilar shapes are located distant from one another. Results support the previous findings of a three-cluster solution while further distinguishing the individual proximities between and within each cluster in more detail.

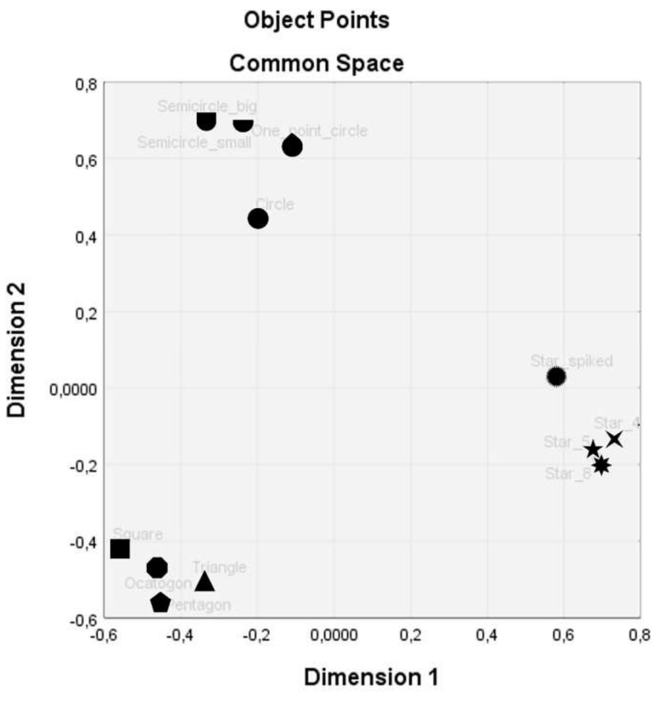


Figure 13. Two-dimensional configuration of 12 geometric shapes using MDS.

Grouping Strategies

Besides identifying perceived similarities of geometric shapes (see previous sections), the study aimed to uncover core processes and strategies that contributed to similarity judgments.

After the free-sorting task was completed, each participant was instructed to retrospectively verbalize their decisions (task 2) and to further label each group by its core characteristics (task 3). Responses from both tasks were subjected to a qualitative content analysis (Mayring, 2014, 2015) to further uncover core processes and strategies from the collected data across participants. In particular, a *reductive content analysis* approach was applied, in which "the category systems are developed inductively out of the concrete material" (Mayring, 2014, p. 13). The analysis was performed manually, in a systematic, sequential, and iterative process, following the sub-procedure of *inductive category formation* proposed by Mayring (2014, 2015).

The analysis followed a distinct research question to set a clear focus on the content to be examined (Mayring, 2014), i.e., *which processes account for the similarity groupings of shapes?* The analysis took into account the audio recordings from the retrospective verbalizations (task 2) and labels assigned to each group (task 3). All relevant text passages from the participants' retrospective verbalizations were extracted and summarized to create condensed, meaningful units tailored to the research question. The assigned group labels derived from the free-labeling task 3 were transcribed, and together with the condensed retrospective verbalizations, transferred to a written protocol. As a result, the written protocol was comprised of each participant's responses, structured by each participant and each group of shapes (see Supplementary Materials Table S4).

The written protocols were scanned line by line. All passages were highlighted that appeared to capture key thoughts or concepts. As this process continued, "labels for codes emerge that are reflective of more than one key thought" (Hsieh & Shannon, 2005, p. 1279). By processing the text, first labels were gradually derived, and text units with similar meaning subsumed under the same label, while new labels were formulated for new thoughts or concepts. Once no new concepts appeared, the initial coding scheme and its logic were revised to achieve a set of labels that were distinct enough to adequately represent the core meanings as well as broad enough to account for the whole range of responses.

The final set of labels became the coding scheme, which was used by two coders who coded all responses independently. This resulted in a 2x177 data matrix (2 coders x 177 responses), with each cell in the matrix containing a code (comprising of one or more labels) or a period character (".") for missing judgments (see Supplementary

Materials Table S4 for an excerpt of the final coding of coder 1). The coding results of both coders were subjected to Krippendorff's alpha inter-coder reliability estimate by applying KALPHA macro for SPSS (Hayes & Krippendorff, 2007). Results indicate a high inter-coder reliability of α = .87, CI [.82 - .93].

In a final interpretative process, codes were related across participants and organized into categories with a higher level of abstraction. Findings suggest three core strategies applied when free-sorting shapes according to their (dis)similarities, i.e., visual, associative, and affective strategies:

Visual strategies. Most participants expressed visual shape properties to explain their grouping decisions. In total, visual strategies were reported 132 times, accounting for 59.5% of all responses. Similarities based on visual characteristics primarily referred to a) the shape's visual appearance and geometry (e.g., similarity due to their vertices, edges, roundness), followed by b) visual hierarchy and containment (e.g., basic shapes versus complex shapes, one shape fits into the other or contains the other), and c) symbiosis and completion (e.g., one shape completes the other, or two shapes together account for a new shape).

Associative strategies. Associative strategies used to group the stimuli were found 52 times (23.4%). When grouping by associations, subjects explained their sorting results a) with reference to natural or human-made objects (e.g., associations referring to street signage, heavenly bodies, tunnel, balloon, or two semicircles together representing an open capsule), or b) by associating shapes to a cartographic context (e.g., shapes representing a pin on a map to mark a point of interest).

Affective strategies. In 17.1% of the responses, or 38 times, participants explained their grouping decisions by evaluating the shapes. Such responses emerged as corresponding to the three dimensions found in semantic and affective space theories (Bakker et al., 2014; Mehrabian & Russell, 1974; Osgood et al., 1957). Hence, participants' evaluative responses were further differentiated based on this deductive, theory-driven consideration, corresponding to the three dimensions of affect – valence, arousal, and dominance. In detail, participants who sorted the geometric shapes by their affective qualities explained their decisions along the dimensions of a) valence (e.g., incomplete, boring), b) arousal (e.g., restless, aggressive, calm), or c) dominance (e.g., showy, brutal, dominant, heavy).

Results from qualitative content analysis were further complemented by quantitative analyses, revealing that in most cases (87%, or 138 times), participants explained their grouping decisions by one of the three strategies. In 20.3% of the cases (i.e., 36 times), participants used two strategies to explain their grouping results. Two participants (i.e., in 1.1% of the cases) used all three strategies to explain their decisions. In one case, the explanation for grouping could not be assigned to any of the categories. Thus, this response was treated as a missing value. The quantitative analysis further showed that female and male participants used visual and affective strategies similarly often to explain their grouping decisions. Associative strategies, on the other hand, were expressed twice as often by males than by females (see Supplementary Materials Table S5 for details).

Discussion

Human communication is notable for its variability and flexible use of signs to share and express information, both verbally and visually. The choice of signs, however, must be selected carefully, as its result will influence how people respond to the information. The selection of signs in visual communication is, thus, a critical process. With a better understanding of why some shapes are perceived as more similar, they can more accurately be distinguished (Hout et al., 2013). This, in turn, can lead to more informed choices, allowing for more effective and associative information visualization.

This research, thus, focused on revealing such symbol qualities. It used the concept of similarity (or sense of sameness) to uncover part of their cognitive structure and relatedness. The empirical study further explored the strategies and processes underlying these similarities. This empirical research aimed to contribute a differentiated perspective on shape proximities and on underlying concepts and processes involved in their perceived similarities with its multi-method approach.

Twelve geometric shapes were used as stimuli in this research. The first part of the study focused on identifying the similarities between the stimuli to reveal their cognitive proximities. Have a quantitative estimate of the proximity between two concepts is particularly beneficial as it further allows to discriminate between them based on informed choices. The concept of similarity is, thus, pivotal in theories in cognitive and communication sciences.

The findings of this research strongly suggest that even simple, geometric shapes imbue qualities that distinguish them from one another. The study discovered three independent similarity clusters based on a set of 12 geometric shapes: polygons, round shapes, and star-like shapes. In addition, findings from cluster analysis indicate a hierarchical order. In particular, the clusters of round shapes and polygons suggest a shared meta-concept, distinguishing both clusters from star-like shapes.

Through qualitative content analysis, the study discovered three particular processes involved in the participants' similarity judgments: visual, associative, and affective strategies. Most frequently, visual strategies were applied when grouping geometric shapes according to their similarities. This finding corresponds with existing literature, claiming that visual qualities are the most powerful of all, which "reach us most directly and deeply" (Arnheim, 1974, p. 97). Besides visual characteristics, also associations and affective-evaluative judgments accounted for how (dis)similar visual stimuli were experienced – although to a less significant extent. The participants' affective-evaluative responses emerged to correspond to the three dimensions of semantic and affective space theories: valence, arousal, and dominance (Bakker et al., 2014; Mehrabian & Russell, 1974; Osgood et al., 1957). Affective strategies were, however, mentioned least often.

Female and male participants used visual and affective strategies similarly often. Associative strategies were expressed twice as often by males than females. However, due to the small sample size, these differences cannot claim statistical significance.

As much as this research aims to advance our understanding of shape similarities and underlying processes, it also has limitations:

The results' transferability to more applied scenarios must be regarded as limited. When people make choices, they always do so in particular mindsets and contexts (Ross & Nisbett, 2011). Related research has demonstrated that situations activate specific contents of memory, making related constructs more accessible (Berger et al., 2008). This, in turn, influences associations and behaviors, even without an individual's awareness (Darley & Daniel Batson, 1973; Yi, 1990). Despite the attempt to deprive this study of context, the prevailing associations towards cartography indicate an influence due to the participants' and research study's cartographic background. Associations found in this research through retrospective verbalization must, therefore, not be treated to be exhaustive.

This research studied shape qualities at their most fundamental and purest level. It applied a controlled research approach to explore shape proximities and underlying processes relatively independent of context. By focusing on the effects of map elements in an isolated way, the criterion of ecological validity may, yet, not necessarily be met, i.e., that results may not be transferable to cartographic representations due to their more complex, holistic nature (Montello, 2002; Petchenik, 1977). At the same time, "changing the nature of the map task or the precise design of the test materials often led to variability in the results" (Montello, 2002, p. 295). Thus, both research approaches – controlled and applied studies – have merits and limitations: "the lack of careful isolation of variables in user studies makes it difficult if not impossible to determine whether the results can be generalized to any scenario without identical design and tasks. Without an explanation for why an effect occurs, there is rarely an indication of what and how much can change while maintaining the benefits of a particular design" (Kosara & Haroz, 2018, p. 3). While this study applied a controlled approach, both research approaches are needed in the future to allow for conceptual replications of each other (Kosara & Haroz, 2018).

Against the background of these limitations, future studies are needed to expand upon the present findings. Besides expanding on the types of symbols to be studied, also more diverse user groups must be incorporated in future studies. Research must be extended to applied scenarios, where symbols are employed in different visual contexts, such as in maps.

With a better understanding of shape qualities and their effects on perception and communication, design decisions can likewise be supported, such as to allow for deliberate choices on whether two shapes are similar enough to be acted upon as the same. Being able to discriminate between graphic variables more accurately can help to make more informed decisions. This, in turn, can lead to more associative visualizations in cartography and beyond.

Conclusion

Visual communication requires deliberate decisions to share and express information successfully. The choice of signifiers used to communicate information will affect people's responses. As much as cartographic semiology provides a theoretical framework for geospatial communication, it hitherto cannot explain the effects of visual design choices on human responses and judgments. While empirical findings strongly support the notion that variations in visual representations can change the map reader's responses on multiple levels, it remains unclear why some symbols emerge as more effective in conveying particular information than others.

This study aimed to unravel the subtle communication effects of geometric symbols by encompassing the concept of similarity. In doing so, their cognitive structures and relatedness were disclosed together with three underlying processes, i.e., visual, associative, and affective strategies. Despite future research, which is needed to explore the qualities of visual symbols further, the proximity space uncovered and the more differentiated understanding of underlying processes aim to advance our understanding of visual communication and to enable us to communicate information more effectively in the future.

CHAPTER 6

STUDY 2

Affective Potential of Point Symbols

This empirical research has been published in the ISPRS International Journal of Geoinformation. For the original version, see Klettner, S. (2020). Affective Communication of Map Symbols: A Semantic Differential Analysis. *ISPRS International Journal of Geo-Information, 9*(5), 289. Supplementary materials are available online at http://www.mdpi.com/2220-9964/9/5/289/s1.

Abstract

Maps enable us to relate to spatial phenomena and events from viewpoints far beyond direct experience. By employing signs and symbols, maps communicate about near and distant geospatial phenomena, events, objects, or ideas. Besides acting as identifiers, map signs and symbols may, however, also connote. While most cartographic research has focused on the denoting character of visual variables, research from related disciplines stresses the importance of connotative qualities on affect, cognition, and behavior. Hence, this research focused on the connotative

meanings of map symbols by empirically assessing the affective qualities of point symbols. In three stimulus conditions of cartographic and non-cartographic contexts, affective responses towards a set of eight symbols were assessed by employing a semantic differential technique. The overall findings showed that abstract symbols connote affectively. The findings suggest two particular stimulus clusters of affective qualities that prevailed over all stimulus conditions, i.e., a cluster of asymmetric stimuli and a cluster of symmetric stimuli. Between the intersection of psychology, cartography, and semiotics, this paper outlines theoretical perspectives on cartographic semiotics, discusses empirical findings, and addresses implications for future research.

Introduction

As visual means of communication, maps allow sharing information, ideas, and thoughts and relate to spatial phenomena from a viewpoint beyond direct experience. Maps allow us to communicate and think about the near and the distant, about phenomena, events, and objects that "are not tied to the immediate present" (Krauss, 2002, p. 1). Likewise to any other form of communication, maps are *representations* of such near or distant phenomena but are not the phenomenon itself. As words describe or express, maps depict and express (Howard, 1980). Both words and maps may refer to a particular idea or phenomenon, yet they are not the idea or phenomenon itself (Petchenik, 1977).

When we look at maps, "we see symbols spread out on the space of a document, on paper or a computer screen", and we expect the symbols to be related to geospatial objects or phenomena (Eide, 2016, p. 21). By applying a mutually shared set of signs and semiotic rules, sheer unlimited, meaningful, novel messages about space and time can be communicated through maps. As such, maps are a means of "conceiving, articulating, and structuring the human world" (Harley, 2009/1988, p. 129).

The process of map-making is based on many decisions regarding which information to depict and how to depict it. In that sense, "there is nothing natural about a map. It's a cultural artifact, an accumulation of choices made among choices every one of which reveals a value: not the world, but a slice of a piece of the world; not nature but a slant on it; not innocent, but loaded with intentions and purposes; not directly, but through a glass; not straight, but mediated by words and other signs" (Wood, 2010, p. 78). Hence, maps are never neutral but based on a myriad of choices of *what* to communicate and *how* to communicate.

To this day, the cartographer faces the challenge, as well as the pleasure, of near-infinite variations of visual variables. Yet, which ones are most suitable for a given context, for a given type of spatial information, object, or phenomenon? The variety of methods available to represent information through maps allows for strikingly different results (Thompson et al., 2015). The choices of how we communicate spatial information will affect how people respond to it. In other words, cartographic design decisions will influence the perception and interpretation of maps (Monmonier, 1996). In as far as cartographic semiology provides a theoretical framework in geospatial communication by addressing the denoting qualities of visual variables (Bertin, 1974), it does not encompass their connotative effects on human affect, perception, and cognition.

Between the intersection of psychology, cartography, and semiotics, this research draws attention to the connotative, affective qualities of cartographic point symbols. Shapes are considered as core elements in visual communication over a wide range of disciplines (Arnheim, 1974; Bertin, 1974; Klee, 1920). In cartography, point symbols are used to depict and geo-reference spatiotemporal phenomena, objects, and events. To establish a profound theoretical reference for this research, this paper, first, outlines central semiotic traditions and perspectives on the dimensions and relations of signs (see Theoretical Background). This paper further discusses an empirical study conducted to examine and compare affective qualities of symmetric and asymmetric point symbols in cartographic and non-cartographic contexts (see Empirical Study and Results). Findings and implications for future research are discussed in detail in the sections Discussion and Conclusion.

Theoretical Background

Cartography as a science of human communication is concerned with establishing a mutually shared set of cartographic signs and semiotic rules. In the history of semiotics, two traditions have evolved which study communication either as dyadic or triadic processes. Both approaches emphasize that "the sign is more than its constituent sign vehicle" (Nöth, 1995, p. 79). Dyadic semiotic theorists, such as Saussure, consider the sign as a conceptual object, which consists of an expression (i.e., a *signifier*) and the concept the expression refers to (i.e., the *signified*) (for a synopsis see Nöth, 1995, p. 88). On the other hand, triadic models emphasize that "something is a sign only because it is interpreted as a sign of something by some interpreter" (Morris, 1938, p. 4). Triadic theorists, such as Plato, Aristotle, or later Morris and Peirce, emphasized three semiotic dimensions, i.e., the *sign-vehicle* which acts as a physical sign (i.e., expression or carrier of meaning, such as a sound, mark, or movement), the *referent* (i.e., the phenomenon or object of reference the sign-vehicle refers to), and the *interpretant* (i.e., the sign's effect on the interpreter, such as the meaning or concept the sign-vehicle refers to for the interpreter) (for a synopsis see Nöth, 1995, p. 90).

The perspective of semiotics as a two- or three-dimensional process enables theorists to consider communication through signs as a complex, interrelated process. Triadic models, for example, allow us to distinguish between three dyadic semiotic relations, i.e., those of *syntactics,* which Morris refers to as the rule-based relation between signs; *semantics*, which refers to the relation between sign-vehicle and referent; and *pragmatics*, which refers to the relation between sign-vehicle and interpretant or concept (Morris, 1946).

The triadic structure further prompts semioticians and cartographic theorists to consider the model's triangular relations, such as considering each of the three sign components as possible mediators of sign communication (MacEachren, 1995; Nöth, 1995). For an illustration, see Figure 7 in Chapter 3 of this dissertation.

- *The interpretant as mediator* in the semiotic triangle is regarded as a standard approach, stemming from "Aristotle's definition of words as signs of the soul, and the latter as likenesses of actual things"(Nöth, 1995, p. 89). In this understanding, sign-vehicle and referent are mediated by their interpretant (i.e., sense or meaning), either as a sign-vehicle–interpretant–referent relation or as a referent–interpretant–sign-vehicle relation, in which a thing (i.e., referent) may evoke an idea (i.e., interpretant), which creates a word or symbol (i.e., sign-vehicle) (see Figure 7a). Cartographic research on semiotics, which focuses on the interpretant as a mediator, emphasize the role of a mutually shared set of codes established between the cartographer and the percipient, by which a sign-vehicle is linked to its referents (MacEachren, 1995), such as by specifying the syntactic relationship between graphic variables and their referents (Bertin, 1974).
- From the perspective of *the referent as mediator* (see Figure 7b), the referent (e.g., object) "is a phenomenon of secondness, and the interpretant is one of thirdness" (Nöth, 1995, p. 89). From the perspective of the referent as a mediator, attention is drawn to the categorizations of referents, which cartographic sign-vehicles refer to (MacEachren, 1995), such as the differentiation of geographic versus nongeographic information, spatial versus spatiotemporal dimensionalities, discrete versus continuous phenomena.

- The third perspective considers *the sign-vehicle as mediator* (see Figure 7c), as a "link between thing and meaning" (MacEachren, 1995, p. 246), where something becomes a sign-vehicle of a referent when it gives rise to the idea or thought of that referent (Osgood et al., 1957). Nöth refers to this process as "meaning endowing act", where sense (i.e., the interpretant) leads to sign production (i.e., sign-vehicle), which refers to an object (i.e., referent) (Nöth, 1995, p. 90). Cartographic research may also refer to the sign-vehicle as a mediator, where something which is not the referent becomes a sign-vehicle of that referent (such as map symbols become sign-vehicles), and as such, mediating between referent and its associated concept or meaning (MacEachren, 1995). As mediators between things and meaning, sign-vehicles give rise to an idea or thought of a referent.

While both sign-vehicle and referent may be of a physical nature, meanings are mental events and difficult to clearly define (Nöth, 1995; Osgood et al., 1957). The measurement of meaning is, therefore, considered a challenging task. Morris, for example, did not include the concept of meaning in his semiotic theory due to its imprecision, proposing "to introduce special terms for the various factors which `meaning´ fails to discriminate"(Morris, 1946, p. 19).

Later, theorists have been attempting to decompose the "many meanings of 'meaning'"(Osgood et al., 1957, p. 2), often relating their findings to two core dimensions, i.e., the *dimension of sense* and *the dimension of reference* (for a terminological synopsis, see Nöth, 1995, p. 94). On the dimension of reference, all cartographic sign-vehicles, such as map symbols, can be considered as identifiers which either apprise, inform, state, designate, indicate, or label. Some map signs, however, may also have a stimulating character, may prescribe, express, or connote (Keates, 1996; MacEachren, 1995). These qualities refer to the dimension of sense. The two dimensions or functions of sign-vehicles may also be regarded as representational versus expressive (Keates, 1996; Morris, 1946), as apprising versus stimulating (Wood, 2010), as denotative versus connotative (Nöth, 1995).

Most cartographic semiotic research on sign-vehicles has focused on the denoting qualities of map signs, attempting to specify explicit properties and attributes to identify optimal characteristics of sign-vehicles (such as symbol size, color hue, etc.) (MacEachren, 1995; Wood, 2010). Yet, map signs may not only depict and denote but also express and connote (Howard, 1980). These connotative qualities can be as powerful as to modulate affective responses and cognitive processes, such as influencing learning, memory, attention, and decision-making, as related research shows (Barrett & Bliss-Moreau, 2009; Loftus & Palmer, 1974; Sianipar et al., 2016).

In the 1950s, the psychologists Osgood et al. (1957) developed the *Semantic Differential* to measure such connotative qualities. The semantic differential technique is based on the premise that any concept (be it a painting, a person, a word, an abstraction, etc.) can be defined or described by its connotative meaning. The technique combines association and scaling procedures, designed to "give an objective measure of the connotative meaning of concepts" (Osgood & Luria, 1954, p. 579). It is based on the attempt to subject meaning to quantitative measurement and allows comparing different stimuli in the same semantic space. Factor analysis usually reveals two or three semantic dimensions of connotative meaning, i.e., *valence (evaluation)*, *arousal (activity)*, and, at times, *dominance (potency)* (Bakker et al., 2014; Barrett & Bliss-Moreau, 2009; Espe, 1985; Mehrabian & Russell, 1974; Osgood et al., 1957; Russell, 1980). It is assumed that whenever humans perceive themselves, other persons, events, or any attitude object, the most relevant discriminations are made in terms of these two or three *affective dimensions*.

As such, affect is considered a psychological primitive (Barrett & Bliss-Moreau, 2009; Wunth, 1902), with some affective response always present within a person (Russell, 2003). Affect can be neutral, moderate, or extreme (Russell, 2003). When affect is moderate or extreme, it can be consciously experienced as pleasant or unpleasant and form the basis of an emotional experience (Feldman Barrett et al., 2007; Russell, 2003). When affect is neutral, it influences conscious experience and behavior more mildly and is rather experienced as *affective qualities*, i.e., as attributes or properties in the surroundings, of stimuli, objects, or events (Bakker et al., 2014; Russell, 1980). Affective qualities are commonly described by affect-denoting adjectives such as pleasant, unpleasant, exciting, boring, safe, upsetting, soothing, etc. Likewise, to human communication, where one cannot communicate without expressing some level of affective state (Barrett & Bliss-Moreau, 2009), objects and events all imbue affective qualities (Russell, 2003). Perceiving and evaluating the affective qualities of the human environment and the stimuli therein can, therefore, be considered a fundamental aspect of human information processing (Russell, 2003) which has "psychological consequences that reach far beyond the boundaries of emotion", influencing decision-making and human behavior (Barrett & Bliss-Moreau, 2009, p. 167).

Recent approaches in cartography have started to emphasize the role of affect in respect to maps (Griffin & McQuoid, 2012). While some attempts aim to represent affective responses of people by means of maps (Nold, 2009), other approaches use maps as a means to collect people's affective responses in different environments (Huang et al., 2014; Klettner et al., 2013). The third strand of affect research in cartography draws attention to the role of maps as triggers of affective responses. The latter attempt strives to disclose how cartographic design, in other words, *the map as a sign-vehicle*, will influence affective responses and related judgments. Recent research strongly supports this notion. Empirical studies show that a change in aesthetic map style (Christophe & Hoarau, 2013; Fabrikant et al., 2012) or visual rhetoric style (Muehlenhaus, 2012, 2013a) will influence people's affective and cognitive judgments, trust, and recall. Research, which systematically studied map symbolization, further suggests that altering particular cartographic variables, such as line symbols or point symbols, will affect map preferences and people's accuracy of judgments (Jenny et al., 2018) as well as influencing detection speed in visual search tasks (Stachoň et al., 2018).

Another crucial factor in visual communication is to accord the map symbol with the information it aims to represent. Research stresses that, besides the variety of means to visualize geospatial information, only a few of those are suitable and effective for a given content and lead to accurate judgments about the depicted phenomenon (Cheong et al., 2016; Kinkeldey et al., 2014; MacEachren et al., 2012; Padilla et al., 2017). Supposedly simple changes in the style of sign-vehicles can lead to substantially different connotations (Chandler, 2007).

Empirical research on the connotative meaning of map signs is, yet, still scarce. Semiotic differentiations are often neglected in cartographic research and applications of semiotics. Keates (1996) stresses that "despite a large number of papers dealing with communication in cartography, relatively few have pursued in detail the analysis of map symbols, and the relationships between map symbols and semiotic theory" (p. 179). Consequently, "the difference of what a map sign means and what it represents has become blurred" (MacEachren, 1995, p. 245). There remains a need for a differentiated understanding of how visual variables can be used to encode information (MacEachren et al., 2012). This research, therefore, draws attention to the connotative qualities of map signs and, in particular, to their role as *cartographic sign-vehicles as mediators of affective responses*.

Empirical Study

Materials and Study Design

This empirical study aimed to reveal the connotative, affective qualities of abstract point symbols in cartographic and non-cartographic conditions. For this, a set of eight achromatic point symbols was created, which composed of six symmetric shapes (i.e., circle, triangle pointing upwards, triangle pointing downwards, square, rhombus, star) and two asymmetric star shapes. Geometric shapes were systematically created by increasing their complexity, i.e., by increasing the number of vertices of an initial point shape. As such an approach could result in an infinite number of shape variations, the number of stimuli was limited to a set of six commonly used symmetric shapes (Arnheim, 1974; Bertin, 1974). Also, two asymmetric star shapes were incorporated in the stimulus set, as related literature indicated particular perceptual qualities of asymmetric shapes (Treisman & Gormican, 1988). The final set of eight shapes was used in three different stimulus sets, i.e., shape stimulus set, map stimulus set 1, and map stimulus set 2 (see Figure 14):

- **Shape stimulus set:** The shape stimulus set comprised the basic eight achromatic point symbols. The stimuli were presented in black on a light-grey background at a size of 300 x 300 pixels embedded in an online survey. Each shape was displayed successively in a randomized order.
- **Map stimulus set 1:** In map stimulus set 1, the eight basic point symbols were set in a cartographic context. Each shape was depicted on a basemap in greyscale. Each map presented one symbol at the exact same location on each map to control for confounding influences. Maps were presented as part of an online survey, at a size of 500 x 377 pixels, displayed successively, and in a randomized order.
- **Map stimulus set 2:** In map stimulus set 2, the set of point symbols were again presented on basemaps in greyscale. Yet, each map presented one symbol type on several positions on the map, i.e., at exact eight positions. The maps were, again, embedded in an online survey, and presented successively, in a randomized order, at a size of 500 x 384 pixels.

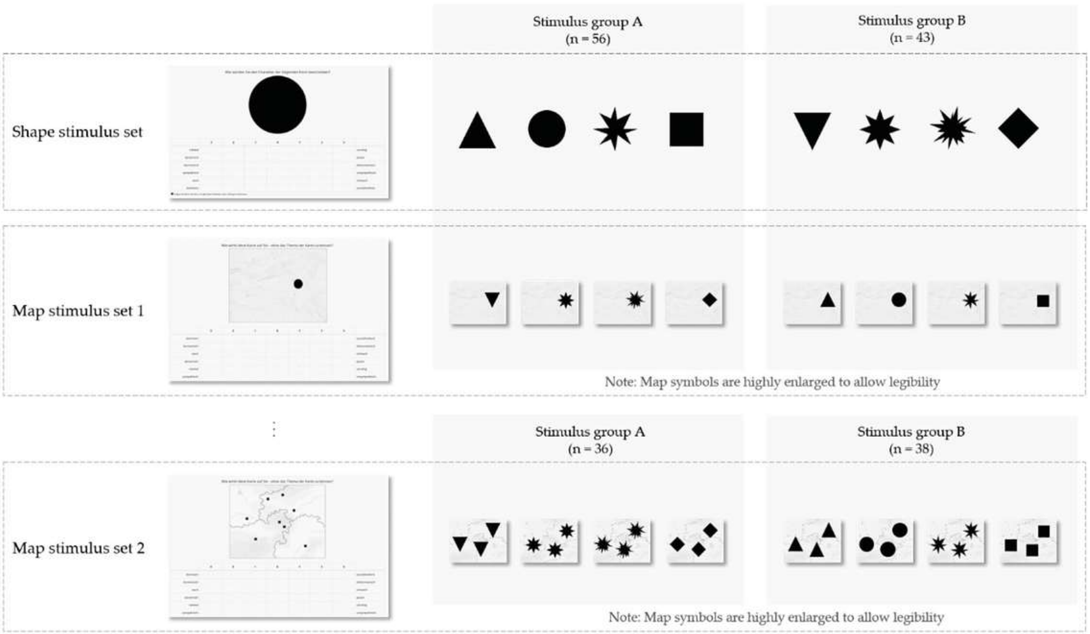


Figure 14. Study design and the three stimulus sets. Screenshots of the survey are shown to the left, illustrating the stimulus materials used in the surveys. Shape and map stimuli used in the study are displayed to the right, according to the two stimulus groups (A and B). Note that map symbols depicted to the right are highly enlarged to enhance legibility.

Affective responses towards the three stimulus sets were collected in two online surveys. Both surveys were carried out in German by using the software LimeSurvey (LimeSurvey GmbH, 2019). The first online questionnaire included the shape stimulus set and map stimulus set 1. The follow-up survey assessed the affective qualities of map stimulus set 2. For all three stimulus sets, a mixed design approach was applied, which randomly assigned participants to one of two stimulus groups (see Figure 14). This approach aimed to minimize learning and response transfer across the stimulus conditions.

A semantic differential technique was employed to assess the stimulus materials' affective qualities in both online surveys. The semantic differential technique uses a dimensional approach to extract the connotative dimensions of simple stimuli to complex concepts. It uses bipolar adjective pairs (e.g., good – bad, weak – strong, active – passive) and rating scales to reveal the stimuli's or concepts' semantic space.

The semantic differential items, in this research, comprised six pairs of bipolar adjective items and were presented on a 7-point Likert scale, ranging from -3 to +3. Items were selected deductively, with reference to the three possible dimensions of affective experiences suggested by the literature, i.e., valence, dominance, and arousal (Bakker et al., 2014; Osgood et al., 1957). For each of the three dimensions, two bipolar items were selected, based on items with high factor loadings, again, as indicated by literature (Barrett & Bliss-Moreau, 2009; Osgood et al., 1957; Russell & Pratt, 1980). The final selection of six bipolar items was translated into German by considering the verbatim expressions revealed in a related qualitative empirical study on shape qualities (Klettner, 2019). Table 2 shows the final set of bipolar adjective pairs in German used in the final questionnaires and translated to English.

Table 2. German semantic differential items used in this study and translated into English.

Bipolar items	Bipolar items in the German original
unappealing – appealing	*unsympatisch – sympathisch*
disharmonic – harmonic	*disharmonisch – harmonisch*
unobtrusive – dominant	*zurückhaltend – dominant*
weak – strong	*schwach – stark*
calm – agitated	*ruhend – unruhig*
passive – dynamic	*passiv – dynamisch*

The questionnaires started by introducing the aims of the study. Participants were instructed to conduct the survey on a device in laptop- or desktop-size. In the next step, participants were randomly assigned to one of the two groups and proceeded with the questionnaire's main task of evaluating each stimulus towards the six bipolar semantic differential items. Each stimulus was presented individually and consecutively in a randomized order. Sociodemographic data were gathered at the end of the survey regarding the participants' affinity for graphic design (self-evaluation on a unipolar 4-point rating scale, from "not at all" to "very affine", with the additional option for "no answer"), an affinity for maps or cartography (unipolar 4-point rating scale, from "not at all" to "very affine", or "no answer"), age, and gender.

Participants

Bachelor's students of Regional Planning were recruited from a course on "Thematic Cartography in Regional Planning" held in winter term 2019/2020 at TU Wien – Vienna University of Technology, Austria. Students participated voluntarily and received course credits in the form of bonus points, which counted towards their final grades. The first questionnaire was sent to students in December 2019, which collected participants' affective responses towards the set of eight shape stimuli and map stimulus set 1. The follow-up survey was sent to the same pool of students in January 2020 to follow-up with assessing the affective qualities of map stimulus set 2.

In total, 100 Bachelor's students completed the first online survey. Since the study was optimized for larger screen devices, such as desktop PCs, laptops, or tablets, one participant who had used a smartphone device was excluded from the final sample. Hence, responses from 99 participants were used for further data analysis (41 males, 57 females, one person of diverse gender). 94 participants indicated their age (mean age = 22.00 years, *SD* = 3.24, *Min* = 18, *Max* = 35). Participants primarily used laptops (85.9%) to complete the questionnaire, followed by desktop PCs (10.1%) and tablets (4.0%). The majority of participants stated their affinity for graphic design to be moderate to high (somewhat affine = 41.1%; quite affine = 31.6%; very affine = 26.3%), while one person reported having no interest in graphic design. The participants' affinity for cartographic design showed moderate in most cases (somewhat affine = 32.6%; quite affine = 56.8%) and high in 10.5% of the cases. In the survey, participants were randomly assigned to one of two stimulus groups, resulting in 56 participants assigned to stimulus group A and 43 individuals assigned to stimulus group B.

The follow-up survey was completed by 77 students of Regional Planning. Three students used smartphones for completing the questionnaire and were, therefore, not included for analysis. Hence, affective responses from 74 participants were taken into account, which primarily used laptops (78.4%), followed by desktop PCs (14.9%), and tablets (6.8%). Age was reported by 65 individuals (mean age = 22.43 years, *SD* = 3.46, *Min* = 19, *Max* = 35). Gender was indicated by 71 participants (33 males, 37 females, one person of diverse gender). The majority of participants stated their affinity for graphic design to be moderate to high (somewhat affine = 36.5%; quite affine = 45.9%; very affine = 16.2%), while one person reported having no interest in graphic design. The participants' affinity for cartographic design, showed to be moderate to high (somewhat affine = 40.5%; quite affine = 48.6%; very affine = 10.8%). Again, a mixed design was applied, randomly assigning 36 participants to stimulus group A and 38 individuals to stimulus group B.

Results

Affective responses towards three stimulus sets were collected through semantic differential scales, resulting in affect ratings from -3 to +3 for each stimulus. Based on these affect ratings, statistical analyses were performed within each stimulus set and between the three stimulus sets, using the statistical software package SPSS (IBM, 2017) and XLStat addon for Microsoft Excel (Addinsoft, 2020).

Semantic Differential - Factor Analysis

To first assess the latent, underlying dimensions tested by the semantic differential items employed, a Principal Component Analysis (PCA) with orthogonal rotation (Varimax) was conducted. The Kaiser-Meyer-Olkin measure verified the sampling adequacy for the analysis, KMO = .69, and all KMO values for individual items > .62, which is well above the limit of 0.5 as recommended by Field (2009). Bartlett's test of sphericity χ^2 (15) = 2786.85, $p < .001$, indicated that correlations between items were sufficiently large for PCA. An initial analysis was run to obtain eigenvalues for each component in the data. Two components show eigenvalues over Kaiser's criterion of 1 and together explain 74.72% of the variance (see Supplementary Materials Table S1, Table S2, and Figure S1 for details).

As suggested by the results of the PCA, the six bipolar semantic differential items refer to two independent components:

1. Component 1 loaded high on the following bipolar items: harmonic – disharmonic, appealing – unappealing, and calm – agitated. Component 1 will, therefore, be labeled as the affective dimension of valence.
2. Component 2 loaded high on the items: weak – strong, unobtrusive – dominant, and passive – dynamic. Component 1 will be labeled as the affective dimension of dominance.

Based on the PCA result, the six bipolar items' ratings were assigned and aggregated according to the two affective dimensions of valence and dominance. Those two dimensions were used as the basis for further analyses.

Affective Differentiation – Within-Group Analysis

To assess the stimuli's underlying affective qualities, valence and dominance ratings were compared for each stimulus. First, descriptive statistics were computed for each stimulus set (see Supplementary Materials Tables S3, Table S4, Table S5). Next, for each of the three stimulus sets, a frequency table was generated. Each cell represents the counts of the participants' ratings from -3 to +3 for each stimulus (see Supplementary Materials Table S6, Table S7, and Table S8). Figure 15 visualizes the rating frequencies by the percentage of ratings from -3 to +3 according to valence and dominance for each stimulus and stimulus set.

In general, stimuli rated negatively on the dimension of valence (i.e., ratings of -3, -2, -1) suggest qualities of dislike, disharmony, and agitation, with -3 indicating high levels of negative valence. Positive valence (i.e., ratings of +3, +2, +1), on the other hand, indicates qualities of appeal, harmony, and calmness, with +3 showing high levels of positive valence. Stimuli rated negatively on the dimension of dominance (i.e., ratings of -3, -2, -1) imply low dominance and relate to the qualities of unobtrusiveness, weakness, passiveness. Positive dominance (i.e., ratings of +3, +2, +1) comprise high levels of dominance, strength, and dynamics.

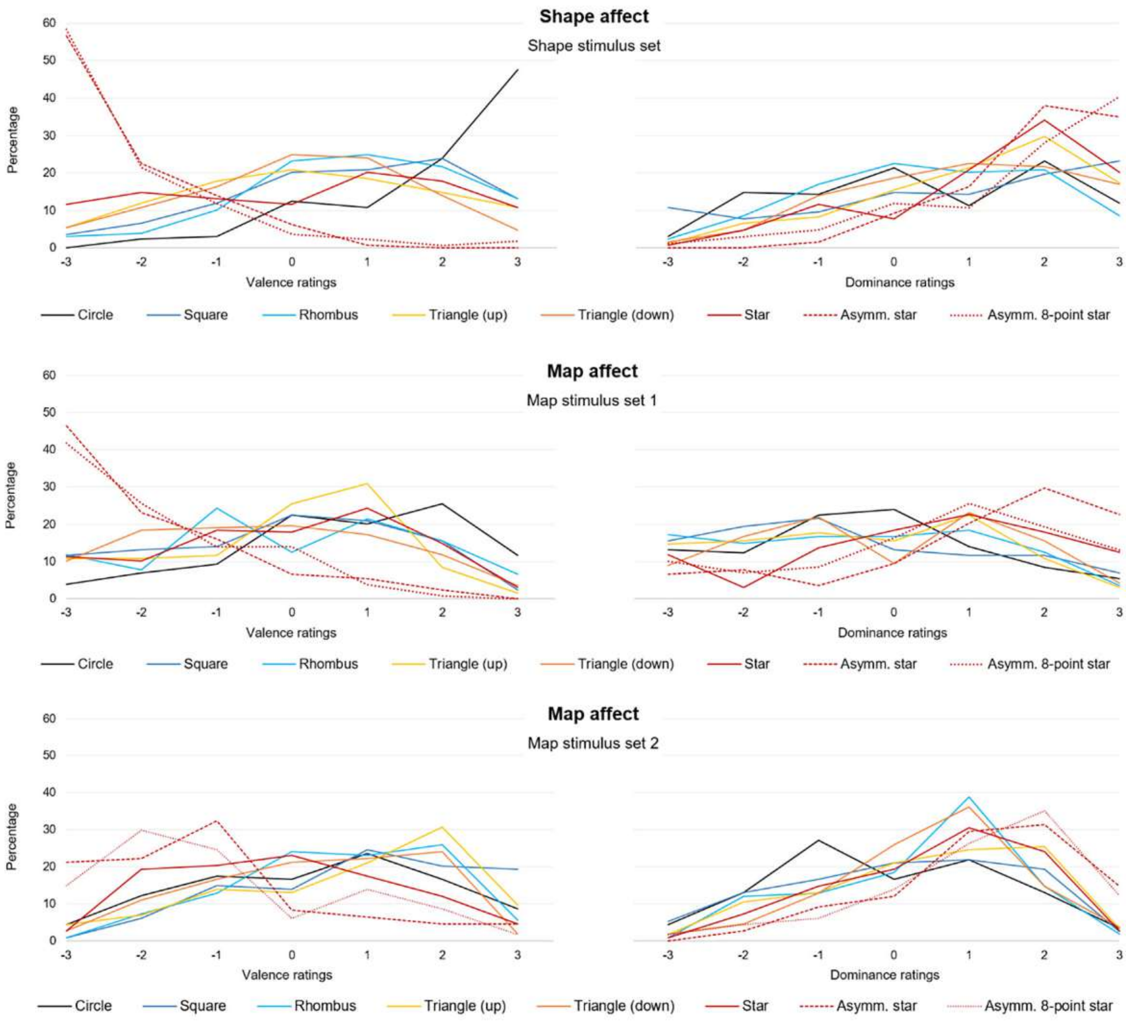


Figure 15. Affect ratings of eight shape stimuli in three stimulus conditions (shape stimulus set 1, map stimulus set 1, and map stimulus set 2). Results are illustrated for valence (left) and dominance (right). Affect ratings range from negative (-3) to positive (+3) valence and to low (-3) to high (+3) dominance (see x-axes). The number of ratings are shown on the y-axes.

To statistically test for differences between the stimuli, multiple pairwise comparisons were performed for each stimulus set. First, each stimulus set's valence and dominance ratings were subjected to a Durbin and Skillings-Mack procedure for nonparametric data. The Durbin and Skillings-Mack test can be considered an extension of the Friedman test, which applies a block design and compares paired samples of unequal size (Chatfield & Mander, 2009). Next, to test for significant differences in greater detail, the data were subjected to a Conover-Iman procedure, which performs multiple pairwise comparisons (Conover & Iman, 1979). Results are reported for each stimulus set in the following sections.

Shape Stimulus Set

Within the shape stimulus set, Durbin and Skillings-Mack revealed high significant differences between the eight shape stimuli on both affective dimensions of valence ($Q(7) = 444.90$, $p < 0.001$) and dominance ($Q(7) = 100.98$, $p < 0.001$) at a significance level $\alpha = 0.05$. A Conover-Iman test was applied to follow up on this finding. A Bonferroni correction set the significance level at $\alpha = 0.0018$, and significant differences of pairwise comparisons were interpreted accordingly (for detailed statistics, see Supplementary Material Table S9).

As a result, the Conover-Iman test suggests five groups of different valence qualities within the shape stimulus set (Table 3). Among those five groups, the circular shape (group A) and the two asymmetric stars (group E) appear to form two distinct groups. This result is supported by Figure 15, which illustrates a high number of high positive valence ratings for the circular shape stimulus and a high number of high negative valence ratings for both asymmetric star stimuli. Three additional valence groups were identified, which comprise symmetric polygonal shapes (groups B, C, and D). Table 3 further reveals several overlaps between these three groups, suggesting groups B, C, and D share similar valence qualities.

For the affective dimension of dominance, Conover-Iman's multiple pairwise comparisons revealed four groups (Table 3). The two asymmetric star stimuli showed high positive dominance (i.e., rated as highly dominant, strong, and dynamic). Yet, none of the four groups show distinct enough dominance qualities to be considered independent (see Figure 15).

Table 3. Results of multiple pairwise comparisons of shape stimuli indicating groups of similar valence and dominance.

Stimulus	Frequency	Sum of ranks	Mean of ranks	Groups (Valence)				
Circle	168	155604.50	926.22	● A				
Rhombus	129	94532.50	732.81		◆ B			
Square	168	120860.00	719.40		■ B	■ C		
Triangle (up)	168	106916.00	636.40			▲ C	▲ D	
Star	129	79942.50	619.71				✷ D	
Triangle (down)	129	79567.50	616.80				▼ D	
Asymm. 8-point star	168	39855.50	237.24					✷ E
Asymm. star	129	28987.50	224.71					✷ E
Stimulus	**Frequency**	**Sum of ranks**	**Mean of ranks**	**Groups (Dominance)**				
Asymm. 8-point star	129	100290.00	777.44	✷ A				
Asymm. star	168	125539.00	747.26	✷ A	✷ B			
Star	129	81415.50	631.13		✷ B	✷ C		
Triangle (up)	168	99149.50	590.18			▲ C		
Triangle (down)	129	70898.50	549.60			▼ C	▼ D	
Square	168	90942.00	541.32			■ C	■ D	
Circle	168	78421.50	466.79				● D	
Rhombus	129	59610.00	462.09				◆ D	

Map Stimulus Set 1

For map stimulus set 1, Durbin and Skillings-Mack showed high significant differences between the eight stimuli on both affective dimensions (valence: $Q(7) = 235.73$, $p < 0.001$; dominance: $Q(7) = 111.66$, $p < 0.001$) at $\alpha = 0.05$. A Conover-Iman test was applied again to follow up on this finding. A Bonferroni correction set the significance level at $\alpha = 0.0018$ (for detailed statistics see Supplementary Material Table S10).

Results suggest three groups of significantly different valence qualities (see Table 4). Group A refers to the map stimulus that depicted a circle, with the highest positive valence ratings of all maps in this stimulus set. Group B comprises symmetric polygons with moderate valence ratings. Group C refers to the two asymmetric stars that revealed the highest number of negative valence ratings (i.e., unappealing, disharmonic, agitated) (see Figure 15).

For the affective dimension of dominance, Conover-Iman suggests four groups of overlapping qualities. While the two maps depicting asymmetric symbols indicate the highest dominance, none of the four groups revealed distinct enough ratings to be considered a unique affect group (see Table 4 and Figure 15).

Table 4. Results of multiple pairwise comparisons of map stimulus set 1 indicating groups of similar valence and dominance.

Stimulus	Frequency	Sum of ranks	Mean of ranks	Groups (Valence)			
Circle	129	105739.00	819.68	● A			
Rhombus	168	114192.50	679.72		◆ B		
Star	168	113034.00	672.82		✷ B		
Triangle (up)	129	86270.50	668.76		▲ B		
Square	129	85176.50	660.28		■ B		
Triangle (down)	168	104689.00	623.15		▼ B		
Asymm. 8-point star	129	43106.50	334.16			✷ C	
Asymm. star	168	54058.00	321.77			✷ C	
Stimulus	**Frequency**	**Sum of ranks**	**Mean of ranks**	**Groups (Dominance)**			
Asymm. star	168	133241.50	793.10	✷ A			
Asymm. 8-point star	129	88048.50	682.55	✷ A	✷ B		
Star	168	111135.50	661.52		✷ B	✷ C	
Triangle (down)	168	93561.50	556.91			▼ C	▼ D
Triangle (up)	129	66187.50	513.08				▲ D
Circle	129	65608.50	508.59				● D
Rhombus	168	85052.00	506.26				◆ D
Square	129	63431.00	491.71				■ D

Note: Map symbols are depicted highly enlarged to allow legibility.

Map Stimulus Set 2

Also for map stimulus set 2, Durbin and Skillings-Mack revealed high significant differences between the eight map stimuli on both dimensions of valence ($Q(7) = 98.64$, $p < 0.001$) and dominance ($Q(7) = 45.64$, $p < 0.001$). A Conover-Iman test was, therefore, again applied to analyze the finding in more detail. A Bonferroni correction set the significance level at α = 0.0018, and pairwise comparisons were interpreted accordingly (for detailed statistics, see Supplementary Material Table S11).

For the affect dimension of valence, Conover–Iman revealed three groups within map stimulus set 2 (see Table 5). Among these groups, however, only group C, which comprises the two maps depicting asymmetric stars, suggests forming a distinct affect group, characterized by negative valence (i.e., unappealing, disharmonic, agitated). Both other groups, A and B, revealed overlaps, suggesting somewhat similar valence.

Conover-Iman revealed three groups for the affect dimension of dominance. Again, the two maps depicting asymmetric stars showed the highest positive dominance (i.e., rated as the most dominant, strong, and dynamic). Group B and C showed lower dominance ratings. As the groups largely overlap, they suggest sharing similar qualities (see also Figure 15).

Table 5. Results of multiple pairwise comparisons of map stimulus set 2 indicating groups of similar valence and dominance.

Stimulus	Frequency	Sum of ranks	Mean of ranks	Groups (Valence)		
Square	114	64620.50	566.85	A		
Triangle (up)	114	61362.00	538.26	A		
Rhombus	108	56467.00	522.84	A		
Triangle (down)	108	51321.00	475.19	A	B	
Circle	114	53840.50	472.29	A	B	
Star	108	44328.00	410.44		B	
Asymm. 8-point star	114	33732.00	295.89			C
Asymm. star	108	29045.00	268.94			C
Stimulus	**Frequency**	**Sum of ranks**	**Mean of ranks**	**Groups (Dominance)**		
Asymm. star	108	61100.50	565.75	A		
Asymm. 8-point star	114	63355.00	555.75	A		
Star	108	48153.00	445.86		B	
Triangle (up)	114	49661.00	435.62		B	C
Triangle (down)	108	46351.00	429.18		B	C
Rhombus	108	44182.50	409.10		B	C
Square	114	42927.00	376.55		B	C
Circle	114	38986.00	341.98			C

Note: Map symbols are depicted highly enlarged to allow legibility.

Affective Differentiation – Between-Group Analysis

To further explore whether affective shape qualities persist over the three different stimulus conditions (i.e., with and without cartographic context), stimulus-triplets were compared. A stimulus-triplet comprises those three stimuli that depicted the same shape type across the three stimulus conditions (e.g., circle presented in the shape stimulus set, in map stimulus set 1, and in map stimulus set 2). Figure 16 contrasts the affective profiles of each stimulus-triplets graphically, concerning their valence and dominance qualities.

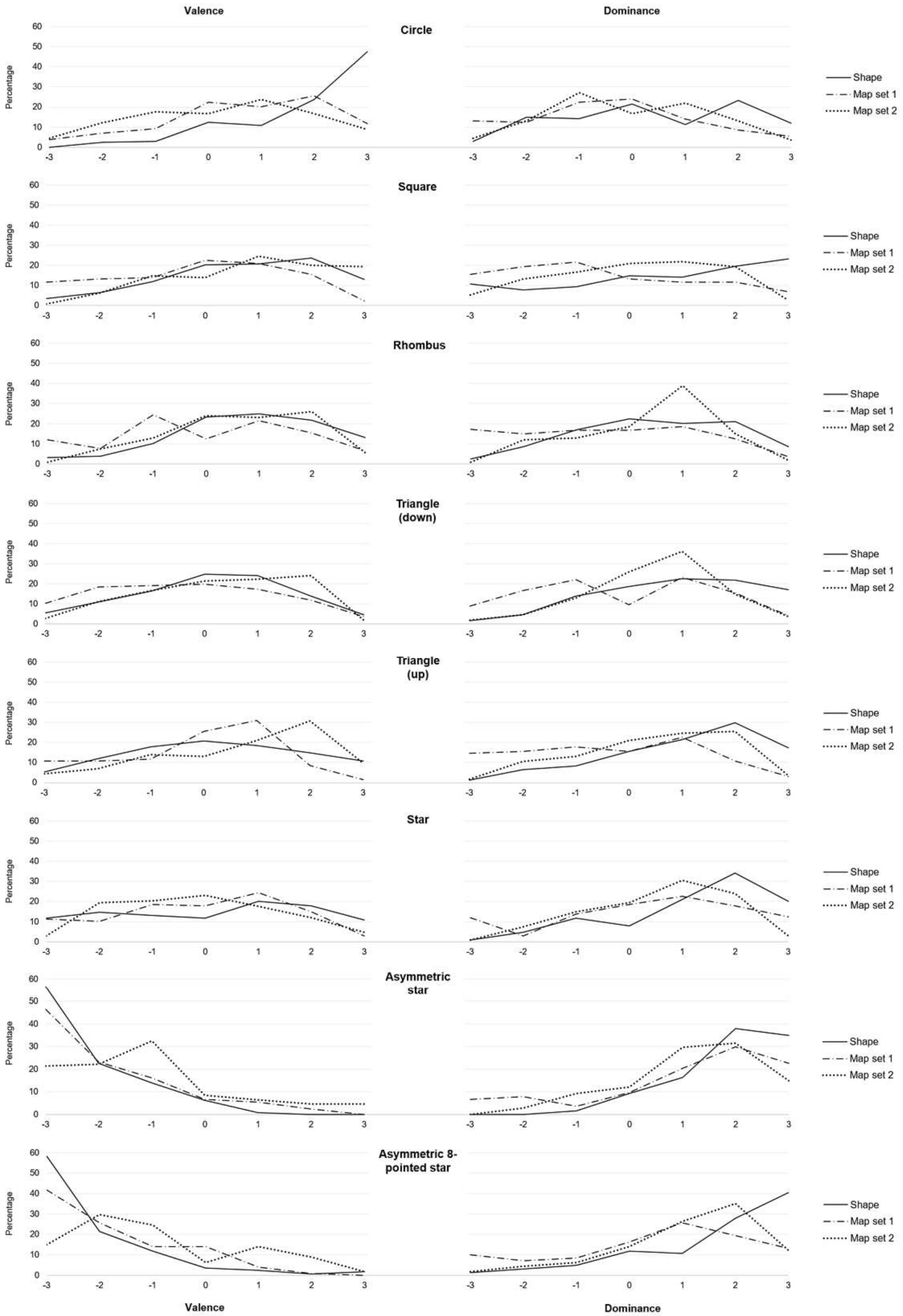


Figure 16. Eight stimulus triplets in comparison. Valence ratings (left) and dominance ratings (right).

To statistically analyze the differences between the stimuli of each triplet, distance scores (*D* scores) were computed, as suggested by Osgood et al. (1957). Each stimulus-triplet was pairwise compared. A distance measure of $D = \sqrt{(x_1 - x_2)^2}$ was applied as proposed by Heise (1970), where x_1 refers to the mean score of stimulus 1 and x_2 to the mean score of stimulus 2 of each stimulus pairing within each triplet. By pairwise comparing the stimuli of each triplet, three *D* scores for each stimulus-triplet are derived (see Table 6). *D* scores were computed separately for the two affect dimensions of valence and dominance. Results are summarized in Table 6, revealing detailed distances for each pair in each stimulus-triplet. Higher scores indicate greater dissimilarity and lower scores greater similarities between the stimuli's affective qualities.

Results show that the star-triplet, in particular, leads to the lowest *D* scores, thus, to highly similar affective ratings on the dimension of valence, in all three stimulus conditions. This finding is also supported by a Kruskal-Wallis analysis for nonparametric data, which found no significant difference between the star stimuli in the three conditions ($H(2) = 1.653$, $p = 0.44$). In all other cases, Kruskal-Wallis indicates a statistical significance of $p < 0.002$ or lower on both affective dimensions of valence and dominance (see Table 6 for detailed distance scores for each stimulus-triplet).

Table 6. Distance scores of each stimulus-triplet pairwise compared. Lower scores indicate lower distances (i.e., greater similarity), while higher scores suggest greater dissimilarity.

	Triangle (up)	Triangle (down)	Circle	Star	Square	Rhomb	Asymm. star	Asymm. 8-pt star
Valence:								
Shape – Map ss	0.36	0.46	1.22	0.20	0.88	0.84	0.36	0.36
Map ss – Map ms	0.83	0.63	0.43	0.03	1.09	0.65	0.81	0.93
Map ms – Shape	0.48	0.17	1.65	0.23	0.21	0.20	1.17	1.29
Dominance:								
Shape – Map ss	1.47	1.05	0.80	0.86	1.17	0.91	0.86	1.23
Map ss – Map ms	0.86	0.65	0.32	0.14	0.61	0.78	0.13	0.62
Map ms – Shape	0.61	0.40	0.48	0.72	0.56	0.12	0.73	0.61

Note: "Shape" refers to stimuli from the shape stimulus set, "Maps ss" refers to stimuli from map stimulus set 1 (i.e., maps depicting a single shape), and "Maps ms" refers to stimuli from map stimulus set 2 (i.e., maps depicting multiple shapes).

Multidimensional Scaling

In the final step of the analysis, multidimensional scaling (MDS) was applied to reduce the data sets' complexity and permit a visual appreciation of the stimuli's overall underlying relational structures and proximities. By quantifying distances between stimuli, MDS reveals a dimensional space, wherein similar stimuli are located proximal to each other and dissimilar ones proportionately farther apart (Hout et al., 2013). Thus, for each of the three stimulus conditions, proximities between the individual stimuli were calculated based on the frequency tables composed previously. The frequency tables were subjected to a PROXSCAL scaling algorithm.

Figure 17 visualizes the result, illustrating the stimuli's relational structure by stimulus set (see Supplementary Material Tables S12 for the coordinates of each stimulus by stimulus set). In the two-dimensional space revealed, similar stimuli are located proximal and dissimilar ones located distantly. MDS suggests two distinct stimulus clusters between all three stimulus conditions, i.e., one cluster of symmetric stimuli and one cluster of those stimuli depicting asymmetric star shapes. Hence, despite different cartographic and non-cartographic contexts, the overall relational structure between symmetric and asymmetric stimuli was found to prevail.

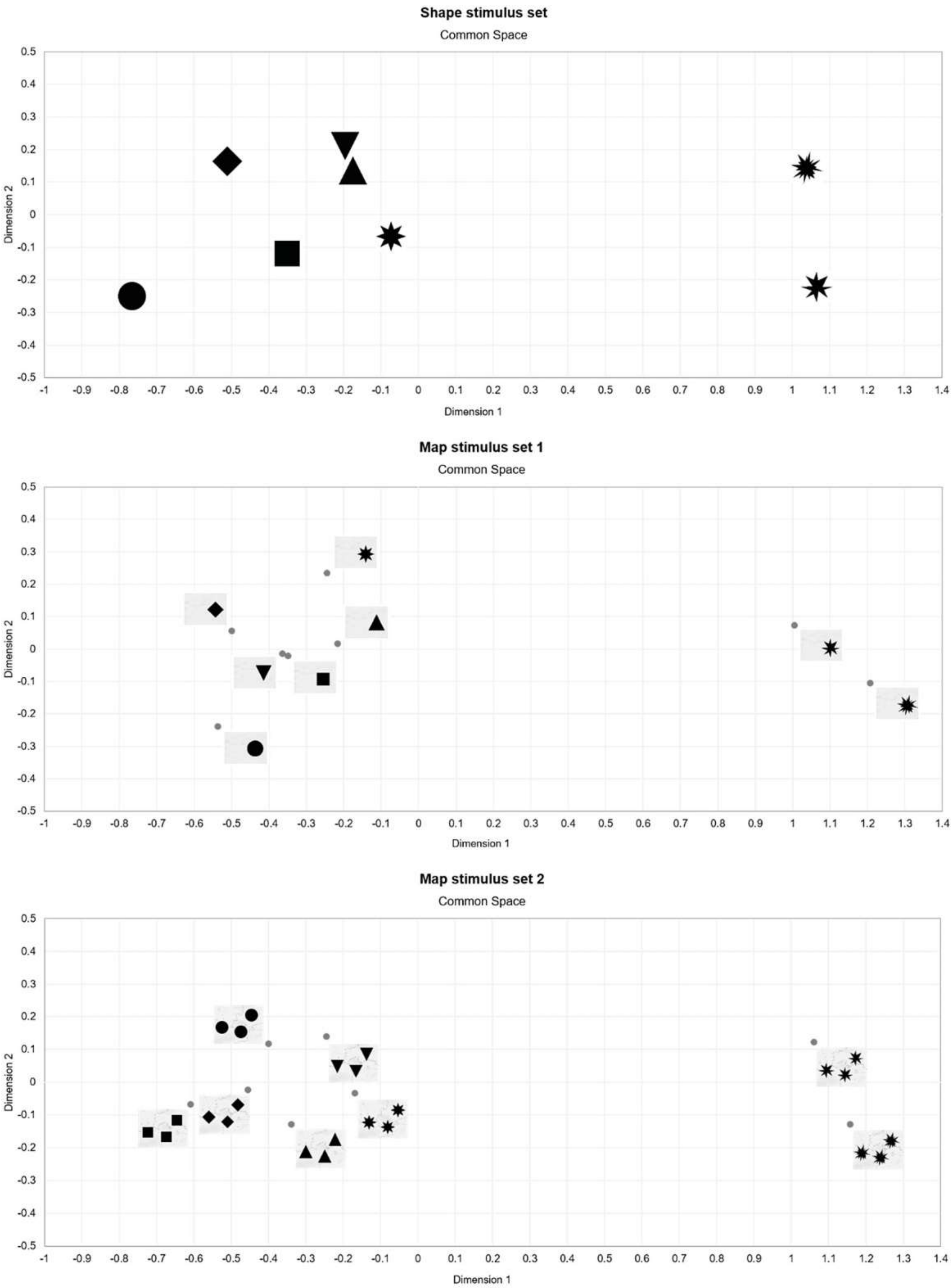


Figure 17. Two-dimensional configuration based on MDS, indicating the proximities between the eight stimuli within each stimulus set.

Discussion

While map signs can be considered identifiers that denote and inform about spatial phenomena, related research stresses that signs also imbue connotative qualities that modulate cognitive processes (Feldman Barrett et al., 2007; Loftus & Palmer, 1974; Sianipar et al., 2016). Semiotic research in cartography has been so far concerned with the denoting qualities of map signs by considering human perception and cognition to specify characteristics and attributes of visual variables (such as symbols size, color hue, etc.). Connotative qualities have, yet, largely been disregarded in cartographic research.

This research, thus, focused on the connotative meanings of point symbols by assessing their affective qualities. Eight stimuli varying by shape were presented in three stimulus conditions of non-cartographic and cartographic contexts. A semantic differential technique was applied to reveal and compare the symbols' affective qualities within and between the three stimulus conditions.

This empirical study used a deductive approach to decide on the number of affective dimensions and the items to employ in the Semantic Differential. Literature indicates two to three affective dimensions, i.e., valence, arousal, and – at times – dominance (Bakker et al., 2014; Barrett & Bliss-Moreau, 2009; Espe, 1985; Mehrabian & Russell, 1974; Osgood et al., 1957; Russell, 1980). Hence, two bipolar items for each of the three affective dimensions were selected. Based on these questionnaire items, a principal component analysis was conducted to confirm, respectively reveal, the number of underlying dimensions tested by the Semantic Differential. The principal component analysis extracted two factors. Factor 1 comprised the bipolar items harmonic – disharmonic, appealing – unappealing, calm – agitated. Factor 2 comprised of the item-pairs weak – strong, unobtrusive – dominant, passive – dynamic. Hence, based on each factor's bipolar items, factor 1 was labeled as *valence,* and factor 2 was labeled as *dominance*.

Such a two-factor solution corresponds with the latest affect research, which emphasizes a two-dimensionality of affect (Barrett & Bliss-Moreau, 2009; Feldman Barrett et al., 2007). Yet, while a two-factor solution corresponds with the latest findings in affect and emotion research, literature moreover suggests *valence* and *arousal* as the two core components of affect. Valence usually refers to evaluative qualities, such as positive, negative, pleasant, unpleasant, appealing, unappealing, etc. Arousal refers to qualities of activation, respectively, stillness. However, in this research, the bipolar item calm – agitated loaded high on the dimension of valence, together with the item-pairs harmonic – disharmonic and appealing – unappealing. Given that this empirical study was conducted in the German language, this unexpected item-loading may indicate cross-cultural and linguistic differences. In the German questionnaire, the item-pair *calm – agitated* translated to “*ruhend*” – “*unruhig*”. The German term “*ruhend*” refers to dormant, static, and stationary qualities, while the term “*unruhig*” refers to qualities such as restless, restive, unquiet, agitated. The findings suggest that the German item-pair may imbue more evaluative valence qualities than their English counterparts. This finding, together with results from related affect and emotion research (Russell et al., 1989; Sianipar et al., 2016), may imply the need for more language-sensitive and culture-sensitive approaches in affect research also in the field of cartography.

Based on the two factors extracted, statistical analyses within and between the three stimulus sets were performed. The overall findings strongly suggest two distinct stimuli clusters of particular affective qualities that prevailed over all three stimulus conditions, i.e., a cluster of asymmetric stimuli and a cluster of symmetric, geometric stimuli. In each of the three stimulus conditions, asymmetric stars scored highly negative on valence (i.e., unappealing, disharmonic, agitated) and highly positive on dominance (i.e., strong, dominant, dynamic). Symmetric shapes, on the other hand, scored moderately positive on valence (i.e., appealing, harmonic, calm) and moderately negative in terms of dominance (i.e., weak, unobtrusive, passive).

Among the symmetric stimuli, the circular shape – when presented singularly – further revealed unique affective responses of high positive valence. Yet, when increasing visual complexity, such as when presented on maps, positive valence decreased. Such a decrease of affect intensity was also found for most stimuli when embedded in visually more complex, cartographic contexts. Only the star stimulus prevailed its affective valence qualities across all three stimulus conditions. In all other cases, the intensity of affect responses decreased on both affective dimensions of valence and dominance. This finding strongly implies that cartographic context and visual complexity influence the degree of affective responses.

At this point, it has to be noted that the cartographic scenarios used in this research referred to simple basemaps in greyscale, freed from any further cartographic context, content, or task. However, maps can vary significantly in terms of their complexities due to their sheer unlimited variety of information to depict, visual variables to employ, and contexts in which maps are used. It can, therefore, expected that affective responses vary in different cartographic settings and scenarios.

And yet, despite the decrease of affect intensity due to context, the affective differentiation between symmetric and asymmetric stimuli appeared distinct and prevailed in visually more complex map scenarios. Empirical research from related fields further supports this notion. They suggest a preference for symmetry, even when symmetric shapes are of higher complexity as asymmetric ones (Eisenman &

Rappaport, 1967) or when shapes are only partially symmetric (Friedenberg & Bertamini, 2015). Research also shows detection time to be significantly higher in visual search tasks for asymmetric shapes (e.g., elliptic versus circular visual stimuli) (Treisman & Gormican, 1988), again suggesting their unique visual qualities. This research contributed to the existing body of knowledge. It revealed affective responses towards symmetric and asymmetric shape stimuli and showed that they persist in visually more complex cartographic context.

The overall findings lead to the conclusion that shapes imbue qualities that can lead to – at times – highly distinctive affective responses. The asymmetric star stimuli studied in this research involved strong and most distinct affective responses, which persisted over different stimulus conditions.

For cartographic communication, the findings imply that asymmetric star shapes strongly connote through qualities of negative valence and positive dominance. Thus, map symbols that are of such qualities may be considered to be more than neutrally denoting identifiers. In cartography, such expressive, connotative symbols must be treated with extra attention as stimuli with strong affective responses can influence cognitive processes and related judgments (Feldman Barrett et al., 2007; Loftus & Palmer, 1974; Sianipar et al., 2016). Findings from this research further suggest that symmetric shapes, on the other hand, were relatively unobtrusive, evoking overall mild affective responses. In a cartographic context, symmetric symbols may, therefore, be considered relatively neutral, denoting map signs.

At this point, the findings indicate that relatively simple maps can lead to distinct affective responses. As simple maps have become increasingly prevalent in our daily lives, the results indicate several practical implications.

Regularly we encounter web maps in daily routines, such as when reading online news or when orienting or navigating in unfamiliar environments. The web as a new medium constrains maps' design to the – at times very small – physical display sizes. Therefore, well-designed web maps require extra attention and are considered "relatively empty" (Kraak & Ormeling, 2011, p. 79). Yet, it remains an open question of how much a simple and relatively empty map can affect how we think about the information depicted, how we imagine a distant event, or how we judge a spatiotemporal phenomenon. How will expressive versus depicting map symbols influence cognitive responses, judgments, memory, and attention in more applied and different scenarios? Which cartographic point symbols of denotative and connotative character are most suitable for encoding which type of information? Will shape stimuli that are affectively congruent with the information or phenomenon they cartographically depict amplify judgments of map affect? And how do affective responses towards maps and map signs differ by culture, age, and user group?

While this research strongly suggests an influence of map symbols on human affect, future research is needed to tackle these open research questions and to continue exploring the possible impact of putative empty maps and innocent map symbols.

Conclusion

Visual communication requires deliberate decisions to share and express information successfully. The choice of the sign-vehicle used to communicate information will affect people's responses. While cartographic semiology provides a theoretical framework to communicate geospatial information by addressing the denoting qualities of cartographic visual variables, it does not encompass the connotative qualities of map symbols and their impact on human affect, perception, and cognition. This research, therefore, aimed to unravel some of the subtle communication effects of cartographic point symbols by studying their affect potential.

This research used a semantic differential technique to assess the affective qualities of symbol shape in three stimulus conditions of cartographic and non-cartographic context. It revealed detailed affective profiles on the two affect dimensions of valence and dominance. It further identified clusters of stimuli based on their affective qualities.

The findings suggest symmetry and asymmetry as crucial factors in how shapes are affectively experienced. The asymmetric stimuli studied in this research involved the strongest affective responses, which persisted over both non-cartographic and cartographic stimulus conditions. For cartographic communication, the overall findings infer that symbols imbue qualities that can lead to highly distinctive affective responses and may, therefore, not be considered as neutral map symbols.

Yet, current findings aim to be expanded upon. Future research is needed to explore the connotative impact of map symbols on more heterogeneous user groups and in different cultures. Research is also needed to continue exploring how the findings of this research translate to more diverse and applied cartographic contexts, such as when depicting different types of geospatial information or increasing the level of visual complexity. With a deeper understanding of the subtle communication effects of cartographic symbols, graphic variables may more accurately be distinguished, leading to more deliberate decisions in the map-making process.

CHAPTER 7

STUDY 3

Contextual Congruence of Point Symbols

This empirical research has been published in the ISPRS International Journal of Geoinformation. For the original version, see Klettner, S. (2020). Form Follows Content: An Empirical Study on Symbol-Content (In)Congruences in Thematic Maps. *ISPRS International Journal of Geo-Information, 9*(12), 719. Supplementary materials are available online at http://www.mdpi.com/2220-9964/9/12/719/s1.

Abstract

Through signs and symbols, maps represent geographic space in a generalized and abstracted way. Cartographic research is, therefore, concerned with establishing a mutually shared set of signs and semiotic rules to communicate geospatial information successfully. While cartographers generally strive for cognitively congruent maps, empirical research has only started to explore the different facets and levels of correspondences between external cartographic representations and processes of human cognition. This research, therefore, draws attention to the principle of contextual congruence to study the correspondences between cartographic point symbols and different geospatial content. An empirical study was carried out to explore the (in)congruence of cartographic point symbols with respect to positive, neutral, and negative geospatial topics in monothematic maps. In an online survey, 72 thematic maps (i.e., 12 map topics 6 symbols) were evaluated by 116 participants in a mixed design. The point symbols comprised five symmetric shapes (i.e., Circle, Triangle, Square, Rhomb, Star) and one Asymmetric Star shape. The study revealed detailed symbol-content congruences for each map topic as well as on an aggregated level, i.e., by positive, neutral, and negative topic clusters. Asymmetric Star symbols generally showed high incongruences with positive and neutral topics while highly congruent with negative map topics. Symmetric shapes, on the other hand, emerged to be of high congruence with positive and neutral map topics whilst incongruent with negative topics. As the meaning of point symbols showed to be susceptible to context, the findings infer that cognitively congruent maps require profound context-specific considerations when designing and employing map symbols.

Introduction

When we look at maps, “we see symbols spread out on the space of a document, on paper or a computer screen”, and we expect these symbols to refer to geographic space (Eide, 2016, p. 21). Through the mediation of signs, maps enable us to relate to spatial phenomena and events from a viewpoint beyond direct experience (Keates, 1996). By this, maps enable us to imagine near and distant events, some of which we would never encounter otherwise. As such, cartographic maps are a form of communication, a means of “conceiving, articulating, and structuring the human world” (Harley, 2009/1988, p. 129).

However, albeit a map may be designed to convey a single focus of interest, it does not convey a single universal message (Thompson et al., 2015). The elements of a map are independent, associative signs and symbols with a reference fixed by convention but not fixed by a single, unequivocal reference (Bertin, 1974; Langer, 1953). The map-making process must, therefore, follow particularly informed choices and deliberate decisions since the variety of methods and visual variables available to represent information allow for strikingly different results based on a single dataset (Thompson et al., 2015).

One of the first decisions made by the cartographer concerns the type of symbolization to employ for a given topic (MacEachren, 1982). Yet, to this day, the cartographer faces the challenge – as well as the creative joy – of near-infinite variations of signs and symbols to choose from. This challenging fact is addressed by cartographic semiotic frameworks, which aim to provide theoretical and practical guidance for cartographic design decisions. And still, which visual variables are most suitable for a given context? Which ones most congruent with a given type of spatial information, object, or phenomenon? While existing semiotic frameworks provide some theoretical direction, the selection of the most suitable visual signifiers remains a challenging task (Michaelidou et al., 2005). At the same time, cartographic semiotic frameworks have so far predominantly addressed the dimension of cognitive, analytical congruence to help guide the selection between different types of visual variables (Bertin, 1974). These frameworks, however, do not encompass the dimensions of contextual congruences, such as when to employ a particular symbol shape for a given type of content. Such decisions are crucial since they will affect how map-readers respond to the cartographic representation (Jenny et al., 2018; Muehlenhaus, 2013b).

This research, therefore, draws attention to cartographic symbols as communication vehicles of contextual congruence. Point symbols are considered a core visual variable in cartography and over a wide range of visual disciplines (Arnheim, 1974; Bertin, 1974; Klee, 1920). In cartography, point symbols are employed in thematic maps to represent nominal data and to refer to and locate geospatial events and objects. This research introduces the principle of contextual congruence to study the correspondence between symbol shape and geospatial content. This paper, first, outlines semiotic perspectives on the dimensions and relations of signs as communication vehicles. It further reports an empirical study that aimed to identify (in)congruences between cartographic point symbols and different positive, neutral, and negative geospatial topics in monothematic maps. Finally, findings and implications for future research are addressed and discussed.

Theoretical Background

Congruence is a quality or state of agreeing or coinciding (Merriam-Webster, n.d.), a condition of broadly corresponding to something or being in agreement with it in its essentials. Effective graphics are considered to follow the principle of congruence, where "the structure and content of the external representation should correspond to the desired structure and content of the internal representation" (Tversky et al., 2002, p. 249). Cartographic maps are such external representations. They depict a particular selection of geographic space on a spatial scale smaller than 1:1 (Klippel et al., 2005). As maps are constraint by scale, they require cartographic generalization (Axelsen & Jones, 1987). Maps, therefore, simplify and regularize, reduce dimensionality, omit some information, and exaggerate others. The way maps schematize information is comparable to how human minds schematize information (Tversky, 2000).

High congruence between external representations and internal representations is recognized as beneficial as it enhances cognitive processing fluency (Tversky, 2000; Winkielman, Schwarz, Reber, et al., 2003) and problem-solving (Tversky, 2000; Vessey, 1991). High processing fluency is regarded even to be hedonically marked, i.e., eliciting positive affective reactions (Winkielman, Schwarz, Fazendeiro, et al., 2003). Contrariwise, "visualizations that do not match the mental schema require cognitive transformations to make the visualization and mental representation align" (Padilla et al., 2018, pp. 3–4). The mental effort needed to correct mental mismatches and resolve cognitive discrepancies can increase errors, increase the time to complete a task, and demand higher working memory (Padilla et al., 2018; Vessey et al., 2006). Cartographers, thus, strive for creating cognitively congruent maps, such as by employing map symbols that are associative to the type of information they refer to (Bertin, 1974).

Maps are, yet, the result of a myriad of choices, which, in turn, result in selective representations (Kent, 2018) that are never value-free or neutral (Wood, 2010), but "culturally determined and ethnocentric in origin" (Axelsen & Jones, 1987, p. 447). As such, cartographic communication is considered a complex process. It is a process between the map maker and map user (Board, 2011; Kent, 2018; Koláčný, 1969), "wherein thought originating in one human mind is converted by that mind into physical forms according to rules developed by the culture in which he [she] lives" (Petchenik, 1977, p. 184). The map and its elements are apprehended by the map reader, who construct meaning by interpreting its symbols, colors, and visual expressions, and the like (Petchenik, 1977; Thompson et al., 2015).

Cartographic communication from a semiotic perspective is considered a triadic, interrelated process between *the sign-vehicle,* which refers to the physical sign, *the referent,* which stands for the phenomenon or object of reference the sign-vehicle refers to, and *the interpretant*, which comprises the sign-vehicle's effects on the interpreter, such as its meaning (Morris, 1938, 1946; Nöth, 1995). As meanings are mental events, they are difficult to measure and challenging to distinctively define (Nöth, 1995; Osgood et al., 1957). Due to its imprecision, the semiotician Charles Morris even deliberately excluded the concept of meaning from his semiotic theory (Morris, 1946).

Later, theorists have decomposed the "many meanings of 'meaning'" (Osgood et al., 1957, p. 2), suggesting two core dimensions: the *dimension of reference* and the *dimension* *of sense* (Nöth, 1995). On the dimension of reference, all cartographic sign-vehicles can be considered identifiers which either apprise, inform, state, designate, indicate, label, or denote (MacEachren, 1995; Nöth, 1995). Map signs may, however, also connote, prescribe, express, and stimulate ideas (Keates, 1996; MacEachren, 1995). Hence, whilst map signs may be analytically congruent with a specific type of content, some may be more – and others less – contextually congruent, such that different map signs may stimulate different associations and ideas about a depicted geospatial phenomenon. Cartographic maps and the signs therein are, therefore, regarded to communicate on both semiotic dimensions of meaning, i.e., on the dimension of reference and on the dimension of sense (MacEachren, 1995; Nöth, 1995).

Throughout the past decades, cartographic semioticians have focused on the dimension of reference. They have aspired to establish a mutually shared set of signs and semiotic rules to enhance geospatial communication. One of the most prominent examples of such cartographic semiotic frameworks was established in the late 1960s by the French cartographer Jacques Bertin, who appeared to be the first to formally propose semiotic rules to help guide the cartographic design process (Bertin, 1974/1967). He proposed a set of six fundamental visual variables for two-dimensional maps (i.e., size, color value, texture, color hue, orientation, and shape). He further proposed a set of rules to guide their cartographic employment, such as when they may be considered suitable to represent quantitative, ordinal, or nominal data (Bertin, 1974). Bertin's semiotic framework aimed to cover the core "manipulable primitives of graphic sign vehicles from which any information graphic can be built" (MacEachren et al., 2012, p. 2497).

While Bertin's framework is still generally accepted in information visualization and cartography (MacEachren et al., 2012), it has also been criticized for being dogmatic, limitedly empirically verified, and incomplete (MacEachren, 1995). Bertin's semiology has, therefore, been expanded over the years, such as to meet the characteristics of different map types and map uses (e.g., static tactile maps, dynamic visual maps, dynamic audio maps) (MacEachren, 1995) as well as for different data characteristics, such as for visualizing geospatial uncertainty (MacEachren et al., 2012; McKenzie et al., 2016).

In recent years, cartographic semiotic research has further begun to empirically assess the effects of cartographic design decisions on human responses. Empirical research, for example, showed that cognitively congruent visualizations, i.e., those of greater cognitive fit, will produce faster and more effective decisions (Padilla et al., 2018). The draw to cognitively congruent map symbols can already be found in school children, indicated by the associative and metaphorical use of signs and symbols even at an early age (Michaelidou et al., 2005; Voženílek et al., 2014). Empirical studies further showed that supposedly simple changes of cartographic style lead to substantially different experiences and responses. Visual map style was found to influence map readers' judgments, trust, liking, and recall (Muehlenhaus, 2012, 2013a), as well as emotional responses (Christophe & Hoarau, 2013; Fabrikant et al., 2012). Likewise, the style of line shapes in origin-destination flow maps (e.g., curved versus straight flow lines) significantly impacted the map users' preferences and influenced judgment accuracy (Jenny et al., 2018). Empirical research, moreover, highlights a significant impact on map reading intuitiveness, judgments, and preferences towards maps based on how uncertainty is cartographically visualized (Cheong et al., 2016; Kinkeldey et al., 2014; MacEachren et al., 2012; Padilla et al., 2017). Empirical research on abstract map symbols further suggests a significant influence on detection speed in visual search tasks (Stachoň et al., 2018) as well as on associative and affective responses (Klettner, 2019, 2020b) based on symbol type.

While cartography allows for a great variety of signs and symbols to visualize geospatial information, the aforementioned empirical findings strongly suggest that only a few of them may be considered effective and suitable for a given context and content.

Cartographic semiotic research has so far strongly focused on the dimension of reference, i.e., on analytic congruences between sign and meaning. Theorists, however, further emphasize the dimension of sense as a crucial factor in cartographic communication processes, such that the meaning of signs may vary by context. Such semiotic differentiations have, however, often been neglected in cartographic research and applications of semiotics. Keates (1996), for instance, argued that "despite a large number of papers dealing with communication in cartography, relatively few have pursued in detail the analysis of map symbols, and the relationships between map symbols and semiotic theory" (p. 179). Consequently, "the difference of what a map sign means and what it represents has become blurred" (MacEachren, 1995, p. 245).

Research highlights the persisting need for a differentiated understanding of how visual variables can be used to congruently represent geospatial information by considering the different dimensions of meaning. This research, therefore, draws attention to cartographic point symbols employed in thematic maps and explores their congruence with different geospatial contexts.

Empirical Study

An empirical study was carried out to explore how congruent and incongruent cartographic point symbols are experienced in different geospatial contexts. In the study, geospatial context referred to three types of content, i.e., geospatial topics of a positive, neutral, or negative character. For each of the three content groups, monothematic maps were created, in which point symbols for representing a given map topic were systematically varied. The final set of monothematic maps was used as stimulus material, and the perceived symbol-content congruence of each map was rated by study participants. The following sections describe the materials and methods of this empirical study in detail.

Materials and Study Design

An online survey was carried out to empirically assess the (in)congruence of abstract map symbols with respect to different thematic map content. Twelve map topics were selected a priori by the experimenter, i.e., four positive, four neutral, and four negative topics, to test for symbol-content congruences (see Table 7).

Table 7. Map topics used in the study.

Valence	Map ID	Map Topics	No. of Symbols
positive	1	City awarded for clean energy	°
	2	National parks	°°°
	3	Urban park with high biodiversity	°
	4	Cities with excellent water quality	°°°
neutral	5	Art college	°
	6	Art galleries	°°°
	7	Lookout tower	°
	8	Outdoor stages	°°°
negative	9	Flood-affected area	°
	10	Melting glaciers	°°°
	11	Traffic accident	°
	12	Smog polluted cities	°°°

Note: ° indicates one map symbol, °°° indicates three map symbols.

For each map topic, a set of six thematic maps were created, where each map depicted one of six abstract symbols, i.e., Circle, Triangle, Square, Rhomb, Star, and Asymmetric Star (for examples, see Figure 18). The map symbols used in this research refer to commonly used symmetric shapes in thematic cartography and related visual disciplines (Arnheim, 1974; Bertin, 1974). In addition, one asymmetric star shape was incorporated into the stimulus set, as related literature indicates particular perceptual qualities of asymmetric shapes, such as quicker detection times in visual search tasks (Treisman & Gormican, 1988) and distinct negative hedonic qualities of asymmetric star symbols (Klettner, 2020b). Map symbols were displayed in black in 50 percent transparency on light-hued basemaps. Basemaps were created to correspond with each map topic thematically. As a result, the basemaps used for the twelve map topics varied by content and scale. For example, the basemap for illustrating a "Traffic accident" displayed a street network, while the basemap for locating a "Lookout tower" indicated urban structures and settlements. Topics that referred to events of a single location were depicted by maps displaying one map symbol, while topics referring to events of multiple locations were represented by three map symbols (see Figure 18 for examples). The final stimulus set comprised 72 maps as a result of six map stimuli employed for each of the twelve map topics.

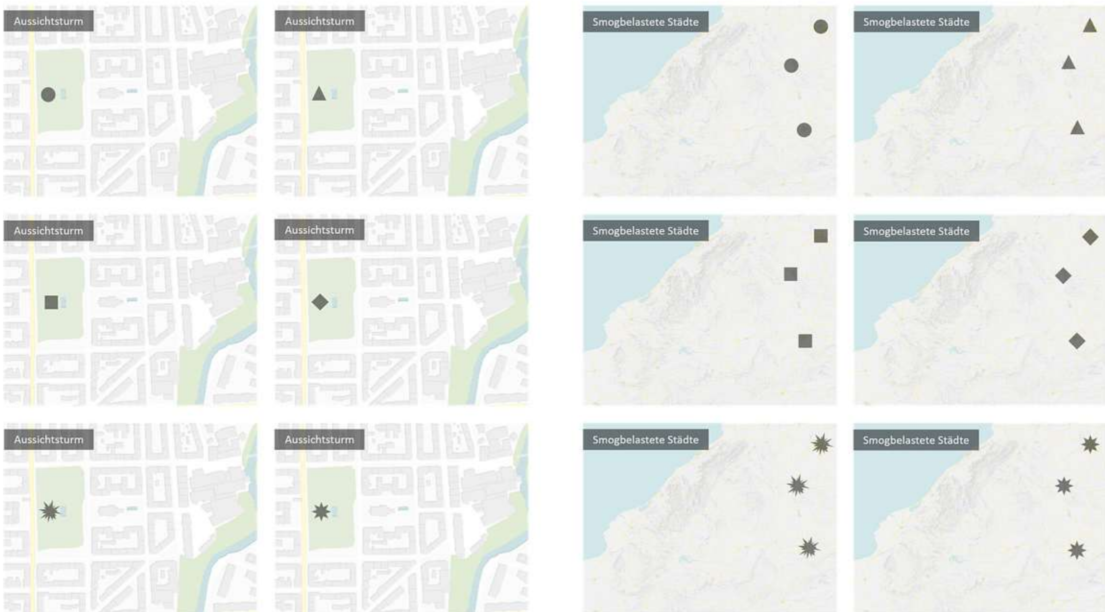


Figure 18. Examples of two map sets: "Lookout tower" (left), "Smog polluted cities" (right).

A mixed design approach was applied, which randomly assigned participants to one of two stimulus groups. This approach aimed to minimize learning and response transfer across the stimulus conditions. As a result, each participant assessed half of the stimulus set, i.e., 36 maps. The online survey was carried out in the German language using the software LimeSurvey (LimeSurvey GmbH, 2019).

After the survey briefly introduced the study's aim, which was phrased as to explore how symbols and maps are subjectively perceived, participants were instructed to proceed with map evaluation tasks. Participants were asked to rate the (in)congruence between each map topic and its cartographic representation on a unipolar 6-point rating scale. The rating scale ranged from 0 (i.e., the cartographic representation does not suit the topic at all) to 5 (i.e., the representation suits the topic very well). Each map stimulus was presented individually, consecutively, and in a randomized order, at a size of 500 x 377 pixels.

After the map evaluation task, participants rated each map topic on an 11-point Likert scale, from −5 (very negative) to +5 (very positive). These topic ratings were later subjected to empirically identify homogeneous topic clusters of positive, neutral, and negative valence (see section Topic Analysis in Results).

Sociodemographic data were gathered at the end of the survey regarding the participants' affinity for graphic design (self-evaluation on a unipolar 4-point rating scale, from "not at all" to "very affine", with the additional option for "no answer"), their affinity for maps or cartography (unipolar 4-point rating scale, from "not at all" to "very affine", or "no answer"), age, and gender. At the end of the survey, participants were also asked to indicate the devices they used for completing the survey (i.e., desktop PC, laptop, tablet, or smartphone).

Participants

Bachelor's students of Regional Planning were recruited from a course on "Thematic Cartography in Regional Planning" held in winter term 2019 at TU Wien—Vienna University of Technology, Austria. Students participated voluntarily and received course credits in the form of bonus points, which counted towards their final grades. The online survey was sent to students in December 2019.

In total, 116 students completed the survey (49 males, 64 females, one person of diverse gender, two missing responses). Participants were randomly assigned to one of two stimulus groups, resulting in 63 participants who completed stimulus material A and 53 individuals who completed stimulus material B, which both comprised a set of 36 map stimuli. Of all participants, 109 persons indicated their age (M = 22.10, SD = 3.29, Min = 18, Max = 35). The majority of participants used laptops to complete the questionnaire (85.3%), followed by desktop PCs (10.3%), tablets (3.4%), and smartphones (0.9%, i.e., one person). Most participants indicated their affinity for graphic design to be moderate to high (somewhat affine = 29.3%; quite affine = 37.9%; very affine = 25.9%), while one person reported no interest in graphic design (0.9%). Seven individuals (6.0%) did not answer this question. The participants' affinity for cartographic design showed to be moderate in most cases (somewhat affine = 30.2%; quite affine = 50.9%) and high in 12.9% of the cases. Seven individuals (6.0%) did not report their affinity for cartographic design.

Results

The study collected symbol-content congruency ratings for 72 map stimuli (12 maps x 6 stimulus conditions) from 116 participants in a mixed study design. It also collected valence ratings for each of the twelve topics. These two sets of data were statistically analyzed by using the statistical software package SPSS (IBM, 2017) and XLStat addon for Microsoft Excel (Addinsoft, 2020).

First, valence ratings were subjected to statistical analyses to identify homogeneous topic clusters (see section Topic Analysis for details). These topic clusters were subsequently used to analyze the participants' symbol-content congruency ratings on a cluster-level and individually by each map topic (see section Map Analysis).

Topic Analysis

The study used twelve topics that were selected a priori. To reveal the topics' positive, neutral, and negative quality, participants' valence ratings were subjected to statistical analysis. The topics' valence ratings generally ranged from very negative (−5) to very positive (+5). The descriptive statistics of these ratings are summarized in the Supplementary Material Table S1.

A hierarchical cluster analysis was performed based on the topics' valence ratings to identify topic clusters of similar qualities statistically. An agglomerative clustering approach was applied, which starts with each item as a cluster and progressively links the items based on their estimate of distances to one another. A cluster distance measure of average linkage was employed, which balances the limitations of single and complete linkage methods, i.e., using information about all pairs of distances to assign cluster membership, not just the nearest or the farthest item pairs.

Results indicate a three-cluster solution (see Figure 19) and confirm the three clusters of positive, neutral, and negative topics that had been initially compiled a priori by the experimenter (see Table 7). The cluster analysis dendrogram further indicates a meta-proximity between neutral topics and positive topics, suggesting a more proximal relation between the selected neutral and positive topics and a more distant relation of both towards the negative topic cluster.

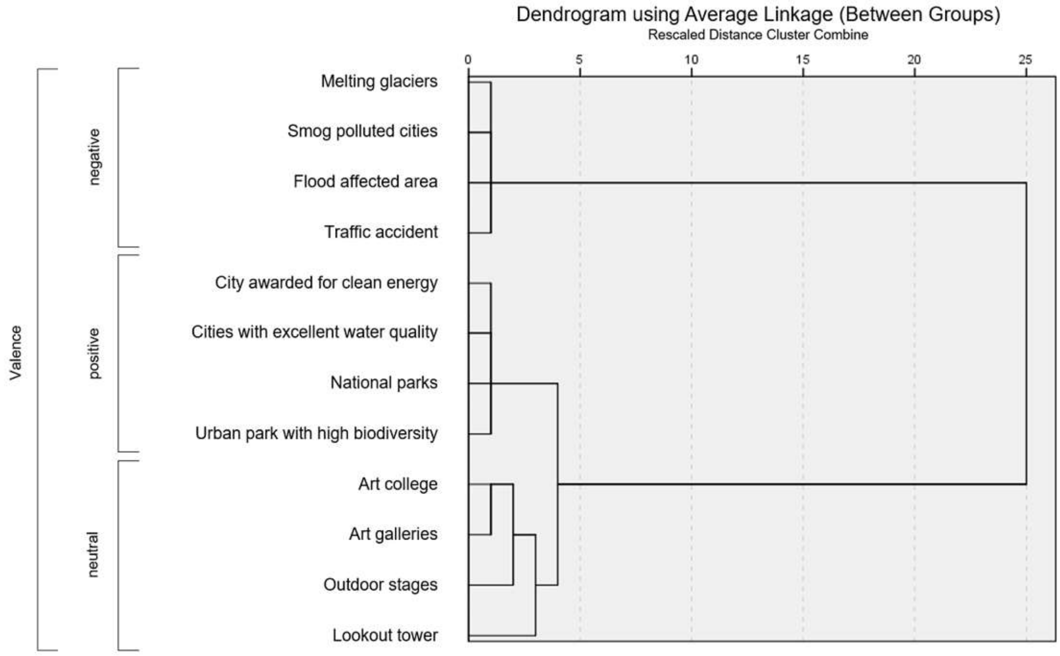


Figure 19. Dendrogram based on agglomerative hierarchical cluster analysis of topic valence ratings.

The findings from hierarchical cluster analysis were subsequently used for the next stages of data analysis, where the twelve thematic maps were assigned to their corresponding positive, neutral, or negative topic cluster. In the next stages of analysis, differences between symbol-content congruency ratings were, first, statistically analyzed by each topic cluster before they were assessed individually by each map topic (see section Map Analysis).

Map Analysis

Based on participants' symbol-content congruency ratings of the 72 thematic map stimuli (i.e., 12 map topics × 6 symbols), mean ratings were computed for each map and each map symbol. Figure 20 visualizes the results, indicating somewhat similar ratings for symmetric map symbols when representing positive or negative content, while the Asymmetric Star symbol appeared to be rated least suitable for referring to positive or neutral map content. In contrast, Asymmetric Star symbols showed to be rated as most congruent for cartographically relating to negative geospatial topics.

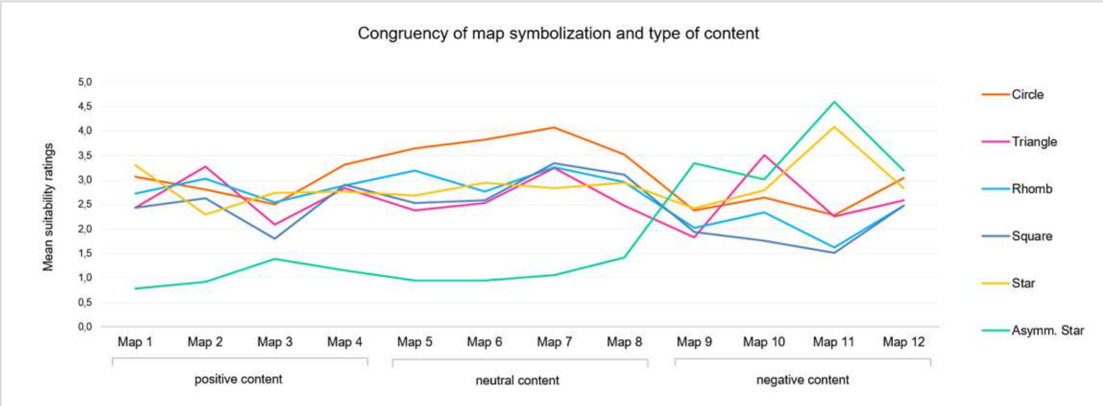


Figure 20. Mean ratings of map content and symbolization (in)congruence.

Participants' symbol-content (in)congruency ratings were subjected to statistical analyses to identify significant differences between the map stimuli. First, participants' responses were analyzed on an aggregated level, i.e., according to the three topic clusters identified by agglomerative hierarchical cluster analysis. Second, symbol-content congruences were analyzed individually, i.e., according to each of the twelve map topics. The following sections will discuss the two approaches of analysis, i.e., by topic cluster and by each topic, in detail.

Both stages of analysis followed a two-step procedure:

- In the first step, symbol-content (in)congruency ratings were subjected to a Durbin-Skillings-Mack procedure for nonparametric data to identify overall significant differences. The Durbin-Skillings-Mack procedure reveals if the null hypothesis must be rejected, i.e., if at least one result of symbol-content congruence significantly differs from another. The Durbin-Skillings-Mack test can be considered as an extension of the Friedman test. While the Friedman test can only be used in cases of complete paired samples, the Durbin-Skillings-Mack test applies a block design and, thus, allows to compare paired samples of unequal size (Chatfield & Mander, 2009).
- In the next step, post hoc Conover-Iman analyses were conducted to identify subsets of homogeneous symbol-content congruences in greater detail. The post hoc Conover-Iman procedure performs multiple pairwise comparisons for nonparametric data based on rank differences (Conover & Iman, 1979). Post hoc procedures generally explore the data for between-group differences by comparing all possible combinations of pairs (Field, 2009). As such statistical procedures conduct multiple pairwise comparisons, they also correct the significance levels such that the overall Type I error rate (i.e., significance level α, which is the probability of rejecting the null hypothesis

given that it is true) across all comparisons remains 0.05 (Field, 2009). Hence, a Bonferroni correction was applied as part of the post hoc Conover-Iman analyses to ensure that despite multiple pairwise comparisons, the cumulative Type I error remains below 0.05.

Topic Clusters and Symbol Congruence

In the first stage of analysis, participants' congruency ratings were aggregated and analyzed according to the three positive, neutral, and negative topic clusters, which had been identified by agglomerative hierarchical cluster analysis. For each of the three valence clusters, a Durbin-Skillings-Mack procedure was performed, revealing highly significant differences ($p < 0.001$) between the symbol congruency ratings for either of the three topic clusters (see Table 8).

Table 8. Results of Durbin-Skillings-Mack analysis of symbol-content congruence by three map clusters.

Map Topic Cluster	Q	df	p
Positive map cluster	229.34	5	<.001***
Neutral map cluster	308.87	5	<.001***
Negative map cluster	143.12	5	<.001***

Note: Q represents Durbin-Skillings-Mack test statistics. Significance level: $\alpha = .05$. ***$p < .001$.

In the next step, Conover-Iman post hoc tests were performed for each of the three map clusters to follow up on the significant findings. As part of the analysis, a Bonferroni correction was applied, which controls for Type I error by dividing α by the number of pairwise comparisons. The ratings of six map symbols were pairwise compared within each map cluster and resulted in 15 pairwise combinations. The Bonferroni correction set the significance levels at $\alpha = 0.0033$ (i.e., Bonferroni corrected $\alpha = 0.5/15$). Differences between the multiple pairwise comparisons were interpreted accordingly (for detailed Conover-Iman test results, see Supplementary Material Table S2).

Based on the results of the Conover-Iman post hoc procedure, Demšar graphs were computed to visualize the results of critical differences within and between the map symbols for each topic cluster (Demšar, 2006); see Figure 21. Demšar graphs illustrate critical differences between mean ranks in a way that groups that are not significantly different are connected by horizontal lines. In those cases, the null hypothesis cannot be rejected, i.e., that the pairs' mean ranks must be considered equal. In contrast, any pair that is not connected with a horizontal line can be regarded to differ with statistical significance.

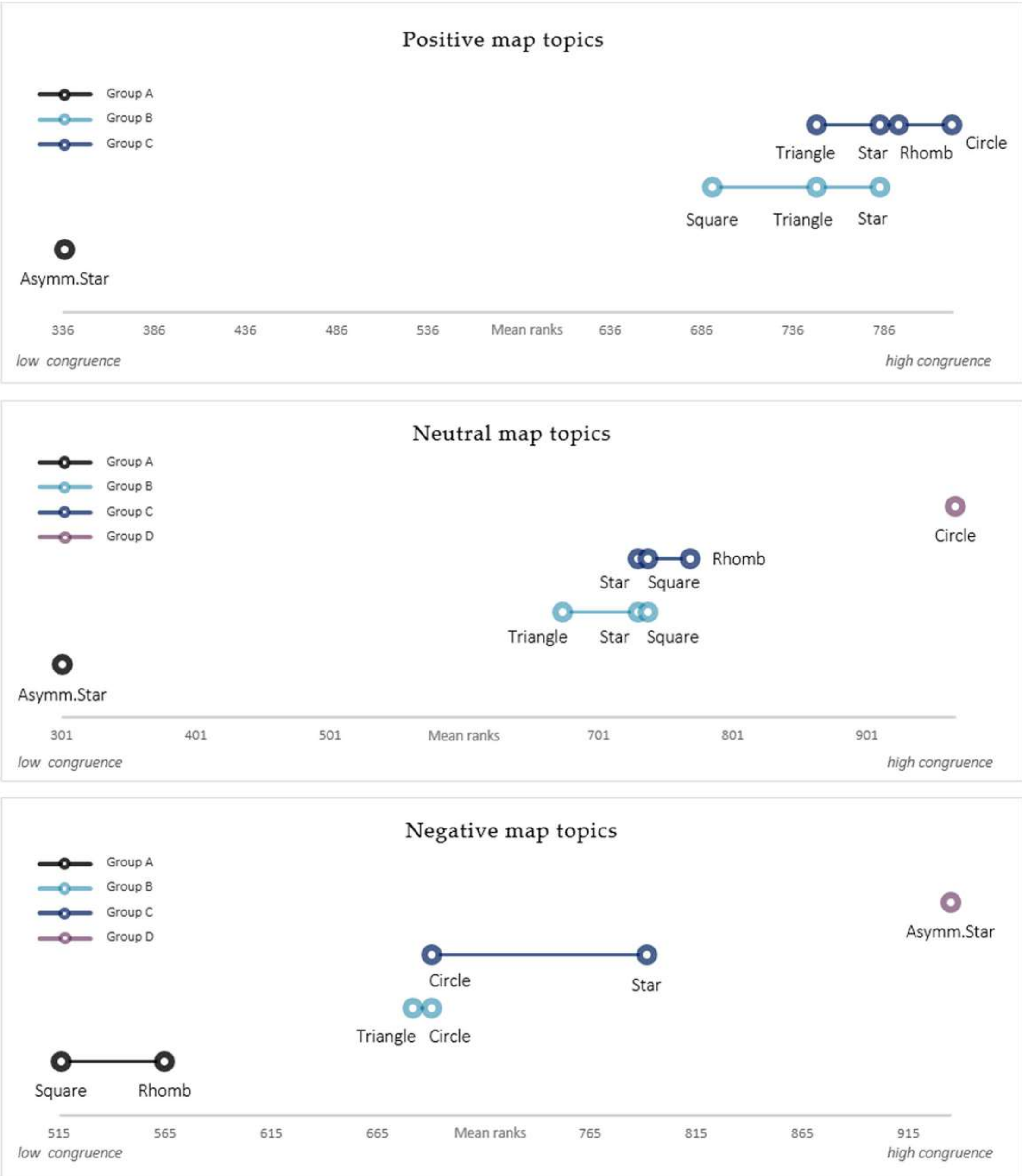


Figure 21. Demšar graphs based on Conover-Iman multiple pairwise comparisons, illustrating the (in)congruence between map symbols when depicting positive, neutral, and negative topics.

Positive topic cluster. Based on the set of six cartographic point symbols, a Conover-Iman post hoc analysis suggests three homogeneous symbol subsets when depicting positive map topics (see Group A, B, and C in Figure 21 top). The results showed that symmetric shapes were rated most suitable for depicting positive content. Among the symmetric shapes, two particular symbol subsets emerged (Group B and Group C).

Group C refers to map symbols of highest congruency ratings, i.e., Circle, Rhomb, Star, and Triangle, followed by Group B of second highest congruence, i.e., Star, Triangle, and Square. Conover-Iman also discloses some similarities between Group B and C, illustrated by Star and Triangle's overlaps in Figure 21 (top). The third subset comprises the Asymmetric Star symbol, rated as least suitable for depicting positive map topics (see Group A).

Neutral topic cluster. When depicting neutral map topics, Conover-Iman post hoc analysis suggests four homogenous subsets among the six-point symbols studied (see Figure 21 center). The first subset comprises Circles rated as most congruent with neutral map topics (see Group D). The four symmetric polygonal shapes were assigned to two homogeneous yet partially overlapping subsets (see Group C and D). The results further found that Asymmetric Stars were rated as significantly least congruent for representing neutral geospatial topics (see Group A).

Negative topic cluster. For the negative map topic cluster, the Conover-Iman analysis suggests four homogeneous symbol subsets (see Figure 21 bottom). The results revealed that the Asymmetric Stars were generally rated most congruent for depicting negative map topics (see Group D). Two subsets of moderate congruence further emerged, i.e., Circle and Star (see Group C) and Triangle and Circle (see Group B), with partial overlaps. The fourth group referred to the map symbols Square and Rhomb, which formed a distinct subset of lowest congruency ratings when to cartographically depicting negative topics (see Group A).

Positive Map Topics and Symbol Congruence

At the next stage, statistical analyses were performed for each map topic to explore topic-symbol correspondences in greater detail. Findings from Durbin-Skillings-Mack tests suggest highly significant differences ($p < 0.001$) between the six map symbols for each of the four positive map topics (see Table 9 for details).

Table 9. Results of Durbin-Skillings-Mack analyses of symbol-content congruence of four positive map topics.

ID	Positive Map Topics	Q	df	p
1	City awarded for clean energy	59.75	5	< .001***
2	National parks	60.41	5	< .001***
3	Urban park with high biodiversity	20.70	5	< .001***
4	City with excellent water quality	45.40	5	< .001***

Note: Q represents Durbin-Skillings-Mack test statistics. Significance level: $\alpha = .05$. ***$p < .001$.

In the next step, congruency ratings were subjected to Conover-Iman post hoc analyses. The post hoc analyses identified symbols that significantly differed from one another. The results of each positive map topic are illustrated in Figure 22 and discussed in the following sections in detail.

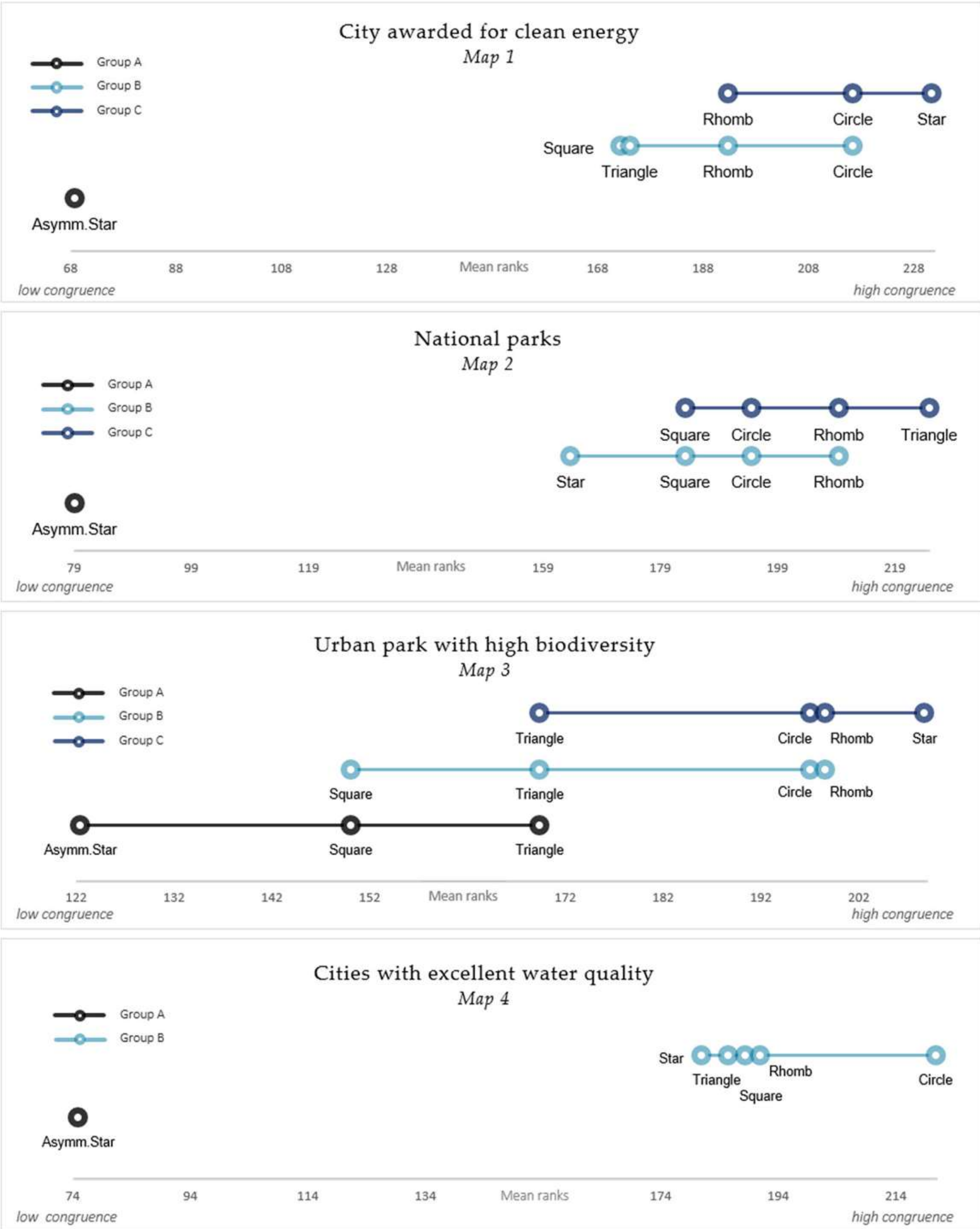


Figure 22. Four positive map topics: Demšar significance graphs illustrating the results of multiple pairwise comparisons, indicating groups of (dis)similar symbol-content congruences.

Map #1: City awarded for clean energy. Conover-Iman test suggests three subsets of congruences for the given map topic (for detailed test results, see Supplementary Material Table S2). Demšar significance graphs further visualize the critical differences between these three congruence subsets (see Group A, B, C of Map 1 in Figure 22). The results show that the Asymmetric Star significantly differed from all other shapes, characterized by the lowest congruency ratings for the given map topic (Group A). The other two homogeneous subsets comprise the five symmetric symbols (Groups B and C). Group C was revealed to form the symbol subset of highest content-congruency ratings, i.e., Star, Circle, and Rhomb, followed by the subset of Circle, Rhomb, Triangle, and Square (Group B). These results, however, further indicate some similarities between Groups B and C.

Map #2: National parks. Conover-Iman's multiple pairwise comparisons suggest three homogeneous symbol-subsets for the given map topic (for detailed test results, see Supplementary Material Table S4). Demšar graphs further illustrate these results (see Group A, B, C of Map 2 in Figure 22). The Asymmetric Star referred to a distinct subset (Group A), characterized by significantly lowest congruency ratings. In contrast, the five symmetric symbols were rated to correspond significantly better for depicting the map topic "National parks" (see Groups B and C). Overall, the Triangular shape emerged to be most congruent with the given map topic, followed by Rhomb, Circle, and Square (Group C). Conover-Iman results further suggest some similarities between Group B and Group C, as indicated by overlaps between some of the shapes of these two subsets (see Figure 22).

Map #3: Urban park with high biodiversity. Conover-Iman post hoc analysis identified three homogeneous symbol subsets for this map topic, yet, also revealing some overlaps between the three groups (for detailed test results, see Supplementary Material Table S5). Demšar graphs illustrate the critical differences between the three subsets (see Map 3 in Figure 22). The first subset of lowest congruency ratings comprises the Asymmetric Star, followed by Square and Triangle (Group A). The second subset of moderate to high congruence refers to the Square, Triangle, Circle, and Rhomb (Group B). The third homogeneous symbol subset comprises the asymmetric Star, rated as most congruent with the given map topic, followed by Rhomb, Circle, and Triangle (Group C). As mentioned, despite uncovering three homogeneous subsets, the results also indicate partial overlaps, suggesting some similarities between the three symbol groups (see Figure 22).

Map #4: Cities with excellent water quality. Two distinct symbol subsets were found based on Conover-Iman analysis (for test results, see Supplementary Material Table S6). One subset refers to the Asymmetric Star, characterized by significantly lowest congruency ratings (see Group A of Map 4 in Figure 22). The other distinct subset comprises the five symmetric shapes rated to be significantly more congruent with the given topic (see Group B of Map 4 in Figure 22). The Circle was rated as most congruent within that group, followed by Rhomb, Square, Triangle, and Star (Group B). Hence, the results revealed a significant preference towards symmetric map symbols when representing "Cities with excellent water quality".

In summary, the findings revealed the lowest congruence ratings for Asymmetric star symbols for each of the four positive map topics. Polygonal shapes, on the other hand, generally showed higher congruences. Yet, preferences for the most congruent polygonal symbol varied by map topic, suggesting the symbols' context-specific meanings.

Neutral Map Topics and Symbol Congruence

For each of the four neutral topics identified by agglomerative hierarchical cluster analysis (see section Topic Analysis), Durbin-Skillings-Mack tests were performed to explore for significant differences between their perceived symbol-content congruences. The results revealed highly significant differences within each map set, suggesting that some map symbols were experienced to be more congruent—and others less—within either of the four neutral topics (see Table 10 for details).

Table 10. Results of the Durbin-Skillings-Mack test for neutral map topics.

ID	Neutral Map Topics	*Q*	*df*	*p*
5	Art colleges	62.72	5	<.001***
6	Art galleries	60.68	5	<.001***
7	Lookout tower	64.08	5	<.001***
8	Outdoor stages	39.69	5	<.001***

Note: *Q* represents Durbin-Skillings-Mack test statistics. Significance level: $\alpha = .05$. ***$p < .001$.

In the next step, participants' congruency ratings were subjected to Conover-Iman post hoc tests. This allowed following up on the significant findings from the Durbin-Skillings-Mack analysis, as this procedure explored differences between the six map symbols in greater detail. The results of each neutral map topic are illustrated in Figure 23 and discussed in the following sections.

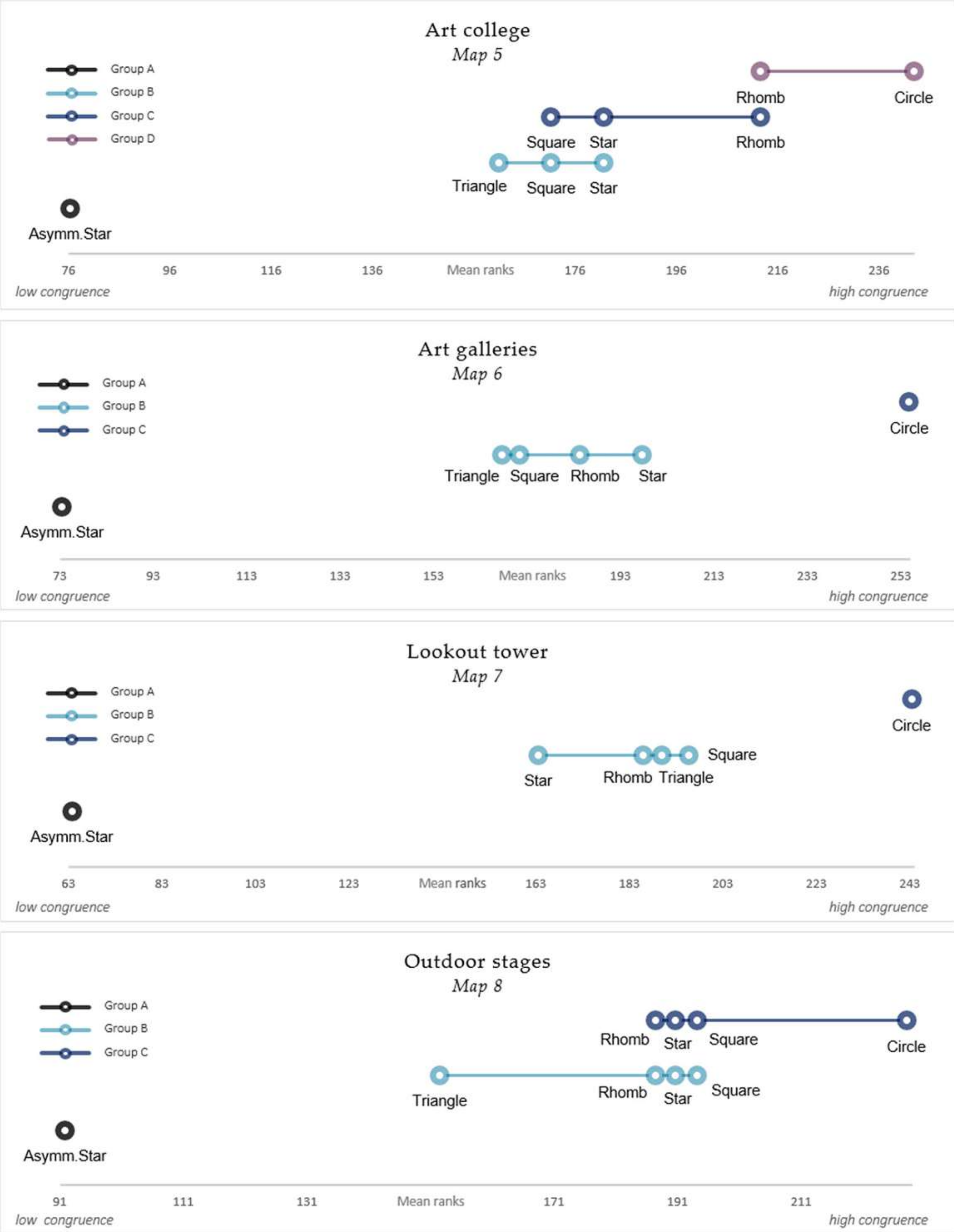


Figure 23. Four neutral map topics: Demšar significance graphs illustrating the results of multiple pairwise comparisons, indicating groups of (dis)similar symbol-content congruences.

Map #5: Art college. Conover-Iman's multiple pairwise comparisons identified four subsets of homogeneous symbol-content congruency for this map topic (for detailed test results, see Supplementary Material Table S7). Demšar diagrams were computed to illustrate the results (see Groups A, B, C, D of Map 5 in Figure 23). The Asymmetric Star was revealed to refer to a distinct subset (Group A), characterized by significantly lowest congruency ratings. In contrast, the Circular shape was rated as most congruent with the map topic, followed by Rhomb (Group D). Rhomb, Star, and Square were found to comprise a subset of the second-highest congruence (Group C), followed by Star, Square, and Triangle (Group B). The results further imply similarities between the three subsets of symmetric shapes, indicated as partially overlapping graphs in Figure 23 (see Group B, C, D of Map 5).

Map #6: Art galleries. For cartographically representing "Art galleries", Conover-Iman post hoc analysis suggests three distinct homogeneous symbol subsets (for Conover-Iman test results, see Supplementary Material Table S8). Demšar graphs illustrate these findings (see Groups A, B, C of Map 6 in Figure 23). The first subset refers to the Asymmetric Star shape (Group A), which revealed the lowest congruency ratings significantly. In contrast, the Circular map symbol was found to form a distinct subset of highest congruence (Group C), while the subset of Star, Rhomb, Square, and Triangle was found to be of distinct, moderate congruence (Group B).

Map #7: Lookout tower. The Conover-Iman test suggests three symbol groups of similar congruence (for detailed results, see Supplementary Material Table S9). Demšar graphs illustrate the results (see Groups A, B, C of Map 7 in Figure 23). The first subset, comprising the Asymmetric Star (Group A), was least congruent with the map topic, while the Circular shape was revealed to refer to a distinct subset of high congruence (Group C). Square, Triangle, Rhomb, and Star (Group B) suggest a distinct homogeneous subset of moderate symbol-content congruence.

Map #8: Outdoor stages. Conover-Iman analysis revealed three homogeneous symbol-subsets for this map topic (for detailed results, see Supplementary Material Table S10). Group A, B, and C are illustrated in Figure 23 (see Map 8). The first subset comprises the Asymmetric Star, which revealed the lowest congruency ratings (Group A). In contrast, the Circle was rated as most congruent for representing the map topic, followed by Square, Star, and Rhomb (see Group C). The third homogeneous subset comprises the four polygonal shapes Square, Star, Rhomb, and Triangle (see Group B). The results suggest overlaps between some of the polygonal shapes of Group C and B (see Square, Star, and Rhomb), which indicate some similarity between these subsets (for details, see Demšar graphs of Figure 23).

In summary, the findings revealed the lowest congruence ratings for Asymmetric star symbols in each of the neutral map topics. Symmetric shapes, on the other hand, generally showed higher congruences for these map topics. Among the symmetric shapes, depictions by Circles were favored across all map topics, which is suggested by their high congruence ratings.

Negative Map Topics and Symbol Congruence

Durbin-Skillings-Mack tests were performed for each of the four negative map topics that explored negative topic-symbol relations. The results suggest significant differences within three of the four negative map topics (see Table 11 for details). Highly significant differences between the set of six map symbols were found for the three maps indicating "Floods", Melting glaciers", and "Traffic accident". No statistically significant differences were found between the map symbols depicting "Smog polluted cities", indicating that the six map symbols were experienced to be equally congruent when depicting this particular topic.

Table 11. Results of the Durbin-Skillings-Mack test for negative map topics.

ID	Negative Map Topics	*Q*	*df*	*p*
9	Flood affected area	18.89	5	.002**
10	Melting glaciers	36.05	5	<.001***
11	Traffic accident	115.17	5	<.001***
12	Smog polluted cities	9.80	5	.081

Note: Q represents Durbin-Skillings-Mack test statistics. Significance level: $\alpha = .05$. $^{**}p < .01$. $^{***}p < .001$.

In the next stage of analysis, Conover-Iman post hoc tests were performed to explore the congruences between symbol type and map topic in greater detail. The findings of symbol-topic congruences are illustrated by Demšar significance graphs for each of the four negative map topics (see Figure 24). The following sections discuss the results in detail.

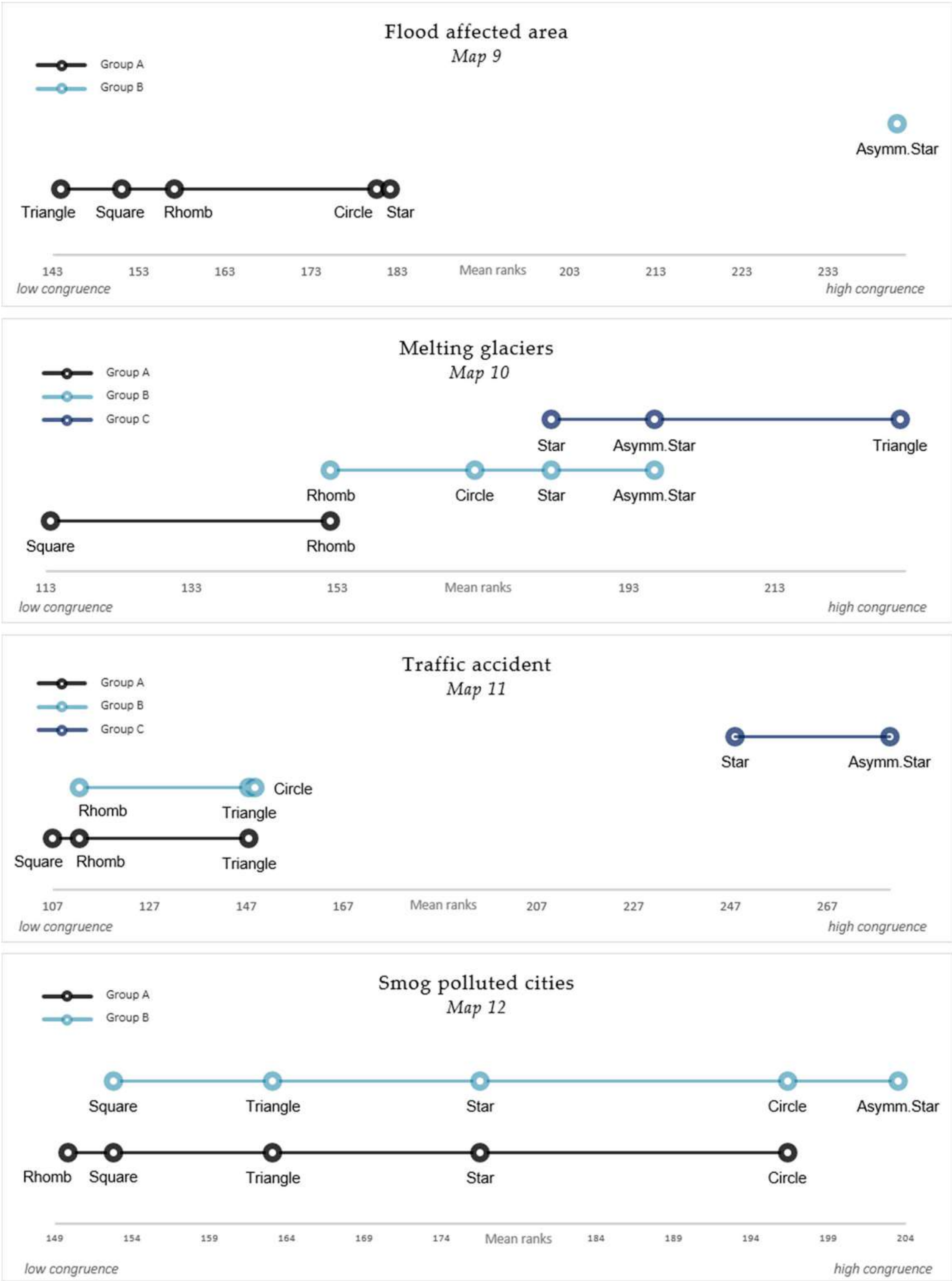


Figure 24. Four negative map topics: Demšar significance graphs illustrating the results of multiple pairwise comparisons, indicating groups of (dis)similar symbol-content congruences.

Map #9: Flood affected area. For this map topic, the Conover-Iman analysis suggests two homogeneous symbol subsets (see Group A and B of Map 9 in Figure 24; for Conover-Iman test results see Supplementary Material Table S11). Symmetric shapes refer to Group A, with the Triangle rated as least congruent, followed by Square, Rhomb, Circle, and Star. In contrast, the Asymmetric Star was rated as most congruent with the given map topic, thus, forming a distinct symbol subset of high congruence (Group B).

Map #10: Melting glaciers. Between the six map symbols, Conover-Iman multiple pairwise comparisons identified three symbol subsets for this topic (see Group A, B, C of Map 10 in Figure 24; for detailed Conover-Iman test results, see Supplementary Material Table S12). The first subset comprises Square and Rhomb, characterized by low congruence (see Group A). The second symbol subset was found to be of moderate congruence, comprising Rhomb, Circle, Star, and Asymmetric Star (see Group B). The subset of highest congruency ratings emerged to refer to the Triangular symbol, followed by Asymmetric Star and Star (Group C). Despite the homogeneity within each of the three subsets, Conover-Iman further discloses partial overlaps between some symbols of the three subsets, suggesting some similarity between them.

Map #11: Traffic accident. A Conover-Iman post hoc analysis revealed three subsets of homogeneous symbol-topic congruence for this map topic (for detailed test results, see Supplementary Material Table S13). Demšar graphs visualize the subsets' critical differences (see Map 11 in Figure 24), suggesting two subsets of low congruency ratings. One of these subsets uncovered the Square as a symbol of least congruence, followed by Rhomb and Triangle (Group A). The second subset comprises the symbols Rhomb, Triangle, and Circle (Group B). Group B showed to be fairly similar to Group A (see Map 11 in Figure 24 for details). The subset of highest congruency ratings referred to the Asymmetric Star and symmetric Star (Group C). Hence, the two star symbols suggest being most suitable to depict traffic accidents in maps.

Map #12: Smog polluted cities. Durbin-Skillings-Mack revealed no significant differences between the participants' symbol-topic congruency ratings for this topic (see Table 11). Pairwise comparisons between the six map symbols based on the Conover-Iman analysis support this finding (for detailed results, see Supplementary Material Table S14). Besides the highest congruency ratings for the Asymmetric Star symbol and lowest congruency scores for Rhomb and Square, these ratings did not significantly differ. Demšar graphs illustrate these results (see Map 12 in Figure 24).

In summary, the findings suggest high congruences of Asymmetric stars with negative map topics and lower congruences of symmetric shapes. Yet, congruences vary by map topic, suggesting the symbols' context-specific meanings. The following section (Discussion) discusses the findings in detail.

Discussion

As visual means of communication, maps employ signs and symbols to relate to geospatial phenomena and events. As such, maps support the communication and imagination of geographic space and related events from a viewpoint beyond direct experience. At the same time, maps are selective and based on a myriad of decisions. The visual variables employed in maps, such as map signs and symbols, are based on abstractions and generalizations.

When choosing such visual variables, cartographers generally strive for congruence, where the schematization of the external representation aims to correspond to structures of the internal representation. Cartography is, therefore, concerned with establishing a mutually shared set of signs and semiotic rules to communicate geospatial information successfully. Cartographic semiotics provide some guidance for selecting visual variables from an analytic perspective, such as when to employ visual variables for a given type of data. Yet, it does not address contextual congruence, such as when to use a particular symbol shape for a given type of geospatial content. This research, therefore, aimed to contribute to closing this research gap by investigating the contextual congruence of cartographic point symbols with different types of geospatial information.

In detail, this research examined the perceived (in)congruence of a set of six-point symbols in monothematic maps of positive, neutral, and negative valence. The six-point symbols comprised five symmetric shapes (i.e., Circle, Triangle, Square, Rhomb, Star) and one Asymmetric Star shape. In an online survey, 72 maps (i.e., twelve map topics in six symbol variations) were evaluated by 116 participants in a mixed design approach. Participants evaluated each map topic's congruence and its depiction by the different point symbols on a 6-point rating scale. Four positive, four neutral, and four negative map topics were assessed by the participants. Participants' congruency ratings were subjected to statistical analyses. First, symbol-content congruency ratings were analyzed on an aggregated level, i.e., by the three positive, neutral, and negative topic clusters. Second, symbol-content congruency ratings were analyzed individually, i.e., by each of the twelve map topics.

The clustered congruency ratings showed that Asymmetric Stars were least suitable to represent positive content. In contrast, the five symmetric shapes were generally highly congruent with positive map topics. Congruency ratings for neutral topics revealed similar results. Asymmetric Stars were least congruent with neutral map content, while polygonal, symmetric shapes led to high congruence ratings. Results further disclosed a significant preference for Circular map symbols for depicting neutral map topics. Hence, results suggest that Circular point symbols may best represent neutral topics, while symmetric polygonal map symbols may be considered a second-best alternative. While incongruent with positive and neutral topics, Asymmetric Star symbols were significantly preferred for depicting negative events. In contrast, Star, Circle, and Triangle were generally rated as moderately congruent with negative topics, while Square and Rhomb were experienced as least congruent for cartographically referring to negative events.

While the clustered findings propose general tendencies of symbol-topic relations, also topic-specific visualization preferences were revealed at a more detailed analysis level. For example, Triangles were rated to best correspond to representing "National parks" and "Melting glaciers", while symmetric Stars showed to be the preferred choice for representing "Cities awarded for clean energy" and "Urban parks with high biodiversity". For depicting "Traffic accidents", the Asymmetric Star and symmetric Star were both found to be significantly favored.

These findings suggest the role of *iconicity*, which refers to the conceived similarity or analogy between the form of a sign-vehicle and its meaning. Abstract, geometric shapes are generally considered to be of low iconicity, while associative and pictorial point symbols are regarded as moderately to highly iconic (MacEachren, 1995). The results of this study indicate that cartographic context may have increased the iconicity of abstract map symbols. The topic of "Melting glaciers", for example, may have been associated with mountains, which may be visually associated and abstracted by triangular shapes. On the other hand, traffic accidents may be associated with collision and conflict, often graphically abstracted by star-like shapes. In this research, contextually more iconic symbols may have been experienced as more congruent with the given map topics, as participants' draw towards those map symbols indicate. Yet, as these findings only allow to conjecture the influence of iconicity on congruence, future research is needed to systematically and empirically explore its influence in depth.

Related research further suggests that when people make evaluative judgments, they draw on a range of different processes (Winkielman, Schwarz, Fazendeiro, et al., 2003). Such processes may relate to cognitive and affective responses (Winkielman, Schwarz, Reber, et al., 2003). This research even stresses that some affective response is always involved in evaluative judgments. These affective responses may be based on stimulus attributes and caused by the dynamics of information processing, i.e., by processing fluency (Winkielman, Schwarz, Fazendeiro, et al., 2003). *Processing fluency* is considered hedonically marked, such as that high fluency elicits positive affective reactions (Winkielman, Schwarz, Fazendeiro, et al., 2003).

The findings of this study may support a tendency towards such affectively congruent map symbols. Negative map topics in this research referred to rather dynamic spatiotemporal events (e.g., smog, floods, traffic accident). In contrast, positive and neutral topics predominantly referred to relatively static geospatial occurrences (e.g., national parks, biodiversity, art galleries, lookout tower). These different qualities may have influenced participants' congruence judgments, such as favoring dynamic character symbols for dynamic topics. Osgood et al. (1957), for example, referred to such dynamic qualities of stimuli as the affective dimension of *activit*y, for which he found "some relation to physical sharpness or abruptness" (p. 38).

Such particular stimulus-affect correspondences are supported by related empirical research on map symbols, which found that asymmetric star symbols were experienced as highly dynamic and of negative valence. In contrast, symmetric shapes were regarded as neutral or slightly positive and of relatively static quality (Klettner, 2020b). Related research further showed that point symbols are experienced visually, associatively, and affectively (Klettner, 2019). Topic-specific visualization preferences may have, thus, resulted due to either of these dimensions. These findings suggest that the principle of congruence may be a crucial factor in cartographic communication. Yet, future research is needed to dissect its dimensions and explore its effects in greater detail.

So far, this research provides the first empirical insights into symbol-content relations of such kind. Yet, the study also encompasses some shortcomings:

This research used a limited set of six map symbols. Besides the attempt to incorporate the most common abstract cartographic point symbols, the possible number of map symbols is sheer unlimited. At the same time, cartographic nominal point symbols used in practice may not only be manipulated by shape but also by color, size, and other qualities. In this study, such additional symbol properties were excluded deliberately, as they would have influenced the results. Future research may, however, extent the set of point symbols, such as by studying the influence of such additional symbol properties on congruence.

Future studies may also consider increasing the complexity maps, as the findings of this study are limited to monothematic maps of low visual complexity. In addition, the number of geospatial topics used in this study was limited to a selection of twelve topics. This also limits the findings' transferability of this research. Hence, despite studying a greater variety of point symbols and thematic maps of higher visual complexity, a more extensive set of map topics may be used in future studies. This would also help provide more insights into the external validity of this research.

Another shortcoming refers to the selection of map topics, which was undertaken a priori by the experimenter. Topics were selected to be of positive, neutral, and negative character. While statistical analysis confirmed such three homogenous clusters, results further showed a more proximal relation between the neutral and positive topic clusters with a greater distance towards the negative cluster. Mean ratings further showed that the neutral topics used in this study were rated slightly positive. As such, they may not be considered entirely neutral. The selection of maps towards a set of distinctively positive, neutral, and negative geospatial topics may be improved in future studies, such as by conducting prestudies for prior topic assessments.

Future research also needs to consider more heterogeneous groups of participants, as this study relied on students only. Participants of this study can be characterized as young adults with high education and a moderate to high affinity to graphic design and cartography. The findings of this research must, therefore, be considered restricted to this relatively homogeneous user group. Social semiotics further stress that "people respond culturally and engage emotionally with data and their visualizations" (Aiello, 2020a, p. 50). This is supported by research in cartography, which found that cultural backgrounds influence map perception and performance in cartographic visual search tasks (Stachoň et al., 2018). Such findings strongly imply the impact of cultural sign-conventions on map reading performances. Therefore, it is crucial to continue exploring the effects of cartographic design decisions from the perspectives and backgrounds of different user groups.

Conclusion

Maps are a form of communication: a means of conceiving, articulating, and structuring the human world (Harley, 2009/1988). Through cartographic signs and symbols, maps refer to phenomena and entities in geographic space in a generalized and abstracted way. Cartography generally strives for cognitively congruent map design to communicate geospatial information successfully. However, cartographic research has only started to understand the myriad of relations between the map as an external representation and internal human processes.

This research, therefore, drew attention to the principle of contextual congruence and empirically explored the cognitive correspondences between cartographic point symbols and different positive, neutral, and negative geospatial contexts. Findings strongly imply that context matters. Overall results revealed high congruences of Asymmetric Star symbols when representing negative map topics, whilst highly incongruent when depicting positive or neutral geospatial content. On the other hand, symmetric shapes generally corresponded with positive and neutral map topics while incongruent with negative content. As the meaning of point symbols showed to be susceptible to context, the findings infer that cognitive congruence may be enhanced by integrating context-specific information into the cartographic design, such as when form follows content.

Yet, while this research provided a first empirical basis, the findings aim to be expanded upon. Future research is needed to continue exploring the different semiotic dimensions of sign meanings and their role in cartographic communication processes. A profound understanding of the various context-related communication effects of cartographic signs may allow for more deliberate and informed design decisions. This may contribute to enhancing cartographic communication.

CHAPTER 8

STUDY 4
Point Symbols and Intuitive Judgments

This research has been submitted for publication: Klettner, S. (2021). The Significance of the Cartographic Sign: Influences of Symbol Shape on Intuitive Judgments. *Manuscript submitted for publication.*

Abstract

The maps we encounter in our daily lives have become simpler, smaller, and ever more present. Many of today's maps are designed to be processed fast, intuitively, in daily situations of quick use. At times, they are as simple as to represent only one incident by a single symbol. As neither maps nor maps signs are ever neutral, research on visual semiotics stresses exploring the implicit, connotative effects of signs on human responses. This study, therefore, assessed the influence of simplistic monothematic web maps on map users' judgments. In particular, it examined how the severity of negative geospatial events was perceived based on their depictions by different cartographic point shapes. In total, 72 maps (twelve negative topics, each

depicted by six map symbols) were rated by 82 participants. The results showed that asymmetric star symbols led to the highest estimates about the events' perceived severity, followed by symmetric star symbols. Triangle and rhomb led to the lowest ratings. Circle and square showed the most variable results: they led to high and low ratings dependent on the map's topic. The findings demonstrate that map symbols influence how people imagine geospatial events. These findings call for a more vigorous focus on the connotative meanings of visual signs in cartographic research and practice.

Introduction

Maps have changed profoundly in recent decades. The rise of new and well-accessible technologies, software, and data brought new opportunities for geo-visualization (Słomska, 2018) and subsequently transformed the way maps are made, used, and shared (Kent, 2018). Nowadays, maps are omnipresent, ubiquitous, transient, many of single purpose, many single-themed, created by people of different professions, and easily distributed through the world wide web (Field, 2014).

The web as a new medium to display maps, yet, also constrains the map design to, at times, very small physical display sizes. Thus, well-designed web maps are considered "relatively empty", and their design is recognized to require extra attention (Kraak & Ormeling, 2011, p. 79). Cartographic design decisions are critical. The map user will interpret the map and its content based on those cartographic choices (Monmonier, 1996) and construct internal representations and knowledge (Thompson et al., 2015).

As the maps we encounter in our daily lives have become ever more present, simpler, and smaller, the way we engage in maps has adapted. Regularly we use web maps in daily routines, such as when reading online news or when orienting or navigating in unfamiliar environments. Some of those maps may be designed to support decision-making. Others may be "treated and consumed as pictures"(Kent, 2018, p. 87) or "to provide quick visual delight and nothing more" (Field, 2014, p. 2). Today's web maps may be as simple as to represent only one incident indicated by a single map symbol; not designed to be cognitively processed deliberately or effortfully, but fast, incidentally, and associatively in daily situations of quick use (Evans, 2003; Kahneman, 2002; Kent, 2018). With these new mapping situations, the way the user engages with maps has changed accordingly.

As neither maps nor map signs are ever neutral (Aiello, 2020b; Leeuwen, 2005; MacEachren, 1995; Wood, 2010) they give rise to many possible meanings. Cartographic communication is a complex and multifaceted process (Board, 2011; Kent, 2018; Koláčný, 1969; MacEachren, 1995). It is a one between the map maker and map user, in which "thought originating in one human mind is converted by that mind into physical forms according to rules developed by the culture in which he [she] lives" (Petchenik, 1977, p. 184). It is one in which the map user apprehends the map and its elements to construct meaning by interpreting its elements and expressions (Petchenik, 1977; Thompson et al., 2015).

Cartographic communication from a triadic semiotic perspective conceives the signs as a threefold, interrelated structure between a signifier or *sign-vehicle* (i.e., the physical sign), a *referent* (i.e., a phenomenon or object of reference the sign-vehicle stands for), and an *interpretant*, which comprises the sign-vehicle's effects on the interpreter, such as its meaning (see Peirce's semiotic theory in Nöth, 1995). As mediators between things and meaning, sign-vehicles give rise to ideas or thoughts related to a referent. As such, they mediate between thing and meaning (MacEachren, 1995; Nöth, 1995).

As meanings are mental events, they are challenging to measure and challenging to distinctively define (Nöth, 1995; Osgood et al., 1957). However, most theorists have agreed on two core dimensions of meaning: the *dimension of reference* and the *dimension of sense* (for a synopsis, see Nöth, 1995). On the dimension of reference, all cartographic sign-vehicles can be considered identifiers which either apprise, inform, state, designate, indicate, label, or denote (MacEachren, 1995; Nöth, 1995). Beyond their denoting qualities, maps and map signs function on the dimension of sense, i.e., they connote, prescribe, express, and stimulate different associations (Keates, 1996; MacEachren, 1995).

Most cartographic semiotic research has focused on the dimension of reference by defining the denoting, explicit qualities of cartographic variables together with a set of semiotic rules to guide the cartographic design process (e.g., Bertin, 1974/1967). Yet, map signs may not only depict and denote but also express and connote (Howard, 1980). These connotative qualities can be as powerful as to modulate affective responses and cognitive processes, such as influencing learning, memory, attention, and decision-making, as related research shows (Barrett & Bliss-Moreau, 2009; Loftus & Palmer, 1974; Sianipar et al., 2016).

Loftus and Palmer (1974), for example, demonstrated how simple changes in the phrasing of a question (i.e., using different sign-vehicles) could significantly affect individuals' associations and responses towards a given scenario (i.e., the referent). The researchers tested participants' speed estimations after presenting short films about car accidents. Participants were asked to estimate the cars' speed when they 'contacted', 'hit', 'smashed', and the like. The results showed that the sheer wording significantly affected participants' judgments. The researchers also found a significant impact on people's memory. Participants in the study condition in which the verb 'smashed' was used remembered seeing broken glass. Yet, there was no broken glass in the scenes. This study showed that while sign-vehicles, such as single words, connote many different meanings.

Semioticians have long emphasized the two core dimensions of meaning, i.e., the dimension of reference and the dimension of sense, as essential parts in any form of human communication (Nöth, 1995). Both dimensions together form the meaning of signs (Sternberg, 2009).

Cartographic research has recently begun to explore the dimension of sense, with a focus on the implicit, connotative effects of cartographic design on human responses. Empirical research, for example, showed that supposedly simple changes in map design could lead to substantially different experiences and responses, involving trust in maps, likability, change in opinions, and recall (Muehlenhaus, 2012, 2013a). Different map styles can also lead to different affective responses (Christophe & Hoarau, 2013; Fabrikant et al., 2012) and impact map users' preferences and accuracy judgments (Jenny et al., 2018). Empirical research on abstract map symbols further suggests a significant influence on detection speed in visual search tasks (Stachoň et al., 2018) and on associative and affective responses based on symbol type (Klettner, 2019, 2020a, 2020b).

Smaller displays, the simplification of maps, and their ubiquitous yet incidental engagement call for research that examines the connotative effects of these new map types. The following empirical study, therefore, addressed the connotative meanings of map signs. It assessed the influence of simplistic monothematic map design on map users' intuitive judgments. Specifically, it examined how map users estimate the severity of geospatial events based on their representation by different abstract cartographic point symbols. *Severity,* in this research, is used as an umbrella term for an event's intensity, impact, or magnitude.

Empirical Study

Materials and Methods

An online survey was carried out to empirically assess the influence of abstract map symbols on map users' intuitive judgments. Twelve negative map topics were selected a priori by the experimenter (see Table 12).

Table 12. Twelve map topics used in the study.

ID	Map topics	Map topics in the German original	No. of Symbols
A	Armed Conflicts	*Kriegerische Auseinandersetzungen*	°
B	Traffic Accident	*Verkehrsunfall*	°
C	Villages with Drinking Water Scarcity	*Dörfer mit Trinkwasserknappheit*	°°°
D	Floods	*Überschwemmungen*	°
E	Melting Glaciers	*Schmelzende Gletscher*	°°°
F	Smog Polluted Cities	*Smogbelastete Städte*	°°°
G	Earthquake	*Erdbeben*	°
H	Gas Explosion	*Gasexplosion*	°
I	Wildfires	*Waldbrände*	°°°
J	Poverty Affected Neighborhoods	*Armutsbetroffenheit*	°°°
K	Avalanche	*Lawine*	°
L	Coral Bleaching	*Korallensterben*	°°°

Note: ° indicates one map symbol, °°° indicates three map symbols.

For each map topic, a set of six monothematic maps was created. Each map showed one of six abstract cartographic point symbols, i.e., circle, triangle, square, rhomb, symmetric star, and asymmetric star. Map symbols were displayed in black in 50 percent transparency.

Basemaps were created for each map topic and to thematically correspond. As a result, the basemaps used for the twelve map topics varied by content and scale. Topics that referred to events of a single location were depicted by maps displaying one map symbol, while topics referring to multiple locations were represented by three map symbols (see Figure 25 for examples). The final stimulus set comprised 72 maps based on six abstract cartographic point symbols employed for each of the twelve map topics.

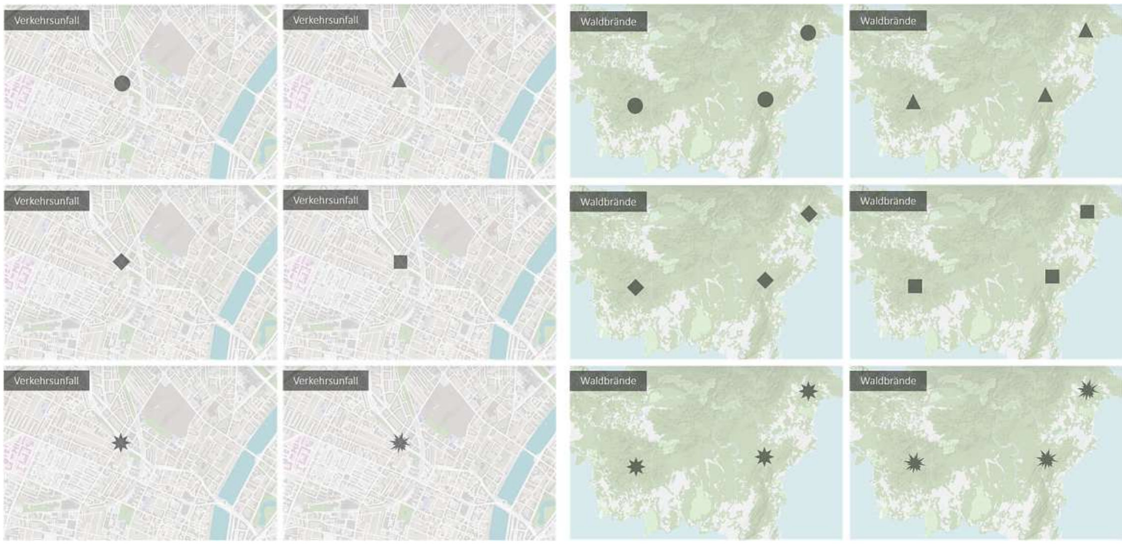


Figure 25. Examples of two map sets. Left (map set B): indicating a traffic accident by one point symbol per map. Right (map set I): locating wildfires by three symbols per map.

A repeated-measures design was applied, where each individual rated each of the 72 map stimuli. The study was carried out as an online survey in the German language using the software LimeSurvey (2019). The survey took approximately 15 minutes to complete and comprised the following sections:

- **Introduction:** The survey, first, briefly introduced the study's aim, i.e., to explore how maps and, in particular, point symbols are subjectively perceived. Afterward, participants were asked to proceed with the main tasks.
- **Map judgments:** In this primary task, participants were instructed to estimate the perceived severity (in German: "*Ausmaß*") of geospatial events based on the map symbols' shapes on a unipolar 11-point rating scale. The rating scale ranged from 0 (very low) to 10 (very high). Each map stimulus was presented individually, consecutively, and in a randomized order, at a size of 550 x 350 pixels.
- **Topic judgments:** After the map judgments, participants rated each map topic on an 11-point Likert scale, from 0 (neutral) to 10 (very negative). As this study aimed to focus on geospatial topics of negative valence, these topic ratings were obtained to conduct a pre-analysis to ensure the topics' perceived negative valence by the participants.
- **Inclusion criteria:** After the topic judgments, participants were instructed to indicate whether they had rated the maps based on symbol size, symbol shape, and/or map topic. Each of the three possible aspects was rated on a 5-point Likert scale, ranging from "always", "mostly", "sometimes", "hardly", to "never". Participants also had the option to indicate other aspects in an open-

ended format. These questions aimed to help include all those participants in the final data analysis who had at least "sometimes" rated the maps based on symbol shape.

- **Sociodemographic data** were gathered at the end of the survey regarding the participants' affinity for graphic design (self-evaluation on a unipolar 4-point rating scale, from "not at all" to "very affine", with the additional option for "no answer"), their affinity for maps or cartography (unipolar 4-point rating scale, from "not at all" to "very affine", or "no answer"), age, and gender. Participants were further asked to indicate the devices they used for completing the survey (i.e., desktop PC, laptop, tablet, or smartphone).

Participants

Participants were recruited from a Bachelor's course, "Thematic Cartography in Regional Planning", held in winter term 2020 at TU Wien, Austria. The online survey was sent to students in December 2020. It was a voluntary part of a course assignment for which students received course credits that counted towards their final grades.

In total, 95 students completed the questionnaire. Responses from 13 individuals were excluded from the data set that violated the inclusion criteria or showed tendencies of random responding[6]. This comprised participants who had "never" or "hardly" considered symbol shape (nine persons); who had based their judgments exclusively on symbol size (two persons); who had mentioned giving random responses (one person); and who had rated each of the twelve geospatial topics to be of neutral valence (one person). Hence, the final data set comprised responses from 82 participants used for data analysis (46 males, 33 females, no person of diverse gender, three missing responses).

The participants' age ranged from *Min* = 19 to *Max* = 43 years (*M* = 22.79, *SD* = 4.02). The majority of participants used laptops to complete the questionnaire (79.3%), followed by desktop PCs (20.7%). Participants indicated their affinity for graphic design to be moderate to high (somewhat affine = 25.6%; quite affine = 53.7%; very affine = 20.7%). The participants' affinity for cartographic design showed to be moderate in most cases (somewhat affine = 32.9%; quite affine = 52.4%) and high in 14.6% of the cases.

[6] *Random responding* refers to responses "in which individuals respond with little pattern or thought" (Osborne, 2013, p. 214). Random responding is a common pattern in research based on human responses and "a potentially significant threat to the power and validity of research" (Osborne, 2013, p. 214). Hence, cleaning data sets from random responses is a common procedure to enhance the quality of data and related findings (Buchanan & Scofield, 2018).

Results

Topic Analysis

Twelve topics were selected a priori for this study. To test their valence, participants rated each topic's negativity level from not at all (0) to very negative (10). The results are illustrated in Figure 26. All topics showed moderate to high negative valence, mean range [5.70 - 8.56]. Map topics of least negative valence were Map B – Traffic Accident followed by Map K – Avalanche. The topic, scoring highest on negative valence, was Map A – Armed Conflicts. As all topics revealed negative valence, each of the twelve map sets was used for further statistical analysis.

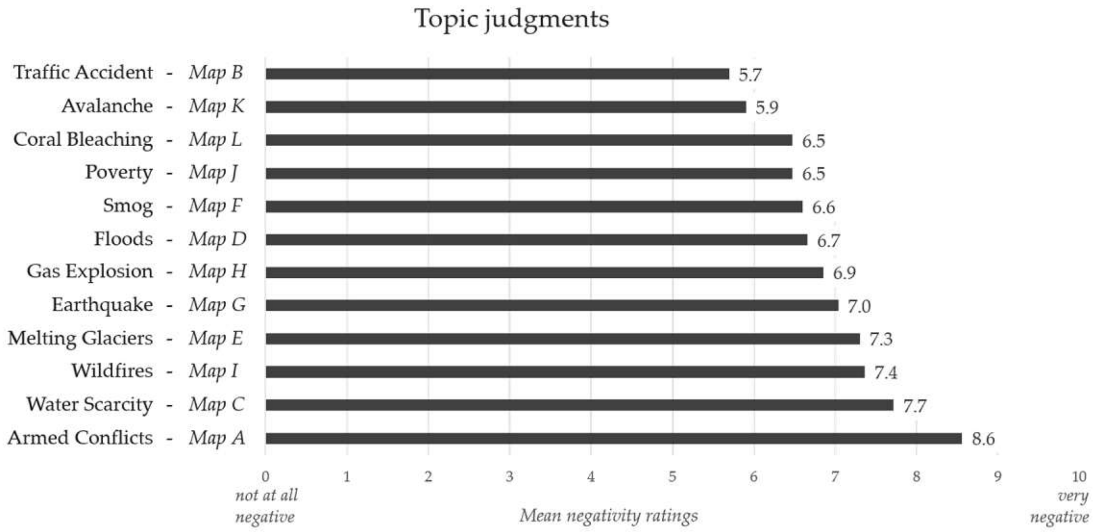


Figure 26. Mean topic ratings (N = 82), ranging from (0) not at all negative to (10) very negative.

Map Analysis

Results from participants' map ratings were subjected to one-way repeated measures analyses of variance (ANOVAs) to test for significant differences between map symbols and perceived severity. First, Mauchly's test of sphericity was employed for each map set to tests the hypothesis that the variances of the differences between conditions are equal (Field, 2009). For each of the twelve map sets, Mauchly's test indicated that the assumption of sphericity had been violated at $p < .001$, suggesting that the variances of the differences between the six symbol types of each map set are unequal (see Table 13). As the data violated the sphericity assumption, a Greenhouse-Geisser correction was applied. The Greenhouse-Geisser correction ($\acute{\varepsilon}$) "varies between 1/k – 1 (where k is the number of repeated-measures conditions) and 1. […] The closer that $\acute{\varepsilon}$ is to 1, the more homogeneous the variances of differences, and hence the closer the data are to being spherical" (Field, 2009, p. 461). The Greenhouse-Geisser further corrects the degrees of freedom used to assess the *F*-ratio (see df_G in Table 13). Hence, the results of the ANOVAs were interpreted according to this correction.

Table 13. Results of one-way repeated-measures analyses of variance (ANOVAs).

		Mauchly's Tests of Sphericity		Tests of Within-Subjects Effects		
ID	**Map topic**	***df***	χ^2	$\acute{\varepsilon}$	df_G	***F***
A	Armed Conflicts	14	68.98***	.73	3.63	63.24***
B	Traffic Accident	14	70.71***	.68	3.42	35.66***
C	Villages with Drinking Water Scarcity	14	50.25***	.79	3.96	13.16***
D	Floods	14	65.29***	.70	3.50	13.40***
E	Melting Glaciers	14	87.59***	.69	3.44	6.40***
F	Smog Polluted Cities	14	53.66***	.77	3.87	19.42***
G	Earthquake	14	39.99***	.81	4.06	26.78***
H	Gas Explosion	14	46.31***	.77	3.86	60.60***
I	Wildfires	14	50.84***	.81	4.05	18.34***
J	Poverty Affected Neighborhoods	14	81.45***	.63	3.17	13.94***
K	Avalanche	14	30.58***	.87	4.33	27.81***
L	Coral Bleaching	14	44.70***	.83	4.13	12.09***

Note: *df* represents degrees of freedom. χ^2 refers to Mauchly's tests of sphericity. $\acute{\varepsilon}$ indicates the Greenhouse-Geisser correction. df_G represents the Greenhouse-Geisser corrected degrees of freedom. *F* refers to Greenhouse-Geisser's corrected *F*-ratio. ***$p < .001$.

The results indicate that participants' judgments were significantly affected by symbol type at $p < .001$ in each of the twelve map sets (see Within-Subjects Effects in Table 13). All twelve ANOVAs suggest rejecting the null hypothesis. In other words, the results suggest that in each map set, at least one symbol led to significantly different judgments about the perceived severity of geospatial events.

Hence, post hoc tests were conducted to examine in more detail which of the symbols led to these significant differences. Post hoc procedures explore the data for between-group differences by comparing all possible combinations of pairs (Field, 2009). As such statistical procedures conduct multiple pairwise comparisons, they also correct the significance levels α, which is the probability of rejecting the null hypothesis given that it is true (also known as Type I error rate). Hence, a Bonferroni correction was applied as part of the post hoc analyses to ensure that despite multiple pairwise comparisons, the cumulative Type I error remains below .05 (Field, 2009). For detailed results on the pairwise comparisons, see Table A1 and Table A2 in Appendix. The pairwise comparisons revealed detailed differences for each set of map topics. The results of the Bonferroni-corrected pairwise comparisons are illustrated in Figure 27, with significant results marked with asterisks.

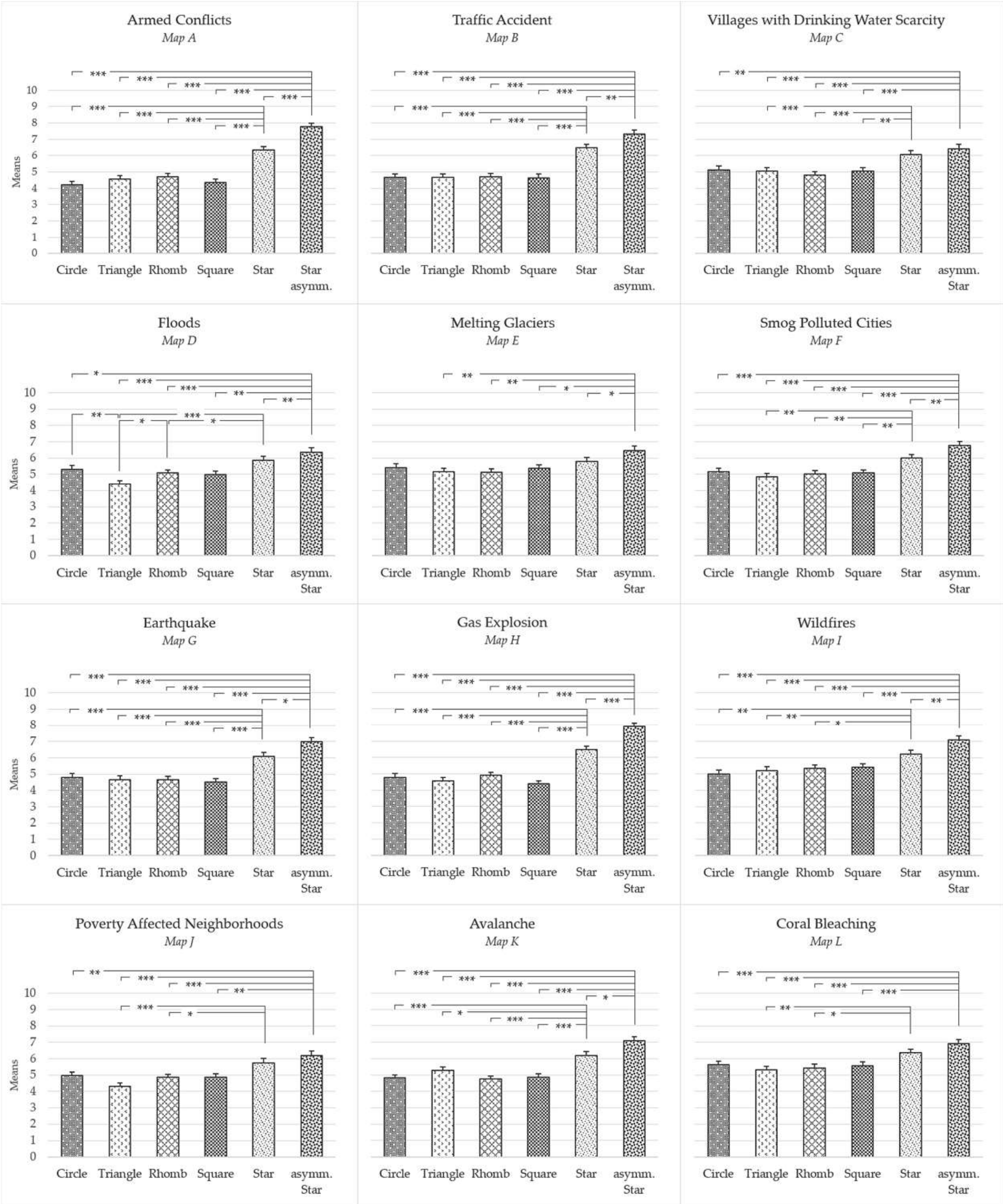


Figure 27. Mean severity judgments of twelve negative map topics ($N = 82$). Post hoc pairwise comparisons based on Bonferroni-corrected significance level. Note: ***$p < .001$, **$p < .01$, *$p < .05$.

Overall twelve map sets, the results revealed the following effects of symbol shape on participants' judgments:

Asymmetric star: The results across all maps show that geospatial events were rated significantly most severe when represented by asymmetric stars. In one case (Map E – Melting Glaciers), the ratings based on the asymmetric star did not significantly differ from the ratings based on circular point symbols. In all other cases, the asymmetric star involved significantly higher ratings than the four polygonal shapes of circle, triangle, square, and rhomb. In most cases, the ratings based on asymmetric star symbols were also significantly higher than those based on symmetric star symbols. Except in three cases (Map C – Water Scarcity, Map J – Poverty, Map L – Coral Bleaching), the judgments triggered by asymmetric stars did not significantly differ from the second-highest ratings based on symmetric stars.

Symmetric star: Overall maps, symmetric stars led to the second-highest severity estimations. In all cases except Map E – Melting Glaciers, ratings based on symmetric stars showed to be significantly higher than the ratings based on triangle and rhomb. In most map topics (seven out of twelve), symmetric stars led to significantly higher judgments about the depicted events than its representation by circles. These maps comprised Map A – Armed Conflicts, Map B – Traffic Accident, Map G – Earthquake, Map H – Gas Explosion, Map I – Wildfires, and Map K – Avalanche. A similar result was found for symmetric star and square: In seven out of twelve map topics, the depiction by symmetric stars led to significantly higher ratings than their depiction by squares (i.e., Map A – Armed Conflicts, Map B – Traffic Accident, Map C – Water Scarcity, Map F – Smog, Map G – Earthquake, Map H – Gas Explosion, and Map K – Avalanche.

Polygonal shapes: The four polygonal shapes, i.e., circle, triangle, square, and rhomb, generally involved the lowest severity ratings and did not significantly differ from each other. Only in one case (i.e., Map D – Floods), the topic depiction by triangle led to significantly lower ratings than its depiction by circle or rhomb. In all other cases, severity estimations based on polygonal symbols were indifferent. Yet, as aforementioned, participants' ratings based on circular depictions evoked at times equally high estimations as symmetric stars (i.e., in six cases: Map C – Water Scarcity, Map D – Floods, Map E – Melting Glaciers, Map F – Smog, Map J – Poverty, and Map L – Coral Bleaching). Similarly, in five cases, topic representations by square symbols led to equally high judgments as depictions by symmetric stars (i.e., Map D – Floods, Map E – Melting Glaciers, Map I – Wildfires, Map J – Poverty, and Map L – Coral Bleaching).

The findings strongly suggest that some cartographic point symbols significantly increase the perceived severity of negative geospatial events. In particular, the results indicate an overall tendency of star symbols (i.e., first, asymmetric stars, followed by symmetric stars) to trigger significantly higher judgments about the perceived severity of negative events than polygonal shapes. Triangle and rhomb involved the lowest severity judgments across all map topics. Circle and square suggest the most variable influence. Judgments based on these symbols led to partly high and low severity estimations depending on context. This finding suggests that circle and square imbue the most variable meaning potential among the tested cartographic point symbols.

Discussion

As visual means of communication, maps enable us to relate to geospatial phenomena and events from a viewpoint beyond direct experience. The visual variables employed in maps, such as map signs and symbols, are abstractions and generalizations, which give rise to ideas about their referents. From a semiotic perspective, map signs are signifiers or sign-vehicles that mediate between a referent and its associated meaning. These meanings can refer to the dimension of reference and the dimension of sense (Nöth, 1995). The dimension of reference comprises the explicit, denoting meanings of maps and map signs, while the dimension of sense comprises all implicit, connotative meanings of maps and signs (Keates, 1996; MacEachren, 1995; Nöth, 1995). Both semiotic dimensions of meaning require attention in cartographic communication.

This research explored the dimension of sense in monothematic web maps of intuitive, associative information processing (Kahneman, 2003). An online survey was carried out to empirically assess the influence of abstract map symbols on intuitive judgments. For this purpose, twelve map topics of negative valence were selected. Each map topic was represented by a set of six maps, employing the following six abstract point symbols: circle, triangle, square, rhomb, symmetric star, and asymmetric star. The empirical study employed a within-subjects design (i.e., a repeated-measures design), where each participant rated the severity (i.e., impact, magnitude, or intensity) of each of the 72 geospatial events.

The findings infer three distinct responses related to symbol shape: First, asymmetric star symbols increased participants' estimates across all map topics significantly. Second, symmetric stars generally involved second-highest estimations. Third, topic depictions by polygonal shapes generally led to significantly lower estimations. Circle and square, yet, showed the most variable, context-specific meanings among the polygonal shapes. In particular, they showed at times comparably high ratings as triggered by symmetric star symbols.

The results correspond with findings from related research, which explored the affective qualities of abstract cartographic point symbols and found that asymmetric star symbols were experienced as significantly more dynamic and negative, while symmetric shapes were rated as neutral or slightly positive, static, and calm (Klettner, 2020b). This study's results are further supported by a study on cognitive shape proximities, which found that star shapes cognitively belong to a different shape cluster than rounded and polygonal shapes (Klettner, 2019).

Besides the three overall shape-related tendencies, the findings further revealed some topic-specific differences. In particular, the two map topics, Map D – Floods and Map E – Melting Glaciers, revealed somewhat different responses. Floods emerged to be the only topic with significant differences between the polygonal shapes. In detail, participants' estimates based on the triangular shape stimulus led to significantly lower judgments compared to representations by circle and rhomb. The topic of melting glaciers also differed. It showed that asymmetric stars did not significantly differ from polygonal shapes and that asymmetric stars and circles led to similarly high estimates. These topic-specific patterns cannot be explained by the topics' level of negativity (see Figure 26). Both topics were rated moderately negative like the other topics. Future research is needed to explore the many possible reasons that may account for these topic-specific patterns.

Related research strongly suggests that when people make evaluative judgments, they draw from various sources, which may relate to cognitive and affective responses (Winkielman, Schwarz, Reber, et al., 2003). Research, for instance, found that abstract shapes may be judged based on their visual, associative, and affective meanings (Klettner, 2019). Qualitative and quantitative research is highly needed to continue exploring the possible dimensions and influences between particular shape-topic relations to allow for profound explanations about the general trends and the differences found in this research.

So far, this research provides empirical insights into the relations between cartographic point symbols and intuitive judgments. Yet, the study encompasses shortcomings as well:

This research used a limited set of six map symbols. Besides incorporating some of the most common abstract cartographic point symbols, the possible number of map symbols is unlimited. At the same time, cartographic point symbols used in practice may not only be manipulated by shape but also by color, size, and other qualities. Such additional symbol properties have been excluded deliberately from the study to control for potential confounders. However, future research is needed to expand on the set of point symbols and consider additional symbol properties, such as color, symbols size, and the like.

The findings of this research are so far limited to simplistic monothematic maps that involve intuitive, low-level information processing (Evans, 2008; Kahneman, 2003). Many maps require more deliberate responses based on reflective, higher-level information processing. Future research is needed to examine more complex map-related decision-making.

So far, the findings of this study are limited to research conditions. The number of geospatial topics was limited to twelve topics of negative valence. This relatively small set of map topics certainly limits the findings' transferability. Future studies may extend the set of map topics and incorporate also map topics of positive or neutral valence. Empirical studies in more applied and realistic map-use scenarios are also needed to test the findings' external validity and generalizability.

Another shortcoming refers to the convenience sampling method applied in this study. The study relied on student participation. Study participants can be characterized as young adults with high education and a moderate to high affinity to graphic design and cartography. The findings of this research are, thus, restricted to this relatively homogeneous user group. Future research may apply probability sampling to include participants with different backgrounds and experiences and to allow drawing conclusions for more heterogeneous groups of map users (Henrich et al., 2010).

Future studies may further explore sign-vehicle–referent judgments from different sociocultural perspectives. From a critical contemporary semiotic viewpoint, visual signs do not have a fixed or specific meaning based on predefined rules. Rather, they have *meaning potential*, based on past uses introduced by society and potential uses that "lie … latent in the object, waiting to be discovered" (Leeuwen, 2005, p. 5). Future research is needed to continue unraveling these latent, connotative meanings in map signs, both from an individual's and sociocultural perspectives.

Conclusion

The maps we encounter in daily lives have become ever more present and simple, many of single purpose and single-themed. Web maps may be as simple as representing only one incident by a single symbol, designed to be processed fast, intuitively, and in daily situations of quick use. Yet, little is known about how these new forms of cartographic communication from a map user's perspective. To better understand the effects of these new map types, this research, hence, examined the connotative effects of map symbols on users' intuitive judgments.

This study assessed how abstract cartographic point symbols influence judgments of negative geospatial events. The findings showed that asymmetric star symbols led to the highest severity ratings across all map topics, followed by symmetric star symbols. Triangle and rhomb led to the lowest ratings across all map topics. On the other hand, circle and square involved high and low severity estimations, depending on context.

The overall findings lead to the conclusion that cartographic signifiers are more than neutral identifiers but, through their connotative meanings, amplify people's judgments about geospatial events, thus implying an influence on how people image such events. Future research is needed to expand upon the findings of this research and to continue unraveling the connotative meanings of map signs and their effects on human judgments. A better understanding of the various denotative *and* connotative effects of cartographic signs may allow for a more holistic understanding of cartographic communication.

Part III

Discussion & Conclusion

CHAPTER 9

Discussion

Summary

Maps are a means of human communication. Through the use of signs and symbols, maps enable us to communicate about geographic space and to relate to spatial phenomena from viewpoints beyond direct experience. As maps are symbolized representations, cartography is deeply concerned with the use of map signs and the meanings they induce.

As signs are polysemic, they give rise to denotative and connotative meanings. So far, cartographic research has primarily focused on the denotative, referential meanings *in* maps (e.g., Bertin, 1974) while disregarding the connotative meanings *of* maps and map signs (MacEachren, 1995). Critical approaches to visual semiotics yet, stress advancing this perspective towards encompassing both meaning dimensions in research and practice (Aiello, 2020b; Kress, 2001; Leeuwen, 2005).

This dissertation, thus, drew attention to the dimension of connotation in cartographic communication. In four empirical studies, it focused on unraveling some of the *connotative meanings of cartographic point symbols* and their effects in simple, monothematic maps from a cognitive-affective user perspective. In doing so, this research aimed to contribute new and empirically grounded insights to the field of critical cartosemiotics.

The following questions guided the research:

- *RQ1*: *Which geometric shapes are experienced to be (dis)similar and why?*
- *RQ2: Which affective responses do (carto)graphic point symbols involve?*
- *RQ3: Which cartographic point symbols are (in)congruent to which type of content?*
- *RQ4: Do cartographic point symbols influence how geospatial events are judged?*

The first empirical study addressed RQ1 (Chapter 5). To answer if – and if so, how– abstract shapes differ, the study used the concept of similarity (or sense of sameness) to disclose the cognitive relatedness of abstract symmetric symbols. It quantified the shapes' cognitive proximities and revealed three homogeneous sub-clusters: a cluster of round shapes, one of polygonal shapes, and one of spiked shapes. The results further suggest that polygonal and rounded shapes share a cognitive meta-concept, which distinguishes them from spiked, star-like shapes. As such, the study demonstrated that abstract shapes cognitively differ. Moreover, it revealed that simple, geometric shapes triggered responses beyond their visual characteristics, i.e., leading to associative and affective responses.

The findings of the first study set the theoretical basis for the three subsequent studies. They explored the associative and affective meanings related to symbol shape in cartographic contexts.

Study 2 addressed RQ2 (Chapter 6). It examined and compared the affective qualities of symbol shape in non-cartographic and cartographic contexts in greater detail. The study demonstrated that abstract point symbols connote on the affect dimensions of valence and dominance. It revealed that asymmetric star stimuli led to highly negative and dynamic affective responses that persisted over non-cartographic and cartographic conditions. Polygonal shapes, on the other hand, involved moderate affective responses. Among the polygonal shapes, circular shapes revealed high positive responses – yet, only when presented isolatedly.

Study 3 addressed RQ3 and focused on unraveling content-related symbol congruences (Chapter 7). The study revealed distinct correspondences between cartographic point symbols and positive, neutral, and negative map topics. It showed that polygonal shapes were most congruent with positive map topics, circular symbols were most congruent with neutral map topics, and asymmetric stars were most congruent with negative topics. The study demonstrated that the meaning of cartographic point symbols is susceptible to context. This, in turn, suggests that cartographic design may be enhanced when guided by context.

Study 4 addressed RQ4 and drew attention to the effects of cartographic point symbols on intuitive judgments (Chapter 8). The study demonstrated that cartographic point symbol influence how negatively geospatial events are interpreted, respectively judged. Asymmetric star symbols led to the highest ratings about the perceived severity of the depicted events, followed by symmetric star symbols. Triangle and rhomb led to the lowest estimates. Circle and square showed the most variable results: they led to high and low ratings depending on map topic. As such, circle and square suggest imbuing the most variable meaning potential.

When comparing the studies' findings, we see that point symbols that were negatively connoted were also considered most congruent with negative geospatial events. Yet, they also led to the highest estimates about the severity of negative events. This is a critical finding. It leads back to one of the most fundamental questions in cartographic theory and practice: Which map symbol to choose? In other words, when to employ map symbols with high contextual congruence yet, high connotative potential? And when to choose symbols with lower contextual congruence yet, lower connotative potential? So far, the findings indicate a possible trade-off. However, as this research could only contribute first empirical insights, future research is needed to answer these crucial questions.

At this point, the cumulative findings of this dissertation research lead to the following conclusions:

- **Cartographic point symbols connote on multiple levels.** Beyond their visual characteristics, abstract point symbols give rise to associative and affective meanings.
- **Symmetric point symbols have distinct cognitive relations and hierarchies.** Symmetric point symbols can be assigned to three clusters: one cluster of round shapes, one of polygonal shapes, and one of spiked shapes. Polygonal and rounded shapes are cognitively more proximal to each other while more distant to spiked, star-like shapes.
- **Symbol connotation corresponds with topic connotation.** Negatively-connoted symbols (such as asymmetric stars of highly negative affective qualities) are most congruent with negative map topics. Positively-connoted symbols (such as polygonal symbols) are congruent with both positive or neutral map topics.
- **Cartographic point symbols influence the interpretation of geospatial events.** Depictions by star symbols increase the estimated severity of negative events. Rhomb and triangle lead to lower perceived severities. Circle and square influence more variable, i.e., context-specific.

Critical Reflection

Strengths

This dissertation focused on a scarcely researched topic in cartography, i.e., connotation in cartographic communication. So far, cartographic research has predominately focused on the denotative dimension of reference, despite semioticians emphasizing the connotative dimension of sense as an integral and crucial factor in any form of human communication (Morris, 1938; Peirce in Nöth, 1995). As semiotic differentiations have hardly been considered in cartographic research and practice (Keates, 1996; MacEachren, 1995; Nöth, 1998), "the difference of what a map sign means and what it represents has become blurred" (MacEachren, 1995, p. 245). By focusing on the connotative meanings of map signs, this dissertation contributed new and empirically grounded insights to the field of cartosemiotics.

This dissertation used an interdisciplinary research approach to study the connotative meanings of map signs. This research integrated theories and approaches from cartography, semiotics, and psychology. It complemented different theoretical and methodological research perspectives, which is considered another strength of this research.

This research applied a mixed-method approach to study the connotative meanings of map signs. It combined qualitative and quantitative research methods. Quantitative methods were used to identify significant differences between stimuli, while the collected qualitative data were used to explain quantitative effects. With this triangulation approach, this research provided a diverse empirical basis and contributed to a more holistic understanding of how map signs connote from diverse methodological perspectives.

This research further used a controlled research approach. It systematically studied the impact of symbol shape, first, in non-cartographic and, later, in cartographic contexts. This research approach is considered another strength of this research as it allowed isolating the variables of interest and systematically explaining their effects (Kosara & Haroz, 2018). This careful isolation of variables allows future researchers to test the findings' replicability and determine whether the results can be generalized to other scenarios of different map design and cartographic tasks.

Limitations

As any research study has not only strengths but also shortcomings, also this research encompasses limitations.

When people make choices, they always do so in particular mindsets and contexts that activate specific memory contents, making related constructs more accessible (Berger et al., 2008; Ross & Nisbett, 2011). These processes influence associations and behaviors, even without awareness (Darley & Daniel Batson, 1973; Yi, 1990). As such, the meaning of map signs may constantly change, given different environments, cultures, and contexts (Hout et al., 2013; Kress, 2001; Leeuwen, 2005). In the light of these considerations, this research could only cover a small range of possible maps and map-use scenarios. As such, the findings' generalizability and transferability must be regarded limited.

This research studied simplistic monothematic maps that require low-level intuitive information processing. While simple, relatively empty web maps have become ever more prevalent in our daily lives (Field, 2014; Kraak & Ormeling, 2011), there are undoubtedly many more complex maps, which require more reflective, higher-level information processing (Evans, 2008; Kahneman, 2003). As this research exclusively studied user responses towards highly simplified maps, the findings are restricted to these map types.

The empirical studies of this research used a limited number of map symbols. Besides the attempt to incorporate the most prevalently used abstract point symbols (Arnheim, 1974; Bertin, 1974; Klee, 1920), the number of possible map symbols is sheer unlimited. Moreover, point symbols used in cartographic practice may not only be manipulated by shape but also by other properties, such as color, symbol size, and the like (Bertin, 1974; MacEachren et al., 2012). Such symbol properties were treated as potential confounders in this research and were excluded from this research. Future studies may, however, expand the stimulus set and consider more symbol properties and their combinations.

Also, the number of map topics was limited in this research. It encompassed a small set of positive, neutral, and negative geospatial topics. The relatively low number of map topics studied in this research certainly limits the findings' transferability and should be extended in future studies to ensure the findings' external validity.

Another limitation of this research refers to its sampling method. The studies used undergraduates from the studies of Urban and Regional Planning. As such, this research used convenience samples. Convenience sampling is a non-probability sampling technique based on the availability of participants. This shortcoming is regarded as the most critical one of this research. It limits the findings' generalizability to a relatively homogeneous group of people: young adults with high education and moderate to high affinity for design and cartography. Henrich et al. (2010) labeled such student samples as *WEIRD* for people from Western, educated, industrialized, rich, and democratic societies. The authors stress that such a sample group cannot account for the diverse cognitive and motivational processes that vary across populations, as many differences "stem from the way in which populations have adapted to diverse culturally constructed environments (Henrich et al., 2010, p. 29). It is, thus, crucial to apply representative sampling methods in future studies to more accurately encompass the extent of human diversity.

Theoretical Implications

This research demonstrated that cartographic point symbols connote on multiple levels. Theoretical semiotic discourses strongly support this finding, emphasizing the many possible meanings of signs (Crampton, 2001; Harley, 1989; Kress, 2001; Leeuwen, 2005; Morris, 1946; Nöth, 1995). By providing a differentiated perspective on the potential connotative meaning dimensions of visual signs, this dissertation contributes empirical findings to the field of visual semiotics.

From a cartographic research perspective, the findings of this research expand the perspective of map signs as purely referential symbols. In cartographic semiotic research, connotative dimensions of map signs have largely been disregarded or treated as a second-order meaning dimension of lower relevance. Consequently, cartographic semiotic frameworks are usually based on logic sign-referent relations (e.g., Bertin, 1974). The connotative effects of cartographic signs have, yet, largely been neglected. The findings of this research, however, demonstrate their relevance.

This research provided empirical evidence that putative simple map signs give rise to meanings beyond their purpose as referential markers. It showed that map symbols evoke affective responses, lead to content-specific correspondences, and influence intuitive judgments. As such, the findings of this research challenge existing cartographic semiotic frameworks. How far do existing cartosemiotic frameworks encompass the most relevant semiotic meaning dimensions that cartographers need to consider when making maps? In other words, are the denoting semantic relations addressed in cartographic semiotic frameworks enough to guide the map-making process?

Future research is needed to answer these fundamental questions and to continue studying the role of connotation in cartographic communication. With a more comprehensive understanding of the denotative *and* connotative meanings of map signs, a more holistic, polysemic cartographic framework may be established.

Practical Implications

The selection for the most appropriate cartographic symbol remains a challenging task until today, despite extensive cartographic cognitive research (e.g., Fabrikant et al., 2010; Griffin et al., 2017; MacEachren, 1992; Montello, 2002; Padilla et al., 2018). A better understanding of the subtle, connotative meanings of cartographic symbols and their effects on human responses may help to design more intuitive and associative maps. The findings of this can thus serve as a first empirical basis to inform cartographic design decisions and to contribute to improving (semi-)automated processes of map design and GIS tools in the long run.

At this point, this research provides two empirical findings which may be used in today's cartographic practice, i.e., the selection of visual map symbols based on their cognitive proximities and the selection of map symbols based on their affective and associative qualities:

Symbol selection by cognitive proximity space

This research provides a first empirical basis on the perceived similarities of geometric shapes (Chapter 5). Three homogeneous groups were identified: one group comprising round shapes, one of polygonal shapes, and one of spiked shapes. Findings further indicate that round shapes and polygons are cognitively more proximal to one another, while cognitively more distant to spiked shapes.

The concept of similarity (or sense of sameness) is pivotal to cognitive and communication sciences. By identifying similarities between two stimuli, part of the stimuli's cognitive structure and relatedness can be revealed. Stimuli that are perceived as more similar can be regarded as more cognitively related. It is, therefore, particularly beneficial to have a quantitative estimate of the proximity between cartographic variables. This allows appropriate discriminations between them.

As the selection for the most suitable visual variable remains a challenge in the map-making process, the proximity space and the hierarchical structure uncovered can help map-makers to discriminate between cartographic point symbols based on these empirical findings. Similar information may, for instance, be represented by symbols that are cognitively more proximal, whilst dissimilar information may be depicted by symbols that are cognitively more distant.

Symbol selection by affective and associative responses

This dissertation further uncovered some of the implicit affective and associative meanings of cartographic point symbols. This research contributed a detailed differentiation of some of the most prevalently used point symbols on the two affective dimensions of valence and dominance (Chapter 6). It provided empirical insights into the perceived congruences between cartographic point symbols and positive, neutral, and negative map topics (Chapter 7). This research further demonstrated the consequences of cartographic symbolization on how geospatial events are interpreted, respectively judged (Chapter 8).

These empirical findings may be used as first guidance for map-makers to select between cartographic point symbols based on their connotative meanings. Yet, the findings provide only an initial empirical basis. More research is needed to allow establishing a solid foundation for guiding cartographic decision-making.

Future Directions

This dissertation demonstrated that putative simple map signs connote. It provided empirically grounded findings that have implications for cartosemiotic theory and cartographic practice. Future research is, however, needed to allow drawing conclusions for different map types, map use scenarios, and map users:

As this dissertation focused on the effects of abstract point symbols in simple monothematic maps, the findings of this research are limited to map-use scenarios of low-level, intuitive processing. Many more complex maps involve higher cognitive load demanding reflective, high-level reasoning (Evans & Stanovich, 2013; Kahneman, 2003). Quantitative and qualitative research studies are, thus, needed to explore the connotative effects of map signs in more complex map-use scenarios and different applied cartographic contexts. Findings will help explain how far the effects found in this research prevail in more complex map-use scenarios.

At the same time, there are many more possible sign properties apart from a symbol's shape, such as color, pattern, symbol size, and so forth. In cartographic practice, they are used in many combinations. As the possible combinations of these characteristics are sheer unlimited, they allow for creating a great variety of different stimulus materials and combinations for exploring their connotative effects in future studies.

Future research is also needed to more fully explore the potential meanings of map signs from the perspectives of different user groups. The studies of this research used a convenience sampling method and, thus, derived its findings from a relatively homogeneous group of study participants. It is, however, crucial to apply probability sampling in future studies to meet the criterion of representativeness and to allow drawing conclusions for the general population (Henrich et al., 2010).

Critical semiotics, further, stress that the meanings of visual signs are dynamically changing (Aiello, 2020b). Meanings are based on past and potential uses introduced by society, lying "latent in the object, waiting to be discovered" (Leeuwen, 2005, p. 5). Future research is needed to continue unraveling these latent, connotative meanings of map signs within and between different socio-cultural contexts.

At this point, this research provided a first empirical foundation, demonstrating that visual signs give rise to meanings on various connotative dimensions. Against this background, it is all the more important to continue exploring the connotative meanings and effects of cartographic signs. In doing so, an integral cartosemiotic framework may be established in the future, one that encompasses both denotative *and* connotative meanings of map signs.

CHAPTER 10

Conclusion

Cartographic maps are never documents of truth. They are selective and subjective representations of conceptions of reality, based on simplifications, abstractions, and generalizations (Downs & Stea, 2011; Monmonier, 1996; Tversky, 2000). As such, they are a powerful means for articulating and structuring the human world, influencing our conception of geospatial reality (Harley, 2009/1988). A profound understanding of how maps and map signs communicate is, therefore, crucial.

This dissertation was devoted to the study of connotation in cartographic communication. It aimed to contribute to a better understanding of the connotative meanings of cartographic symbols and their implicit effects on map users' affective and associative responses.

Four studies were conducted to explore the connotative meanings of abstract cartographic point symbols. The empirical findings demonstrate that cartographic symbols give rise to meanings beyond the denoting dimension of reference. Cartographic point symbols were found to communicate visually, associatively, and affectively. This research further revealed their cognitive proximities and hierarchies, disclosed their affective qualities, identified symbol-content congruences, and demonstrated that by changing the shape of the cartographic signifier, geospatial events are interpreted and judged differently.

This dissertation, thus, provided a diverse empirical basis of how cartographic signs connote. The findings emphasize the polysemy of cartographic signs and the need for considering their diverse meanings in cartographic research and practice.

Appendix

Appendix – Chapter 8

Table A1. Post hoc pairwise analyses of map sets A-F.

			Post hoc analysis					
ID	**Map topic**	**Symbol**	Circle	Triangle	Rhomb	Square	Star	Star asymm.
A	Armed Conflicts	Circle	-					
		Triangle	1.000	-				
		Rhomb	.380	1.000	-			
		Square	1.000	1.000	.985	-		
		Star	**.000*****	**.000*****	**.000*****	**.000*****	-	
		Star asymm.	**.000*****	**.000*****	**.000*****	**.000*****	**.000*****	-
B	Traffic Accident	Circle	-					
		Triangle	1.000	-				
		Rhomb	1.000	1.000	-			
		Square	1.000	1.000	1.000	-		
		Star	**.000*****	**.000*****	**.000*****	**.000*****	-	
		Star asymm.	**.000*****	**.000*****	**.000*****	**.000*****	**.009****	-
C	Villages with Drinking Water Scarcity	Circle	-					
		Triangle	1.000	-				
		Rhomb	1.000	1.000	-			
		Square	1.000	1.000	1.000	-		
		Star	.067	**.000*****	**.000*****	**.006****	-	
		Star asymm.	**.002****	**.000*****	**.000*****	**.000*****	1.000	-
D	Floods	Circle	-					
		Triangle	**.001****	-				
		Rhomb	1.000	**.018***	-			
		Square	1.000	.188	1.000	-		
		Star	1.000	**.000*****	**.032***	.052	-	
		Star asymm.	**.046***	**.000*****	**.000*****	**.001****	**.001****	-
E	Melting Glaciers	Circle	-					
		Triangle	1.000	-				
		Rhomb	1.000	1.000	-			
		Square	1.000	1.000	1.000	-		
		Star	1.000	.372	.144	1.000	-	
		Star asymm.	.059	**.005****	**.001****	**.026***	**.017***	-
F	Smog Polluted Cities	Circle	-					
		Triangle	1.000	-				
		Rhomb	1.000	1.000	-			
		Square	1.000	1.000	1.000	-		
		Star	.100	**.001****	**.004****	**.002****	-	
		Star asymm.	**.000*****	**.000*****	**.000*****	**.000*****	**.007****	-

Note: $N = 82$. Bonferroni-adjusted significances for multiple pairwise comparisons; $^{***}p < .001$, $^{**}p < .01$, $^{*}p < .05$.

Table A2. Post hoc pairwise analyses of map sets G-L.

ID	Map topic	Symbol	Post hoc analysis					
			Circle	Triangle	Rhomb	Square	Star	Star asymm.
G	Earthquake	Circle	-					
		Triangle	1.000	-				
		Rhomb	1.000	1.000	-			
		Square	1.000	1.000	1.000	-		
		Star	**.000*****	**.000*****	**.000*****	**.000*****	-	
		Star asymm.	**.000*****	**.000*****	**.000*****	**.000*****	**.017***	-
H	Gas Explosion	Circle	-					
		Triangle	1.000	-				
		Rhomb	1.000	1.000	-			
		Square	1.000	1.000	1.000	-		
		Star	**.000*****	**.000*****	**.000*****	**.000*****	-	
		Star asymm.	**.000*****	**.000*****	**.000*****	**.000*****	**.000*****	-
I	Wildfires	Circle	-					
		Triangle	1.000	-				
		Rhomb	1.000	1.000	-			
		Square	1.000	1.000	.570	-		
		Star	**.001****	**.004****	**.014***	.054	-	
		Star asymm.	**.000*****	**.000*****	**.000*****	**.000*****	**.001****	-
J	Poverty Affected Neighborhoods	Circle	-					
		Triangle	.089	-				
		Rhomb	1.000	.116	-			
		Square	1.000	.101	1.000	-		
		Star	.234	**.000*****	**.012***	.057	-	
		Star asymm.	**.009****	**.000*****	**.000*****	**.001****	.543	-
K	Avalanche	Circle	-					
		Triangle	1.000	-				
		Rhomb	1.000	.441	-			
		Square	1.000	1.000	1.000	-		
		Star	**.000*****	**.014***	**.000*****	**.000*****	-	
		Star asymm.	**.000*****	**.000*****	**.000*****	**.000*****	**.016***	-
L	Coral Bleaching	Circle	-					
		Triangle	1.000	-				
		Rhomb	1.000	1.000	-			
		Square	1.000	1.000	1.000	-		
		Star	.071	**.001****	**.010***	.172	-	
		Star asymm.	**.000*****	**.000*****	**.000*****	**.000*****	.227	-

Note: $N = 82$. Bonferroni-adjusted significances for multiple pairwise comparisons; $^{***}p < .001$, $^{**}p < .01$, $^{*}p < .05$.

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