Đurđica Živković
6281496
Bachelor Computer Science
11. Semester
s3946437@stud.uni-frankfurt.de

Bachelor-Thesis

Principles of Cognitive Maps

Presented by

Đurđica Živković

Text Technology Lab
Goethe University Frankfurt

First examiner: Prof. Dr. Alexander Mehler

Vienna, October 4, 2021

Abstract

This thesis analyses the concept of a cognitive map in the research fields of geography. Cognitive mapping research is essential as it investigates the relations between cognitive maps and external representations of space that people regularly use by acquiring spatial knowledge, such as maps in geographic information systems. Moreover, cognitive maps, when expanded on semantic maps, explain the relations between people and things in a non-physically environment, where the considered space is not spanned by distance but with other non-spatially variables. Nevertheless, cognitive maps are often distorted. Although a good formation of a cognitive map is vital in navigation processes, cognitive distortions are barely investigated in the field of geography. By analyzing the relevant work, especially Tobler's first law of geography, a new lexical variant of Tobler's first law could be stated that could presumably describe a specific distortion in the processing of landmarks in cognitive maps.

Contents

List of Figures

1 Introduction

“We organize stuff in the world the way we organize stuff in the mind” ([80], ch. 10). These are the words the famous professor of psychology, Barbara Tversky, used to define the 9th law of cognition, explaining how our mind forms the structure in our everyday life. According to Tversky ([78], pp. 14-15), our brain constructs the mental representations of our surroundings that help us in reorientation, navigation through space, and perspective-taking. She further states that these mental representations are often metaphorically referred to as *cognitive maps*, though a term map can lead to misunderstandings.

Although maps in geography used to be considered generally as a tool, they certainly are a scientific product, which is crucial in geographic information science ([21], p. 344). Over the centuries, the map has become an essential method for storing and representing the knowledge of the earth's surface ([29], p. 709). With further development of computers, on-screen maps became more popular, and all that led to the digitalization of geospatial data and the development of the first software packages with geospatial data known as *Geographic Information Systems* ([42], p. 1). First Geographic Information Systems were developed in the 1960s, and they served as the computer application for managing large amounts of geographic information that would otherwise be very difficult to do by hand on regular maps ([29], p. 709). As the internet became more accessible among the general public, individuals had the opportunity to easily generate and share their (geographic) data with the rest of the world ([42], p. 1). It all resulted with the phenomenon known as *user-generated content* and later with its special case called *Volunteered Geographic Information* ([28], p. 212).

1.1 Personal Motivation

As I have begun my research on the cognitive maps and spatial concepts in geography, I found it very interesting, especially the overall representation of maps: from cognitive maps in human navigation to map structures in geographic information science. As a result of the overall representation of maps, the knowledge of cartography, maps, and geography is used in various scientific research projects. For instance, in the current pandemic situation, scientists used many geospatial techniques to understand the spread mechanism better and examine the spatial distribution of COVID-19 cases, using mapping methods and Geographic Information Systems ([37], p. 1).

Since the research field of cognitive maps in geography caught my interest, I am going to clarify the essential aspects of geographic information science in general and emphasize the importance of cognitive maps in them through the idea of Tobler's first law of geography.

1.2 Aims, Objective and Structure of Thesis

The first two chapters of my thesis should give the reader a detailed introduction to maps and Geographic Information Systems as a visualization tool. Additionally, I am going to explain cognitive maps and how they are formed in our minds. Moreover, I will touch on the importance of humans' ability to navigate, the role of salient landmarks in it, and spatial distortions that often occur in orientation with landmarks.

Subsequently, I intend to explain what Volunteered Geographic Information is and state some well-known projects established with Volunteered Geographic Information.

Furthermore, I will introduce the reader to the First law of geography, most known as Tobler's First Law. As a result of my research, I am going to present Tobler's First Law as an intersection of cognitive maps and Volunteered Geographic Information research.

1.3 Research Questions

The purpose of my work is to show the relevance of cognitive maps in geography and geographic information science. Therefore, I will demonstrate common spatial bias in Volunteered Geographic Information and cognitive distortions in cognitive maps by examining and ultimately comparing various scientific articles on this topic. Accordingly, the main research questions are:

1. Could these common spatial biases in medially conveyed Volunteered Geographic Information be explained with Tobler's First Law?
2. How could Tobler's First Law be used to explain distortions in cognitive maps?

2 Visualization of Geospatial Data

As stated by Harvey ([33], p. 3), owing to geographic information and maps, we have the knowledge of the world in the form that we have today: People use map-like presentations regularly to verify and expand their spatial knowledge, and so they learn the things they otherwise never would. However, he explains that the environment surrounding us compared to maps of that same environment often displays many differences: some elements are missing, others are simplified or exaggerated.

According to Kraak and Ormeling ([42], p. 4), the process of understanding, storing, and learning geospatial data includes several different stages of spatial visualization formation. As it can be seen in the figure 2.1, objects in the space that is surrounding us can be captured and recorded with different techniques. Initially, the captured GI is selected and presented in a digital landscape model and later in a digital cartographic model that also serves as a database. These models are then displayed on maps (permanent or on-screen maps). Consequently, the users reading and studying these maps form a cognitive map containing the geospatial data processed into an idea about space ([42], p. 6).

Correspondingly, I distinguish the three visualization grades of geospatial data related to my research: maps in cartography, Geographic Information System (GIS), and cognitive maps. This chapter will present maps, GIS, and cognitive maps, their history, and their uses in everyday life.

2.1 Map as a Visualization Tool

Maps are one of the earliest artifacts humans have used ([25], p. 80). First maps were engraved with figures of humans, animals, houses, paths, and central points ([73], pp. 2-3). Early paper maps were drawn in 3D from a planar perspective. As maps began to adopt aerial perspective, many symbols for buildings and objects kept 3D orientation, e.g., church as a box with a cross on top ([47], as cited in [35], pp. 31-32).

As a mechanism utilized to visualize geospatial data, people use maps to understand geospatial relationships better ([42], p. 1). A map can be considered as a spatial information system and a reliable tool to inspect an area that gives the reader essential answers about an area, such as distances between objects, position, direction, size of an area, and nature of the patterns ([41], p. 40). In this way, maps act as an interactive interface between humans and the environment ([26], p. 102). The map also serves as a storage and communication tool for spatial knowledge that can convey various information on spatial relations between objects, present the results of analyses, and overall support humans in decision making ([46], p. 241). They represent the natural way people think and communicate about space, so the small children can also produce them ([25], p. 80).

Although it is impossible to represent the earth's surface perfectly, maps can portray the relative geographic information of the spatial features where the surface of the earth is portrayed on a plane projection ([21], p. 345). Maps are usually two-dimensional for various reasons. It is easier for cartographers to represent space in two dimensions, but also because people already perceive the environment as two-dimensional sketches, thus three-dimensional information can sometimes even be redundant ([77], p. 73). However, to make effective maps, cartographic rules or cartographic grammar should be followed ([42], pp. 2-3).

Maps are mainly designed to convey information. Another characteristic of maps stated by Tversky is that they are a simplified representation of the real world and are adapted to users ([77], p. 74). Thus, sometimes, cartographers distort maps to omit unnecessary data and provide users with easily understandable, more readable spatial data ([26], p. 104). The purpose of this kind of regularization of maps is to communicate just the needed information and omit irrelevant information. An example of that regularization is the London subway map. This schematic map mainly consists of straight lines, ignoring the fine distinction of curves ([77], p. 74; [26], p. 104). Maps can also have inconsistent scales or perspectives, e.g., a tourist map could have city streets presented with a frontal view of famous landmarks so that tourists can find the landmarks easier ([77], pp. 74-75).

2.2 Geographic Information System

We live in a time of digitalization. The new technology is evolving very fast and is becoming the main component of how we perform the tasks in our life. Hence, the maps evolved as well. Nowadays, the maps we use for finding objects and routes or for planning events and activities are often generated in just one application on our smartphones ([14], ch. 1). With this new technology, people can now do things that previously only experienced scientists could ([33], p. 8). The system that makes it possible and contains all this spatial information is called Geographical Information System (GIS) - the symbiosis of the newest information technology for processing geographic information with cartography and geography [33], p. 8).

One of the commonly accepted definitions of GIS is undoubtedly the one by Dueker and Kjerne. They described GIS as “A system of hardware, software, data, people, organizations, and institutional arrangements for collecting, storing, analyzing, and disseminating information about areas of the earth” ([20], pp. 7-9, as cited in [33], pp. 297-298). According to Harvey ([33], pp. 297-298), this well-known definition of GIS includes the most significant stakeholders of our social system using the spatial data in these four ways, but it is missing a geographical and cartographical side of GIS. Hence, Harvey suggests that the following definition by Chrisman completes the first definition and serves as an addition to the explanation of GIS: (GIS is) "Organized activity by which people measure and represent geographic phenomena then transform these representations into other forms while interacting with social structures" ([10], p. 13, as cited in [33], pp. 297-298).

The idea of making maps with computers occurred very early, in the mid-20th century. As Harvey stated, many scientists (among others, Warntz, Horwood, and Tobler) with various scientific backgrounds had motives to make maps with computers, e.g., to create maps easier without the constant need to redraw them. Mapping was finding its place in many different disciplines because maps served as an analytical tool ([33], pp. 74-75). In the beginning, it was vital to build a database in order to be able to produce maps that were previously created manually, and once the needed data was collected, the phase of spatial analysis of previously collected data followed ([41], pp. 8-9). The enormous potential of computers and new technology combined with the need for spatial analysis led to the evolution and growth of these computer-based geographic information processing applications known as GIS ([48], p. 45). As stated in ([42], pp. 1-4), with the new on-screen maps, maps were not just the medium for storing and presenting geospatial data anymore; they were a new technology that offered many helpful features for people, for instance, to inspect the suitable locations for different occasions.

GIS consists of an enormous amount of data and helps us in creating maps, comparing the features of different maps, finding the perfect location for many various occasions, finding the fastest route for a specific time of the day, or measure lengths, distances, and heights ([14], ch. 1). As Harvey ([33], pp. 266-267) stated, the development of GIS made work with maps tremendously easier: this new, although, for our understanding today not so fast approach, offered many people the possibility to get suited maps in a much faster way than ever before. Nowadays, a map is a representation of multiple multimedia overlays and an immense source of information with even more significant potential for the future world of geospatial handling ([42], pp. 1-4). In general, since the mid-1970s, GIS is rapidly growing and becoming the system we know today, which has an enormous impact on our lives and on the economic sector ([33], p. 75).

In today's modern society, most people use GI-supported applications on their mobile devices and other gadgets without even realizing they rely on them. Moreover, almost every aspect of human activity is now somehow related to GIS and is becoming increasingly dependent on it: from government departments, telecommunications, marketing, traffic management, tourist guides, banking, weather forecasting, and health and environmental research ([45], pp. 190-191). Examples of the usage of GIS that are relevant for people in their everyday life are numerous, for instance: the use of GIS in travel information systems which show and warn people of slow traffic and congested highways; the use of GIS in business market analysis to help business owners to find best places for advertisement or map the competition; GIS in tracking the spread and development of contagious diseases, such as influenza, to help health professionals to assess the effectiveness of antiviruses and identify the risk of a pandemic; and many others ([33], pp. 76-77). Another excellent example of GIS usage in research is the online publication *Our World In Data*[1]. They present the findings and statistics in scientific research by analyzing a large amount of data with GIS to tackle global problems such as hunger, poverty, war, or child mortality. The data can be represented in the form of a map, diagram, or table and is regularly updated. For instance, the figure 2.2 shows their map that displays the share of the people of each country in the world who received at least one dose of the COVID-19 vaccine.

2.2.1 Significance of Cartography in GIS

To some geographers and cartographers at the end of the last century, GIS was a sort of a "threat" to replace cartography ([48], p. 1). Whereas, others believed that cartography is becoming even more interesting and exciting with the arrival of new modern technologies ([73], pp. 2-3).

Geographic Information Science (GIScience) and GIS have changed the cartography and the way users think, create, and use maps ([46], p. 245). As explained by Longley, *map* is nowadays a term that stands for analog or digital output from a GIS. Whereas before the invention of GIS, a physical map was also the database, now it is only one way to present the geographic information from GIS-database ([46], p. 241). As a consequence of the new technologies, maps are becoming more digital and interactive; hence it is now tremendously easy for users to contribute to GIScience and create their own maps in many flexible ways ([46], pp. 245-246). A GIS database is being transformed, and geographic information from it is being processed with many steps, such as data collection, editing, data analysis, lastly, concluding in a map ([46], p. 241).

Although GIS would theoretically function without map presentation, only with geographic information, it would be hard to formulate and imagine all spatial relations because many of the ideas in GIS were inherited from maps ([41], p. 40). In other words, GIS without maps would be difficult to imagine.

2.3 What are Cognitive Maps?

Mark et al. ([49], pp. 748-750) explained that the late 70s were years when the first research projects on geographical cognition as part of psychology were conducted. They explained that back then, scientists were most interested in the mental representation of the geographical place, especially in how does understanding and distortion of environments evolve. According to Tversky ([78], p. 14; [81],

[1] https://ourworldindata.org/

pp. 66-67), this mental representation is based on elements in space and spatial relations between them. Moreover, to function in space, i.e., estimate the distance between the objects, navigate through space, describe routes, Tversky suggests that people make these mental representations of space, also known as *cognitive maps*, but also cautions that these mental representations of space differ from the external representations of space, such as maps in cartography. However, she argues that a concept of a cognitive map is too restrictive and presents two other commonly supported metaphors for mental representations: *spatial mental models* and *cognitive collages* ([78], pp. 14-15).

The concept of a cognitive map was first introduced by E.C. Tolman in 1948. Together with his team of researchers, Tolman ([76], pp. 189-192) observed the behavior of rats wandering in the mazes, i.e., labyrinths. They concluded that when hungry rats were continuously fed at the end of the maze for several days, rats began to learn the fastest paths to the end of the maze, making fewer errors each time. Tolman explained that the stimuli that led the rat down the right path resulted in learning a *cognitive map* in the rat's brain. This cognitive map helped the rat to find the end of the maze, each time faster and with fewer blind-entrances than last time. Tolman tried to explain humans' abilities to navigate and way find based on the experiment with laboratory rats and, thereby, present the cognitive maps in the human brain and throw light on how people learn and think about the environment ([76], pp. 198; [40], p. 2). He also contributed to the development of the behavioral approach in psychology ([76], p. 189) and the meaning of *latent learning* ([76], pp. 193-195).

Tolman wrote about cognitive maps as a general, systematic organization of knowledge, "referring to a rich internal model of the world that accounts for the relationships between events and predicts the consequences of actions" ([6], p. 490). Due to its multidisciplinary nature, the term cognitive map has had many explanations (see [40], pp. 1-3). The commonly most accepted and used definition of cognitive maps is the one by Downs and Stea ([19], p. 7, as cited in [40], p. 1):

> cognitive mapping is a process composed of a series of psychological transformations by which an individual acquires, stores, recalls, and decodes information about the relative locations and attributes of the phenomena in his everyday spatial environment.

Since humans' behavior is flexible, we can learn from past experiences and apply the learned knowledge to new situations, i.e., use this information for our spatial decisions in the future ([6], p. 490). Hence, cognitive maps are not constant but dynamic, and as we interact more with maps and specific geographical spaces, they are constantly developing and adapting [40]. Consequently, cognitive maps are often presented as chunks of multimedia spatial information ([78], p. 15), i.e., "complexes of mental images and concepts that humans have in mind when thinking about places" ([52], p. 40).

According to Kitchin, a lot of alternative expressions for cognitive maps were developed in the last century: from cognitive configurations, cognitive collages, abstract maps, mental images to spatial representation and spatial mental models (see [40], p.

5). Kitchin explains that the reason for so many different interpretations lies in the versatile background of cognitive mapping research with a large spectrum of different viewpoints.

The potential of cognitive maps in psychology was not recognized at first, but only later, when the experimental and development psychologists showed interest in the research of humans' thinking and learning processes, respectively, with the evolution of the behavioral approach in geography when the scientists were interested in how people make decisions (See generally [49], pp. 748-749).

Parallel to the research on cognitive maps in geography and psychology, neuroscientific research on cognitive maps also emerged. Few decades after Tolman introduced the concept of cognitive maps and assumed the possibility to describe cognitive maps with psychological functions, first findings in neuroscience proved the existence of hippocampal place cells ([59], as cited in [7], p. 1). With their findings, O'Keefe and Dostrovsky concluded that "[...] the hippocampus provides the rest of the brain with a spatial reference map" ([59], p. 174). The latest research in neuroscience shows that place and grid cells placed in the hippocampal-entorhinal region, besides the euclidian space for navigation, can also map experience and position it in a cognitive map ([7], p. 1(1)). Furthermore, Schafer et al. ([63], pp. 476-477) researched the mapping of social life in a *"relational social space"* and state that this process requires *"social navigation."* They discuss that mapping of social cognitive space, i.e., mapping of non-spatial data, takes place in the same regions as spatial data mapping. Moreover, they explained that cognitive mapping occurs on different levels of abstraction: from *"physical space"* where the specific location and its surrounding environment is mapped, over *"social information in physical space"* where besides physical space also some abstract information is being mapped, to *"social space"* where the information is being fully processed in an abstract social dimension, such as our relations of affiliation and power to others, rather than in a physical dimension.

2.3.1 Systematic Errors in Memory for Environments

By regularly walking through a specific space and memorizing spatial features, humans learn to navigate through this environment and form a cognitive map that acts as an individual perception of the space ([55], p. 44). According to Tversky ([79], p. 131), cognitive maps are an individual judgment of space, distance, and orientation, so they often can be distorted representations of the environment. She presented systematic errors that frequently arise in cognitive maps and thereby distinguished errors in a hierarchical representation of space, errors in cognitive perspective, and systematic distortions in memory for landmarks, i.e., cognitive reference points. In this subsection, I will briefly describe these distortions and present an interesting novel distortion of cognitive maps.

When people, in order to learn the relative location of a geographic feature, first remember the location of a larger geographical unit rather than the exact location of an object, we talk about distortion in a hierarchical representation of space ([78], p. 15). In their experiments, Stevens and Coupe ([68], as cited in [79], p. 132) found out that people, instead of learning the exact location of a city, remembered the location of a state in which the city is located. Thus, when they need to remember the location of a city, people retrieve the city's superordinate (state), leading to spatial distortion in a cognitive map.

When people are explaining or imagining spatial relations, they usually take a different cognitive perspective, i.e., another person's perspective or a cognitive perspective of another space (imagine themselves in a different place) ([80], ch. 6). Moreover, people also tend to judge distances between nearer landmarks as comparatively larger than the distances between faraway landmarks, which is also leading to distortions in cognitive perspective ([78], p. 16). The same perception is also manifested in social life: The differences between individuals of the same social or political group are often conceived very strong, whereas the people that belong to another social group are considered to be "all the same" ([80], ch. 3).

Tversky ([78], pp. 16-17) further describes two more cognitive spatial distortions: distortions in alignment and rotation. A well-known example of an alignment error is when people incorrectly align the USA with Europe and South America with Africa. Similar to the alignment, one more error happening as a "natural consequence of perceptional processing" is *rotation* ([79], p. 137). The rotation error happens when the orientation of a reference frame and an object are conflicted so that the object's natural axis is rotated towards its reference frame ([44], p. 193).

Since people often use the nearest landmarks to describe a route or location, it is necessary to mention that landmarks often cause distortions in cognitive maps ([79], p. 133). Given that the next chapter reveals some more research on landmarks, I will write more about landmarks and distortions in the perception of landmarks in the chapter 3 and lastly in chapter 5, where I am also going to explain the interconnectedness of TFL and cognitive maps.

In their research on the lexical encoding of geographic information, Mehler et al. ([52], p. 41) introduced a novel distortion of cognitive maps. Their work developed a framework called Multiplex Topic Networks that extract thematic structure from texts about specific places, and analog to cognitive maps, they interpreted their findings in *thematic maps* ([52], p. 1). Mehler et al. ([52], p. 41) concluded that places are thematically represented by few *rhemes* (what is said about place), and instead of developing and expressing personal views of the specific place, people rather accept the suggested rhemes in order to ensure shareability and "continued existence of the wiki". Hence, people unintentionally participate in producing and supporting stereotyped thematic maps of a place.

Lastly, Kitchin (see [40], pp. 12-14) discussed in what way cognitive mapping could affect cartography and how to ensure an unembellished information flow between cartography and cognitive mapping. Moreover, Lloyd ([43], p. 109, as cited in [40], p. 13) argues that in order to create better maps, cartographers need to investigate cognitive processes used by studying a map. Kitchin ([40], p. 13) also suggests that cartographers could improve mapping by understanding which parts of maps contribute to creating distortions in cognitive maps.

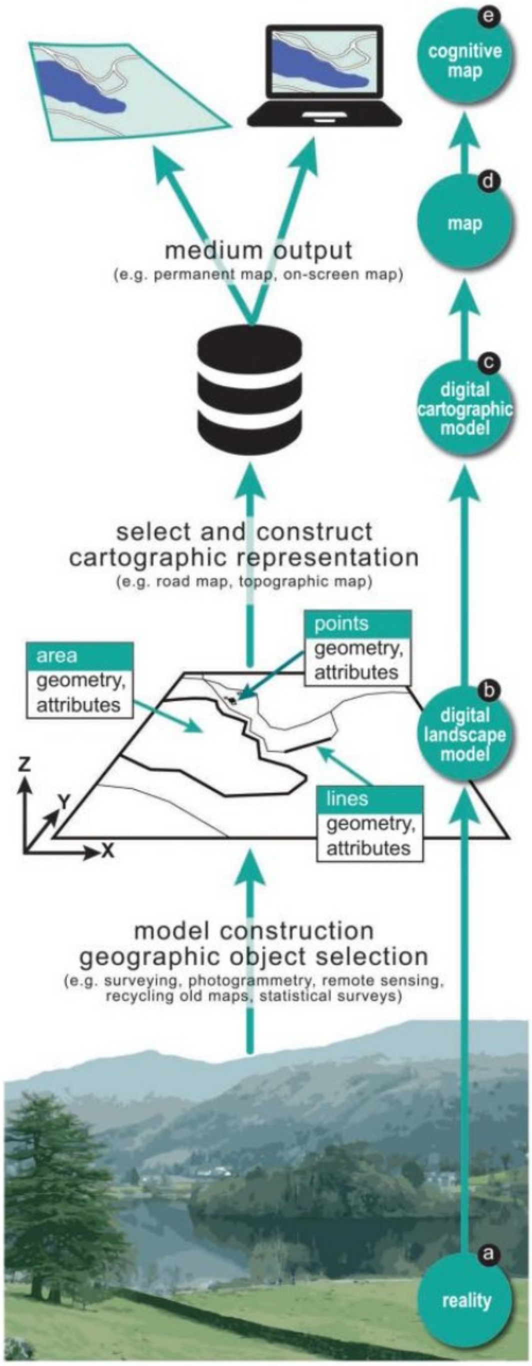

Figure 2.1: The process of storing geospatial data in a cognitive map. Retrieved on 04.02.2021. Source: ([42], p. 6)

.

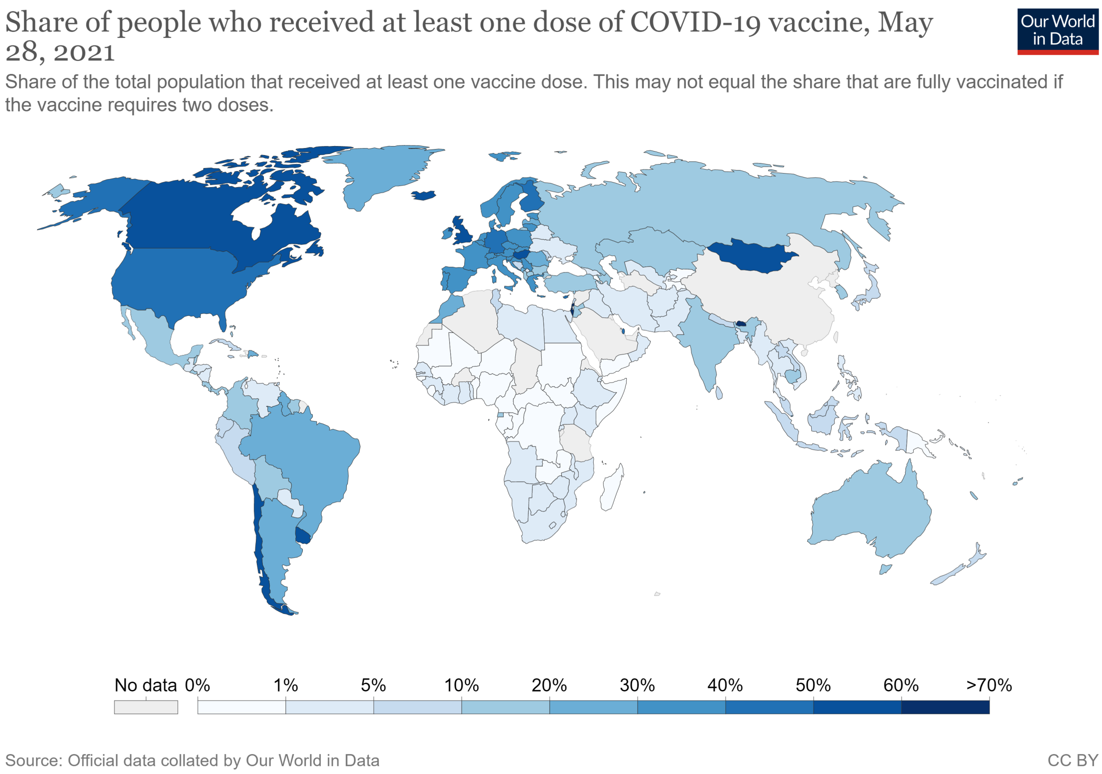

Figure 2.2: Share of people of each country who received at least one dose of COVID-19 vaccine. Retrieved on 29.05.2021, 18:10h. Source: https://ourworldindata.org/covid-vaccinations

3 The Importance of Landmark Salience for Human Navigation

Montello ([57], p. 193) states that along with the term cognitive map, the term landmark is believed to be the most universally used in spatial cognition science. He implies that the concept of landmarks is often exaggerated as it is used in various distinctive contexts, which makes landmarks a concept that can lead to misconceptions when used. Moreover, some scholars broadly use the concept of landmarks, often to address any decision point in the environment ([66], p. 39).

In this short chapter, a reader will be briefly introduced to the concept of landmarks and their importance in human navigation and spatial cognition. Lastly, I will state some examples of the research findings that refer to the existence of cognitive spatial distortion in the processing of landmarks.

3.1 On Human Navigation and Landmarks

As Montello ([56], p. 143) stated in his earlier work, humans gain knowledge about space that is surrounding them by simply experiencing it. He further explains that people constantly learn about new locations, distances, and directions. Conclusively, this knowledge learned from experiences accumulates and grows, hence can later be used in wayfinding. According to Lynch ([39], pp. 2-3), for a city to be "legible," it needs to have salient and easily recognizable areas, streets, and landmarks. Moreover, in navigating and wayfinding, various cues are used, such as the appearance, color, or size of an object, so that wayfinding is mastered through the use and the structure of cues acquired from a surrounded environment ([39], pp. 3-4). In wayfinding and directing, landmarks are proven to be extremely important because these salient objects are easy to memorize and recognize when spotted ([56], p. 144). Therefore, identifying the environment and its landmarks is of great importance.

In their recent research on the processing of landmarks in maps, Keil et al. ([38], p. 1) conducted two experiments and concluded that the visual complexity of a digital map is responsible for the number of relevant and processed landmarks while learning a route. They further state that modern gadgets available to us provide us with digital mapping services for route planning and navigation, such as OpenStreetMap (OSM) and Google Maps. These digital maps contain pictograms of salient objects, i.e., landmarks, that serve better route planning and memorizing. Moreover, Keil et al. claim that landmarks help create a cognitive map of a space. In extension, the number of landmarks and other reference objects on digital maps changes with the adjusted width of a map: The impact of landmarks on a digital map while learning a route decreases with increased distance to the route([38], p. 2). Similar to TFL, which implies that "near things are more related than distant things,"([74], p. 236), we now have the trade-off between the landmarks and size of a displayed route, making the landmarks displayed on a digital map more related to the route if the route is "near," i.e., zoomed in.

3.2 What Makes a Landmark Salient?

Throughout history, many scientists (see, e.g., [56], [39], [13]) in the fields of geography, cartography, sociology, and psychology tried to explain and find a unique definition of a landmark, i.e., a point of reference that could help people navigate in familiar or unfamiliar space, and explain characteristics of a landmark. The following paragraphs present the ideas from some of the authors about what makes a landmark salient.

In his well-known book *The Image of the City*, Lynch ([39], pp. 46-47) defined five qualities of a city, landmarks being one of them. He also named some landmark characteristics, describing how they can help navigate and orient. For example, he named singularity as an essential characteristic of a landmark because for a landmark to be easily recognized and memorized; it needs to single out and contrast from the rest of the environment - with size, age, or shape - and be unique in some way. Moreover, Lynch also described a distant landmark as a characteristic that is important and most helpful to people that are not familiar with a city ([39], pp. 78-83).

Sorrows and Hirtle ([66], pp. 45-46) proposed three categories of landmarks: visual, cognitive, and structural landmarks. As a *visual landmark*, they defined the object that stands out of the background with its visual characteristics, making it spatially prominent, although easily recognizable and memorizable. A *cognitive landmark* is a landmark that is standing out with its meaning in the immediate space and can have a specific meaning, e.g., police station, or a meaning uncommon or essential in its environment. As Sorrows and Hirtle further explain, with its nature, cognitive landmarks can be individual and often not interpreted by people who are unfamiliar with the environment. A *structural landmark* differentiates from its surrounding by the role or prominent location in the structure of a place, e.g., Trafalgar Square in London ([66], pp. 45-46).

Furthermore, Röser et al. ([61], p. 210) investigated three major salience concepts: visual, structural, and semantic. They experimented on human wayfinding and landmark salience and found that, e.g., an acoustic landmark is better recognized than a visual landmark. However, in wayfinding, it is shown that the multimodality of landmarks' representation is very important ([61], pp. 212-213). Moreover, as the authors conclude, famous landmarks are better recognized than non-famous landmarks due to our prior knowledge about them. One more important finding in this experiment was that the ideal influence of landmarks was when they were placed before the intersection on the side where to turn ([61], p. 213). Similarly, Albrecht and von Stuelpnagel ([2], p. 311) found out that for navigation, it was helpful when the landmark was located in the turning direction and that it could be disorienting if a landmark would be on the opposite side of an intersection.

Miller and Carlson ([54], p. 184) conducted two experiments on landmarks' salience. Participants of the experiments have learned a route in a virtual museum and took a memory test to recognize the museum's objects. Later they had to describe the learned route and drew a sketch map of the route. Miller and Carlson concluded that spatial features, like a landmarks' position on an important intersection, were crucial in navigation. Furthermore, they confirmed the findings of many researchers that when recognizing a landmark, perceptual features, such as color and size, were also of great importance ([54], p. 190).

After reviewing the findings, it can be concluded that a landmark is a complex cognitive structure. Whether a human will process some object in the environment as salient depends on many different aspects. Moreover, a salient landmark for one human does not have to be salient for another. It depends on an individual cognitive understanding, i.e., the cognitive map of a person trying to navigate. In the following section, the reader will be introduced to cognitive spatial distortions in the perception of landmarks.

3.3 Cognitive Spatial Distortion in Perception of Landmarks

It is believed that people first learn the relative location of a landmark, then a route around the landmark, and lastly, fill in the survey knowledge ([79], p. 133). Since many different factors participate in the formation of our mental spatial representations, the information on the position and relation of geographic objects in a cognitive map is often distorted ([18], p. 175).

Accordingly, the research by Röser et al. ([61], pp. 212-213), which was already mentioned in the last section, also proved some negative influence of landmarks when a few more landmarks were added. They concluded that the recognizing performance was worse due to the confusing influence of landmarks: it resulted in a distorted representation of survey knowledge.

Furthermore, Sadalla et al. ([62], as cited in [79], pp. 133-134) came to the conclusion that landmarks cause false metric assumptions in judgments: distance from an ordinary building to a landmark is judged smaller than the distance from that ordinary building to a landmark, in other words: "landmarks draw buildings closer to them" ([79], p. 133).

One more well-known cognitive spatial distortion is the hierarchical processing of landmarks, i.e., clustering of the landmarks in hierarchies based on their similar appearance or meaning. Distances between these landmarks are judger biased according to the cluster they belong to. The examples of findings for this distortion are, e.g., the ones made by Allen ([3], as cited in [13], p. 100), Hirtle and Jonides ([36], p. 208), and McNamara ([51], p. 87). Since I am going to refer to these findings one more time to answer my research question, I will explain them in chapter 5, subsection 5.2.2.

4 Volunteered Geographic Information

With the rise of the internet, GIScientists developed interactive maps, where people could also add geographical information and share it with the world ([42], p. 1). Consequently, in 2007, Goodchild defined this kind of information as *Volunteered Geographic Information* (VGI), a specific case of the phenomenon of user-generated data, also known as Web 2.0 ([28], p. 212). In this chapter, I will present research on VGI, i.e., explain what VGI is, what are motivational factors for VGI, and where is VGI commonly used and created.

4.1 What is VGI?

Most people believe in the myth about a well-mapped world. On the contrary, there is a significant bias in the mapping of the world: On the one hand, some parts of the world are mapped and continue to be mapped, whereas, on the other hand, a significant part of the world has lower mapping entries ([22], pp. 517-518; [31]). The reason for this digital division could lie in the government that is no longer willing to pay for mapping services or in uneven access to the internet worldwide ([28], p. 217). It is also known that due to natural disasters, the affected areas may change very quickly. That is why it is essential to have updated and first-hand information ([60], as cited in [8], p. 556).

In the last over a decade, as the popularity and usage of web mapping technology and crowdsourced GI have increased, the phenomenon of online communities that create VGI occurred ([46], p. 27). At the beginning, scientists used various names to describe this phenomenon: from crowdsourced information, over neogeography, to terms like citizen science (see generally [71], p. 2). Moreover, the term VGI became commonly used in 2007 when Goodchild presented it. Since then, more and more scientists and researchers were interested in exploring the field of VGI by writing articles and presenting new findings on VGI. By creating, updating, and using VGI, GI databases developed, and it led to the known concept of the *wikification of GI systems* ([46], p. 27).

When the number of VGI-related articles available on Google Scholar through the years is compared (see [9], p. 2), one can see the enormous growth of the number of VGI articles available throughout the years. Figure 4.1 shows the number of articles of every second year: from about 99 articles in 2007, around 2810 articles in 2013, to 14500 articles to this date.

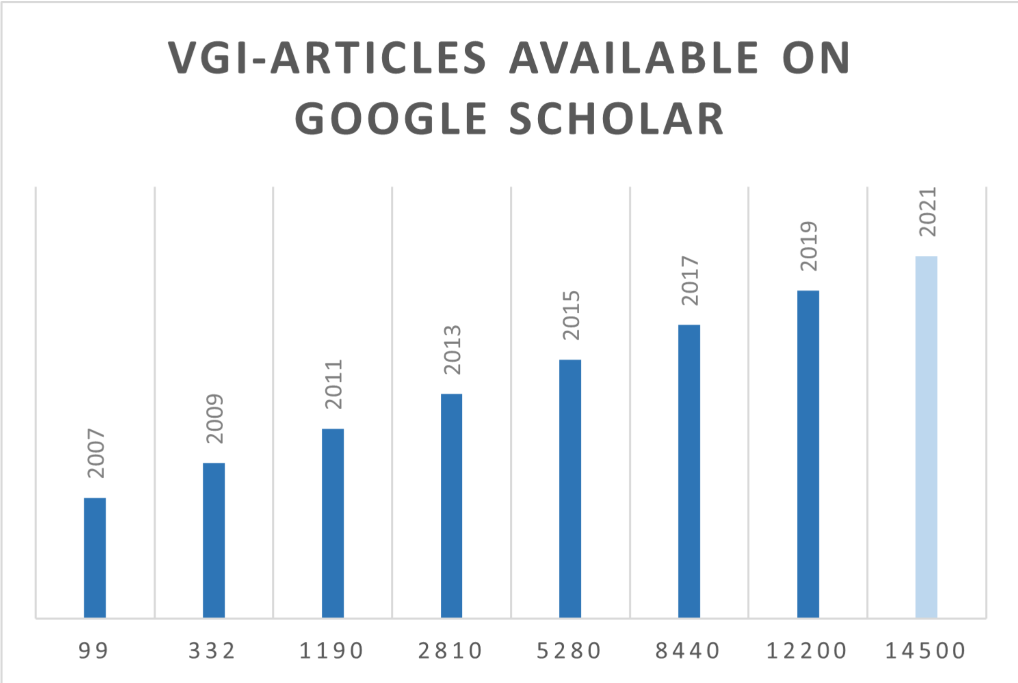

Figure 4.1: Number of references on Google Scholar on 02.05.2021 matching the term "volunteered geographic information" throughout the years. Created on 02.05.2021, 21:12h. Source: https://scholar.google.com/

In his influential journal article *Citizens as sensors: The world of volunteered geography*, Goodchild documented the engagement of many private citizens who were not from official geographic agencies, as they contributed to the creation of geographic information ([28], p. 212). He also states that a significant contribution to the development of VGI was the establishment of well-known projects *Wikimapia* and *OpenStreetMap* (OSM). These projects attracted many users interested in contributing to VGI and creating their content on the web ([46], p. 27, ([28], p. 220). Nowadays, due to the low cost and widespread of GPS and smartphones, users can now easily contribute to VGI using social media platforms such as Facebook, Twitter, Instagram, Flickr, and VGI projects Wikimapia and OSM ([9], p. 2). Every person with access to the internet can add their own description to a geographic feature on earth, whether it is a state, a city, a building, or any other kind of geographic feature, but also edit descriptions and check for the accuracy and correctness of all entries ([28], p. 212). With five senses and intelligence to process the information from senses, humans are numerous natural sensors ([28], pp. 217-218).

4.2 Motivation for VGI

As Fritz et al. ([27], p. 94) stated, VGI consists of two components: *spatial information* component and *volunteer* component. The *volunteer* component is crucial. Thus the main things to discuss here are the motivational factors, i.e., what motivates users to contribute data to VGI systems? Since good, of quality VGI data is very time-consuming, there is a great debate on why the people contribute to VGI and what kind of motivation lies behind it ([28], p. 212). Some of the obvious reasons are self-promotion, sense of belonging, empathy, altruism, or communication of Geographic Information (GI) to friends and family ([8], pp. 563-566). According to Fritz et al., to recognize the motivational aspects, one should initially differentiate the types of contributors, i.e., "understand the nature of volunteers" ([27], p. 94).

Coleman et al. ([11], pp. 341-342) offered a typology with five different categories of contributors: from *Neophytes* – people with no previous knowledge on the subject, but are willing to contribute to VGI; over *Interested Amateurs* - contributors who already have a bit of interest and experience; *Expert Amateur* – possess a significant amount of knowledge, but do not do that for a living; *Expert professionals* – studied the subject, has much experience, and to it for living; to *Expert Authority* – someone who studied the subject, has much experience, and can provide high-quality information.

A good example of a project which explains some of the possible motivational aspects in the praxis is the citizen science project *iNaturalist*[1]. Contributors take photos of any plant or an animal and lookup for it on iNaturalist to see if it is already in the database. If not, they have the opportunity to define this new plant or animal. With every entry confirmed by other users, the account becomes more relevant and reputable. The possible motivational aspects for these contributions are numerous: Networking with other contributors, protecting nature, exploring nature, fun, learning, altruism, self-efficacy, reputation, and many more.

4.3 Usage of VGI and Well-known VGI Projects

In the last few paragraphs, I already mentioned some examples of VGI-usage. In this section, I am explicitly reflecting on OSM and Wikimapia since they are valuable and presumably the most known VGI projects.

4.3.1 OpenStreetMap

OpenStreetMap (OSM)[2] was founded in 2004 to provide all people with free access to geospatial data, which, for regular users, was often very costly and complicated to get. OSM nowadays is a free open map that allows everyone to generate, edit, and use geospatial information about any geographic feature, such as information about roads,

[1] https://www.inaturalist.org/
[2] https://welcome.openstreetmap.org/

buildings, streets, businesses, and objects in nature. OSM "*produsers*" ([11], p. 332) are various: from individual users, map enthusiasts, GIS scientists, different kinds of companies, organizations, government departments, and many others, making it in total about 5 million registered users and over 1 million contributors to OSM.

The great importance of OSM contributions also lies in mapping places in emergency situations that were previously often poorly mapped, such as in case of natural or human-made disasters ([32], p. 232). Zook et al. ([83], p. 9) describe in their work the example of the mapping activity in Haiti after the strong earthquake in January 2010. Haiti, like many developing countries around the world, lacked a decent digital map. Immediately after the earthquake, demand for well-mapped streets and objects increased to help affected people as soon as possible. The World Bank and companies such as GeoEye, Digital Globe, and Spot released the free-to-use of high-quality satellite imagery [65]. That is when the crowdsourcing and data collection of geographic information by volunteers was urgently needed ([83], p. 16). As Soden [65] explained, in order to enable disaster relief management and help the people in need, volunteers worldwide began mapping the affected areas on OSM, and in a short time succeeded in mapping roads, streets, buildings, and other spatial features, making it far the best map of Haiti until then. Soden further explains that the value of the OSM as a free open map in disaster management relief was first recognized in Haiti as many organizations used it for disaster relief.

Moreover, in the same year, the organization *Humanitarian OpenStreetMap Team* was founded with the purpose of creating community mapping projects that will build resilience to natural and climate-change disasters in many countries [65]. The figures 4.2 and 4.3 display the progression of mapped data of Haiti on OSM made by volunteers in just a couple of days. The figure 4.4 represents the current state of mapped data of Haiti on OSM.

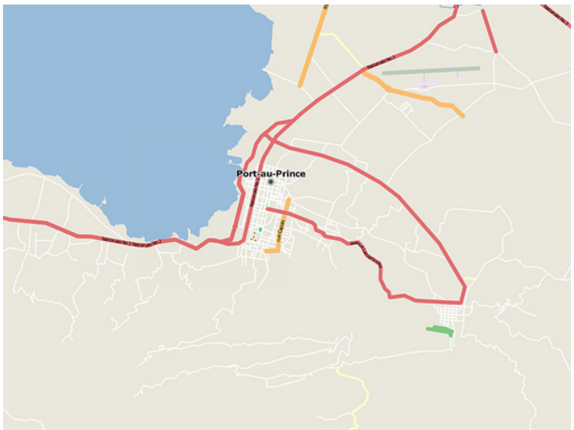

Figure 4.2: Snapshot of OpenStreetMap data of Haiti on January 10, 2010, before the earthquake. Retrieved on 28.04.2021. Source: [50]

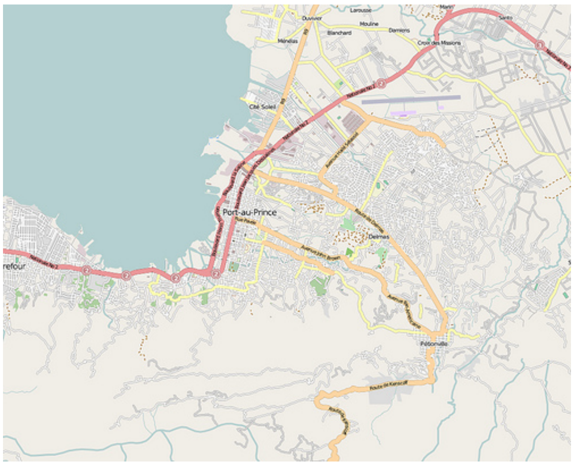

Figure 4.3: Snapshot of OpenStreetMap data of Haiti on January 12, 2010, right after the earthquake. Retrieved on 28.04.2021. Source: [50]

4.3.2 Wikimapia

Similar to the already described OSM, Wikimapia[3] is a web service created to enable users to tag geographic places and other geographic features and contribute geographic information. Users can add a comment and write personal views on a specific geographic place, making it a platform where the reader can acquire new information about a place, often both from a tourists' and locals' point of view. Moreover, when a user selects a specific place on Wikimapia, Wikipedia articles and other insightful informational sources are often linked, enabling users to gain general information about that place. There are also some other helpful options on Wikimapia, such as calculating a distance between several geographic positions or an option to zoom a map according to the size of an average house, street, city, country, or a whole world map.

Although Wikimapia is a great platform to acquire geographical knowledge, it is also stained with a known VGI bias, namely unequal mapping of the world. Whereas some popular and highly populated places are well mapped, other, less popular places are often insufficiently mapped. Furthermore, Wikimapia gives the user an opportunity to map places in various languages, making the content of Wikimapia language-dependant.

4.4 Delimitations of VGI

VGI is nowadays being collected in various ways, such as: via loyalty cards to analyze people's purchasing habits, by allowing to exploit private information, e.g., "ticking" the box to accept the terms, or from messages published on Twitter or photos posted in Flickr ([46], p. 399). There is much debate on what "volunteered"

[3] http://wikimapia.org/

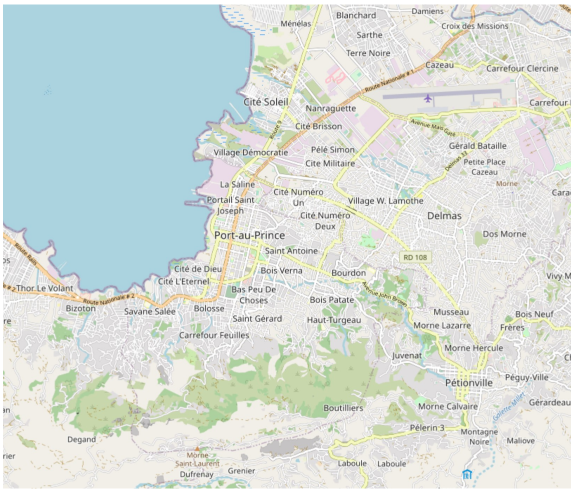

Figure 4.4: Snapshot of OpenStreetMap data of Haiti today, on April 28, 2021. Created on 28.04.2021, 21:33 h. Source: OpenStreetMap of Haiti (https://www.openstreetmap.org/map=13/18.5503/-72.3248)

geographic information represents. Some GIS scientists represent the opinion that VGI refers only to GI that the contributors are entirely aware of and is created solely to contribute to VGI projects like OSM ([34], p. 34).

In this subsection, I will present the concepts that are understood under *delimitations of VGI*: *Contributed Geographic Information* (CGI) and *Ambient Geographic Information* (AGI).

4.4.1 Contributed Geographic Information

Harvey ([34], pp- 31-34) discussed the difference within crowdsourced data, distinguishing at the same time volunteered and contributed data. According to Harvey, VGI refers only to this contributed GI that the contributors are entirely aware of and where the permission for collecting and reusing GI is transparent. With that said, he states that VGI is user-controlled and functions on the opt-in concept: users choose freely to collect spatial data. He also states that, unlike in VGI, data in CGI works on the opt-out concept and collects personal data about the user all the time: phone tracking, tracking from a car navigation system, credit cards tracking, shopping tracking, and many other kinds of unaware tracking of data. In other words, there is no or limited user control of data collection in CGI ([34], pp- 32-33).

4.4.2 Ambient Geographic Information

Stojanovski et al. ([69], pp. 223-224) describe that the trending of social media and the invention of cellphones that enabled GPS led to the evolution of *Social Media Geographic Information*, causing the enhanced number of georeferenced multimedia data on social media platforms like Facebook, Twitter, Instagram, or Flickr. All this information is being passively contributed to VGI. Stefanidis et al., motivated by the developments in social media and possibilities that new technologies offered, developed a framework for harvesting this passively contributed geographic information and referred to such data as *Ambient Geographic Information* (AGI) ([67], p. 320). According to Stefanidis et al. ([67], p. 319), Social Media Geographic Information differentiates from VGI because it does not have directly contributed geographic information: The goal of published content on social media is not geographic location. Instead, as they further explain, multimedia content often has "geographic footprints," e.g., the originating location of a tweet or referenced geographic location from a social media content context.

A good example for this kind of VGI is, as described by Stojanovski et al. ([69], pp. 224-225), a "microblogging" platform Twitter. As a platform with hundreds of millions of users, Twitter is an excellent example of a place for rapidly spreading the newest information from across the world. The information often has georeferenced data. Thus, Twitter users share local news, opinions on trending topics, or commenting on the trending tweets from other users, making Twitter a platform where users can read first-hand information and an excellent platform for extracting VGI content ([69], pp. 224-225).

5 TFL as Intersection of Cognitive Mapping- and VGI-Research

Previous chapters reviewed some visualization aspects of geographic information (such as maps, cognitive maps, and GIS), the role of landmarks' salience in developing a cognitive map (particularly the cognitive distortions in the processing of landmarks), and subsequently, the importance of VGI. This final chapter will write about Tobler's First Law of Geography (TFL) as an intersection of previous chapters and round it off by referencing some findings that prove the relatedness of discussed topics to TFL. Therefore, I will explain the principal components of TFL, i.e., what is meant with "*near*," "*distant*," "*related*," "*law*," or "*things*," and I will state sequential lexical variants of TFL, also represented in a figure 5.1.

5.1 About TFL

Many scientists (see, e.g., [53],[72],[82],[4],[58]) admired Tobler's contribution to the concept of interconnectedness in geography. For instance, geographer and GI-scientist Daniel Sui in his review *Tobler's First Law of Geography: A Big Idea for a Small World?*([72], p. 269) states:

> Tobler's influence has clearly crossed the boundaries of cartography, as evidenced by his groundbreaking work in fields as diverse as spatial analysis, migration studies, spatial interaction modeling, and geographic information science (GIScience). The most ambitious of all, perhaps, was his attempt to define the first law of geography.

Tobler is considered a pioneer of his time in the fields of spatial interpolation, spatial dependence, and spatial autocorrelation. In his paper *A Computer Movie Simulating Urban Growth in the Detroit Region*([74], pp. 234-236), Tobler simulated Detroit's population growth from 1910 to 2000. In order to measure the degree of similarity of Detroit's population distribution, he compared the numbers from existing statistics and calculated a correlation coefficient, concentrating on birth, death, and migration processes. Consequently, he developed an urban growth mathematical model, which he used to predict a map of population distribution. He concluded that the population growth depends not only on the previous population of a particular place but also on the population of all the surrounding places. The graphical simulation model was a 3D wire-frame presentation of a city in the form of a movie ([82], p. 1). To initiate his findings, Tobler defined the First Law of Geography, stating that *"everything is related to everything else, but near things are more related than distant things"* ([74],

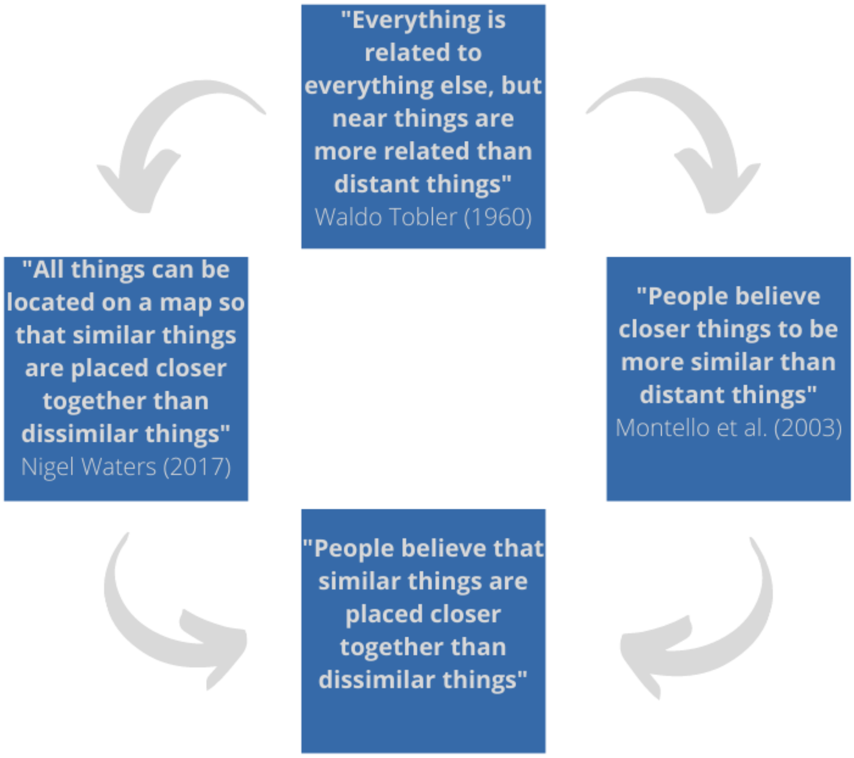

Figure 5.1: Variations of TFL

p. 236). Waters ([82], p. 2) explains that with the “first” law of geography, Tobler surely meant the most important law, having distance as an essential variable in geography that makes “things” related to each other. Moreover, Waters presumes that with “things,” Tobler especially meant people, i.e., distribution of these “things” regarding the effect of distance-decay in geographic space.

Conclusively, Sui ([70], p. 146) states that TFL is based on spatial dependence and now is a rule and a basis for processing spatially autocorrelated structures. He further says that TFL constitutes a unique way of thinking about how everything is interconnected - “related”, and how the interrelatedness changes through space. In this manner, Sui describes TFL as being consistent with distance decay, gradually reducing the effect of distance on interrelatedness between things in space. TFL is crucial for spatial analysis techniques and the geographic conception of space and is becoming more and more relevant as we discover new definitions of near and related, as Sui stated. Novel ways to measure spatial autocorrelation support the adaption of TFL in physical, cultural, and socioeconomic domains ([70], p. 146).

There are also scientists (see, e.g., [5],[30],[64]) who criticized TFL and tried to diminish its influence, primarily because Tobler decided to use the word "law" in it. Especially harsh critics were from Jonathan Smith, who criticized Tobler's casual use of the word law and imposed needed requirements for something to be declared a law ([64], pp. 294-295). Tobler, on the other hand, used the words "first" and "law" to communicate his findings better and mark the importance of the relations in geography he was trying to explain ([75], pp. 304-305). Moreover, as he stated, he favors the definition of law by physicist Richard Feynman. Feynman specifies that in order to make a law, one must first take an "educated guess on how the nature works" ([72], p. 270), then "compute the consequences" and "compare the result" ([24], p. 156, as cited in [75], p. 305).

5.2 Diverse Understandings of Distance and Lexical Variants of TFL

TFL insinuates that there are "[...] local factors and circumstances that can potentially make one area significantly different from other areas" ([72], p. 272). Hence, distance is also a component of TFL that triggered much discussion among scholars, especially in geography. There are numerous research articles on when things are considered to be near or distant. The concept of distance has also been changing throughout decades, especially with constantly advancing communicational technologies. "Things" are now being connected, without necessarily being physically near, through social networks. Couclelis states that this phenomenon is also known as *death of distance*, as named by Frances Cairncross in 1995, where he describes the process of the world becoming a global village ([12], p. 387). Furthermore, Couclelis says that modern technology, i.e., new ways of communication, enabled more effortless and more affordable transportation and reduced the people's need for movement. Among other things, that is something that affected the occurrence of various critics to TFL (see also [5],[30],[64]).

Nevertheless, the interest in the research of TFL did not decrease. If anything, the interest in the study of "nearness" and "distance" in the context of TFL intensified. Hence there are now diverse variations of TFL that discuss the meanings of distance, nearness, and relatedness on another level than it was initially defined in TFL.

As described in *Dictionary of Distance* and later in *Encyclopedia of Distances* by Deza and Deza ([17], pp. vii-viii), there are infinite ways to measure distances. They describe that distance is usually a concept defined by a degree of closeness between objects or thoughts. When talking about distance, it generally means the physical distance, which can be measured with many kinds of metrics, for instance, spatial units or time or cost of travel (See [15]). Often enough, it also meant the distance in the form of relatedness and similarity (See [17]), which means that something is nearer when it is related or similar. In this case, distance is essentially subjective, making this kind of non-physical distance difficult to measure.

Moreover, in the process of *spatialization*, to indicate some semantic relatedness, non-spatial data are represented in an "*arbitrary*" defined spatial reference frame ([23], p. 31) as "*spatial metaphors*" ([58], p. 316). These reformulations led to the first lexical variant of TFL that I will cite in my thesis, namely the Inverse of TFL, defined by Nigel Waters: "All things can be located on a map so that similar things are placed closer together than dissimilar things" ([82], p. 4-5). Meaning, "things" can be placed into a corresponding spatial reference frame based on semantic relatedness. Similarly, prior to Waters, Montello et al. introduced the *First Law of Cognitive Geography* (FLCG), which states that "*people believe closer things to be more similar than distant things*" ([58], p. 317). He, so to speak, reformulated the TFL by drawing a parallel to a spatial rule of closer places on earth being more similar and thereby focused on "*distance-similarity metaphor*": People perceive nearer things as more related - "*more similar*", than distant things.

In the following two subsections, I will represent the connection of TFL to the concepts of VGI and cognitive maps that have already been explained. In conclusion, I will define an inverse to the latter cited FLCG as a verbal explanation of cognitive distortion in the processing of landmarks.

5.2.1 TFL in VGI

As already described in chapter 4, a characteristical "flaw" of VGI is that VGI-content often reveals biases leading to an uneven representation of VGI-content across the world. Moreover, through the (textual) VGI, there can be a significant difference between the VGI-content that is contributed to a specific place by locals and the VGI-content by tourists.

Unlike the tourists who perceive (stereo)typical objects such as well-known and salient landmarks, locals perceive different objects as landmarks, such as a favorite restaurant or a coffee shop, and often use these as their spatial reference. It is indeed so because of the subjective nature of VGI. Meaning, every contributor creates VGI that seems to be most important to him or her regarding a precise location. Thus, the VGI created by locals is often more curated, more relevant, and essential for a better and "real" description of some place. It may also contain sensitive data that change the picture of a place. For instance, Capineri stated an example of this kind of bias in VGI by observing contributions to the Wikipedia site of the town Esfahan in Iran. The English version contains VGI content that shows and describes the fascinating architecture and famous ceramic decorations. In contrast, Capineri noted that the Farsi version includes descriptions of some local artifacts and sensitive topics such as near distance of nuclear activity ([9], p. 24). This kind of VGI bias indicates the relation of VGI to TFL: "near things are more related" - contributions from people who are near are more related, more relevant, and more important.

Similarly, Adams and McKenzie ([1], p. 201) investigated the spatially referenced natural language descriptions and occurring themes associated with the places. They state that perception of a place results from people's subjective experiences of the place or information about the place. Using topic modeling techniques on travel blogs, Adams and McKenzy extracted the themes that are most related to specific places and measured the similarity of places, and thus found a connection to TFL, where near places were described with more similar topics than distant places ([1], p. 209).

5.2.2 TFL in Cognitive Maps

In this last subsection, I will revisit cognitive spatial distortions once again to link them with TFL and represent a new lexical variant of TFL.

An important factor in forming cognitive spatial distortions is *subjective distance* or *cognitive distance*. According to Deza and Deza ([16], p. 359), *subjective distance* could be defined as "[...] a mental representation of actual distance molded by an individual's social, cultural and general life experiences." The cognitive spatial distortion relevant for this research is the distortion in the processing of landmarks in cognitive maps, i.e., hierarchical distortions in estimating distances between landmarks.

In his research in 1981, Allen found evidence of inconsistencies in the spatial-route knowledge according to the judgment of across-cluster distances to be consistently longer than the equal within-cluster distances ([3], as cited in [13], p. 100). Hirtle and Jonides proved another example of landmark distortion ([36], p. 208). In their article *Evidence of hierarchies in cognitive maps*, they analyzed spatial clustering of landmarks based on non-spatial information that subjects of the experiment had about these landmarks. Hirtle and Jonides conclusively offered evidence for landmarks' cluster distances, having across-cluster distances overestimated and within-cluster distances underestimated ([36], p. 215). The results from their research can also be seen in the figure 5.2. McNamara ([51], p. 87) also examined hierarchical theories by conducting experiments on direction judgments, object recognition, and euclidian distance estimation. Among other things, he proved that when objects in the same and different regions were compared, participants underestimated distances between objects in the same region, and parallel, overestimated distances between objects in different regions ([51], p. 106). Meaning, participants "clustered" the objects by regions, perceiving the objects of the same region as more similar and thus as nearer.

The experiments stated in last paragraph provided new insights into the relationships between the concepts of "things", "similar," and "near". Through rewording of the FLCG, another lexical variant of TFL, the *Inverse of the First Law of Cognitive Geography*, could be stated as: *People believe that similar things are placed closer together than dissimilar things.* The Inverse of the FLCG could explain this spatial distortion that often occurs in cognitive maps by processing landmarks. Moreover, this hypothesis can also be validated through recent neuroscientific research on cognitive maps. Bellmund et al.([7], pp. 1(1)-3) examined the firing of place and

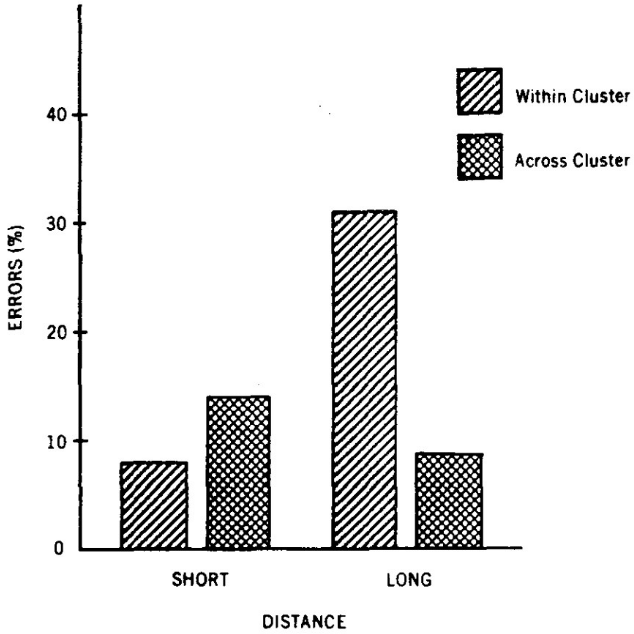

Figure 5.2: "Histogram of error percentages by distance category": "For short distances, subjects tend to classify a distance as 'long' if a pair is across cluster compared with within cluster, and to do quite the opposite for long distances." Source: ([36], pp. 214-215).

grid cells in the hippocampus and related regions of the brain. Their research reveals that this process continuously encodes the space in a constraint dimension, having neighboring positions being similarly represented "due to partially overlapping firing fields across the population of cells"([7], pp. 2). Hence, they proposed a framework for *cognitive spaces*. Lastly, they concluded that place and grid cell population code maps the information in the hippocampal-entorhinal region, across the cognitive space that is being spanned by specific variables, "resulting in nearby positions for similar stimuli and larger distances between dissimilar stimuli"([7], pp. 1(1)). An example of cognitive spaces can be seen in the figure 5.3.

Lastly, research similar to the latter mentioned study of Bellmund et al. is the one by Mehler et al. where the concepts of cognitive maps and VGI have been intercorrelated in the field of lexical encoding of geographic information. They developed a framework called *Multiplex Topic Networks* that extracts thematic structure from crowdsourced (VGI) texts that contain georeferenced data. Mehler et al. investigated the similarity of geographic places based on the resulted thematic structure. They concluded that geographic places are placed in neighboring locations of semantic places based principally on their thematic similarity, not on the physical distance between places. Accordingly, their results could also be interpreted with the components of TFL and its lexical variants: Geographic places with similar thematic structures are placed closer together in the semantic places of networking themes than the dissimilar ones.

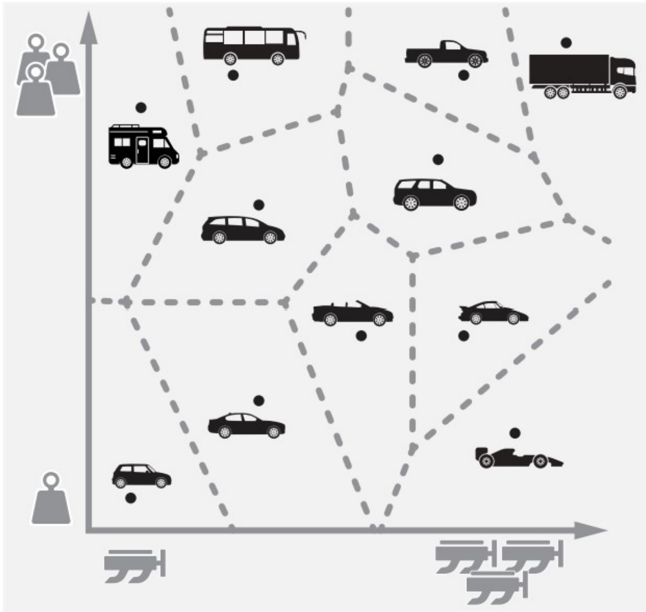

Figure 5.3: Cognitive space spanned by a dimension of two variables: car weight and engine power. It can be seen that similar stimulation objects are placed nearby in a cognitive space. Source: ([7], p. 2).

5.3 Discussion

By discussing TFL and its core components and semantically reversing their meaning or perspective, other lexical variants of TFL resulted from it. Hence, a new lexical variant of TFL has been defined: *People believe that similar things are placed closer together than dissimilar things.* To sum up my conclusions, I am going to answer my research questions with the help of TFL and its lexical variants.

As a reminder, the first research question was stated as follows: "*Could these common spatial biases in medially conveyed Volunteered Geographic Information be explained with Tobler's First Law?*" Based on the analysis of the existing literature and research conducted in VGI, a relation between the biases in data contributed to VGI and the main ideas of TFL found. The revision of existing VGI articles confirms the previous findings that generated data is often biased. For instance, it is found that VGI of a specific place is more relevant when it is contributed by the people who live nearby ([9], p. 24), clearly indicating the relevance of TFL in it. Moreover, Adams and McKenzie ([1], p. 201) concluded that near places are described with similar topics, thereby also connecting TFL with the comprehension of space based on VGI.

To assess my second research question, namely: "*How could Tobler's First Law be used to explain distortions in cognitive maps?*", my hypothesis, the Inverse of FLCG, could explain and confirm the research on the often occurred cognitive spatial distortions in the processing of landmarks in cognitive maps. Meaning, people often process landmarks as clustered and organized in hierarchies. Thereby, they process these, based on similarity clustered landmarks, as more close positioned than they are, resulting in the in-cluster distances being judged relatively smaller than the across-cluster distances ([3], as cited in [13], p. 100). Conclusively, we can use TFL to explain that the objects processed in a cognitive map as similar are understood as physically or semantically closer. This conclusion indicates the possible existence of *semantic maps* or *semantic cognitive spaces* that map spatial data in a space represented and spanned by non-spatial variables. Moreover, recent studies (see [52],[7],[63]) also suggested the concepts of different semantic spaces where non-spatial data are mapped on a dimension spanned by variables that indicate (dis)similarity in some manner, independent of its physical distance.

Due to the theoretical nature of this research and a broad spectrum of discussed topics, it was not possible to further examine the accuracy of my hypothesis. TFL is for sure an important law of geography, relevant and applicable as well in geography as in other social sciences and further. With the help of the core components of TFL, the spatial and semantic relations between things can be explained easier.

6 Conclusion

The aim of this work was to introduce the reader to the concepts of cognitive maps, VGI, and TFL, incidentally also reflecting on GIS, maps in general, and the importance of landmarks in cognitive maps. Moreover, to answer the research questions of this thesis, the concepts of cognitive maps and VGI were associated with TFL in the last chapter. By reviewing the findings from some VGI articles, a relation to TFL has been found where the typical bias of VGI could be explained with TFL or a lexical variation of TFL. Furthermore, a new lexical variant of TFL, namely the Inverse of FLCG, is stated in order to assess and explain a common cognitive distortion in cognitive maps where similarly processed landmarks are thought to be spatially closer positioned than the ones that are processed as dissimilar in a cognitive map. In summary, the hypothesized Inverse of FLCG confirms previous research in this field.

To examine the Inverse of FLCG, further research in this field is crucial. Advanced cognitive mapping research could be used to explain cognitive processes better and further assess the abilities of cognitive maps to comprehend the physical and cognitive space around us. Scientists in the cognitive mapping research could further work on examining and explaining the distortions of cognitive maps to find solutions for making humans' environment and external representations of space that they consume more appropriate for them to acquire the knowledge easier and use the full potential of cognitive maps for personal and social gains. It is hoped that this study will stimulate further research in this field.

List of Abbreviations

VGI Volunteered Geographic Information

GIS Geographic Information System

GI Geographic Information

GIScience Geographic Information Science

TFL Tobler's First Law

OSM OpenStreetMap

CGI Contributed Geographic Information

AGI Ambient Geographic Information

FLCG First Law of Cognitive Geography

Bibliography

[1] Benjamin Adams and Grant McKenzie. "Inferring thematic places from spatially referenced natural language descriptions". In: *Crowdsourcing Geographic Knowledge: Volunteered Geographic Information (VGI) in Theory and Practice*. Ed. by Daniel Sui, Sarah Elwood, and Michael Goodchild. Vol. 9789400745. Springer Netherlands, 2013, pp. 201–221. ISBN: 9789400745872. DOI: 10.1007/978-94-007-4587-2_12. URL: https://link.springer.com/chapter/10.1007/978-94-007-4587-2_12.

[2] Rebecca Albrecht and Rul von Stuelpnagel. "Memory for salient landmarks: Empirical findings and a cognitive model". In: *German Conference on Spatial Cognition*. 2018, pp. 311–325. ISBN: 9783319963846. DOI: 10.1007/978-3-319-96385-3_21.

[3] Gary L Allen. "A developmental perspective on the effects of" subdividing" macrospatial experience." In: *Journal of Experimental Psychology: Human Learning and Memory* 7.2 (1981). URL: https://psycnet.apa.org/record/1981-30016-001.

[4] Luc Anselin and Xun Li. "Tobler's Law in a Multivariate World". In: *Geographical Analysis* 52.4 (2020), pp. 494–510. ISSN: 15384632. DOI: 10.1111/gean.12237.

[5] Trevor J. Barnes. "A paper related to everything but more related to local things". In: *Annals of the Association of American Geographers*. Vol. 94. 2. Taylor Francis Group, 2004, pp. 278–283. DOI: 10.1111/j.1467-8306.2004.09402004.x. URL: https://www.tandfonline.com/doi/abs/10.1111/j.1467-8306.2004.09402004.x.

[6] Timothy EJ Behrens et al. "What is a cognitive map? Organizing knowledge for flexible behavior". In: *Neuron* 100.2 (2018), pp. 490–509. ISSN: 10974199. DOI: 10.1016/j.neuron.2018.10.002.

[7] Jacob L.S. Bellmund et al. *Navigating cognition: Spatial codes for human thinking*. 2018. DOI: 10.1126/science.aat6766. URL: http://science.sciencemag.org/.

[8] Nama R. Budhathoki and Caroline Haythornthwaite. "Motivation for Open Collaboration". In: *American Behavioral Scientist* 57.5 (2013), pp. 548–575. ISSN: 0002-7642. DOI: 10.1177/0002764212469364. URL: http://journals.sagepub.com/doi/10.1177/0002764212469364.

[9] Cristina Capineri. "The Nature of Volunteered Geographic Information". In: *European Handbook of Crowdsourced Geographic Information*. Ed. by Cristina Capineri et al. Ubiquity Press, 2016. Chap. 2. DOI: 10.5334/bax.

[10] N. R. Chrisman. "What does 'GIS' mean?" In: *Transactions in GIS* 3.2 (1999), pp. 175–186. ISSN: 13611682. DOI: 10.1111/1467-9671.00014.

[11] David J Coleman, Yola Georgiadou, and Jeff Labonte. "Volunteered Geographic Information: The Nature and Motivation of Produsers *". In: *International Journal of Spatial Data Infrastructures Research* 4.4 (2009), pp. 332–358. DOI: 10.2902/1725-0463.2009.04.art16. URL: https://ijsdir.sadl.kuleuven.be/index.php/ijsdir/article/view/140.

[12] H Couclelis. "The Death of Distance". In: *Environment and Planning B: Planning and Design* 23.4 (1996), pp. 387–389. ISSN: 0265-8135. DOI: 10.1068/b230387.

[13] H. Couclelis et al. "Exploring the anchor-point hypothesis of spatial cognition". In: *Journal of Environmental Psychology* 7.2 (1987), pp. 99–122. ISSN: 15229610. DOI: 10.1016/S0272-4944(87)80020-8.

[14] Michael N. DeMers. *GIS For Dummies®*. John Wiley Sons, 2009, Chapter 1. URL: https://learning.oreilly.com/library/view/gis-for-dummies/9780470236826/05_236826-ch01.xhtml.

[15] Elena Deza and Michel-Marie Deza. "Distances in Geography, Geophysics, and Astronomy". In: *Dictionary of Distances*. Elsevier, 2006. Chap. 25, pp. 309–317. DOI: 10.1016/b978-044452087-6/50025-1.

[16] Elena Deza and Michel-Marie Deza. "Non-Mathematical and Figurative Meaning of Distance". In: *Dictionary of Distances*. Elsevier, 2006, pp. 350–370. DOI: 10.1016/b978-044452087-6/50028-7.

[17] Elena Deza and Michel-Marie Deza. "Preface". In: *Dictionary of Distances*. Elsevier, 2006, pp. vii–ix. DOI: 10.1016/b978-044452087-6/50000-7.

[18] Frank Dickmann et al. "Spatial Distortions in Cognitive Maps — a Chance and Challenge to Enrich the Principles of Map Design". In: *KN - Journal of Cartography and Geographic Information* 63.3 (2013), pp. 174–181. ISSN: 2524-4957. DOI: 10.1007/bf03546131. URL: https://link.springer.com/article/10.1007/BF03546131.

[19] Roger M. Downs and David Stea, eds. *Image and Environment: Cognitive Mapping and Spatial Behavior*. Chicago, IL: Transaction Publishers, 2017. URL: https://books.google.de/books?hl=hr&lr=&id=dnwkmQ1fuUAC&oi=fnd&pg=PR8&dq=image+and+environment+downs+and+stea&ots=xqXa-yYXxO&sig=1nxLnNXm0-MHi6hn0tpV23WjlPE&redir_esc=y#v=onepage&q=imageandenvironmentdownsandstea&f=false.

[20] K. J. Dueker and D. Kjerne. *Multipurpose cadastre: Terms and definitions*. Falls Church, VA: American Soc. for Photogrammetry and Remote Sensing, 1989. URL: https://scholar.google.com/scholar?hl=hr&as_sdt=0%2C5&q=Dueker+and+Kjerne+%281989%29&btnG=#d=gs_cit&u=%2Fscholar%3Fq%3Dinfo%3Ajl1QcZfeXesJ%3Ascholar.google.com%2F%26output%3Dcite%26scirp%3D0%26hl%3Dhr.

[21] Max Eckert and W Joerg. "On the Nature of Maps and Map Logic". In: *Bulletin of the American Geographical Society* 40.6 (1908), pp. 344–351.

[22] John E Estes and D Wayne Mooneyhan. "Of Maps and Myths". In: *Photogrammetric engineering and remote sensing* 60.5 (1994), pp. 517–524.

[23] Sara Irina Fabrikant et al. "The first law of cognitive geography: distance and similarity in semantic space". In: *Proceedings of GIScience 2002* (2002), pp. 31–33. URL: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.19.4820&rep=rep1&type=pdf.

[24] Richard Feynman. *The Character of Physical Law*. Cambridge, MA: MIT Press, 1967. URL: https://books.google.at/books?hl=hr&lr=&id=SJNPDgAAQBAJ&oi=fnd&pg=PP6&dq=richard+feynman+the+character+of+physical+law&ots=Vb4fLPqsru&sig=j3hhEdQOgWgL3rUY3gexH9OJ3YY&redir_esc=y#v=onepage&q=richardfeynmanthecharacterofphysicallaw&f=false.

[25] A. U. Frank. "Spatial Communication with Maps: Defining the Correctness of Maps Using a Multi-Agent Simulation". In: *Spatial Cognition II: Integrating Abstract Theories, Empirical Studies, Formal Methods, and Practical Applications*. Ed. by C. Freksa et al. Springer Berlin Heidelberg, 2000, pp. 80–99.

[26] Christian Freksa, Moratz, and Thomas Barkowsky. "Schematic Maps for Robot Navigation". In: *Spatial Cognition II: Integrating Abstract Theories, Empirical Studies, Formal Methods, and Practical Applications*. Ed. by C. Freksa et al. Springer Berlin Heidelberg, 2000, pp. 100–114. ISBN: 3540675841. URL: https://books.google.com/books?hl=en&lr=&id=XFmrCAAAQBAJ&oi=fnd&pg=PR3&dq=Spatial+Cognition+II:+Integrating+Abstract+Theories,+Empirical+Studies+&ots=9lZQk2C3xl&sig=PRK7NGzrBhEQ4KX3M6XcDiz9ang.

[27] S Fritz, L See, and M Brovelli. "Motivating and Sustaining Participation in VGI". In: *Mapping and the Citizen Sensor*. Ed. by G Foody et al. Ubiquity Press, 2017, pp. 93–117. DOI: 10.5334/bbf.e.

[28] Michael F. Goodchild. "Citizens as sensors: The world of volunteered geography". In: *GeoJournal* 69.4 (2007), pp. 211–221. ISSN: 03432521. DOI: 10.1007/s10708-007-9111-y.

[29] Michael F Goodchild. "GIScience, Geography, Form, and Process". In: *Annals of the Association of American Geographers* 94.4 (2004), pp. 709–714. DOI: 10.1111/j.1467-8306.2004.00424.x.

[30] Michael F. Goodchild. "The validity and usefulness of laws in geographic information science and geography". In: *Annals of the Association of American Geographers*. Vol. 94. 2. Taylor Francis Group, 2004, pp. 300–303. DOI: 10.1111/j.1467-8306.2004.09402008.x. URL: https://www.tandfonline.com/doi/abs/10.1111/j.1467-8306.2004.09402008.x.

[31] Mark Graham. *Mapping the uneven geographies of information worldwide / The Policy and Internet Blog*. 2013. URL: https://blogs.oii.ox.ac.uk/policy/mapping-the-uneven-geographies-of-information-worldwide/ (visited on 05/27/2021).

[32] Carlos Granell and Frank O. Ostermann. "Beyond data collection: Objectives and methods of research using VGI and geo-social media for disaster management". In: *Computers, Environment and Urban Systems* 59 (2016), pp. 231–243. ISSN: 01989715. DOI: 10.1016/j.compenvurbsys.2016.01.006.

[33] Francis Harvey. *A primer of GIS: fundamental geographic and cartographic concepts*. 2nd Editio. The Guilford Press, 2016. ISBN: 978-1-4625-2217-0.

[34] Francis Harvey. "To Volunteer or to Contribute Locational Information? Towards Truth in Labeling for Crowdsourced Geographic Information". In: *Crowdsourcing Geographic Knowledge*. Ed. by Daniel Sui, Sarah Elwood, and Michael Goodchild. Springer, Dordrecht, 2013. Chap. 3, pp. 31–42.

[35] S. C. Hirtle. "The use of maps, images and "gestures" for navigation". In: *Spatial Cognition II: Integrating Abstract Theories, Empirical Studies, Formal Methods, and Practical Applications*. Ed. by C. Freksa et al. Springer Berlin Heidelberg, 2000, pp. 31–40.

[36] Stephen C. Hirtle and John Jonides. "Evidence of hierarchies in cognitive maps". In: *Memory Cognition* 13.3 (1985), pp. 208–217. ISSN: 0090502X. DOI: 10.3758/BF03197683. URL: https://link.springer.com/article/10.3758/BF03197683.

[37] Bin Jiang and Chris De Rijke. "A power-law-based approach to mapping COVID-19 cases in the United States". In: *Geo-spatial Information Science* July (2021), pp. 1–7.

[38] Julian Keil et al. "Effects of visual map complexity on the attentional processing of landmarks". In: *PLoS ONE* 15.3 (2020), pp. 1–20. DOI: 10.1371/journal.pone.0229575.

[39] Kevin Lynch. *The Image of the City*. 1960. URL: https://books.google.at/books?hl=hr&lr=&id=NL74DwAAQBAJ&oi=fnd&pg=PA1&dq=lynch+1960&ots=izz2_HRG35&sig=VJ0UVpdgzv3vGoXkRPkf9ZFiM4o&redir_esc=y#v=onepage&q&f=false (visited on 04/29/2021).

[40] Robert M. Kitchin. "Cognitive maps: What are they and why study them?" In: *Journal of Environmental Psychology* 14.1 (1994), pp. 1–19. ISSN: 15229610. DOI: 10.1016/S0272-4944(05)80194-X.

[41] Menno Jan Kraak and Ferjan Ormeling. *Cartography: Visualization of geospatial data*. Adison Wesley Longman Limited, 1996.

[42] Menno Jan Kraak and Ferjan Ormeling. *Cartography: Visualization of geospatial data*. 4th Editio. CRC Press, 2020. ISBN: 9781315847184. DOI: 10.4324/9781315847184. URL: https://books.google.de/books?hl=hr&lr=&id=nPvvDwAAQBAJ&oi=fnd&pg=PP1&ots=O7TQjGLqbb&sig=eaTh6r2G2sUI_gwWInKEFHOdcEO&redir_esc=y#v=onepage&q&f=false.

[43] Robert Lloyd. "The estimation of distance and direction from cognitive maps". In: *The American Cartographer* 16.2 (1989), pp. 109–122. ISSN: 00941689. DOI: 10.1559/152304089783875415.

[44] Robert Lloyd and Christopher Heivly. "Systematic Distortions in Urban Cognitive Maps". In: *Annals of the Association of American Geographers* 77.2 (1987), pp. 191–207.

[45] Paul A. Longley. *Geographic Information Systems (GIS)*. Ed. by Karen Kemp. 2008.

[46] Paul A. Longley et al. *Geographic Information Science and Systems*. 4th Editio. John Wiley Sons, 2015.

[47] Alan MacEachren. *How maps work: Representation, Visualization Design*. New York: Guildford Press, 1995.

[48] Alan M. Maceachren and D. R. Fraser Taylor, eds. *Visualization in Modern Cartography*. Vol 2. Vol. 2. Pergamon, 1994. DOI: 10.1016/B978-0-08-042415-6.50008-9.

[49] David M. Mark et al. "Cognitive models of geographical space". In: *International Journal of Geographical Information Science* 13.8 (1999), pp. 747–774. ISSN: 13623087. DOI: 10.1080/136588199241003.

[50] Mikel Maron. *Flickr Photos*. 2010. URL: https://www.flickr.com/photos/mikel_maron/page2.

[51] Timothy P. McNamara. "Mental representations of spatial relations". In: *Cognitive Psychology* 18.1 (1986), pp. 87–121. ISSN: 00100285. DOI: 10.1016/0010-0285(86)90016-2.

[52] Alexander Mehler et al. "From topic networks to distributed cognitive maps zipfian topic universes in the area of volunteered geographic information". In: *Complexity* 2020 (2020). ISSN: 23318422. arXiv: 2002.01454.

[53] Harvey J Miller. "Tobler's First Law and Spatial Analysis". In: *Annals of the Association of American Geographers* 94.2 (2004), pp. 284–289.

[54] Jared Miller and Laura Carlson. "Selecting landmarks in novel environments". In: *Psychonomic Bulletin and Review* 18.1 (2011), pp. 184–191. ISSN: 10699384. DOI: 10.3758/s13423-010-0038-9.

[55] Alexandra Millonig and Katja Schechtner. "Developing Landmark-Based Pedestrian-Navigation Systems". In: *IEEE Transactions on Intelligent Transportation Systems* 8.1 (2007), pp. 43–49. DOI: 10.1109/TITS.2006.889439. URL: https://www.researchgate.net/publication/3428010.

[56] Daniel R Montello. "A New Framework for Understanding the Acquisition of Spatial Knowledge in Large-Scale Environments". In: *Spatial and temporal reasoning in geographic information systems*. Ed. by M. J. Egenhofer and R. G. Golledge. New York: Oxford University Press, 1998, pp. 143–154.

[57] Daniel R Montello. "Landmarks are Exaggerated". In: 31 (2017), pp. 193–197. DOI: 10.1007/s13218-016-0473-5.

[58] Daniel R. Montello et al. "Testing the first law of cognitive geography on point-display spatializations". In: *Spatial Information Theory*. Vol. 2825. Springer Verlag, 2003, pp. 316–331. ISBN: 3540201483. DOI: 10.1007/978-3-540-39923-0_21. URL: https://link.springer.com/chapter/10.1007/978-3-540-39923-0_21.

[59] J. O'Keefe and J. Dostrovsky. "The hippocampus as a spatial map. Preliminary evidence from unit activity in the freely-moving rat". In: *Brain Research* 34.1 (1971), pp. 171–175. ISSN: 00068993. DOI: 10.1016/0006-8993(71)90358-1.

[60] Riva Richmond. *The tech savvy lend a hand in Haiti*. 2010. URL: https://scholar.google.com/scholar?hl=hr&as_sdt=0%2C5&q=The+tech+savvy+lend+a+hand+in+Haiti&btnG=.

[61] Florian Röser, Kai Hamburger, and Markus Knauff. "The Giessen virtual environment laboratory: Human wayfinding and landmark salience". In: *Cognitive Processing* 12.2 (2011), pp. 209–214. ISSN: 16124782. DOI: 10.1007/s10339-011-0390-3.

[62] Edward K. Sadalla, W. Jeffrey Burroughs, and Lorin J. Staplin. "Reference points in spatial cognition". In: *Journal of Experimental Psychology: Human Learning and Memory* 6.5 (1980), pp. 516–528. ISSN: 00961515. DOI: 10.1037/0278-7393.6.5.516. URL: /record/1981-25004-001.

[63] Matthew Schafer and Daniela Schiller. *Navigating Social Space*. 2018. DOI: 10.1016/j.neuron.2018.10.006.

[64] Jonathan M Smith. "Unlawful Relations and Verbal Inflation". In: *Source: Annals of the Association of American Geographers*. Vol. 94. 2. 2004, pp. 294–299.

[65] Robert Soden. *4 Years On, Looking Back at OpenStreetMap Response to the Haiti Earthquake*. 2014. URL: https://blogs.worldbank.org/latinamerica/4-years-looking-back-openstreetmap-response-haiti-earthquake (visited on 04/28/2021).

[66] Molly E. Sorrows and Stephen C. Hirtle. "The nature of landmarks for real and electronic spaces". In: *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*. Vol. 1661. Springer Verlag, 1999, pp. 37–50. ISBN: 3540663657. DOI: 10.1007/3-540-48384-5_3. URL: https://link.springer.com/chapter/10.1007/3-540-48384-5_3.

[67] Anthony Stefanidis, Andrew Crooks, and Jacek Radzikowski. "Harvesting ambient geospatial information from social media feeds". In: *GeoJournal* 78.2 (2013), pp. 319–338. ISSN: 03432521. DOI: 10.1007/s10708-011-9438-2. URL: http://geocommons..

[68] Albert Stevens and Patty Coupe. "Distortions in judged spatial relations". In: *Cognitive Psychology* 10.4 (1978), pp. 422–437. ISSN: 00100285. DOI: 10.1016/0010-0285(78)90006-3.

[69] Dario Stojanovski et al. "Social Networks VGI: Twitter Sentiment Analysis of Social Hotspots". In: *European Handbook of crowdsourced geographic information*. 2016, pp. 223–235. DOI: 10.5334/bax.q.

[70] Daniel Sui. *First Law of Geography*. Ed. by Karen Kemp. 2008.

[71] Daniel Sui, Sarah Elwood, and Michael Goodchild. "Volunteered Geographic Information, the Exaflood, and the Growing Digital Divide". In: *Crowdsourcing geographic Knowledge: Volunteered geographic information (VGI) in theory and practice*. Ed. by Daniel Sui, Sarah Elwood, and Michael Goodchild. Springer, 2013. Chap. 1, pp. 1–14. ISBN: 9789400745872. DOI: 10.1007/978-94-007-4587-2.

[72] Daniel Z Sui. "Tobler's First Law of Geography: A Big Idea for a Small World?" In: *Annals of the Association of American Geographers*. Blackwell Publishing, 2004, pp. 269–277.

[73] Norman J. W. Thrower. *Maps and civilization: cartography in culture and society*. 3rd Editio. The University of Chicago Press, 2008, pp. 1–7. URL: https://books.google.com/books?hl=hr&lr=&id=cGeCNa_vookC&oi=fnd&pg=PR9&dq=maps+and+civilization+thrower&ots=ongx2MIzoM&sig=iLslL6rOmI-a7BMycMYwgBVBHeU.

[74] W. R. Tobler. "A Computer Movie Simulating Urban Growth in the Detroit Region". In: *Economic Geography* 46 (1970), pp. 234–240. ISSN: 00130095. DOI: 10.2307/143141.

[75] Waldo Tobler. "On the First Law of Geography: A Reply". In: *Annals of the Association of American Geographers* 94.2 (2004), pp. 304–310.

[76] Edward C. Tolman. "Cognitive maps in rats and men". In: *Psychological review* 55.4 (1948), pp. 189–208.

[77] B. Tversky. “Some Ways that Maps and Diagrams Communicate”. In: *Spatial Cognition II: Integrating Abstract Theories, Empirical Studies, Formal Methods, and Practical Applications*. Ed. by C. Freksa et al. Springer Berlin Heidelberg, 2000, pp. 72–79.

[78] Barbara Tversky. “Cognitive maps, cognitive collages, and spatial mental models”. In: *European conference on spatial information theory*. Springer, 1993, pp. 14–24. ISBN: 9783540572077. DOI: 10.1007/3-540-57207-4_2.

[79] Barbara Tversky. “Distortions in cognitive maps”. In: *Geoforum* 23.2 (1992), pp. 131–138. ISSN: 00167185. DOI: 10.1016/0016-7185(92)90011-R.

[80] Barbara Tversky. *Mind in motion: How action shapes thought*. Hachette UK, 2019.

[81] Barbara Tversky. “Structures of mental spaces: How people think about space”. In: *Environment and Behavior* 35.1 (2003), pp. 66–80. ISSN: 00139165. DOI: 10.1177/0013916502238865.

[82] Nigel Waters. “Tobler’s First Law of Geography”. URL: https://www.researchgate.net/profile/Nigel_Waters/publication/328723512_Tobler's_First_Law_of_Geography/links/5bddc630299bf1124fb95453/Toblers-First-Law-of-Geography.

[83] Matthew Zook et al. “Volunteered Geographic Information and Crowdsourcing Disaster Relief: A Case Study of the Haitian Earthquake”. In: *World Medical Health Policy* 2.2 (2010), pp. 6–32. DOI: 10.2202/1948-4682.1069.

Erklärung

Hiermit erkläre ich, dass ich die vorliegende Arbeit selbständig und ohne Benutzung anderer als der angegebenen Quellen und Hilfsmittel verfasst habe. Ebenso bestätige ich, dass diese Arbeit nicht, auch nicht auszugsweise, für eine andere Prüfung oder Studienleistung verwendet wurde.

Ort, Datum

Đurđica Živković