Cartographic Perspectives

The Journal of nacis

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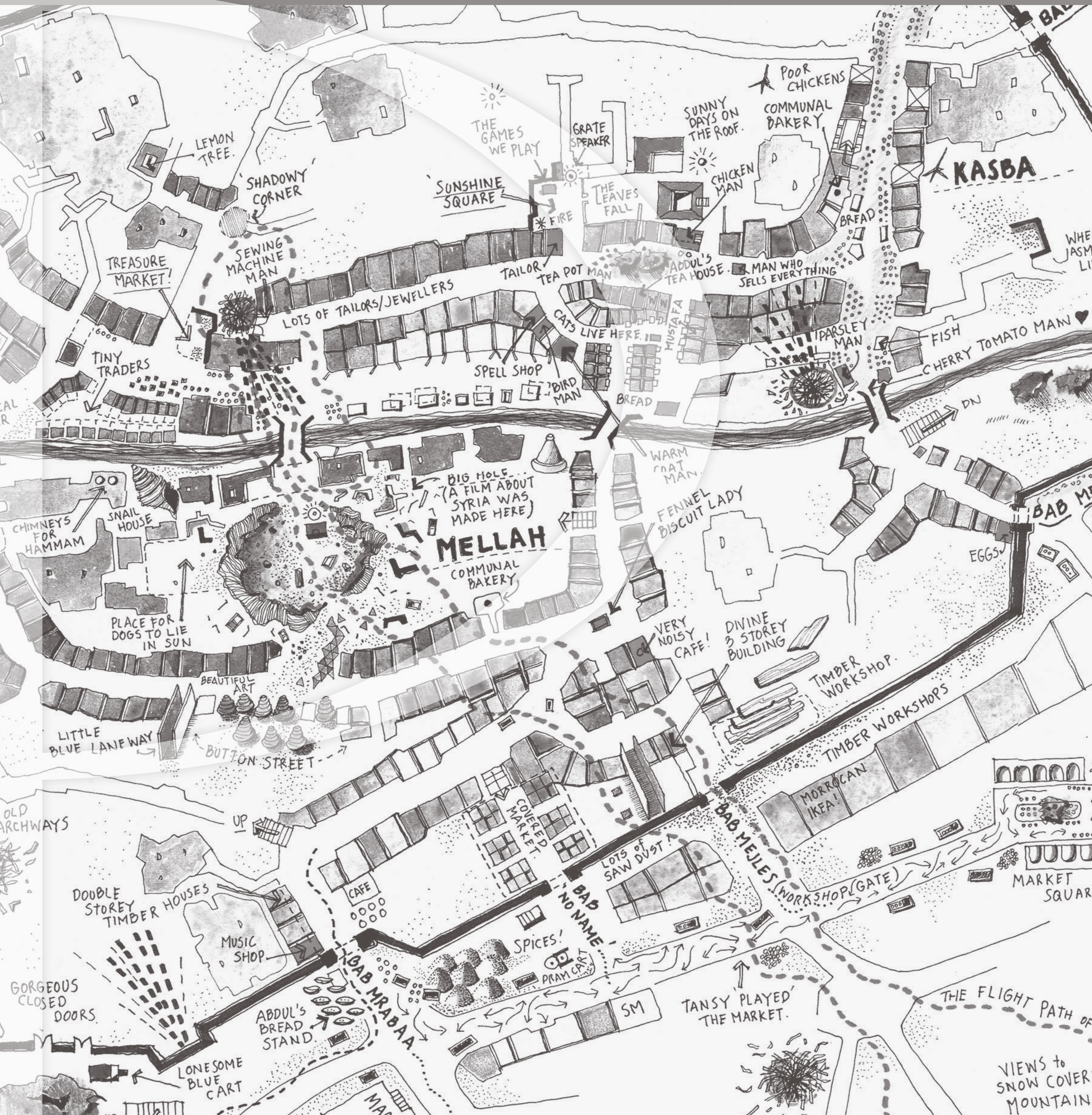

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ABOUT THE COVER: *Detail from* From The Village Of Fez To The City Of Sefrou, *by Alex Hotchin, recently recognized as a 2018 Honorable Mention by the* Atlas of Design. *To see more of Alex's work, visit* alexhotchin.com.

LETTER FROM THE EDITOR

As I write this letter, I am looking forward to a number of things: the end of my school year (odd, I know, for those of you in the Northern Hemisphere who find school just getting started again . . .), the upcoming NACIS Annual Meeting, and the publication of the *Atlas of Design, Volume IV*. It is actually a close contest as to which one I am awaiting most keenly. Luckily for me, each of these events will occur within about a week of each other.

The title *Atlas of Design* can be read in several ways. Of course the term atlas connotes that maps are involved in some way. But is the book itself an atlas? One can find many descriptions of what an atlas is meant to be, if one goes to look. For example, the International Cartographic Association has a Commission on Atlases, and their **webpage** presents several definitions, which mainly have in common some notion of an atlas being an organised collection of maps. In this basic sense, *Atlas of Design* meets this definition, in that it is a collection of maps whose order has been considered carefully by the editors. Many atlases order their components spatially, with adjacent locations depicted in sequences of maps. Francis Harvey has argued that we could view atlases as exhibitions, in his examination of Herbert Bayer's 1953 *World Geo-graphic Atlas* (spreads from this atlas are available online through the David Rumsey Map Collection: **davidrumsey.com**). Exhibitions, of course, are often structured to provide a narrative exploration of a topic. So one way of thinking about the *Atlas of Design* is that it is an exhibition of contemporary cartographic excellence. In fact, the book's website (**atlasofdesign.org**) describes it as a "gallery."

For me, at any rate, atlases are a place where discovery can happen: of places you may not have had the opportunity to go, and of relationships between phenomena that might not have been apparent from examining individual maps in isolation. Applying this concept to the title, perhaps what the *Atlas of Design* does is present previously unknown (at least to many readers) locations in the landscape of cartographic design. By examining the maps within the *Atlas*, one can discover both new ways of seeing the world and new ways of showing the world: the geography and the cartography. So pick it up, and be cartographically inspired! This issue of *CP* features two connections to the *Atlas of Design*. Firstly, one of the maps in the *Atlas of Design, Volume IV* is drawn from the *Ecological Atlas of the Bering, Chukchi, and Beaufort Seas*, a book which Daniel Cole reviews in these pages. Secondly, Daniel Huffman's piece in the *PRACTICAL CARTOGRAPHER'S CORNER* illustrates one of the cartographic techniques he applied to the *Ecological Atlas*.

In *CP 90*, you will find two *PEER-REVIEWED ARTICLES*. In the first, Fritz Kessler, the current President of NACIS, puts on some of his other hats: those of Associate Professor of Geography and Senior Research Associate in the John A. Dutton e-Education Institute. Fritz is currently co-authoring a textbook on map projections with Sarah Battersby, and his contribution here to *CP* developed out of the thinking he's been doing for that book. In his paper, he examines the evolution of how map projection concepts have been presented in cartography textbooks over the twentieth and early twenty-first centuries, and he recommends what materials on map projections should be included in today's textbooks to prepare students for a variety of professional roles that require knowledge about map projections.

In the second article, Lukáš Herman and his colleagues from Masaryk University in the Czech Republic present an experimental tool they have developed to help designers and developers to study the maps of tomorrow that we are building today: those developed in 3D environments. As 3D becomes ever more prevalent in cartographic displays, it is critical that we develop an understanding of when and how 3D capabilities help readers to see spatial and spatiotemporal relationships more clearly, and what design features best support map readers as they work with such displays. A challenge in understanding what works and what does not, especially in the case of interactive 3D displays, has been that is has been difficult to observe how users interact with 3D environments: how often do they pan, zoom, or rotate the displays, and can they find the answers to questions effectively and quickly? The 3DmoveR tool facilitates observing and understanding such user behaviours in 3D environments.

In *CARTOGRAPHIC COLLECTIONS*, Elizabeth Skene and Krista Schmidt describe their work in establishing a digital collection of historic and regional maps at Western Carolina University. They describe the planning process that helped them to implement their scanning and cataloguing operation and discuss how, in order to provide the widest possible access to the collection, they included the maps in two different library catalogues and provided search terms that would be more useful to library patrons than the Library of Congress Subject Headings. A side benefit to the project has been the deepening of the library's connections to the local community.

In the *PRACTICAL CARTOGRAPHER'S CORNER*, Daniel Huffman shows us the secret to how he created a complex line style that he used in some of the maps he created for Audubon Alaska's recent *Ecological Atlas of the Bering, Chukchi, and Beaufort Seas*. Daniel builds the style using a combination of tools in Adobe Illustrator's appearance panel, along with the program's knockout group capability, and he presents an introduction to why these particular tools can be helpful for cartographers generally.

In keeping with his much-appreciated tradition of sharing with the cartographic community, Daniel does double-duty in this issue, writing about his approach to teaching cartography in *VIEWS ON CARTOGRAPHIC EDUCATION*. Here, he discusses both the philosophy that drives how he teaches cartography as well as some pedagogical strategies he has tried and their relative merits or demerits.

In *VISUAL FIELDS*, Steven Holloway shares his artwork, which arises from his practice of stopping to listen to place. Frequently drawn to water, Steven's contribution explores several different rivers and a lakeshore using maps, photographs, and lithographs, all accompanied by poems.

Four book *REVIEWS* complete *CP 90*. Jörn Seemann reviews *Imagery and GIS: Best Practices for Extracting Information from Imagery*. Jörn's review situates this volume within the range of introductory texts on image processing. He finds that it presents a compromise between technical, practical, and visual detail, which may be of benefit for some audiences. Daniel Cole's review of *Ecological Atlas of the Bering, Chukchi, and Beaufort Seas* finds that the authors and cartographer have achieved their goal of producing a "comprehensive trans-boundary atlas that represents the current state of knowledge" of the ecology of this region; an atlas that is also beautiful. John Swab praises Mark Monmonier's latest monograph, *Patents and Cartographic Inventions: A New Perspective for Map History*, for providing insights into 19th and early 20th century cartographic innovations, even when they were commercially unviable and therefore did not see wide implementation. Last but not least, Tanya Buckingham reviews the *Oxford Atlas of the World, Twenty-Fourth Edition*. She notes that the updates to this most recent edition are modest when compared with the past four editions, implying that a yearly update of the world atlas in your collection may not be the best use of your map collecting resources.

Whether you plan to experience October's NACIS Annual Meeting in person, online via our video stream, or through the Twitter hashtag **#nacis2018**, I invite you to first whet your appetite for cartographic learning by perusing the cartographic scholarship and practice reported on in this issue of *CP*.

Amy L. Griffin
Cartographic Perspectives Editor

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Map Projection Education in Cartography Textbooks: A Content Analysis

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As developments in the field of map projections occur (e.g., the deriving of a new map projection), it would be reasonable to expect that those developments that are important from a teaching standpoint would be included in cartography textbooks. However, researchers have not examined whether map projection material presented in cartography textbooks is keeping pace with developments in the field and whether that material is important for cartography students to learn. To provide such an assessment, I present the results of a content analysis of projection material discussed in 24 cartography textbooks published during the twentieth and early twenty-first centuries. Results suggest that some material, such as projection properties, was discussed in all textbooks across the study period. Other material, such as methods used to illustrate distortion patterns, and the importance of datums, was either inconsistently presented or rarely mentioned. Comparing recent developments in projections to the results of the content analysis, I offer three recommendations that future cartography textbooks should follow when considering what projection material is important. First, textbooks should discuss the importance that defining a coordinate system has in the digital environment. Second, textbooks should summarize the results from experimental studies that provide insights into how map readers understand projections and how to choose appropriate map projections. Third, textbooks should review the impacts of technology on projections, such as the web Mercator projection, programming languages, and the challenges of projecting raster data.

KEYWORDS: map projection; datum; content analysis; cartographic education; history of cartography

ACKNOWLEDGEMENTS

I extend thanks to the three anonymous reviewers and Amy Griffin, the Editor of *Cartographic Perspectives*, for their helpful comments that improved this article. I also appreciate the help of Dr. Terry Slocum for his editorial assistance.

INTRODUCTION

While developing a forthcoming book, *Working with Map Projections: A Visual Guide to their Selection*, I wanted to include an overview chapter on projections. This overview chapter is important, as my book is written for mapmakers with little background knowledge of the subject. To assist in determining appropriate projection material to include in this chapter, I arbitrarily sampled cartography textbooks published since 1990 and reviewed their contents, as these textbooks often contained overview chapters on projections. A casual inspection revealed considerable variation in the material they included. For example, one textbook explained in detail the steps needed to select a projection, while another provided no guidance. Further inquiry into textbooks written prior to World War II revealed that most placed emphasis on the technical skills needed to graphically construct projections. However, due to advancements in computer technology, these skills are no longer relevant and are not found in more recent textbooks. The variation in coverage that I found sparked my interest to more thoroughly examine what projection material was included in textbooks from 1900 to the present.

This paper consists of three major sections. The first section summarizes the results of a content analysis of projection material presented in 24 cartography textbooks published during the twentieth and early twenty-first centuries, which were randomly selected from a larger set of textbooks, each containing a discussion of projections within a holistic discussion of mapmaking. The textbooks were published in English between 1900 and 2014. Briefly, the content analysis involved reading through each projection discussion and recording projection-specific words (e.g., "conformal"). These words were then used to create categories (e.g., map projection properties), and the categories were then used to characterize the projection material that was presented in the surveyed textbooks.

The second section discusses developments in the field of projections that took place during the twentieth and early twenty-first centuries, including new projections, methods of symbolizing distortion patterns, and applications of projections for specific map purposes. Some developments, such as programming languages, took place outside the field of projections, but were quickly integrated into the field during the latter half of this time period.

The third section ties together the results of the content analysis with these developments, with the ultimate goal of recommending what projection material should be included in future textbooks by summarizing earlier material and augmenting it with new developments that are significant for introductory students to learn. For example, viewing distortion across a projection's surface is obviously important for students to learn because of the differences between projections and their suitability for different mapping purposes. However, other developments may be important in a general sense but are not significant from a teaching standpoint. For instance, Lee's (1965) conformal map of the world in a triangle satisfied a specific mathematical curiosity, but does not have any practical cartographic advantage. Thus, learning about Lee's projection would not be particularly impactful from a teaching perspective.

CONTENT ANALYSIS OF MAP PROJECTION MATERIAL IN CARTOGRAPHY TEXTBOOKS

Krippendorff (2019) divides content analysis into qualitative and quantitative approaches. Qualitative content analysis is concerned with drawing parallels between objects, whereas quantitative content analysis (which was utilized for this research) involves counting the frequency of objects or their attributes. Objects can include maps, images, written text, or verbal communication. The basic idea is to record the frequency of an object (e.g., counting the number of times the word "terrorist" appears throughout a series of newspapers) across a specific time period or particular media, gathering numerical data that can reveal patterns or themes. In return, these counts can be used to answer specific research questions (e.g., is the word "terrorist" used more frequently in newspapers since the events of 9/11?).

Content analysis has been applied in a variety of disciplines and provided insight into numerous cartographic research questions. Gilmartin (1992) used content analysis to contextualize 25 years of cartographic research appearing in three cartography journals. Using a combination of content analysis and focus groups, Monmonier and Gluck (1994) studied participants' views of animated cartographic software. Gluck (1998) applied content analysis as one of several qualitative techniques when investigating cartographic and geospatial images from the 1994 annual reports of 153 United States corporations. To examine the variation in map design across eleven editions of *Goode's World Atlas,* Muehlenhaus (2011) likewise employed it. I have previously (Kessler and Slocum 2011) used content analysis to examine map design in thematic maps published in the *Annals of the Association of American Geographers* and the *Geographical Journal* during the twentieth century. Most recently, Muehlenhaus (2013) administered the technique to evaluate the communicative characteristics of 256 persuasive maps.

Shreier (2012) outlines five steps that characterize a content analysis. She identifies the first step as the formulation of the research question. In the second, the researcher selects the appropriate material for the content analysis. The third step involves selecting the individuals who will perform the content analysis. During the fourth step, the categories that will be used to organize the data collected during the content analysis are defined. The fifth step rounds out the process by presenting and interpreting the findings of the content analysis. As shown in the following discussion, I applied these steps to carry out a content analysis of projection material in cartography textbooks from 1900 to 2014.

STEP 1: IDENTIFY THE RESEARCH QUESTION

One way that many students learn about projections is through cartography textbooks. Ideally, projection material included in these textbooks should keep pace with the developments in the broader mapping field. However, no studies exist that survey projection material included in these textbooks to determine if in fact students are being presented with material that will help them work with projections. This is the fundamental aim of this study.

STEP 2: SELECTING THE MATERIAL FOR THE CONTENT ANALYSIS

Selecting cartography textbooks for this study involved three substeps. In the first substep I reviewed sources to identify potential textbooks to include in the study. Fryman (1996) and Fryman and Sines (1990; 1998) listed cartography titles (mostly from the 1950s onward) that were adopted in university cartography courses. Examining bibliographies from textbooks published between 1940 and 1960 helped me to choose textbooks published between those decades. Finding textbooks older than 1940 (before cartography was accepted as a formal field of academic study), required searching for words like "mapping," "topography," or "surveying" in book titles. Keyword searches in online library catalogs (e.g., WorldCat) also provided assistance in identifying textbooks from throughout the study period. Since my primary language is English, I only considered English-language textbooks in this substep. At the conclusion, a total of 67 textbooks were identified as candidates to include in the study.

The second substep focused on examining each candidate textbook to see if the subject of projections was included. To be considered for this study, at a minimum, a candidate textbook had to contain at least some portion of a chapter or an appendix discussing projections. Textbooks on GIS, remote sensing, or projections tend to focus on methods of spatial analysis, satellite imagery, and the mathematical equations of projections, respectively, and were not included in this study. There were 48 textbooks that met the conditions of the second substep, listed in Appendix A.

The third substep used stratified random sampling from the 48 textbooks identified in substep 2; this was done to save time over conducting analysis on the entire group. I began the sampling by placing each of the 48 textbooks into the decade in which it was published. I then randomly sampled two textbooks from each decade. To avoid oversampling multiple editions of the same textbook, only one edition of each title was selected. Table 1 lists the 24 textbook titles, authors, and publication dates used for this study.

STEP 3: CHOICE OF WHO PERFORMS THE CONTENT ANALYSIS

An important methodological concern in content analysis is who performs the coding process. Schreier (2012, 34) explains that a content analysis should impart "objectivity and reliability," and thus multiple coders ideally should be employed. However, she offers that using one coder is possible, and that the coder can be the one doing the research. For example, Gilmartin (1992), Edney (2014), and Muehlenhaus (2011) each were the only coder in their own content analysis research. For this study I chose to be the coder for three reasons. First, I wrote three chapters on projections for *Thematic Cartography and Geovisualization* (Slocum et al. 2005). This was an invaluable experience that provided insight into how the subject of projections should be integrated into a cartography textbook. Second, I have taught a course on introductory cartography for twenty years. As the subject of projections has been an integral part of the course's lecture topics, I am aware of the struggles that students face when learning this subject. Third, I have researched and published material relevant to teaching projections such as how people comprehend distortion across a projection (e.g., Battersby and Kessler 2012).

Schreier (2012, 199) recommends that if a single coder is used, then one third of the material should be re-coded after a 10–14 day hiatus. Thus, I reexamined a random sample of eight of the 24 textbooks after a hiatus of 12 days; these are marked with an asterisk after the date in Table 1. After re-coding the eight textbooks and following the same methodology as outlined here, the results were consistent with the initial findings of the content analysis.

Decade	Textbook Title and Edition	Author(s)	Publication Date
1900	*Maps, Their Uses and Construction*	James Morrison	1902
	Text Book of Topographical and Geographical Surveying	Charles Close	1905*
1910	*Maps and Map Making*	Edward Reeves	1910
	Topographic, Trigonometric and Geodetic Surveying, Including Geographic, Exploratory, and Military Mapping with Hints on Camping, Emergency Surgery, and Photography	Herbert Wilson	1912
1920	*Maps and Surveys (2nd ed.)*	Arthur Hinks	1923
	Topographic Mapping	Lawrence Roberts	1924*
1930	*Cartography*	Charles Deetz	1936
	The World in Maps: A Study in Evolution	Walter Jervis	1937*
1940	*The History and Technique of Map Making*	Helmuth Bay	1943
	General Cartography (2nd ed.)	Erwin Raisz	1948*
1950	*Mapping*	David Greenhood	1951*
	Elements of Cartography	Arthur Robinson	1953
1960	*An Introduction to Mapwork and Practical Geography*	John Bygott and D. C. Money	1962*
	Maps: Topographical and Statistical	Thomas Birch	1964
1970	*Cartographic Methods*	George Lawrence	1971
	Map Use: Reading, Analysis, and Interpretation	Phillip Muehrcke and Juliana Muehrcke	1978
1980	*Thematic Maps: Their Design and Practice*	David Cuff and Mark Mattson	1982*
	Basic Cartography for Students and Teachers: Volume 1	Roger Anson and Ferjan Ormeling	1984
1990	*Cartography: Thematic Map Design (2nd ed.)*	Borden Dent	1990
	Introductory Cartography	John Campbell	1991
2000	*Map Use and Analysis (5th edition)*	John Campbell	2005
	Thematic Cartography and Geovisualization (2nd ed.)	Terry Slocum, Bob McMaster, Fritz Kessler, and Hugh Howard	2005*
2010	*Cartography and Visualization of Spatial Data (3rd ed.)*	Menno-Jan Kraak and Ferjan Ormeling	2010
	Principles of Map Design (2nd ed.)	Judith Tyner	2014

Table 1. *The 24 cartography textbooks selected for this study. An asterisk after the date indicates that the textbook was used in the re-coding process, as described in step 3 of the methodology.*

STEP 4: DEVELOPING CATEGORIES TO ORGANIZE PROJECTION WORDS DURING THE CONTENT ANALYSIS

Once the 24 textbooks were selected, I carefully read each projection section three times. During the first reading, I recorded descriptive data about each section that discussed projections, including the number of pages, illustrations, tables, and equations relating to projections. The second reading involved recording projection-specific words (e.g., "conformal," or an individual projection name). As a given projection word was encountered in a section, it was entered alphabetically into a single column in a spreadsheet (Figure 1). An additional column was included in this spreadsheet to record notes relating to the context in which the word was presented. For example, the term "sphere" could take on several different meanings depending on the context in which it was used. It could relate to the idealized form of Earth's shape, the stage of the projection process where Earth is conceptually reduced in size to the same scale as the final map, or an idealized mathematical figure. When the same term was presented in different contexts throughout a section, the word would be entered separately into the spreadsheet for each meaning, with a note explaining the context in which that term appeared. If a word was encountered whose relationship to projections was uncertain, the *Glossary of Mapping, Charting, and Geodetic Terms* (Department of Defense 1980) was consulted for a definition.

To create categories for the content analysis, the projection words entered into the spreadsheet during the second reading (Figure 1) were carefully examined, and those that shared similar concepts were combined together under an appropriate category name. For example, projection words like "latitude," "longitude," "great circles," and "small circles" characterize elements of the graticule, and so these words were combined into a category titled "Characterizing the Graticule." This process was repeated for all words from the spreadsheet, creating a total of ten categories, which are listed in Table 2. The words that were used to develop the category names were then listed alphabetically under each category in a new spreadsheet (Figure 2). The top three rows in Figure 2 show the textbook title, author, and publication date, respectively. The left-hand column lists the category names (only Characterizing the Graticule category is shown in Figure 2) and the words that were used to develop the category name resulting from the second reading.

Projection Word	Context Notes
Airy's azimuthal	Projection name
Albers equal area conic	Projection name
Angles	Spatial relationship
Arbitrary / Conventional	Classification of projections
Areas	Projection property
Azimuthal	Projection property
Azimuthal equidistant	Projection name
Azimuths / Directions	Spatial relationship
Bonne pseudoconic	Projection name
Cassini's equidistant cylindric	Projection name
Clarke's "Twilight" azimuthal	Projection name
Co-latitude	
Collingnon pseudocylindric	Projection name
Compression	Distortion description
Concentric circles	Graticule arrangement
Cone	Developable surface

Figure 1. *A portion of the spreadsheet showing the alphabetized listing of projection words and context notes from the second reading.*

Data-Driven Map Projection Categories
Graphical Construction
Geodesy
Recommended Map Projections
Mathematics of Map Projections
Map Projection Parameters
Map Projection Process
Characterizing the Graticule
Map Projection Classes
Map Projection Properties
Map Projection Distortion

Table 2. *Category names I developed for the content analysis, generated from individual projection-related words recorded from the 24 sampled textbooks.*

Book Title →	Text Book of Topographical and Geographical Surveying	Maps and Map Making	Topographic, trigonometric and geodetic surveying, including geographic, exploratory, and military mapping with hints on camping, emergency surgery, and photography	Maps and Surveys (2nd ed)	Topographic Mapping	Cartography	The World in Maps: A Study in Map Evolution	The History and Technique of Map Making	General Cartography (2nd ed.)	Mapping	Elements of Cartography
Author →	Charles Close	Edward Reeves	Herbert Wilson	Arthur Hinks	Lawrence Roberts	Charles Deetz	Walter Jervis	Helmuth Bay	Erwin Raisz	David Greenhood	Arthur Robinson
Publication Date →	1905	1910	1912	1923	1924	1936	1937	1943	1948	1951	1953
Characterizing the Graticule	1	1	1	1	1	1	1	1	1	1	1
Network (Imaginary)			1	1		1					
Graticule / Grid	1						1		1	1	1
Degree-net			1	1							
The graticule	1		1	1		1	1		1	1	1
Visual characteristics of the graticule		1	1	1							1
Descriptions of a projection's graticule	1	1	1	1	1	1	1			1	1
Almucantars (parallel circles from the center)						1					
Antipode											1
Compass Rose						1					1
Gore (lune shaped)										1	
Latitude		1	1	1	1	1	1		1	1	1
Parallel	1	1	1	1	1	1	1		1	1	1
Small circle						1			1	1	1
Orthodrome											
Equator			1		1		1		1	1	1
Circumscribing circle											
Large (Great Circle)		1		1		1		1	1	1	1
Longitude		1	1	1	1	1			1	1	1
Meridian	1	1	1	1	1	1	1		1	1	1
Prime meridian							1		1	1	1
International Date Line (180°th Meridian)									1		
Antimeridian											

Figure 2. *A portion of the spreadsheet displaying the occurrence of projection words in the Characterizing the Graticule category, according to each textbook.*

Once the ten categories were developed, the third reading involved reexamining each projection section and recording the occurrence of projection words that appeared in each textbook for a given category. Projection words that appeared in a given textbook were assigned a value of 1 in the spreadsheet (Figure 2) according to the category in which the word belonged. For example, if a textbook used the word "antipode" a value of 1 was coded in the spreadsheet as that word related to the Characterizing the Graticule category. Not all assignments of 1 were clear-cut. For example, as I mentioned earlier, textbooks used the word "sphere" in one of three different contexts: one for Earth's assumed shape (Geodesy category), the idealized mathematical figure (Mathematics of Map Projections category), and as an intermediate step during the projection process (Map Projection Process category). Thus, it was important to pay attention to the context in which the word was used so that a proper assignment of 1 was recorded.

STEP 5: REPORTING AND INTERPRETING THE RESULTS

Descriptive Data

Of the 24 textbooks sampled, six presented projection material as a portion of a chapter, eight did so within exactly one chapter, two used an appendix, and eight dedicated more than one chapter. The total number of pages used to present projection information ranged from 151 (Morrison 1902) to only a few paragraphs (Lawrence 1971). Most of the textbooks were richly illustrated with individual projections. There were five textbooks that included more than 50 illustrations, the largest number being 61 (Slocum et al., 2005). Four textbooks included fewer than 10 illustrations: Deetz (1936) showed only three while Roberts (1924), Jervis (1937), and Bay (1943) did not include any. All of the illustrations were produced in black and white. The inclusion of equations and tables was dichotomous—textbooks either had many equations and tables or none. Generally speaking, if a textbook included equations, then those equations expressed the spherical form rather than the ellipsoidal form of projections. Textbooks early in the study period tended to have a greater number of equations than those later in the study period. These equations were essential as they provided the mathematics of how to graphically construct projections. Thirteen of the textbooks throughout the study period did not include any equations. Similar to equations, tables were more often found in textbooks that were published earlier in the study period. In early textbooks, tables often listed the plotting coordinate values needed for the graphical construction of projections. Other tables presented values showing the length of a degree of latitude and longitude.

All textbooks included a definition of the term "projection" and there was general agreement about what that definition entailed. For example, Close (1905, 92) defined a projection as a "system on which the terrestrial meridians and parallels are represented on paper." This and the other definitions collectively agreed that a projection systematically transforms points from Earth's curved surface to the plane.

Categories Derived from Content Analysis

This section discusses the individual categories of projection words derived from the content analysis. The discussion highlights the percentage of textbooks that contain each category and summarizes the specific projection-related words contained in each textbook. Recognizing the large expanse of time covered by the twentieth and early twenty-first centuries, I sought a way to divide this time period into a temporal framework that would facilitate reporting the results of the content analysis. One way to divide this period is to consider the impact of the computer on the field of cartography, specifically within the realm of projections. I have previously used this approach

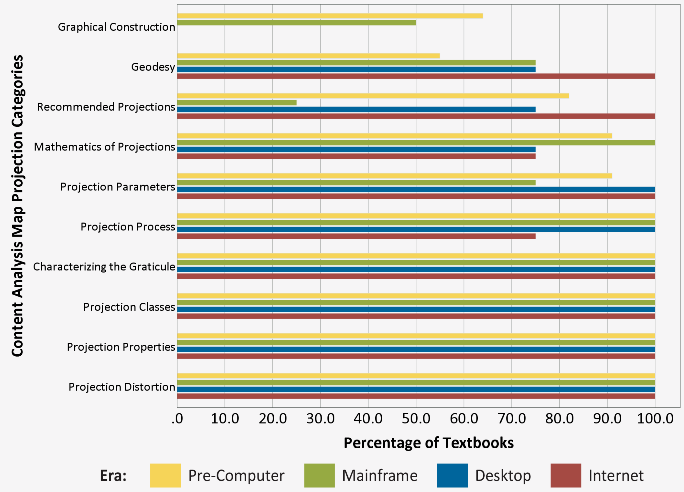

Figure 3. *Percentage of textbooks that contain words related to the different categories reported by individual eras.*

(Slocum and Kessler 2015), dividing the twentieth and early twenty-first centuries into four separate eras demarcated by the onset and evolution of computing technology: Pre-Computer Era (1900–1958), Mainframe Computer Era (1959–1976), Desktop Computer Era (1977–1990), and Internet Era (1991 onward). Using these four eras, the results of the content analysis are summarized in Figures 3 and 4. Figure 3 provides the percentages of textbooks containing words from each map projection category found in each individual era and Figure 4 reports the percentages of textbooks containing words from each map projection category for all eras combined.

Graphical Construction Category

The Graphical Construction category refers to a process by which concepts of plane geometry were used to draw curves and partition straight lines representing the graticule on paper. Thirty-nine percent of textbooks across all eras included the Graphical Construction category.

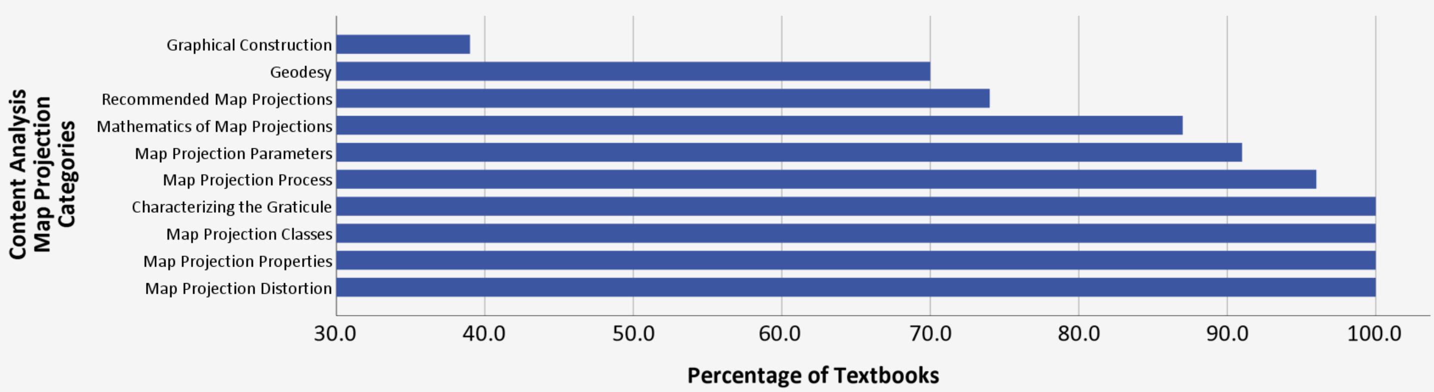

Figure 4. *Percentage of textbooks that contain words related to the different categories across all eras.*

However, Figure 3 shows that this category was only relevant to the Pre-Computer and Mainframe Computer eras. Once desktop computers became widely accessible, this category became irrelevant.

Geodesy

The Geodesy category included words that describe Earth's shape and size. Seventy percent of all textbooks included words that relate to geodesy (Figure 4). Figure 5 shows the percentage of textbooks that included the three most common words in this category across each era: "reference ellipsoid," "semi-major axis," and "sphere." Overall, 43% of the textbooks contained all three of these words, with all words occurring more frequently in the two most recent eras.

The reference ellipsoid is an important concept when making accurate, large-scale maps of the Earth's surface (e.g., in topographic mapping) while other maps, such as thematic or general reference maps, typically do not have the same accuracy requirements. In the Pre-Computer Era, considerable effort was needed to incorporate a reference ellipsoid when making maps. Beginning with the Mainframe Computer Era, cartographers started using digital data where coordinate system definitions and automation allowed the reference ellipsoid to be seamlessly integrated into the mapping process, thus reducing the cartographer's effort. In this context, it is interesting to see that the percentage of textbooks that included "reference ellipsoid" as part of the discussion increased from 18% in the Pre-Computer Era, to 50% in the Mainframe Era, and to 75% for the Desktop Computer and Internet Eras.

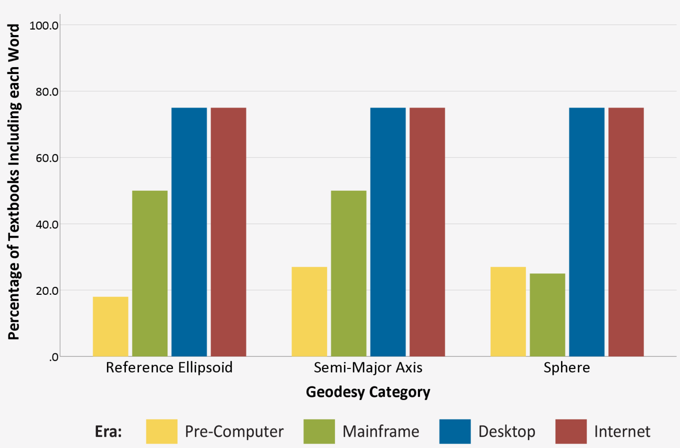

Figure 5. *Percentage of textbooks containing the three most common words within the Geodesy category, according to individual eras.*

This growth seems consistent with the increasing reliance on digital data as time evolved.

Recommended Map Projections

The Recommended Map Projections category indicated which textbooks recommended certain projections for particular map purposes. This category also included guidelines related to selecting an appropriate projection. In total, 55 unique projections were recommended by the 24 textbooks studied. Figure 4 shows that 74% of textbooks across all eras recommended one or more projections, and Figure 3 indicates that the Pre-Computer Era and Internet Era saw the greatest number of textbooks recommending projections at 82% and 100%, respectively. Figure 6 shows the projections that were recommended most frequently across all eras. The azimuthal equidistant, Lambert azimuthal equal area, Mercator, and sinusoidal were popularly recommended in every era.

Aside from recommending certain projections, a total of 12 textbooks across all eras also included guidelines that linked individual projections to specific map purposes. Guidelines on selecting projections appeared in 45%, 25%, 75%, and 75% of the textbooks in the Pre-Computer, Mainframe Computer, Desktop Computer, and Internet Eras, respectively. Generally speaking, textbooks offered selection guidelines that could be classified as either very simple or detailed. The simplified selection guidelines (found in 25% of the 12 textbooks with guidelines) indicated, for example, that conic projections are suitable for east to west trending landmasses or that equal area projections are appropriate for thematic maps. The detailed guidelines worked through the selection process using a sample dataset and ultimately recommended a specific named projection. For example, a detailed approach in the Pre-Computer Era appeared in Deetz (1936) who

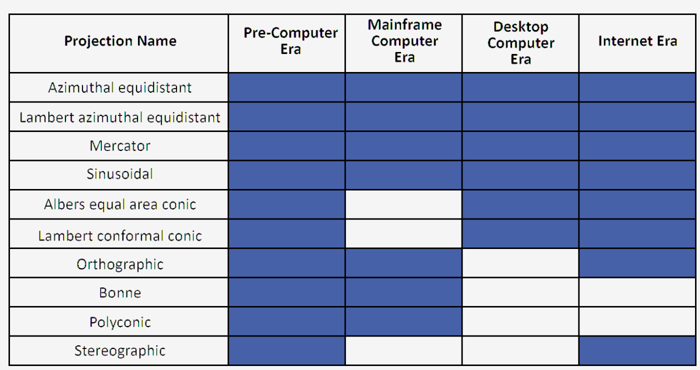

Figure 6. *The most frequently recommended projections in textbooks, according to individual eras.*

discussed the appropriateness of 15 projections. His guideline discussed each projection's graticule arrangement, the projection's property, whether the projection possessed any special characteristic, and the utility of the projection. The detailed selection guidelines were more often found in the Desktop Computer and Internet Eras. For example, in the Desktop Computer Era, Dent (1990) created tables that recommended specific projections based on various criteria, such as the extent of the geographic region to be mapped. In the Internet Era, comprehensive selection guidelines were presented by Slocum et al. (2005) who devoted an entire chapter to selecting projections. They framed their chapter on Snyder's (1985) projection selection guidelines and then used that framework to explain how a suitable projection was determined based on different data sets, geographic areas to be mapped, map scales, and map purposes.

Mathematics of Map Projections

The Mathematics of Map Projections category included 27 words that relate to explaining the mathematical principles used in the projection process. In total, 87% of textbooks utilized one or more of these words. Figure 3 shows the percentage of textbooks that included this category in each of the four eras, while Figure 7 shows the percentage of textbooks that included the three most common words in this category across each era: "cosine of latitude," "rectangular coordinates (Cartesian)," and "sphere." The Pre-Computer Era reported the greatest variety of and the greatest overall frequency of mathematical words. In addition to the three previously mentioned most common words, others like "sine of the latitude," "cone constant," and "radius of curvature" were more frequent in this era than in other eras. This occurrence seems reasonable as these words are directly related to the process of graphically constructing projections, which dominated this era.

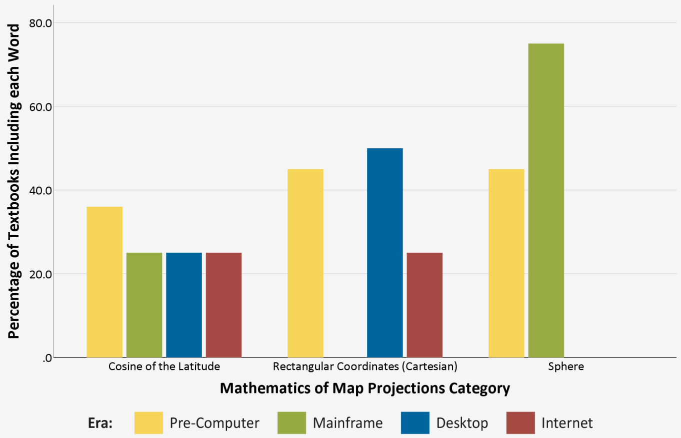

Figure 7. *Percentage of textbooks containing the three most commonly found words within the Mathematics of Map Projections category, according to individual eras.*

Map Projection Parameters

The Map Projection Parameters category refers to the variables that mapmakers manipulate to change the appearance or distortion patterns of a projection (e.g., which standard lines are utilized). This category appeared in 91% of all of the textbooks (Figure 4) and 24 unique words were recorded. Considering all eras, only two texts, Jervis (1937) and Birch (1964), did not include any words related to discussing projection parameters. The most frequently occurring projection parameter word across all eras was "standard parallel(s)" or "standard line(s)," found in 63%, 75%, 100%, and 100% of the textbooks in the Pre-Computer, Mainframe Computer, Desktop, and Internet Eras, respectively. Words relating to a projection's aspect, such as "normal," "polar," and "equatorial," also appeared in almost every textbook across the different eras. Interestingly, the specific words associated with "normal aspect" saw considerable variation across the eras. For example, normal aspect was often defined according to the *typical* aspect in which a projection was shown (e.g., an azimuthal projection was typically shown as centered on a pole whereas a cylindric projection was typically shown as aligned along the Equator). Thus, "normal aspect" was not consistently applied to one particular aspect but was dependent upon the projection class and could be easily misunderstood unless the reader knew the particular projection class being referenced.

Map Projection Process

The Map Projection Process category refers to the steps involved in projecting Earth's curved surface to the map. Words relating to this category were found in 22 of the textbooks, with 30 unique words being recorded. In total, 96% of the textbooks included words relating to this category (Figure 4). Given this high percentage, there was little difference in the frequency of word usage across the eras when explaining the projection process. The most frequently occurring words across all eras included "developable surface," "tangent," "cone," "cylinder," and "plane." Other words such as "light bulb," "light source," "eye-point," "point of sight," "radiating," "rays of light," and "peel off" were mnemonic devices that described how the graticule was projected onto the planimetric surface, although none of these words were found in more than two textbooks in any given era.

Characterizing the Graticule

The Characterizing the Graticule category included any term that was used to characterize the graticule's appearance on a map. Every textbook used one or more words to characterize the graticule, and a total of 37 unique words were utilized. There was little variation in the use of these words across the different eras. Figure 8 shows the seven most frequently appearing words in this category across all eras. Of interest is that "parallel" or "latitude" was included more than "meridian" or "longitude," which is not surprising given that many spatial phenomena studied in geography have one or more characteristics that vary only according to latitude.

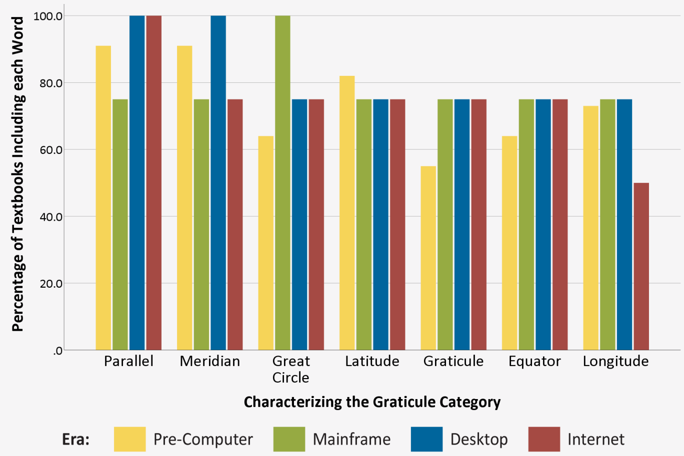

Figure 8. Percentage of textbooks containing the most common words from the Characterizing the Graticule category, according to individual eras.

Map Projection Classes

The Map Projection Classes category included words that relate to one of the projection classes (e.g., "cylindric," "conic," "azimuthal," and "pseudocylindric"), which are used to describe the overall visual shape and appearance of the graticule. This category was found in all of the textbooks throughout the different eras (Figure 4), with 20 unique words being recorded. The "conic" (87%) class was referenced more frequently than either the "cylindric" (83%) or "azimuthal" (61%) classes across all eras. Not all classes appeared in some of the eras. For example, "pseudoazimuthal" and "pseudoconic" were not reported until the Desktop Computer Era. As another example, it was noted that "geometric" and "conventional" were important terms used during the Pre-Computer Era to refer to the methods of constructing projections graphically and mathematically, respectively. These terms were also used to classify projections. Given that graphical construction techniques have not appeared in textbooks since the 1960s, it is somewhat surprising to see these words included in textbooks published during the Mainframe Computer, Desktop Computer, and Internet Eras.

Map Projection Properties

The Map Projection Properties category focused on words related to the projection properties (e.g., "equal area," "conformal," "equidistance," and "azimuthal"). A projection with one of these properties will preserve one of the spatial relationships found on Earth's surface, such as distances or areas. This category was found in 100% of the textbooks (Figure 3), with 27 unique words being recorded. Figure 9 shows the percentage of textbooks that included the five most frequently appearing words across all eras: "Equal area," "conformal," "equidistant," "azimuthal," and "compromise." Across all eras, "equal area" (and its synonym "equivalent") was reported in every textbook. The frequency of this term is consistent with the fact that the textbooks included in this survey tended to focus on thematic mapping, in which equal area projections are often appropriate. Another common term was "conformal" (and its synonym "orthomorphic"), which was found in 91% of the textbooks in the Pre-Computer Era and all of the textbooks in the remaining eras. Generally, the remaining properties of "equidistant," "azimuthal," and "compromise" were more common in the two most recent eras.

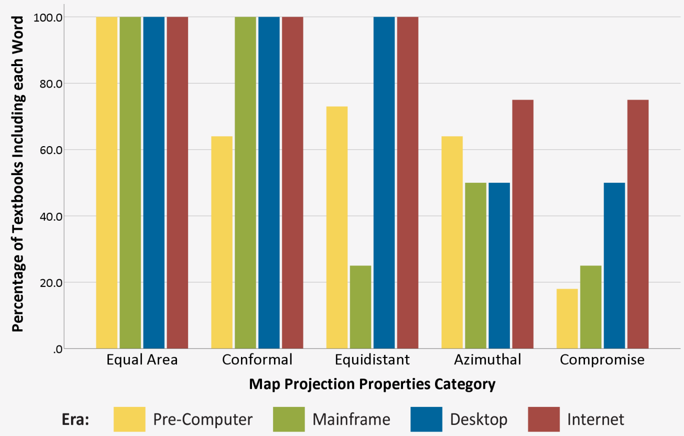

Figure 9. Percentage of textbooks that contained the three most common words from the Map Projection Properties category, according to individual eras.

Map Projection Distortion

The Map Projection Distortion category focused on the fact that Earth's curved surface cannot be projected without error, that the error can be quantified according to the type of distortion (areal, angular, or scale), and that this result can be graphically portrayed on a map. Figure 3 illustrates that 100% of the textbooks sampled throughout the four eras discussed projection "distortion." Specific words commonly utilized with distortion are, "area," "angular," "scale," and "shape;" these were referenced in 96%, 82%, 65%, and 50% of textbooks, respectively, across all eras. Words used to conceptualize distortion included "peeling skin off of fruit," "squashed," "stretched," "exaggeration," "flattening a ball," and "compressing." These and other words relating to distortion were not consistently adopted as they all appeared in two or fewer textbooks and did not span the four eras.

While it is not likely that cartography students will need to understand the mathematics of deriving distortion measures, being able to visualize distortion across a projection's surface is important (e.g., to select an appropriate projection). Distortion visualization has had a rather long history of development. An early graphical method for viewing distortion across a projection's surface is Tissot's (1859) indicatrix, which presents a visual impression of the type and amount of distortion at any given point. The first reference in my study to utilize Tissot's indicatrix was Robinson (1953). Reference to the indicatrix concept would not appear again until the Desktop Computer Era when Cuff and Mattson (1982) and Anson, Ormeling, and the ICA (1993) used the phrase "ellipse of distortion" to refer to Tissot's indicatrix. In the same era, Dent (1990) discussed the concept of the indicatrix, but did not illustrate the graphic on a projection. Also in this era, Campbell (1984) reported what appears to be the indicatrix, but the concept was confounded by the suggestion that the axes of the symbols only represent scale changes along the parallels and meridians, which is not the case. In the Internet Era, Slocum et al. (2005) and Tyner (2014) included "indicatrix" in their discussion.

A range of other graphical methods were used to illustrate distortion on projections (see Mulcahy and Clarke 2001, for a summary of methods). For example, Reeves (1910) showed a series of human head profiles to illustrate the effect of distortion on different projections. Robinson (1953) illustrated distortion with isocols, which were synonymously referred to as "isoanamorphic lines," "isoperimetric curves," and "isograms." Anson, Ormeling, and the ICA (1993) presented distortion on a projection with shading between adjacent isocols. Dent (1990) included the words "tearing," "compression," and "shearing" in an illustration to point out the changes to the graticule that can result from a projection. He also showed how a square shape was distorted across the sinusoidal projection, mentioning that it is at the periphery of the projection where shapes are most distorted. Slocum et al. (2005) used a combination of the indicatrix and shaded isocols to illustrate distortion. Overall, none of the graphical methods used to display distortion appeared more frequently than others over the time period of the study.

DEVELOPMENTS IN THE FIELD OF MAP PROJECTIONS

This section briefly discusses developments that occurred during the twentieth and early twenty-first centuries that impacted the field of projections. This discussion, coupled with the results of the content analysis, will be integrated in the next section to provide recommendations on appropriate projection material that should be included in future cartography textbooks. I argue that there were three specific developments that impacted projections. First, computer technology was developed, which fundamentally changed the way projections were integrated into the mapmaking process. Second, experimental studies were conducted that investigated various aspects of a map reader's understanding of projections. Third, advanced mathematical principles were applied to the field, which resulted in a refinement of existing projections that could be included in specialized mapping software.

ADVANCEMENTS IN COMPUTER TECHNOLOGY

This section discusses three impacts that computer technology had on the field of projections. First, the development of computer technology in the twentieth century removed much of the manual burden of working with projections that was common in the Pre-Computer Era. Starting in the Mainframe Computer Era, automation in cartography, specifically programming languages, facilitated the ability to calculate and plot projections. Programming languages also enabled specialized mapping software (e.g., desktop GIS) to emerge in the Desktop Computer Era, which provided users with access to a diversity of pre-existing projections. For example, ARC/INFO version 6.0 provided the user with 34 named projections (Esri 1991). Two notable projection software packages that emerged during the Desktop Computer Era were WORLD (a DOS-based program) and Geocart (a Mac-based program); both packages enabled users to plot isocols or Tissot's indicatrix on a projection's surface. In the Internet Era, Geocart version 3.0 enabled users to depict increasing amounts of distortion with a continuous tone of light to dark color values (Figure 10). Armed with the visualizations provided by these graphical methods, mapmakers were able to make better informed decisions about which projection was best suited to their purpose.

A second impact of computer technology is that digital data need a coordinate system definition, which allows the alignment of individual data layers. At a minimum, this definition involves specifying a datum and its associated reference ellipsoid. In addition, a projection can be selected. The datum and projection each serve a specific function. For example, Chrisman (2016) argued that certain measurements carried out in a GIS environment (e.g., distances) should always be computed on a datum's reference ellipsoid, as those measurements are not subjected to the distortion that would be introduced by a projection. However, datums are not suitable for mapping the results of a spatial analysis as a datum reports latitude and longitude values. An appropriate projection must be selected that meets the needs of a specific map purpose (e.g., preserving areal relations for a choropleth map). Therefore, mapmakers have increasingly needed to become familiar with the roles that datums (and their associated reference ellipsoids) and projections play when working with digital data.

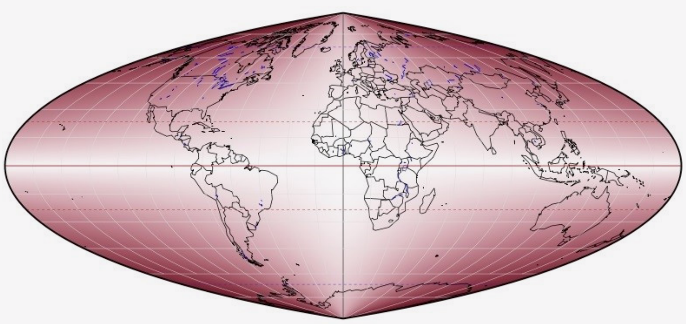

Figure 10. Darker colors represent increasing angular distortion on the quartic authalic pseudocylindric projection. Color gradations were available in Geocart starting in 2010. Image created in Geocart (www.mapthematics.com).

The third impact can be seen in the interactive nature of the World Wide Web, which has facilitated the ability to explore different kinds of projections and their associated distortion patterns. For example, Lapaine, Tutić, and Triplat (2014) published a freely available tool that permits users to explore different cylindric projections, their graticule arrangements, and their distortion patterns. The web also made new uses of projections. Particularly noteworthy is the web Mercator, which is utilized in mapping services such as Google Maps. A non-conformal projection, the web Mercator is derived by forcing the ellipsoidal form of latitude and longitude coordinates through a spherical form of the Mercator cylindric conformal projection equations (Battersby et al. 2014).

EXPERIMENTAL STUDIES

Until shortly after World War II, few experimental studies set forth to understand how people perceived or reacted to different map designs. In short, mapmakers were working with little knowledge of how the maps were being used or understood by readers. Although not the first to do so, Robinson's landmark text *The Look of Maps* (1952) proposed a research agenda to understand map design; this agenda eventually morphed into cognitive cartographic studies, which are still being conducted today (Montello 2002). While the *Look of Maps* did not specifically call for experimental studies to be carried out with respect to projections, cartographers have investigated how projections play a role in map design and are understood by the map reader.

Dahlberg (1991) suggested that understanding map readers' preferences for overall shapes of projections should be considered as a variable in map design when selecting a projection, especially for global-scale maps. For example, we might wonder whether readers prefer maps whose graticule mimics the globe's appearance, with curved meridians and parallels. In this context, studies by Werner (1993) and Šavrič et al. (2015) examined preferences for overall projection shapes at global scales. Werner's study suggested that pseudocylindric projections were preferable to cylindric, and uninterrupted pseudocylindric projections were favored over interrupted ones. Šavrič et al. also found that map readers liked smooth, elliptical rather than sinusoidal curves for meridians, straight rather than curved lines for parallels, and poles represented as points, but that map readers had no preference for pole line edges.

How map readers reconcile projection distortions with their mental maps is another line of experimental studies. Battersby and Montello (2009) investigated whether map readers' mental maps of the world were overly influenced by the Mercator projection. Their results suggested that map readers were rather competent in estimating relative areas of landmasses and that they were not relying upon a mental map based on a Mercator or Mercator-like projection. With colleague Sarah Battersby, I have also previously explored (Battersby and Kessler 2012) how map readers visualize distortion on projections. One finding from our study is that map readers favored one of three regions (Antarctica, Greenland, and the polar regions) as cues in assessing the distortion on a projection and that training or expertise with projections does not necessarily provide map readers with a skillset necessary for understanding distortion.

Research by Downs and Liben (1991) examined drawings and mnemonic devices, which have often appeared in cartography textbooks to illustrate projection concepts (e.g., a light source casting shadows on a developable surface). Their findings suggested that what may be intuitive to an expert geographer may not be self-evident to map readers. They concluded that the commonly used mnemonic device of the light-source casting a shadow on a cone, cylinder, or plane developable surface does not necessarily help all map readers understand how Earth's curved surface is projected onto a map. As a solution to this problem, they suggested having map readers develop an understanding of light sources and shadows using extremely simple shapes, and then gradually move toward more complex shapes (such as a landmass).

Experimenters have also studied the spatial abilities of readers when using projections to solve map-based tasks. One study, conducted by Anderson and Leinhardt (2002), examined the difficulty that map readers face when applying rules that work on a sphere (e.g., extending a "straight" line on a globe eventually returns to itself) to a plane when considering the influence of projection distortion. Their study contrasted the abilities of domain experts, advanced novices, pre-service teachers, and novices to construct a path of shortest distance (or great circle) between pairs of cities on a map. They found that experts were able to perform the tasks significantly better than the other groups and that advanced novices performed better than the novices or pre-service teachers. They reasoned that the experts and advanced novices understand how projections distort Earth-map relationships and specifically how the Mercator projection distorts great circles. Thus experts and advanced novices were able to use existing rules of how lines appear on a sphere to generate advanced visualizations to arrive at a solution for a plane. Novices and pre-service teachers did not have advanced rules, could not create serviceable visualizations of the problem, and thus generally guessed at their solutions.

ADVANCED MATHEMATICAL PRINCIPLES

As Snyder (1993) recounts, the 1700s and 1800s were important times in the development of more advanced mathematical principles. Least squares, calculus, complex algebra, series approximations, elliptic functions, and conformal mapping were some of the principles that were developed during these two centuries. These principles eventually would be applied to derive more sophisticated forms of projection equations that would allow for more accurate mapping.

Projections developed before the 1900s predominantly used a spherical Earth model. In the 1900s some of these earlier projections were recast using the more complex ellipsoidal Earth model. This recasting was partly due to the development of reference ellipsoids in the 1800s, which provided a more accurate means of modeling Earth's size and shape compared to the spherical model. This more accurate Earth modeling resulted in maps that provided more accurate coordinate positioning, which was advantageous for topographic maps and nautical charts. Advanced mathematical principles were needed to derive the complex, ellipsoidal-based projection equations. While Albers (1805) was able to employ trigonometric functions to develop the spherical form of the projection equations for the Albers equal area conic projection, Adams (1927) later applied integral calculus in deriving the ellipsoidal form of the equations.

RECOMMENDED MAP PROJECTION CONTENT

Table 3 ties together the results of the content analysis with the developments in projections for the purpose of recommending material that should be included in future cartography textbooks. Recommendations are grouped into eight categories, six of which were derived directly from the content analysis. The remaining two were added in recognition of the impact of recent computer technology.

In this section I review each of the categories shown in Table 3 and discuss the projection material that is recommended for future cartography textbooks. Obviously, the depth to which the material in each category is expounded upon would vary depending on the specific focus of the textbook. For example, a textbook that is more focused on thematic cartography may contain more discussion on the Map Projection Parameters or Map Projection Distortion categories, whereas a textbook focused more on web mapping may benefit from an extended discussion of material related to the Map Projections and the World Wide Web category.

GEODESY

Cartography textbooks need to expand material in the Geodesy category in three ways. First, greater emphasis needs to be placed on explaining the concept of a datum and its importance to digital data. In most mapping software, the user specifies a datum rather than a particular reference ellipsoid; the datum definition automatically couples with the associated reference ellipsoid. Second, textbooks need to discuss that a complete coordinate system definition includes a datum and projection. This discussion would include a review of common datums and map projections. Third, it is important that students realize that digital data sets commonly have unique datum assignments, and in order to bring disparate datums into a common coordinate system a transformation is needed. While datum transformations are often included in mapping software, their sheer number can be confusing (e.g., there are 34 unique datum transformation between NAD27 and WGS84 in ArcMap version 10.5). Documentation on which transformations are appropriate or even available for different datums is not readily available, which only adds to the confusion.

RECOMMENDED MAP PROJECTIONS

Weighing the decisions needed to select an appropriate projection can be challenging. The content analysis found that cartography textbooks contained a range of projection selection guidelines. Some included rudimentary guidelines while others presented more comprehensive ones. To augment the more comprehensive guidelines, I recommend that textbooks include evidence from experimental studies that offers insights, for example, into map readers' preference for overall projection shapes. I also recommend that textbooks review web resources that assist in selecting projections, such as the Projection Wizard (Šavrič, Jenny, and Jenny 2016).

MATHEMATICS OF MAP PROJECTIONS

Map projections are inherently math based, and mathematical material was consistently found in textbooks across all eras. Although the cartographer no longer calculates projections by hand, the mathematics of projections continues to play an integral role in a computer environment. To convey its importance, I offer two recommendations. First, textbooks should review the basic mathematical principles involved with projections (e.g., including worked examples of simple projection equations that demonstrate how latitude and longitude values are converted into Cartesian coordinates). Second, it is important that textbooks explain the distinction between the spherical and ellipsoidal forms of map projection equations, so that decisions can be made on when each form is appropriate for specific map purposes and map scales.

MAP PROJECTION PARAMETERS

The content analysis indicated that, beginning with the Desktop Computer Era, all textbooks included the Map Projection Parameters category. Two important points, however, were missing. First, students need to understand how to skillfully alter the default projection parameters to suit a given map purpose. To develop this skill, the specific terms presented in textbooks need to be consistent. Adopting familiar terms such as "equatorial," "oblique," and "polar" to define a projection's aspect would make it clear to the student where the geographic center of the map is located. Second, once equipped with a consistent terminology, textbooks need to convey how different projection parameters impact the distortion pattern and what

Categories	Recommended Material
Geodesy	• Explain the importance of datums when using digital data • Describe what constitutes a complete coordinate system definition (a datum and projection) • Ensure students understand the importance of datum transformations
Recommended Map Projections	• Explain that map readers have preferences for overall projection shapes • Ensure students understand that different symbolization methods can require certain projection properties • Utilize web-based interactive map projection selection guidelines to help students in selecting projections
Mathematics of Map Projections	• Discuss that projections are inherently mathematical and present basic mathematical principles involved • Introduce the distinction between spherical and ellipsoidal forms of projection equations • Explain the appropriateness of the ellipsoidal and spherical form for different map purposes
Map Projection Parameters	• Employ a consistent use of projection terminology • Provide knowledge on how to skillfully alter the default projection parameters and teach the impact that those parameters have on a map
Map Projection Process	• Recognize that the light-and-shadow and developable surface concepts may be cognitively challenging for some students to master • Interactively use software or web-based applications to teach the role that mathematics plays • Demonstrate how different graticule arrangements result from the projection process • Explain how the projection process acts on raster data
Map Projection Distortion	• Use cues from the graticule to explain distortion patterns • Explain that map readers possess mental maps that are adaptable to viewing different projections—they are not all cast on the Mercator projection • Show a student how to use cues taken from the projection to understand distortion patterns on a map • Demonstrate that projections fundamentally alter how spherical rules (e.g., great circles appearing as "straight" lines on a globe) appear on a map
Map Projections and Programming Languages (*new*)	• Introduce programming languages (JavaScript) and code libraries (e.g., PROJ.4 and JMPL) that are useful for projections in a digital environment
Map Projections and the World Wide Web (*new*)	• Explain how map tiles are served in a mapping service • Describe the challenges of projecting raster data • Discuss selecting projections for mapping services

Table 3. *The eight categories reported in the content analysis and the recommended map projection material associated with each category.*

that pattern means for the final map. Many projections only have one parameter (e.g., specifying the central meridian) while others have more (e.g., the Albers equal area conic has four: central meridian, two standard lines, and the central latitude). Textbooks should clearly provide examples showing how altering these parameters impacts the distortion pattern and the appearance of the landmasses.

MAP PROJECTION PROCESS

While the mechanics of the map projection process are no longer painstakingly carried out by hand as was done in the Pre-Computer Era, textbooks need to conceptually relate how a projection utilizes latitude and longitude values to create a map. The content analysis showed that the Map Projection Process category included many different graphic and mnemonic methods used to convey this difficult concept. One commonly used method is the idea of a light source and associated shadows cast on a cone, cylinder, and plane as intermediary developable surfaces between the globe and map. The research reported by Downs and Liben (1991), however, suggested that using the light-and-shadows in concert with developable surfaces is not necessarily well-matched to the cognitive abilities of all students. One alternative model would be to use mathematical equations to show how latitude and longitude coordinates are entered into simple projection equations and then projected. By reviewing a few projection equations and which parameters are available, the student would begin to learn the individual parameters of an equation and the utility that these parameters have.

None of the projection material in the textbooks surveyed discussed how the projection process operates on raster data, which is not subjected to the same considerations as vector data when being projected. For example, as Usery and Seong (2001) report, projecting raster data produces considerable error based on the chosen projection, raster pixel size, and latitude of the location being projected. Yet, in the web environment, raster map tiles are subject to projection in web mapping services.

MAP PROJECTION DISTORTION

Distortion is an inherent consequence of the projection process. While all of the textbooks in the study included some discussion of distortion, I believe that future textbooks must address two considerations related to distortion. First, they should demonstrate the impact that distortion has on the user's ability to complete a given task. Evidence from experimental studies suggests that map readers have different levels of understanding of distortion, which will affect their ability to interpret a map. Second, textbooks should explore different methods that help students visualize the distortion patterns that appear across a projection's surface. Given these methods, students will then be able to select one or more that they feel are useful, and are better suited to their mapping needs. Textbooks could consider adopting the approach taken by Olson (2006), who offered a solution where visual evidence from the graticule could be used as a cue to help identify general patterns of distortion. The graticule exhibits certain characteristics on the Earth's surface (e.g., parallels are equally spaced). A projection can alter those characteristics, depending on the kind of projection used, in specific ways that indicate the kind of general distortion pattern that is present on the map. For example, on a conformal projection, the spacing between parallels increases as one moves from the Equator toward the poles, indicating that there is increasing scale and area distortion.

Finally, I recommend that textbooks consider referencing interactive web-based resources that students can use to explore distortion patterns on projections, such as Flex Projector (Jenny and Patterson 2013), which is freely available. It allows students to view and explore 30 pre-existing projections (although its different options also allow an infinite number of customizable projections).

NEW CATEGORY: MAP PROJECTIONS AND PROGRAMMING LANGUAGES

A new category not revealed through the content analysis, Map Projections and Programming Languages, considers the utility of a programming language when translating projection equations into a computer environment. While most mapping software packages offer a sizeable number of projections, there may be a special map purpose for which a projection is not presently or easily available. In such cases, the user would need to be familiar with a language to write the code for that projection. Although there are many programming languages available that can be used to program projections (see Kessler et al. 2017 for a review), textbooks should make students aware of languages such as JavaScript, C++, R, or specialized projection code libraries (e.g., PROJ.4 and Java Map Projection Library [JMPL]) that can simplify the code needed to incorporate a projection in a mapping application.

NEW CATEGORY: MAP PROJECTIONS AND THE WORLD WIDE WEB

The other new category, Map Projections and the World Wide Web, considers the diverse ways in which projections are integrated into the web. For example, the following are some intriguing web-based applications: FlexProjector (allows users to interactively design a projection), ProjectionWizard (allows users to explore selecting a projection), and Projection Viewer (allows students to learn about projection distortion). The web Mercator, one of the more frequently used projections on the web, is used to display map tiles. The tile format used by mapping services re-emphasizes the need to explain how raster data are projected and the utilitarian function that the web Mercator performs. While Battersby et al. (2014) offered that the web Mercator is "good enough" for most web-based mapping tasks they cautioned that this projection is not necessarily advantageous for the appropriate display of different geographic areas as one zooms in and out of a web map or changes the latitude of a location. These concerns were addressed by Jenny (2012), who developed the Adaptive Composite Map Projections as an alternative to the web Mercator. Rather than using one projection for all zoom levels or changes in the latitude of a location, Jenny makes use of different projections to present the geographic area of interest with lower distortion.

PROJECTION KNOWLEDGE AND CARTOGRAPHERS' ROLES IN THE WORKPLACE

The overarching perspective that is proposed here in recommending projection material for future cartography textbooks is based on equipping cartography students with the knowledge needed to work with projections in a digital environment while understanding the impact that those projections have on the map and the map reader. Obviously, practicing cartography is different today than it was at the beginning of the 1900s. In the Pre-Computer Era, a "one-size fits all" approach to cartographic education was sufficient to prepare students with the appropriate knowledge and skills to enter the workplace. However, as technology has continued to evolve, employer expectations place new demands on what is contained within textbooks and taught in the classroom.

The workplace is no longer dominated by cartographers slumped over drafting tables drawing maps. Today, there are a variety of cartographic roles. Among others, there are print cartographers, web application developers, citizen cartographers, GIS analyst-technicians, and mapping software developers. Thus, cartography textbook authors should tailor their projection material according to the scope and audience of their textbook. Each of these roles requires not only a basic understanding of projections, but oftentimes specialized projection knowledge that allows cartographers to carry out their assigned tasks. The following discussion provides a brief summary of these example roles and integrates the material from Table 3 to recommend specific projection material for future textbooks. Figure 11 provides a summary of these recommendations.

A static cartographer compiles various data layers in a digital environment to produce a map that will be printed or displayed on screen. When choosing a projection, they

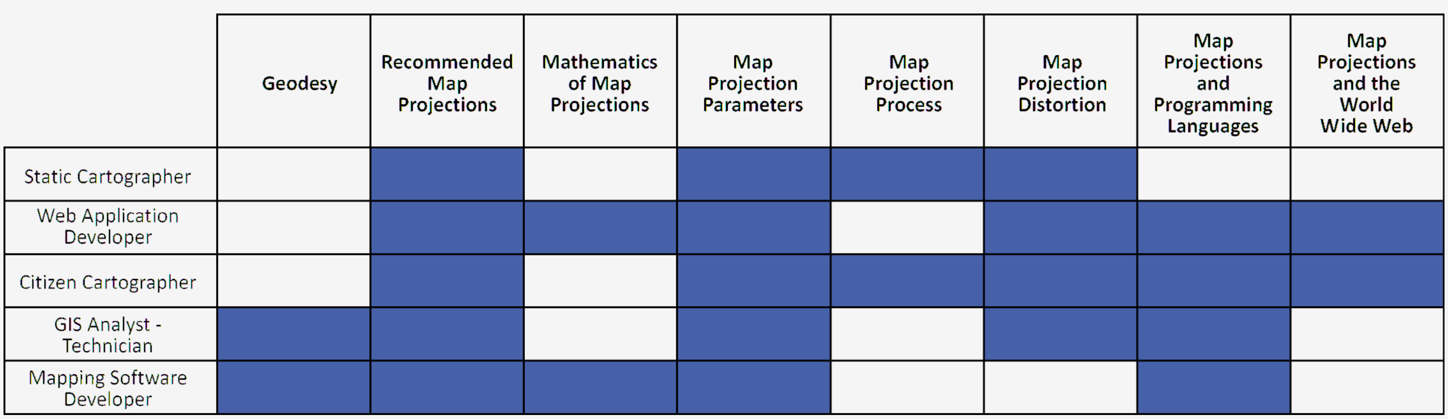

Figure 11. *A summary of recommended projection material according to the projection categories and the example cartographer roles.*

would need to know which projections would be suitable, understanding that symbolization methods may have certain requirements that the projection should meet. They would also likely need to be familiar with the overall projection process (e.g., understanding how it creates different arrangements of the graticule and which arrangements are advantageous to the map purpose). Knowledge of the appropriate values for the different projection parameters, and their effect on distortion patterns, would also be important, especially with medium and small scale maps. In a related sense, they would also benefit from knowing how map readers view and understand distortion on a map.

A cartographer working as a web application developer would likely be involved in creating or maintaining a web mapping service. They would need to know the advantages and disadvantages of the web Mercator as well as be comfortable in their knowledge about other projections that could be incorporated into a web environment. They would benefit from using resources associated with programming languages such as JavaScript libraries (e.g., Data Driven Documents [D3]). If they were integrating a projection other than the web Mercator, they would need to be familiar with how to choose a projection, alter its parameters, and evaluate its distortion pattern against the intended map purpose. If a desired projection didn't exist in one of the JavaScript libraries, they may have to have enough of a mathematical background to write the code for a specific projection equation.

Citizen cartographers use software or web applications to create maps, but have not had any formal education in mapmaking. They may use open source software or web applications to produce maps in either print or digital formats. The software or applications they use may have a limited number of projections that are offered or parameters that can be changed. They would need to know the advantages and limitations of recommended projections. Once a specific projection is selected, they would likely need to alter one or more of the projection parameters to control the overall distortion pattern. They would benefit from considering the arrangement of the graticule and the impact that arrangement may have on map readers. Knowledge of a programming language may be useful to them as they may need to write the code for a projection that is not presently available. For a web-based mapping service, they may want to consider a cylindric projection other than the web Mercator to serve map tiles.

The GIS analysts-technicians are professionals who incorporate digital data in both vector and raster formats into their workflow. This workflow involves defining a coordinate system (i.e., a datum and projection) that is appropriate for the map purpose. To tailor the projection for a particular map purpose, they may need to alter one or more projection parameters, and understand how these parameters can be manipulated to minimize distortion over the mapped area.

The mapping software developer may use higher-level programming languages (e.g., C++) to write the code that makes mapping tools available to the end user. They need to be familiar with common datums and their appropriate transformations. They would also need to consider which projections are suited for the software's analysis tools or the potential kinds of maps and intended purposes that may be desired by the end user. Once a set of projections has been selected, the developer could either rely on existing code libraries in a particular a programming language, or, if a desired projection is not available, they may need to translate projection equations into a programming language. To assist the end user with manipulating projection parameters, the developer would need to understand the range of possible values for each projection parameter in order to set default values.

CONCLUSION

In this paper I have presented the results of a content analysis of projection material found in a sample of 24 English-langauge cartography textbooks published during the twentieth and early twentry-first centuries. The overall goals of the content analysis were twofold. First, I wanted to see what particular projection material was presented in the textbooks published in the various eras. Second, I wanted to see whether the projection material from the various eras reflected developments in projections associated with each era.

The content analysis demonstrated that projection content from the Characterizing the Graticule, Map Projection Classes, Map Projection Properties, and Map

Projection Distortion categories was found in every textbook throughout the study period. Other categories, such as Geodesy and Recommended Map Projections, saw an increased presence in the textbooks from the start to the end of the study period. On the other hand, the Map Projection Process category showed a decreased presence in textbooks in the latter part of the study period. Interestingly, the Graphical Construction category disappeared from the textbooks from the 1960s onward. This disappearance can be explained by the development of computer automation, which replaced much of the manual burden that mapmakers faced during the earlier part of the study period.

Eight categories of projection information are recommended for inclusion in future cartography textbooks, six of which stemmed from the content analysis (Geodesy, Recommended Map Projections, Mathematics of Map Projections, Map Projection Parameters, Map Projection Process, and Map Projection Distortion). Two additional categories (Map Projections and Programming Languages and Map Projections and the World Wide Web) were derived from developments in projections. Knowledge contained within these categories is considered essential in helping students to learn how to successfully work with projections in a digital environment.

Cartographic education today clearly has changed since the beginning of the twentieth century. Technological advances have diversified the roles that cartographers assume in the workplace. These roles ask individuals to possess general knowledge about projections (e.g., knowing how to select a given projection for a map purpose). In addition, some roles require specific knowledge about projections (e.g., programming a projection in the JavaScript language). To that end, I recommend that the specific projection material chosen to be included in cartography textbooks should be organized as a function of the varied roles that cartographers now assume in the workplace. Some of many possible examples of these roles include static cartographer, web application developer, citizen cartographer, GIS analyst-technician, and mapping software developer. For instance, I recommend that the static cartographer be versed in projection material from Recommended Map Projections, Map Projection Parameters, Map Projection Process, and Map Projection Distortion. On the other hand, the GIS analyst-technician should be equipped with projection material from Geodesy, Recommended Map Projections, Map Projection Parameters, Map Projection Distortion, and Map Projections and the World Wide Web. By considering these varied roles, and the projection categories I have outlined in this paper, future cartography textbook authors will be better able to tailor their projection materials to the needs of a modern audience.

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APPENDIX A: A LISTING OF ALL 48 TEXTBOOKS CONSIDERED FOR THIS STUDY

Decade	Textbook Title and Edition	Author(s)	Publication Date
1900	*Maps, Their Uses and Construction*	G. James Morrison	1902
	Text Book of Topographical and Geographical Surveying	Charles Close	1905
	Mathematical Geography	Willis Johnson	1907
	Practical Geography	Frederick Mort	1908
1910	*Maps and Map Making*	Edward Reeves	1910
	Topographic, Trigonometric and Geodetic Surveying, Including Geographic, Exploratory, and Military Mapping with Hints on Camping, Emergency Surgery, and Photography	Herbert Wilson	1912
	Handbook of Geography: Descriptive & Mathematical	Eml Reich	1918
	Map Reading and Topographical Sketching	Edwin Stuart	1918
1920	*Maps and Surveys (2nd edition)*	Arthur Hinks	1923
	Topographic Mapping	Lawrence Roberts	1924
	Maps: How they are made; how to read them	Henry Dickson	1926
	Mathematical Geography	Alexander Jameson and Michael Ormsby	1927
1930	*Drafting and surveying course*	U.S. Army Engineering School	1930
	Map Drafting and Lettering	Howard Saunders and Howard Ives	1931
	Cartography	Charles Deetz	1936
	The World in Maps: A Study in Evolution	Walter Jervis	1937
1940	*The History and Technique of Map Making*	Helmuth Bay	1943
	Cartography, Map Making	Hubert Bauer	1945
	General Cartography (2nd edition)	Erwin Raisz	1948
	Advanced Surveying and Mapping	George Whitmore	1949

Decade	Textbook Title and Edition	Author(s)	Publication Date
1950	*Down to Earth: Mapping for Everybody*	David Greenhood	1951
	Elements of Cartography	Arthur Robinson	1953
	A Guide to the Compilation and Revision of Maps	Department of the Army	1955
	Mathematical Cartography	Aleksei Graur	1956
1960	*Principles of Cartography*	Erwin Raisz	1962
	An Introduction to Mapwork and Practical Geography	John Bygott and D. C. Money	1962
	Maps: Topographical and Statistical	Thomas Birch	1964
	Cartography	Robert Maxwell	1964
1970	*Cartographic Methods*	George Lawrence	1971
	Cartographic Design and Production	John Keates	1973
	Maps and Map Making	Robert Duru	1977
	Map Use: Reading, Analysis, and Interpretation	Phillip Muehrcke and Juliana Muehrcke	1978
1980	*Thematic Map Design*	David Cuff and Mark Mattson	1982
	Basic Cartography for Students and Teachers	Roger Anson and Ferjan Ormeling	1984
	Basic Graphics and Cartography	Claude Westfall	1984
	Principles of Thematic Map Design	Borden Dent	1985
1990	*Cartography: Thematic Map Design (2nd edition)*	Borden Dent	1990
	Introductory Cartography	John Campbell	1991
	Mapping it Out: Expository Cartography for the Humanities and Social Sciences	Mark Monmonier	1993
	Mapping: Ways of Representing the World	Daniel Dorling and David Fairbairn	1997

Decade	Textbook Title and Edition	Author(s)	Publication Date
2000	*Map Use and Analysis (5th edition)*	John Campbell	2005
	Thematic Cartography and Geovisualization (2nd edition)	Terry Slocum, Bob McMaster, Fritz Kessler, and Hugh Howard	2005
	Cartography: an Introduction	Mary Spence and Giles Darkes	2008
	GIS Cartography	Gretchen Peterson	2009
2010	*Cartography and Visualization of Spatial Data (3rd edition)*	Menno-Jan Kraak and Ferjan Ormeling	2010
	Making Maps: A Visual Guide to Map Design for GIS	John Krygier and Denis Wood	2011
	Principles of Map Design (2nd edition)	Judith Tyner	2014
	Map Use: Reading, Analysis, Interpretation	Jon Kimerling, Juliana Muehrcke, Aileen Buckley, and Phillip Muehrcke	2016

DOI: 10.14714/CP90.1411

The Design and Testing of 3DmoveR: an Experimental Tool for Usability Studies of Interactive 3D Maps

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Various widely available applications such as Google Earth have made interactive 3D visualizations of spatial data popular. While several studies have focused on how users perform when interacting with these with 3D visualizations, it has not been common to record their virtual movements in 3D environments or interactions with 3D maps. We therefore created and tested a new web-based research tool: a 3D Movement and Interaction Recorder (3DmoveR). Its design incorporates findings from the latest 3D visualization research, and is built upon an iterative requirements analysis. It is implemented using open web technologies such as PHP, JavaScript, and the X3DOM library. The main goal of the tool is to record camera position and orientation during a user's movement within a virtual 3D scene, together with other aspects of their interaction. After building the tool, we performed an experiment to demonstrate its capabilities. This experiment revealed differences between laypersons and experts (cartographers) when working with interactive 3D maps. For example, experts achieved higher numbers of correct answers in some tasks, had shorter response times, followed shorter virtual trajectories, and moved through the environment more smoothly. Interaction-based clustering as well as other ways of visualizing and qualitatively analyzing user interaction were explored.

KEYWORDS: 3D maps; 3D cartography; 3D Movement and Interaction Recorder; 3DmoveR; usability; user performance; X3DOM; web technologies

INTRODUCTION

Applications such as Google Earth and Virtual Earth have led to greater use of the third dimension in cartography and geoinformatics. Despite the wide range of 3D visualization applications (Biljecki et al. 2015), relatively little is known in terms of their theoretical background. As noted by Wood et al. (2005)—and we can still agree with this statement—we do not know enough about how 3D visualizations can be used effectively and appropriately, especially those that are interactive. While Voženílek (2005) mentions that 3D visualization is suitable for presenting data to a public with little experience of cartography, we do not agree with this statement in the case of *interactive* 3D visualization. On the contrary, we anticipate that these displays will be used more effectively by experienced users (experts in 3D interactive visualizations or virtual reality), as stated, for example, by Bowman et al. (2005) and Burigat and Chittaro (2007).

According to Buchroithner and Knust (2013), two types of 3D visualization exist: *pseudo-3D* and *real-3D*. Pseudo-3D visualization is displayed using only monocular depth cues on planar media, generally a computer screen. Real-3D (true-3D), refers to stereoscopic visualizations, which use both binocular and monocular depth cues (Buchroithner and Knust 2013; Torres et al. 2013). In this paper, our research examines the more widely disseminated (and less expensive) type of visualization, pseudo-3D.

Different definitions of 3D maps exist. Bandrova (2006) defines a 3D map as a computer generated, mathematically defined, three-dimensional, highly realistic virtual representation of the world's surface, as well as of the objects and phenomena in nature and society. Schobesberger and Patterson (2007) characterize a 3D map as the depiction of terrain with faux three-dimensionality, containing perspective that diminishes the scale of distant areas. Haeberling, Bär, and Hurni (2008) describe it as the generalized representation of a specific area using symbolization to illustrate physical features. Hajek, Jedlicka, and Cada (2016) state that 3D maps are usually understood as maps containing Digital Terrain Models, 2D data draped onto terrain, 3D models of objects, or 3D symbols.

The main objective of our research was to design, implement, and pilot test an experimental tool for the usability testing of interactive 3D maps, which we called the 3D Movement and Interaction Recorder (3DmoveR). Our own understanding of the term "3D maps" is that they are real-3D or pseudo-3D depictions of the world, including its natural or socio-economic objects and phenomena, constructed from a mathematical basis: a geographical or projected coordinate system with a Z-scale of input data and a graphical projection such as a perspective or orthogonal projection. For our 3D map to be "interactive," we assume it must allow at least navigational (or viewpoint) interactivity (Roth 2012).

We also wanted to conduct an experiment to test Bowman et al.'s (2005) claim that advanced users of virtual reality employ more effective interaction strategies than laypersons, by making our own comparison between expert users of 3D maps and visualizations, and lay users. This experiment would also serve as a demonstration of the possibilities provided by 3DmoveR, which allows the recording of user interactions in a 3D environment.

ASPECTS OF USABILITY

Usability is understood in cartography as a relevant criterion for evaluating maps. The term is defined by ISO standard 9241-11:1998, as the "extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (ISO 1998). Furthermore, ISO standard 19157:2013 goes on to specifically describe usability for the geospatial domain: "Usability is based on user requirements. All quality elements may be used to evaluate usability. Usability evaluation may be based on specific user requirements that cannot be described using the quality elements described above. In this case, the usability element shall be used to describe specific quality information about a dataset's suitability for a particular application or conformance to a set of requirements" (ISO 2013). Usability then is measured as the "degree of adherence of a dataset to a specific set of requirements." The concept of usability can be applied in evaluating cartographic visualizations. Slocum et al. (2001) describe the importance of usability issues in 3D cartographic visualization and further emphasize that developing formal methods of usability assessment is necessary. MacEachren and Kraak (2001) also suggest that specific tools for usability research are needed.

According to ISO/IEC 9126-4:2004, usability is specified according to three parameters (ISO/IEC 2004):

- *Efficiency* determines how quickly and easily a user navigates to the desired information or how quickly they can perform tasks (IEEE 1990).
- *Effectiveness* quantifies a task's success; for example, users may be able to perform a specific task on a map with a 20% error rate (Rubin, Chisnell, and Spool 2008).
- *Satisfaction* expresses the user's feelings about using the subject, or suggests how pleasant it is to use the tested design. This evaluation, however, is very difficult due to its subjective character (Rubin, Chisnell, and Spool 2008).

USABILITY EVALUATION METHODS

Many approaches to evaluating cartographic products exist. It is possible to use a variety of evaluation methods to derive qualitative and quantitative characteristics of the tested product (including 3D maps). Authors such as van Elzakker (2004), Li, Çöltekin, and Kraak (2010), and Rother (2014) provide an overview of usability methods. These are: questionnaire; interview; direct observation; think-aloud protocol; focus-group study, screen capture or screen logging; and eye-tracking.

Generally, these research methods all involve users solving practical tasks with the product being evaluated, while speed, correctness of results, and accuracy of responses are also being monitored. These methods are not used individually, but usually combined to cover the needs of the specific study. This approach is called mixed research design, which was introduced into several disciplines by Cameron (2009), and into cartography by Bleisch (2011) and van Elzakker and Griffin (2013).

3D MAP USABILITY RESEARCH

MacEachren (1995) outlined the need for research on the usability of 3D maps. In most such studies, only static maps have been analyzed (e.g., Kraak 1988; Savage, Weibe, and Devine 2004; Ware and Plumlee 2005; Schobesberger and Patterson 2007; Popelka and Brychtova 2013; Prepernau and Jenny 2015; or Rautenbach, Coetzee, and Çöltekin 2016), or animations of flights over 3D maps (e.g., Torrens et al. 2013).

Few experiments that examined an interactive 3D virtual environment have been published. Herbert and Chen (2014) compared static 3D visualizations to interactive ones but did not study the interaction. Bleisch, Dykes, and Nebiker (2008) assessed the differences between reading 2D bar charts and reading those placed in a 3D environment. Speed and correctness were measured, but information about movement within the 3D environment was neither recorded nor evaluated, even though a 3D interactive environment was enabled. In this case, screen logging would have made it possible to determine whether participants used the interactive capabilities of 3D stimuli. Wilkening and Fabrikant (2013) studied user interaction with Google Earth. Observation and manual recording of the movement types (zooming, panning, tilting, and rotating) were used to collect these data. However, it would be possible to analyze the interaction of users in more detail and more automatically with screen logging or virtual movement recording.

Abend et al. (2012) have also contributed to the analysis of interactive movement in 3D environments; they processed videos captured while a user worked with Google Earth. However, the examination of videos is more demanding than evaluating screen-logging data, which can be analyzed automatically and objectively. Špriňarová et al. (2015) described a mainly qualitative (and to some extent subjective) approach in which participants were observed using similar movement strategies and sequences in a 3D virtual environment, including a terrain model. McKenzie and Klippel (2016) dealt with the problem of wayfinding in a virtual environment and analyzed, inter alia, movement speed. As part of their study, Juřík et al. (2017) recorded and analyzed individual movement types as users interacted with a 3D spatial data visualization across four interactive tasks.

Before we can easily apply, in cartographic research, the approaches and methods used in 3D User Interface (UI) research (for an introduction, see Bowman et al. 2005), there is need for tools that will enable, for example:

- detailed user logging (Ritchie et al. 2008; Sung et al. 2009);
- virtual movement capture to be used for comparing different UIs (Zanbaka et al. 2005);
- virtual trajectory (user path) analysis (Cirio et al. 2013);
- recording of mobile device movement and analysis of resulting trajectories (Büschel et al. 2017) and analysis of 3D rotation (Bade, Ritter and Preim 2005);
- calculating density of presence in a virtual environment (Chittaro and Ieronutti 2004); and
- combining different virtual movement visualization methods (Chittaro, Ranon and Ieronutti 2006).

Few of the above-mentioned methods have been used and implemented in cartography, except by Treves, Viterbo, and Haklay (2015), who tracked and analyzed the movement of their participants using virtual trajectories.

As previously mentioned, most of the usability studies in cartography dealt only with static 3D maps (perspective views) as stimuli. If interactive movement in 3D space was possible, it was neither monitored nor analyzed in detail. Wilkening and Fabrikant (2013), Treves, Viterbo and Haklay (2015), McKenzie and Klippel (2016), and Juřík et al. (2017) are the only exceptions, and the approaches and methods they each used for 3D UI evaluation, especially the screen logging method, have been sources of inspiration for our tool. At the same time, we wanted to improve upon these approaches (eliminate manual records, support different variants of 3D maps) and combine them to allow comprehensive analysis of user interactions. These were our reasons for designing and implementing a new testing tool: to allow speed, the accuracy of responses, and the subjective opinions of participants to be recorded in a mixed research design.

REQUIREMENTS ANALYSIS

As the first step in creating our 3D visualization testing tool, we conducted a requirements analysis in order to determine the features or functions that potential users would find necessary. We focused on two groups when determining user expectations for the tool: (1) researchers who would use it to create and analyze tests, and (2) participants in those researchers' tests. However, for the formal requirements analysis, only the researchers were taken into account. Feedback was received from test participants later, in the evaluation phase (see Appendix 1 and the "Evaluating and Testing" section, below).

Our requirements analysis followed the ISO/IEC 25010:2011 standard (ISO/IEC (2011). An overview of identified requirements is shown in Figure 1, while a detailed description follows in the next section. These requirements could also be used to implement testing tools based on different technologies (programming languages, etc.). We identified both *functional* and *non-functional* requirements (see Figure 1). Functional requirements involve the inputs, behaviors, and outputs that the user expects from a system; these were defined based on the literature review outlined in the previous section. For example,

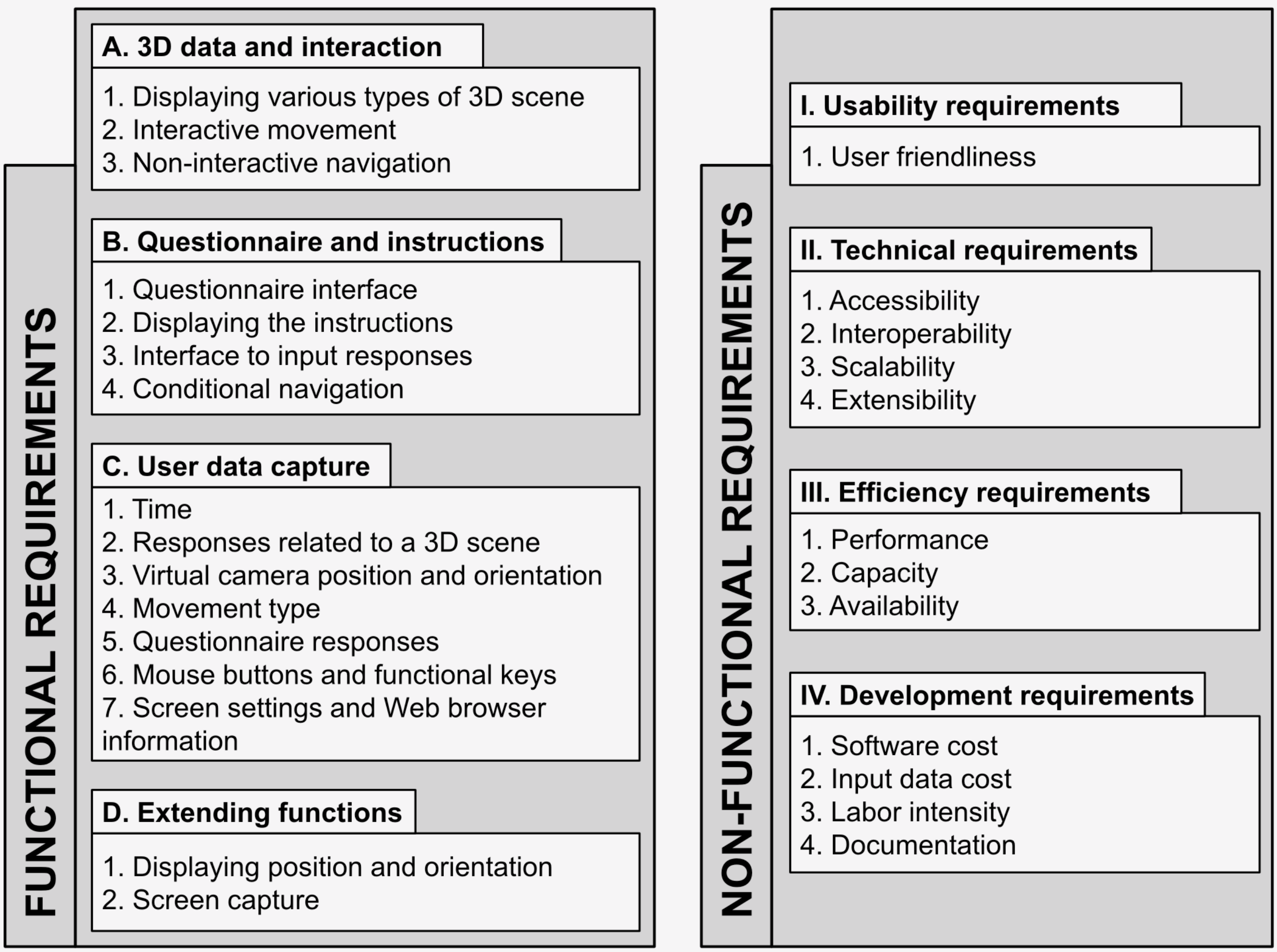


Figure 1. *Package diagram of identified functional and non-functional requirements defined according to ISO/IEC (2011).*

it was important for researchers (i.e., test creators) to be able to record all characteristics they might choose to study, and to modify all the examined variables.

Non-functional requirements specify how the system works, typically including its properties or a condition restricting its operation, such as training needs, costs, or documentation. Lack of success, or bugs in the testing application, may discourage participants from engaging with the test. This is why it is also important for the software to meet non-functional requirements.

FUNCTIONAL AND NON-FUNCTIONAL REQUIREMENTS

We categorized the *functional requirements* of the 3D testing tool into four packages: (A) displaying *3D data and interaction*, (B) displaying the *questionnaire and instructions*, (C) *user data capture*, and (D) *extending functions*.

Functional Requirements

Package A includes requirements related to interactive 3D visualization. These functions are needed to enable a wide range of 3D maps and their individual parts to be tested. As a result, individual controls can be evaluated, different modes of movement compared, or the suitability of symbols used in a 3D map assessed.

A.1. The testing tool should be able to *display various types of 3D scenes* or models. Preferably, it will handle 3D models of terrain (see, for example, Savage, Weibe, and Devine 2004; Popelka and Brychtova 2013; Wilkening and Fabrikant 2013), buildings (Rautenbach, Coetzee, and Çöltekin 2016; McKenzie and Klippel 2016), and abstract objects such as bar charts, etc. (Kraak 1988; Bleisch, Dykes, and Nebiker 2008).

A.2. Different types of *interactive movement* should be possible. Movement permits a fundamentally different affordance than static perspective views of 3D data. It is also one means of dealing with 3D object occlusion. 3D GIS applications often support several types of movement. We can distinguish between 3D movement modes (fly, walk, examine) and concrete types of movement (pan, zoom, rotation), which just consist of the movement mode "examine." In general, the maximum number of these modes should be available in the tool, since the aim of research may be, for example, to determine user preference for different movement types. Specifically, at least the above-mentioned types of movement should be supported, because they are the most common in 3D scenes (Ware and Plumlee 2005).

A.3. *Non-interactive navigation* is also foreseen as a very important functional requirement. Perhaps the most common and useful is a "reset position" function, but non-interactive movement can also mean switching between predefined views (see Ware and Plumlee 2005; Shepherd 2008). A flyby through a 3D scene with a predefined path may also be considered to be a form of non-interactive movement. The efficiency of flybys (used, for example, by Torres et al. 2013) may then be compared to the efficiency of using fully interactive navigation.

Package B includes requirements aimed at displaying instructions and storing user responses and/or opinions.

B.1. A *questionnaire interface* is required, since the testing tool should combine practical tasks (finding solutions to assigned tasks) along with the collecting of subjective responses. A questionnaire may be placed before or after a 3D scene. A questionnaire placed before a scene will likely focus on basic demographic data and previous user experience. A questionnaire can also come after a user solves a task, asking them, for example, to evaluate it, or recall what they remember about the 3D scene. Questionnaires have been used by Schmidt and Delazari (2011), Schobesberger and Patterson (2007), and Preppernau and Jenny (2015), among others.

B.2. A space to *display instructions* for each task should be available. A 3D scene may precede instructions or be displayed simultaneously with the task. Instructions may take the form of text or contain pictures.

B.3. An *interface to input responses* during tasks is necessary. This interface may include the option to select one or more correct answers, free-write responses to open-ended questions, or select features directly from a 3D scene. Participant responses (effectiveness) were monitored by Savage, Weibe, and Devine (2004), Wilkening and Fabrikant (2013), and Preppernau and Jenny (2015).

B.4. *Conditional navigation* may be required for training tasks that need instructions displayed gradually. If a user learns the movement "rotation," for example, instructions on how to perform this type of movement are shown for a period of time up to when the movement is executed (which is predefined). Afterwards, another instruction may be displayed or the user can advance to the next topic.

Package C includes requirements aimed at obtaining objective information related to a user's performance. All these types of records should be interconnected to allow the exploration of relationships. For instance, the connection between previous user experience and speed and accuracy of answers may be then analyzed. The same applies, for example, to reconstructing the sequence of movements a user followed to fulfill the task.

C.1. Capturing *time* data provides indicators related to speed in solving a task. This requirement is key for describing efficiency. The simplest method is to record the time each user needs to perform a given task. Efficiency was monitored, for example, by Preppernau and Jenny (2015), McKenzie and Klippel (2016), and Juřík et al. (2017).

C.2. Capturing *responses related to a 3D scene* is crucial for characterizing effectiveness. It should be possible to record responses (both correct and incorrect) in the form of selecting one correct option, multiple correct options, or responses as free text. User responses were captured and then analyzed, for example, by Savage, Weibe, and Devine (2004), Wilkening and Fabrikant (2013), and Preppernau and Jenny (2015).

C.3. Interaction with virtual environments, especially movement in 3D space, should be captured independently of recording responses and the time needed to solve tasks. Each movement is composed of a change in *virtual camera position and orientation*. Each change of coordinates should be stored. This method is used quite often in 3D UI research (Chittaro and Ieronutti 2004; Bowman et al. 2005; Zanbaka et al. 2005; Chittaro, Ranon, and Ieronutti 2006). It is possible to reconstruct and/or analyze user movement in a 3D virtual environment when coordinates are captured together with a time-stamp (e.g., Cirio et al. 2013). Positions in 3D space may be expressed in various ways within the geospatial domain. Typically, Cartesian coordinates (X, Y, Z) or geographical coordinates (longitude, latitude, and altitude above the reference surface) are used (Treves, Viterbo, and Haklay 2015). An expression of virtual camera orientation, though, is more complicated. Some applications (e.g., Google Earth) use heading, tilt, and roll, which are the values of rotation around individual axes. Another approach is used in the X3D and VRML (Virtual Reality Modelling Language) formats, where three numbers specify the rotational axis and one value gives the angle of rotation around it. A rotation matrix (usually 3×3) can also be used. Preferably, the tool will record coordinates in a common, machine-readable format (e.g., CSV, JSON, or XML).

C.4. Information about the *movement type* (zoom, walk, rotate, etc.) should be captured in a form that can be stored and then processed. All information about the use of non-interactive functions must also be stored. These data are necessary for determining how long users spend on each movement type or studying movement type sequences during navigation in 3D space. As noted by Wilkening and Fabrikant (2013) and Juřík et al. (2017), it is a very important aspect of research in 3D interactive visualization.

C.5. *Questionnaire responses* must be captured in order to assess effectiveness, users' descriptions of previous experience, their satisfaction with the tool, and their ability to learn. Questionnaire responses were captured and then analyzed by Savage, Weibe, and Devine (2004), Wilkening and Fabrikant (2013), and Preppernau and Jenny (2015).

C.6. Capturing the use of *mouse buttons and functional keys* allows a more detailed analysis of user interaction. It is especially important when one type of movement can be performed in several ways (e.g., in Google Earth, a user can either zoom with the mouse wheel, or by clicking and dragging with the right mouse button). This requirement is derived from detailed user logging, a common 3D UI research method (e.g., Ritchie et al. 2008; Sung et al. 2009).

C.7. Capturing *screen settings* (color mode, resolution) and *Web browser information* (type and version) allows user settings and conditions to be monitored.

Two possible and extended functionality requirements have been identified, as defined below.

D.1. Additional tools to *display position and orientation* are often used in virtual environments. These include overview maps or a north arrow. Shepherd (2008) presents the benefits of these navigational aids, Schmidt and Delazari (2011) provide a comprehensive overview of them, and Burigat and Chittaro (2007) tested some of them. The effectiveness of these tools may also be examined in the future.

D.2. The system should be able to *screen capture* at a specific time to log virtual camera position and orientation, for example, when a user enters a response. This capture may serve as a basis for further qualitative user strategy evaluation. An expanded variation is dynamic screen capture (video recording), which permits indirect observation. This method was used, for example, by Abend et al. (2012).

Non-functional Requirements

Non-functional requirements of the 3D testing tool have been categorized into four packages: (I) *usability requirements*, (II) *technical requirements*, (III) *efficiency requirements*, and (IV) *development requirements*.

Since the proposed application is designed for usability testing, it should itself be usable, as defined in Package I.

I.1. The application should be *user friendly*, a particularly critical consideration when the application is designated for usability testing. Performing a task should be simple and intuitive. All important parts of the application must be easy to access, especially virtual environment operation and navigation tools, as well as the elements needed to input responses. Well-known graphical control elements (widgets) should be used in the graphical user interface of the application (buttons, radio buttons, check boxes, or text boxes). User training time should be as brief as possible. A user should be able to work with the application immediately after reading brief instructions and initial explanations. Exporting and subsequently processing the recorded data should be as simple and user friendly as possible.

Package II contains requirements for the software's ability to be used on different platforms, and attributes that affect how much effort is needed to make specific modifications.

II.1. Employing web technologies guarantees maximum *accessibility*. 3D graphics rendering should be considered, as emphasized by Behr et al. (2009). The web application should work independently of the display device or its settings. This applies especially to the different behaviors of various web browsers (such as Internet Explorer, Mozilla Firefox, Google Chrome, Opera, and Safari), which often in practice do not display the same content in the same way. Preferably, the 3D application will display its contents correctly and consistently to a maximum number of users. An installation process should not be needed.

II.2. It is necessary to concentrate on syntactic *interoperability* during the application design phase. Interoperability, according to IEEE 610:1990, is the ability of different systems to work together to provide services and achieve synergies (IEEE 1990). For that reason, standards for technological development and data handling should be used, especially those related to 3D format support (e.g., X3D) and those that are relevant to the web environment (HTML and CSS).

II.3. The application should demonstrate *scalability*, for situations in which researchers demand improvement in non-functional requirements (e.g., speeding up responses or increasing capacity).

II.4. The application should be also feature *extensibility*, allowing researchers or developers to include new features or modify existing ones. Extensibility also allows the definition of additional functional requirements.

Package III is composed of a set of attributes affecting the relationship between the application's performance and the resources it uses, under the stated conditions.

III.1. *Performance* (speed of responses) states how fast the application can complete a request delivered to it. An efficient response time should guarantee at least a 1 Mbps data transfer rate when loading a new 3D scene. We expect 3D model visualizations in sizes up to 15 MB, so expected performance is within 15 seconds. Loading new data and continuous rendering of a 3D scene (i.e., during virtual movement) should also be fast enough. For that reason, technologies with hardware-accelerated rendering are preferred.

III.2. *Capacity* is defined as the limit to the number of simultaneous service requests provided with guaranteed performance. The application should be capable of processing 20 simultaneous requests per second.

III.3. *Availability* means the probability of the application being available. The probability of a catalogue service being available should be 90% across its lifetime. To lessen downtime of the system due to updates and patches, it is therefore preferable that data forming the 3D scene be separate from other system components, such as those that offer movement controls or recording camera positions.

Several requirements related to the testing tool development process are also identified and summarized in package IV. When creating any application, reducing costs associated with development and deployment is usually important.

IV.1. Costs may be divided into *software cost*, spatial data cost, and personal cost (both a person's time and their hourly pay). In terms of web applications, a wide range of software libraries is freely available, allowing costs to be reduced. The testing tool should rely on open source technologies. The final application will be released under a BSD license.

IV.2. Another situation exists for *input data cost* for the data that form the 3D model. Some 3D spatial data are available as free or open data, and fictitious data can be employed for some tasks, but a considerable amount of data have an associated cost. The test creator and the nature of proposed tasks determine which spatial data may be included as stimuli. Non-commercial data are expected to be used.

IV.3. Another component of cost is the *labor intensity* associated with developing the application. This depends on both the condition of processed data (the number of necessary adjustments that must be made to it) and the condition of software tools (the extent to which it is necessary to modify or expand them). The testing tool will be developed on a non-commercial basis as part of a Ph.D. thesis.

IV.4. *Documentation* is foreseen as a non-functional requirement important for the re-use of the testing tool. Test creators will require a tutorial that instructs them on how new experiments are designed. Clear and brief descriptions of controls and functionality will also be included in each test, so there is some assistance for participants.

DESIGN AND IMPLEMENTATION

We designed the experimental application 3DmoveR according to our requirements analysis. Our process was patterned after the "spiral model" (Boehm 1988), a risk-driven model for software projects. Based on a project's risk patterns, the spiral model suggests a blend of process models for its design, such as incremental, waterfall, or evolutionary prototyping. In our own case, we decided to create the software in two iterations. In the first, we designed and implemented an initial prototype, which was then pilot tested. After improving the prototype based on the pilot test, we created a second version for use in another round of pilot testing. This version of the tool was subsequently used in the main experiment.

Open web technologies were chosen to implement 3DmoveR, which comprises a client and a server side (see Figure 2). The client side is built with HTML, JavaScript (JS), jQuery, and X3DOM (a JS library for rendering 3D graphics in web browsers). The data recorded on the client side are posted to the server, where they are stored as CSV files generated by PHP scripts.

Wide support for the X3DOM data format in web browsers was the main reason for its use in 3DmoveR's development. X3DOM also benefits from the ready availability of software for creating 3D input data, documentation, and relevant examples. The X3DOM format uses the X3D data structure, is built on HTML5, JavaScript, and WebGL, and is free of charge for both non-commercial and commercial use (Behr et al. 2009). Common JS events are supported, e.g. for detecting user interaction or measuring time. 3D data can be stored in an HTML file or external files. Other aspects and capabilities of X3DOM are generally described by Behr et al. (2009), Herman and Řezník (2015), and on the web (www.x3dom.org). Herman and Russnák (2016) examine X3DOM utilization in the cartographic and GIS domains.

EVALUATION AND TESTING

We evaluated 3DmoveR through two pilot tests, technical testing, and interviews with experts. Detailed descriptions of the designs, tasks, stimuli, and participants for both pilot tests as well as the resulting software design improvements can be found in Appendix 1. The results of the technical testing with different 3D models are presented in Appendix 2. Here, we summarize the results of these tests, compare them with the defined requirements, and also list the results of consultations with experts.

The 3DmoveR application was able to implement the functional requirements laid out in Figure 1. Terrain data and abstract symbols were used as stimuli in both pilot tests, while 3D city models and 3D models of building interiors were also tested elsewhere (A.1). Interactive movement was successfully implemented in the tool (A.2). Most movement actions driven by a user can be distinguished. Various 3D libraries with different controls can also be used to render 3D models (e.g., Cesium, WebGLEarth, Three.js). The proposed tools only support interaction via a mouse or keyboard and depiction of a 3D scene on standard (2D) screens, which may be seen as a limitation. Non-interactive movement (A.3) was not used in the pilot tests, but its implementation and possible application in visualizing 3D spatial data is described in our earlier publication (Herman and Řezník 2015). Displaying questionnaires (B.1), instructions (B.2), and interfaces to input responses (B.3) presented no complications. All pilot test participants mastered the training task, and therefore we assumed that they understood conditional navigation (B.4). Recording time, type of action, and all responses

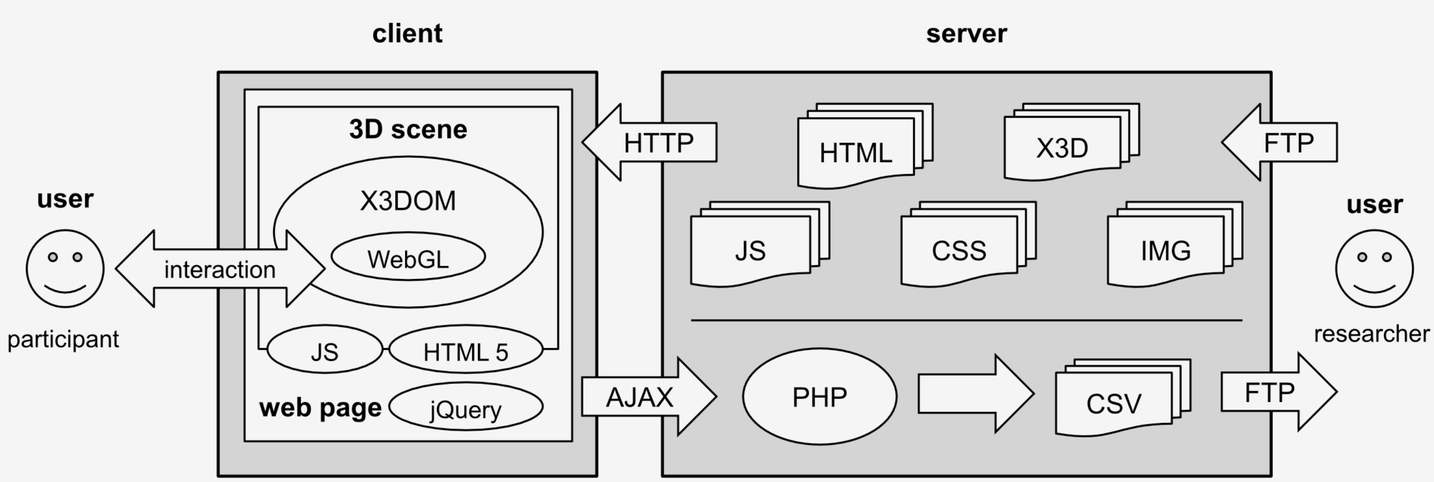


Figure 2. The general architecture of the 3DmoveR application, and the main technologies and formats on the client and server sides.

and configurations functioned correctly (C.1–7). All figures and visualizations reported in section 5 were calculated and constructed from these data. Two possible and extended functionalities were identified in the requirements analysis. The role of displaying position and virtual camera orientation in the 3D scene (D.1) were described by Schmidt and Delazari (2011) and Herman and Řezník (2015). Capturing screenshots (D.2) is also possible with the X3DOM library.

In term of non-functional requirements, the results of our pilot tests (Appendix 1) showed that the application can be considered user friendly (I.1). Users did not report any major problems when using the tool. Although full functionality is only available in Google Chrome, we considered the testing tool to be sufficient in terms of the accessibility (II.1). Ongoing work will aim to support other web browsers. The testing tool was also verified as customizable: each component of the X3D family standards can be used to expand or modify it (II.2–4). Appendix 2 shows different types of 3D data that can be tested in this tool. We also verified that the application's performance (III.1) and capacity (III.2) met the non-functional requirements (results are also presented in Appendix 2). In terms of availability (III.3), no problems were identified, as the application is not intended for high availability (e.g., hundreds of concurrent users).

Our work aimed to minimize operating costs (IV.1–3). The X3DOM library that was used to implement 3DmoveR is open source, and freely available data were used to create stimuli. While we used a commercial program (ArcScene) to prepare input data, freeware or open-source tools could have done the same task. Our previous study (Herman and Russnák 2016) used, for example, Trimble SketchUp. While experiments employing the current form of the testing tool require JS knowledge, a graphical interface to manage tests is envisaged for the future. This would allow administration in a graphical environment instead of via programming code.

Feedback on the first version of the application that we developed was also obtained from experts in various scientific fields: cartography, geography, informatics, and psychology. We asked these experts (assistant professors) to use the application and accomplish a set of tasks; then, we collected their subjective evaluations and implemented their suggestions. For example, the cartographic design of the 3D visualizations was evaluated by senior cartographers from Masaryk University and Palacký University, in the Czech Republic. The software architecture and design were discussed with experts from the Faculty of Informatics at Masaryk University to improve the performance of the application and the data captured during the experiments. The Centre for Experimental Psychology and Cognitive Sciences at Masaryk University evaluated the resulting measures and visualizations and were satisfied with their detail.

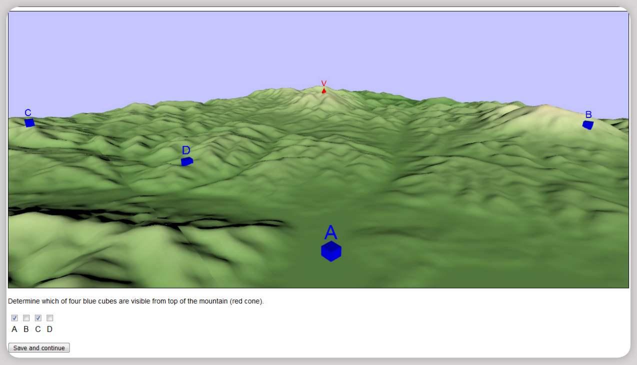
USER STUDY WITH 3DMOVER

In the main study, we wanted to compare the differences in performance and strategies of two user groups: 3D map and visualization experts, and non-expert laypersons (the general public). Our research question was: "Are expert users able to solve the given tasks more quickly, with greater accuracy in their responses, and using a more effective strategy, as predicted by Bowman et al. (2005)?"

Forty participants took part in the test. Half of the participants (20) were experts: cartography graduates who had obtained at least a bachelor's degree (average age 25 years; 4 females and 16 males). The other half of the participants, from the general public (laypersons), were ten psychology undergraduate students and ten final-year high school students (average age 19 years; 14 females and 6 males).

The test battery comprised an introductory questionnaire covering demographics and previous 3D visualization experience, a training task (participants had to try out all three possible types of motion, described below, otherwise they could not continue), and four test tasks with 3D maps. These tasks were selected to reflect basic cognitive processes (see Anderson, Krathwohl, and Bloom 2001). In two of the test tasks, users were presented with four objects and asked to identify which one was located at the highest altitude (Tasks 1 and 2); only one answer could be chosen from among the four options (objects A–D). Two other tasks were focused on the identification of visible objects from the top of a mountain (Tasks 3 and 4). These tasks also offered four options, but any number of them could be selected. Each task began with an instruction page, followed by a page with the 3D scene and an interface for user responses. At the end of the whole testing battery there were concluding questions, in which users offered a Likert-scale subjective evaluation of how difficult they perceived the tasks to have been.

All participants were informed that correct answers were more important than speed, and that their performance time would be recorded. Google Chrome was used for the experiment, as this web browser could be set to full screen mode before it began. Equivalent experimental conditions existed for all participants, including all environmental aspects. Participants were rewarded with small gifts at the end of testing.



Video 1. *Click to see a demonstration of 3DmoveR.*

Digital terrain models from the SRTM (Shuttle Radar Topography Mission) formed the principal stimuli in the main experiment. They were processed in ArcGIS 10.2. The terrain models were visualized in ArcScene with a green-to-brown hypsometric color scheme and a vertical scale (Z factor) set to two times larger than the actual altitudes. The results were exported from ArcScene as VRML (Virtual Reality Modeling Language) files and converted into X3D format using freely available software called View3dScene.

A type of virtual movement called "turntable" in X3DOM was chosen for this experiment, and was also used in both pilot tests. "Turntable" is a specific variant of a more widely used movement mode called "examine." Both "examine" and "turntable" are composed of three specific types of movement: pan (performed by the middle mouse button), zoom (right mouse button or mouse wheel), and rotate (left mouse button). Zoom moves the scene nearer or farther, pan drags the scene side to side, and rotate turns the scene around the center of rotation. As compared to "examine," "turntable" does not allow the longitudinal axis of the virtual camera to be rotated.

RESULTS

Interaction and virtual movement data were collected using 3DmoveR, and then analyzed and visualized. The differences in correct responses (effectiveness) were relatively small between the two user groups we compared. This is likely due to the tasks being relatively simple. Only one participant, a layperson, responded incorrectly in the first task (select the object at the highest altitude); thus, correctness was 95% for laypersons. All participants solved the second (select the object at the highest altitude) and fourth (determination of object visibility) tasks correctly. The greatest difference in effectiveness was recorded in the third task (determination of object visibility). All experts and 15 laypersons (75%) solved the third task without error. However, differences were recorded in the response times (efficiency) and other indicators, as seen in Appendix 3.

INTERACTION AND VIRTUAL MOVEMENT DATA

The descriptive statistics presented in Appendix 3 were used to compare response times, virtual movements, and interaction strategies between two user groups (experts and laypersons). Similar approaches have been used or recommended by Bade, Ritter, and Preim (2005); Zanbaka et al., (2005); Wilkening and Fabrikant (2013); and McKenzie and Klippel (2016). Measures were calculated from each user's virtual trajectory (length, average speed) and virtual camera positions (average height, rotation characteristics), or determined from the duration of individual movement types. We also recorded the moments when interactions were interrupted (delays). Delays longer than one second normally occur at the beginning of a task and just before responding. Shorter delays represent partial interruptions in movements; we assessed movement without interruption as being smoother.

These measures allow statistical testing and comparison of different aspects of user interaction between groups; Appendix 3 contains the results. The Mann-Whitney test was used for this purpose, because most of the measures do not have normal distributions. Where the differences in the figures were significant, experts were more effective (shorter response times, shorter trajectories, fewer delays), which corresponds to our hypothesis that experts are more skilled in handling interactive 3D maps. However, trajectory lengths and the number of delays are usually closely related to response time.

The 3DmoveR tool allows the easy capture of all of the above-mentioned measures. Future researchers can design experiments that compare the performance of individual users and user groups, in order to determine how different 3D visualizations, visualization settings, and other variables affect user interactions.

VISUALIZATION OF INTERACTIONS AND VIRTUAL MOVEMENTS

Task 3 (determination of object visibility) was chosen for a detailed comparison of the strategies of the two groups, as laypersons had the lowest level of correctness, and there were other statistically significant differences between groups.

The spatial component of virtual movements in the two user groups can be illustrated by either visualizing trajectories or using the Gridded AOI (Area of Interest) method. Visualizing trajectories provided only limited results, so we employed the Gridded AOI method. Gridded AOIs were created as cubes (3D Gridded AOI) using a minimum bounding box. In each, the number of virtual camera positions was determined and therefore the density of occurrence in that AOI. Interactive visualizations of 3D Gridded AOIs for experts and laypersons are available at: olli.wz.cz/webtest/3dmover/visualizations_cp.

In addition to the spatial component of user interactions, the temporal component can also be studied. The sequences of each type of movement (rotation, pan, zoom) can be compared. This can be done visually with a sequence chart (Figure 3), but comparison is highly subjective and can be challenging (e.g., in case of large numbers of participants, or with complicated sets of interactions). However, we can identify groups of similarly interacting participants: for example, those who prefer rotation (participants E05, E07, E09, L06, and L08) or participants who use all the movement types and take a long time to solve the

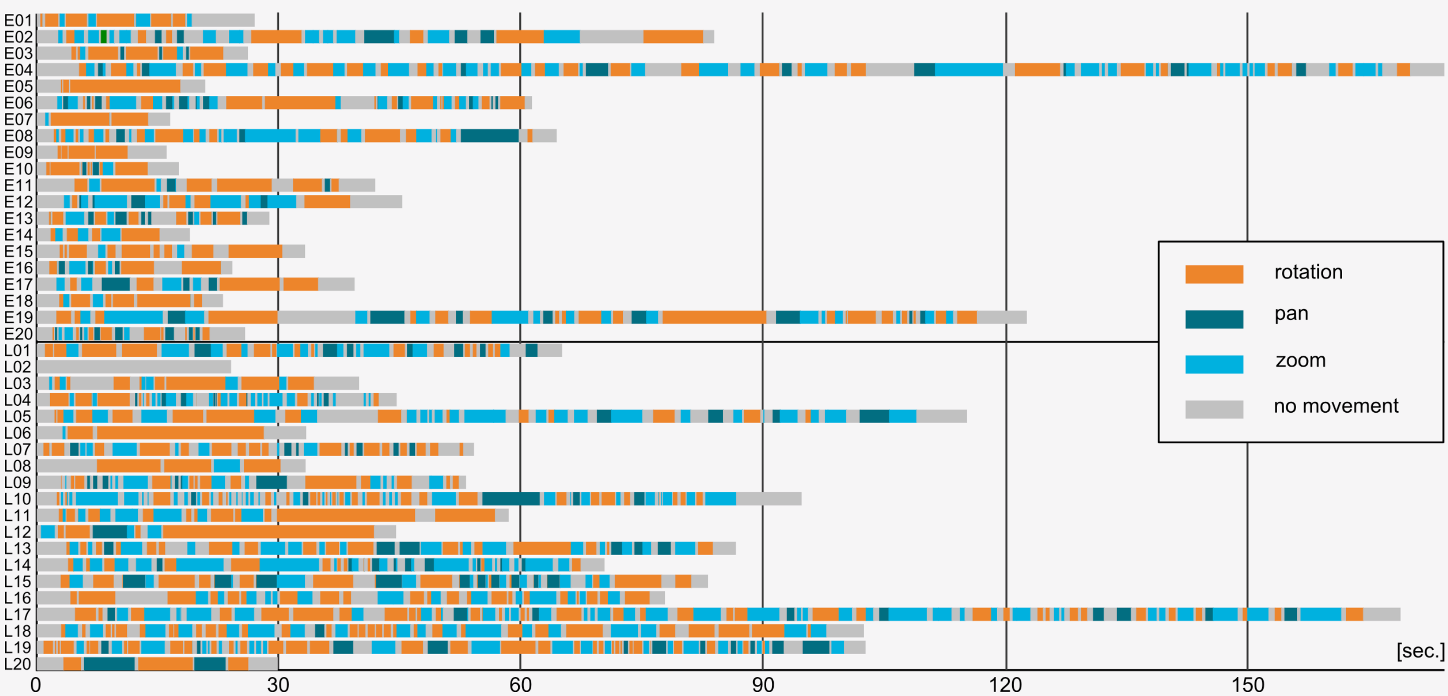


__Figure 3.__ Sequence chart of user interactions. An online version of the sequence chart with sample data is available at: olli.wz.cz/webtest/3dmover/visualizations_cp.

task (participants E04, E19, and L17). There are no clear differences between expert and layperson groups visible in Figure 3.

A more objective way of comparing user interaction sequences is based on the Levenshtein Distance method, which can be calculated with a freely available software tool called Scangraph (eyetracking.upol.cz/scangraph). ScanGraph's output is a matrix of similarities and a graph in which groups of similar sequences are displayed as cliques (Figure 4). For more detailed information about ScanGraph, see Dolezalova and Popelka (2016).

ScanGraph helped to identify the differences between laypersons and experts more quantitatively, but at the same time it created mainly smaller cliques of similar participants (usually with two to five members). Figure 4 shows the 31 calculated cliques; 14 of them are uniform, containing only experts or only laypersons. The various cliques form three larger groups, one with only laypersons, another with only experts, and the third with equal numbers of both participant groups. Two smaller cliques and solitary sequences of participants "E02" and "L02" can also be identified. Participant "L02" solved the problem without any interactions and responded incorrectly (answers A, C, and D).

Besides analyzing groups, we can also go into more detail and study the spatial aspects of user interactions performed by individual participants. We can, for instance, visualize

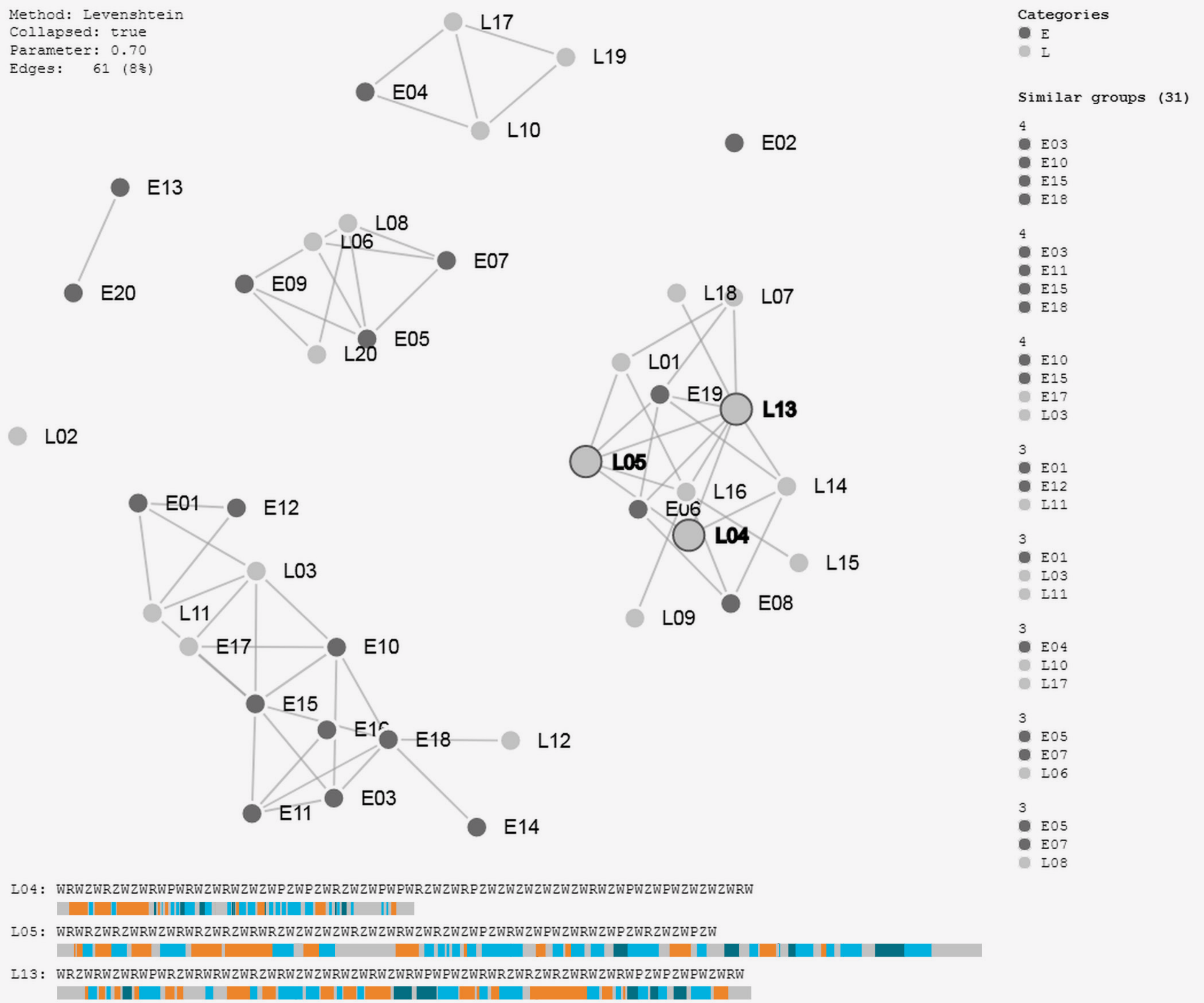


Figure 4. *ScanGraph output of user interaction sequences (L – layperson, E – expert). An interactive version is available at: eyetracking.upol.cz/scangraph/?source=4895429895b2a523e832e67.45570456.*

individual trajectories, highlighting virtual camera orientation, delays at individual virtual camera positions, or both types of information together. In Figure 5, the symbols for virtual camera positions are colored according to the movement type used (rotation/pan/zoom), which we can see greatly affects the shape of the virtual trajectory.

The virtual camera's position and orientation at important moments, such as when answering questions, can be also extracted from the records and screenshots can be reconstructed for examination by researchers. One further way of studying user strategy is to play back the movements of individual participants as animations (screen video). A tool to do this, along with sample data, is available at: olli.wz.cz/webtest/3dmover/visualizations_cp. Screenshots and screen videos are suitable for qualitative evaluation of participants' interactions and their strategies.

We can achieve a deeper understanding of user interactions with 3D visualizations by using a combination of analysis methods, some better suited to the scientific comparison of user groups (Gridded AOI and density calculation,

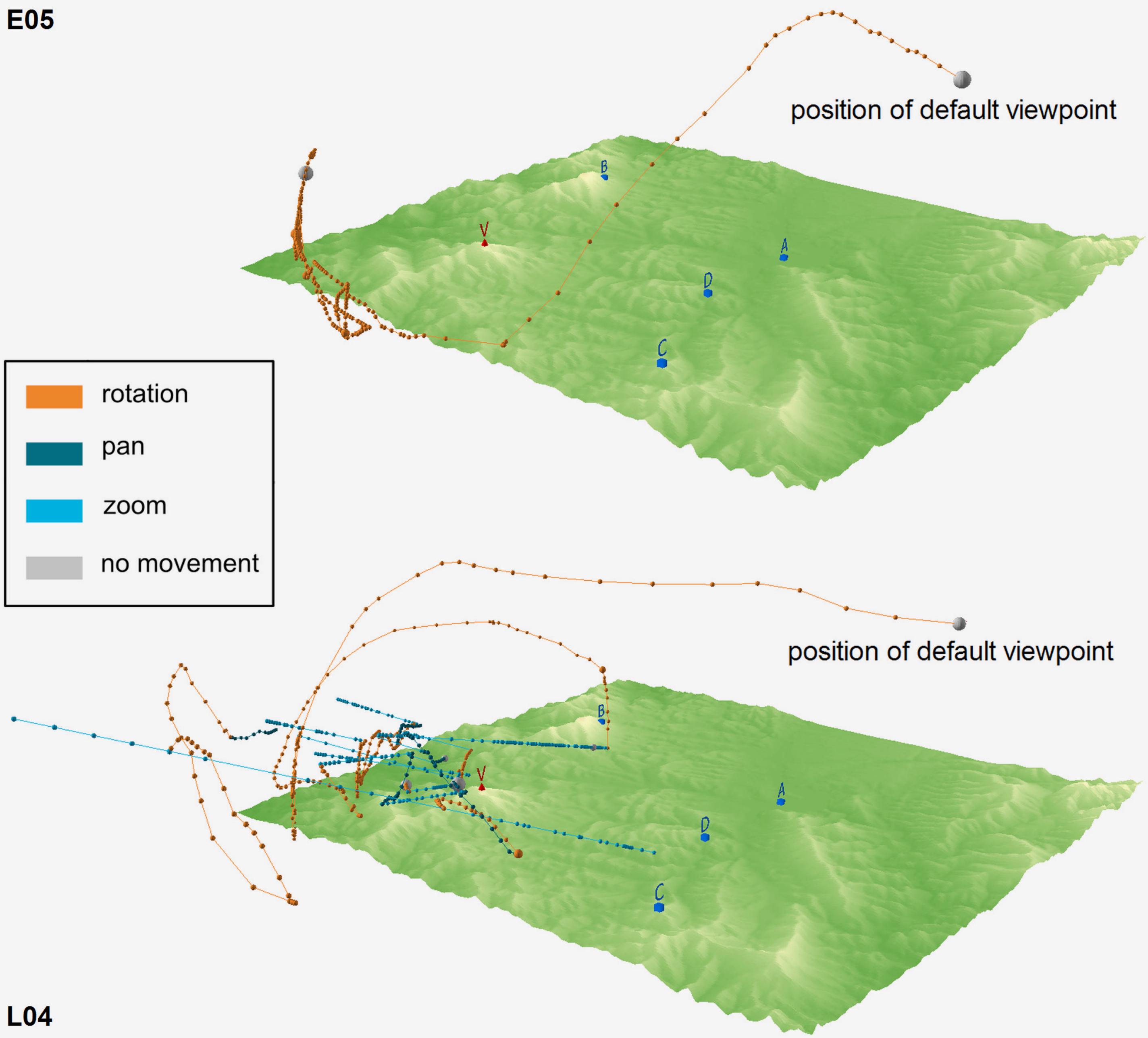


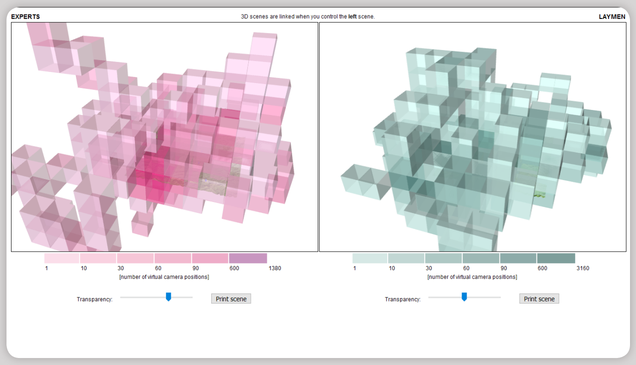
Figure 5. Comparison of the virtual trajectories of participant "E05" and participant "L04". The sizes of the spheres represents delays at individual virtual camera positions. An online version of these visualizations is available at: olli.wz.cz/webtest/3dmover/visualizations_cp.

ScanGraph), and others more suitable for a detailed examination of individual user interactions (sequence charts, visualization of trajectories, screenshots, or screen videos).

DISCUSSION

The experiment demonstrated the unique advantages of 3DmoveR for cartographic research, which allowed the easy recording of data that enabled us to make comparisons between the two user groups (experts vs. laypersons) and between individual participants. The results supported our hypothesis that experts would achieve higher correctness when responding and solve the tasks more quickly. Furthermore, their movements in the virtual environment were smoother, with fewer delays that were shorter than one second. The differences in correctness between experts and laypersons varied between individual tasks. The lowest accuracy was recorded in the third task, which was assessed as the most difficult by both laypersons and experts. These results are probably due to the terrain used in this task having the least roughness and the least variation in color range. The use of a green-to-brown color scale might also have influenced some users to make decisions according to color rather than perception of 3D terrain shapes; we assume that this could have happened in the first two tasks. In subsequent studies, it would be more appropriate to uniformly color the terrain or use an orthophoto as texture. This would also increase the ecological validity of the results: stimuli would be more similar, for example, to an application like Google Earth. The vertical scale (Z factor) of terrain in the test was twice the actual altitude.

It is obvious that there is a learning effect when the results of each test type (selection of an object at the highest altitude and identification of visible objects from the top of a mountain) are examined. In the first tasks of each type (the first and third tasks overall), we recorded statistically significant differences between users in response time and the number of delays. In the second tasks of each type (second and fourth tasks), these differences were less evident. Differences in the correctness between tasks were affected by the first two tasks having only one possible correct answer, while in the third and fourth tasks multiple answers were possible.



Video 2. *Click to see a demonstration of interactive and static methods for analyzing user data.*

We derived a number of individual metrics and visualizations to represent aspects of user interactions. While some differences or dependencies appear to be obvious (such as the correlation between the time a user took to solve a task and the distance they traveled), others need to be further explored and analyzed in the context of future experiments, such as how the correctness of responses depends on the sequence of virtual movement types. It is also possible to design and use other visualization methods, such as a graph showing changes in height of the virtual camera as the task is performed, or one indicating how distance changes between points of interest and the virtual camera.

CONCLUSIONS

The 3DmoveR software we developed was successfully validated through a usability test involving interactive 3D maps. To summarize, the application has the following major advantages:

- It is based on freely available web technologies.
- It is freely available under a BSD (Berkeley Software Distribution) license.
- Usability testing in 3DmoveR does not require installing any special software.
- It is easily modifiable for different 3D scene contents (terrain, buildings, textures, etc.), control positions,

and many other variables. It may also be modified for use in other fields or applications.

- It is versatile, recording data that can easily be used to calculate efficiency, effectiveness, and other aspects of usability or individual strategies. It collects both quantitative and qualitative data and can be combined with other usability research methods.
- 3DmoveR's recordings of user strategies offer researchers new ways to explore usability and other user aspects of interactive 3D maps and 3D visualizations generally.
- It is extensible: the 3DmoveR approach can be combined with eye-tracking (Herman, Popelka and Hejlova, 2017), touch screens (Herman et al., 2016), Oculus Rift and Google Cardboard (X3DOM 2018), other JS libraries (e.g., jsPsych, Webgazer.js), or with complex web tools for usability testing such as Hypothesis (Šašinka, Morong, and Stachoň, 2017).

The English version of the main experiment is available at: **olli.wz.cz/webtest/3dmover/test_eng_cp**, as well as a demo version with different types of stimuli (**olli.wz.cz/webtest/3dmover/demo_eng_cp**).

We tested the capabilities of 3DmoveR in pilot tests and then fully applied its possibilities in the main experiment to compare the performance of two user groups (laypersons and experts). In contrast to the classic approach of map user studies (which use static 3D maps as stimuli and analyze efficiency, effectiveness or satisfaction only), figures calculated from the data recorded in 3DmoveR were used for this comparison. Our hypothesis that experienced users would achieve better results than laypersons when working with interactive 3D maps was confirmed. They achieved higher accuracy when responding and solved tasks more quickly. Their movement in virtual environments was quicker and smoother, as indicated in the statistical testing of calculated delays.

Additionally, we explored a number of options for analyzing user strategies with different visualization and analytical methods (e.g., visualization of trajectories, Gridded AOI, sequence chart, ScanGraph). Further data-driven experiments will expand our knowledge in the usability and cognitive aspects of 3D visualization, and help explain at least some of the theoretical background of 3D cartographic visualization. Testing tools such as 3DmoveR, which permit detailed user interaction analysis, will help make that possible.

ACKNOWLEDGEMENTS

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APPENDIX 1

PILOT TEST 1

A relatively homogenous group of participants with previous 3D spatial visualization experience was chosen for the pilot study. Participants were students at the Department of Geography at Masaryk University. All participants had obtained at least a Bachelor's degree in cartography and all of them had participated in the course "3D Visualization in Cartography" at the time of testing. All participants were tested simultaneously (in a computer room with an appropriate number of computers) to control experimental conditions across participants.

All participants successfully completed the first pilot test. The paper questionnaire that followed was used to identify possible bugs or errors in the 3DmoveR proof-of-concept version. Most participants did not indicate that they noticed any failures or bugs. Two participants highlighted collisions with the terrain as a possible problem when moving virtually through 3D space. One participant had problems with zooming speed during a task.

The second stage of development saw two major changes. The CSV file structure was modified, because it was also necessary to store the end of an individual action (time, position, and virtual camera orientation) for precise analyses of virtual movements. Besides CSV files with detailed movement records, other CSV files containing user responses (effectiveness) and speed (efficiency) were also stored for each task.

Participants	Relatively experienced participants in terms of 3D visualization
Number	14 (9 male, 5 female)
Average Age	24 years
Experience with 3D	Work with 3D models, 3D visualizations, or 3D maps: occasionally (7) or regularly (7)
Stimuli	DTM scenes created from SRTM
Tasks	5 tasks solved with the 3D scene, and 1 afterwards without the 3D scene
With interactive 3D scene	1. Search for an object (blue cube) in the terrain
	2. Select which of two objects is at the highest altitude
	3. Determine which of four objects are visible from the top of the mountain
	4. Select which of four objects is at the lowest altitude
	5. Count the given objects (grey cubes) in the terrain
Without 3D scene	6. Remember objects from the terrain (from task 5)
Additional questionnaires	Introductory: demographic data and previous experience
	Conclusion (paper form): subjective evaluation of task difficulty, as well as reporting possible bugs and errors in 3DmoveR

Table 1. *Design of and participants in Pilot Test 1*

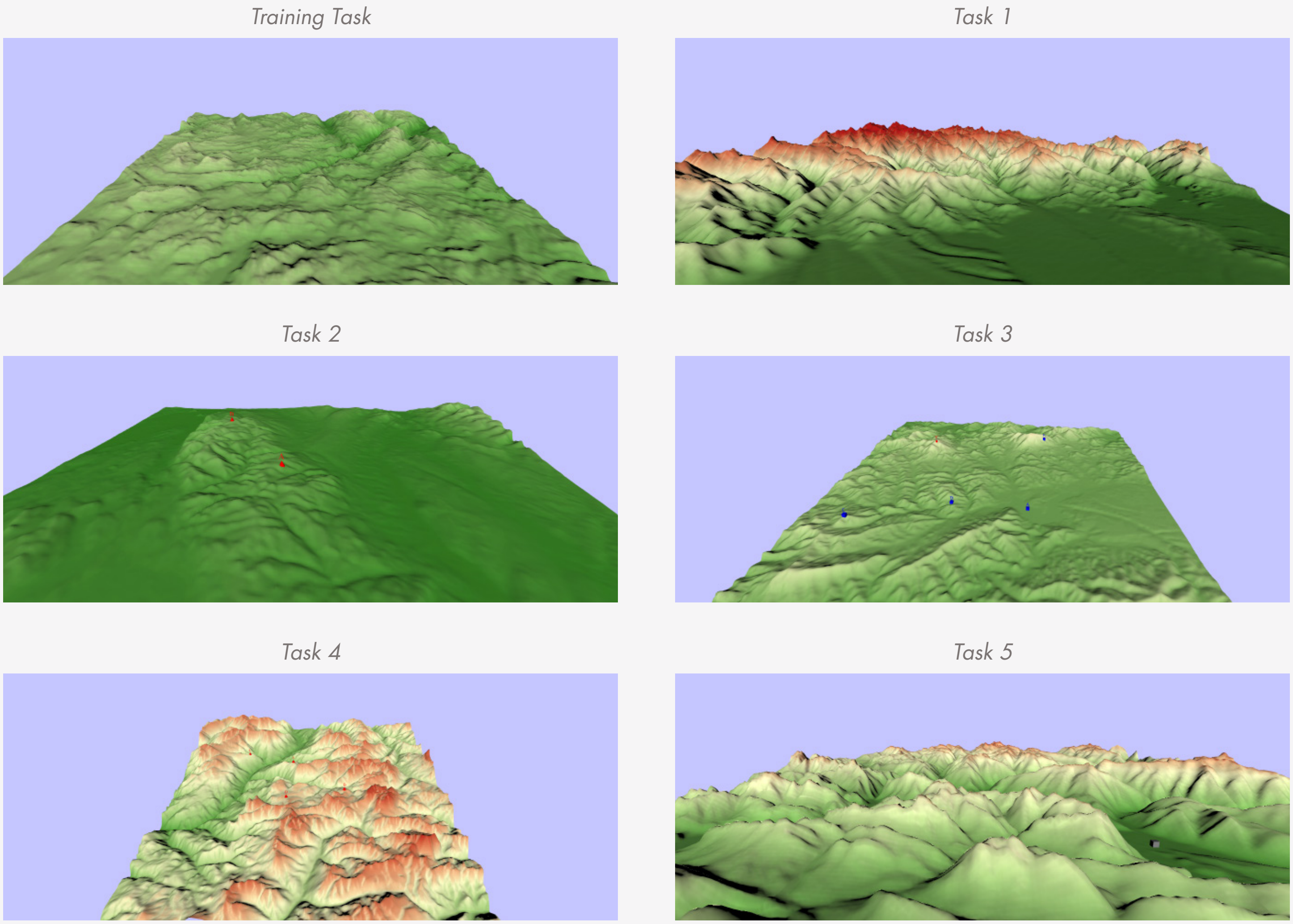


Figure 6. *Terrain models used as stimuli in Pilot Test 1.*

PILOT TEST 2

Eleven attendees of the "European Researcher's Night" event participated in the second experiment. Testing took place on one afternoon and evening on a single PC. Equivalent experimental conditions existed for all participants, including all environmental aspects. Participants were rewarded with small gifts at the end of testing.

For the second pilot test, and to examine the user friendliness of 3DmoveR, the general public was involved. We assumed that users who had less experience with interactive 3D maps would have more problems with controlling the application. Participants were monitored by direct observation; after the test, they were asked about potential problems, bugs, or errors. No problems were reported, and all participants completed the second pilot test. The data obtained in the second pilot test were used for designing and verifying processing procedures, evaluation, and visualization methods. For example, the CSV file structure was reviewed and the size of these files was evaluated. Their size depends on response time and the intensity of interaction (e.g., about 30 seconds of response time corresponds to 560 rows and an 83 kB file size; 1 minute of response time corresponds to 1600 rows and 235 kB). Herman and Stachoň (2016) present preliminary results of this stage.

Participants	General public
Number	11 (8 male, 3 female)
Average Age	23 years
Experience with 3D	Work with 3D models, 3D visualizations, or 3D maps: never (5), rarely (3), or occasionally (3)
Stimuli	DTM scenes created from SRTM
Tasks	4 tasks solved with 3D scenes
With interactive 3D scene	1. Select which of four objects is at the highest altitude (scene 1)
	2. Select which of four objects is at the highest altitude (scene 2)
	3. Determine which of four objects are visible from top of the mountain (scene 3)
	3. Determine which of four objects are visible from top of the mountain (scene 4)
Without 3D scene	None
Additional questionnaires	Introductory: demographic data and previous experience
	Conclusion: subjective evaluation of task difficulty

Table 2. *Design of and participants in Pilot Test 2. Task 3 from Pilot Test 1 and Task 3 from Pilot Test 2 were the same. The same terrain and distribution of objects were used.*

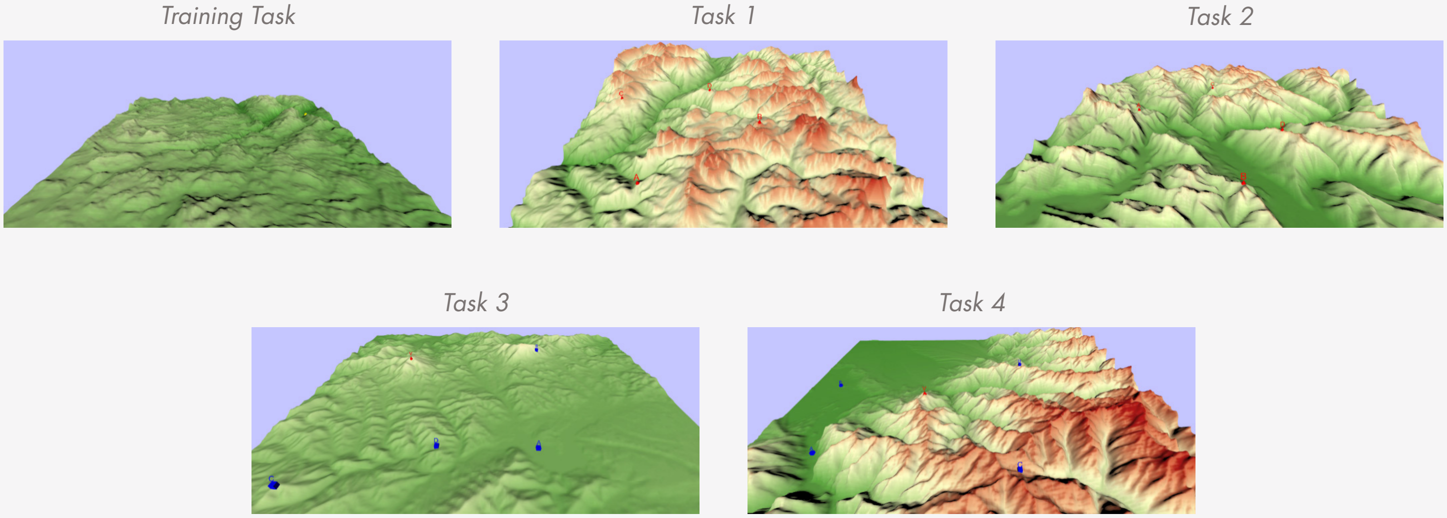
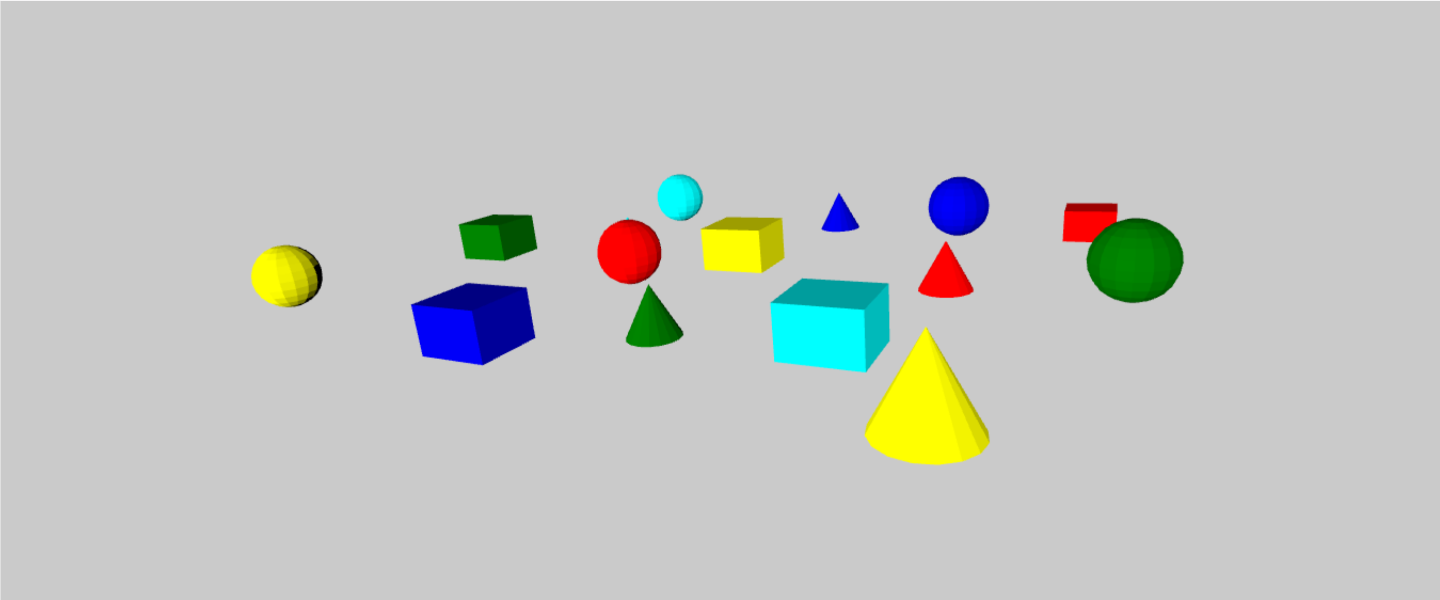


Figure 7. *Terrain models used as stimuli in Pilot Test 2.*

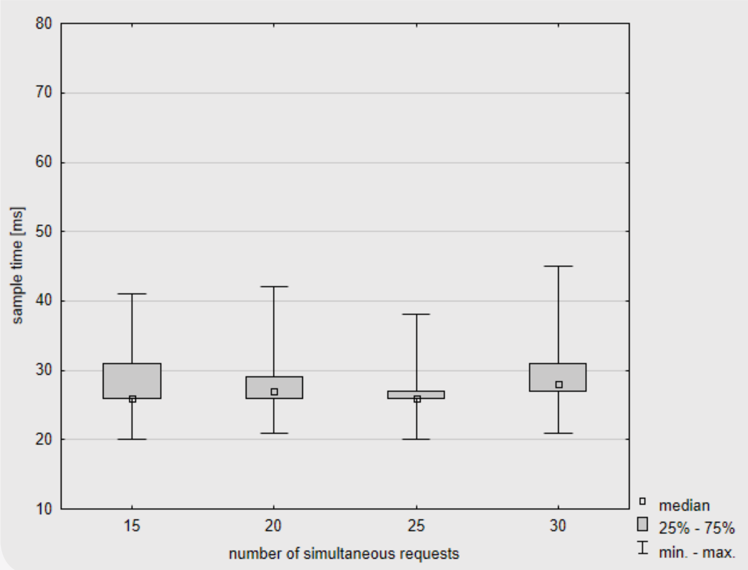
Testing Scene 1



Description of 3D scene	Set of geometric shapes with different colors
Mode of movement used	Examine
Number of HTML files and their total size	1, 12.88 kB
Number of X3D files and their total size	1, 491.520 kB
Total number of data files and their size	**2, 503.808 kB**

Performance

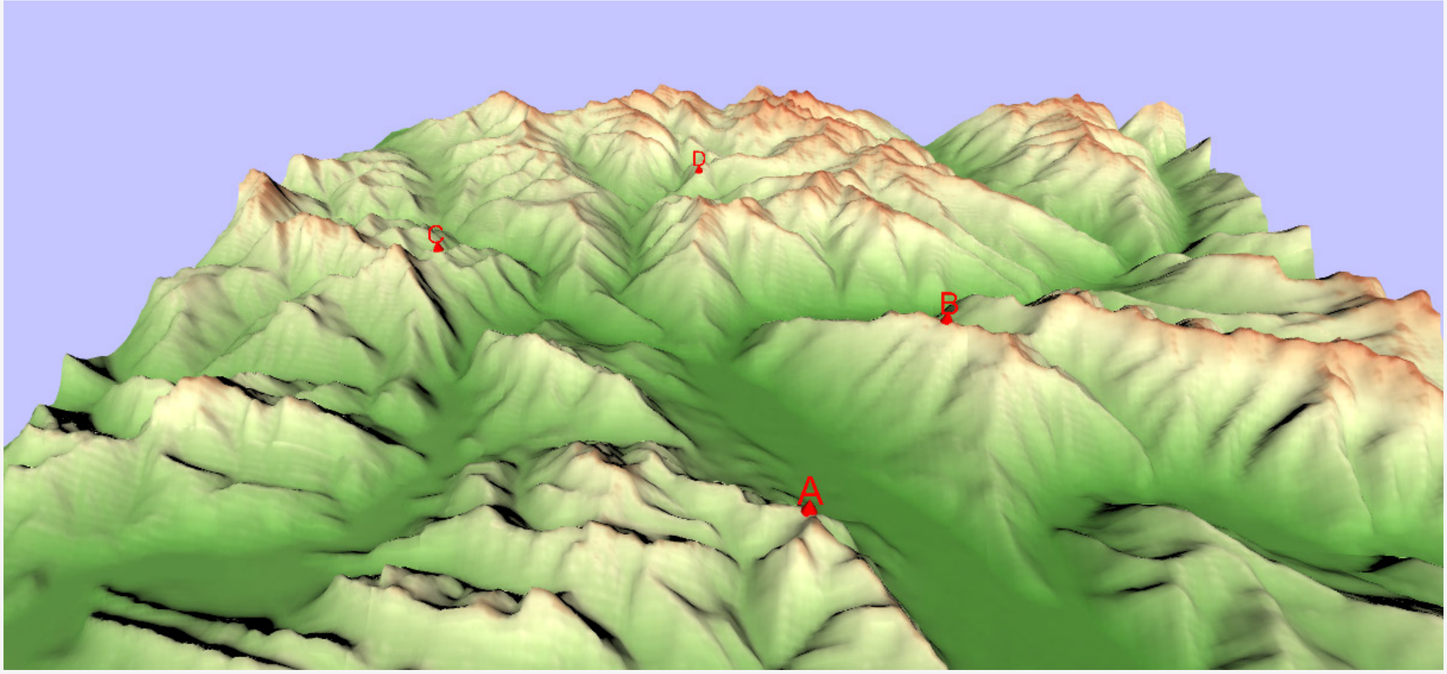
over different numbers of simultaneous requests



overall statistics

mean	28.2 ms
stdv	4.8 ms
maximum	45.0 ms
Q_3	29.8 ms
median	27.0 ms
Q_1	26.0 ms
minimum	20.0 ms

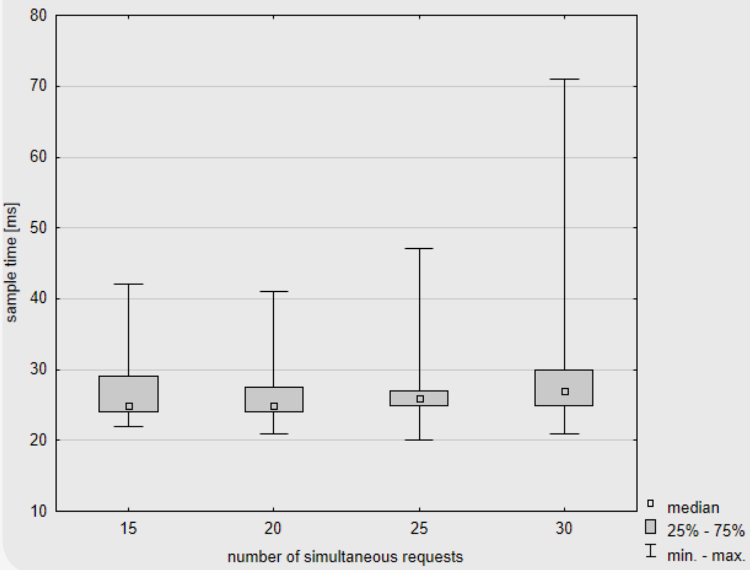
Testing Scene 2



Description of 3D scene	Textured 3D model of terrain with four cones
Mode of movement used	Turntable
Number of HTML files and their total size	1, 8.606 kB
Number of X3D files and their total size	1, 4444.160 kB
Number of texture files (JPEG) and their total size	9, 417.792 kB
Total number of data files and their size	**11, 4870.558 kB**

Performance

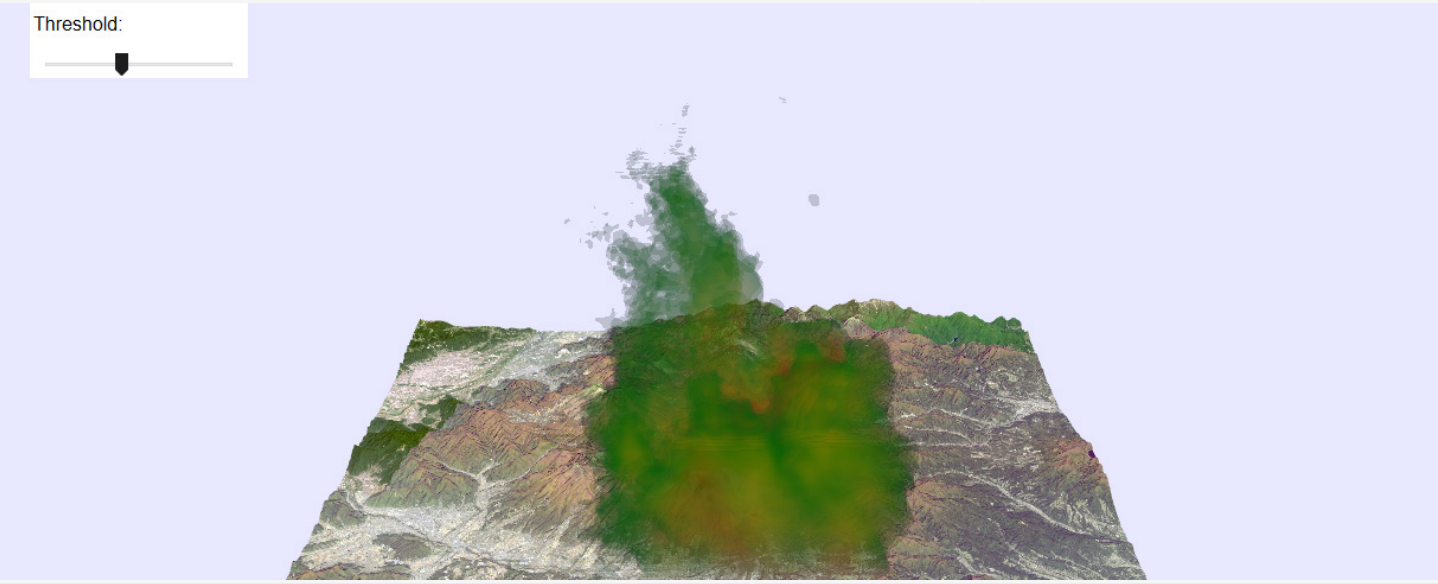
over different numbers of simultaneous requests



overall statistics

mean	27.9 ms
stdv	6.5 ms
maximum	71.0 ms
Q_3	28.0 ms
median	26.0 ms
Q_1	25.0 ms
minimum	20.0 ms

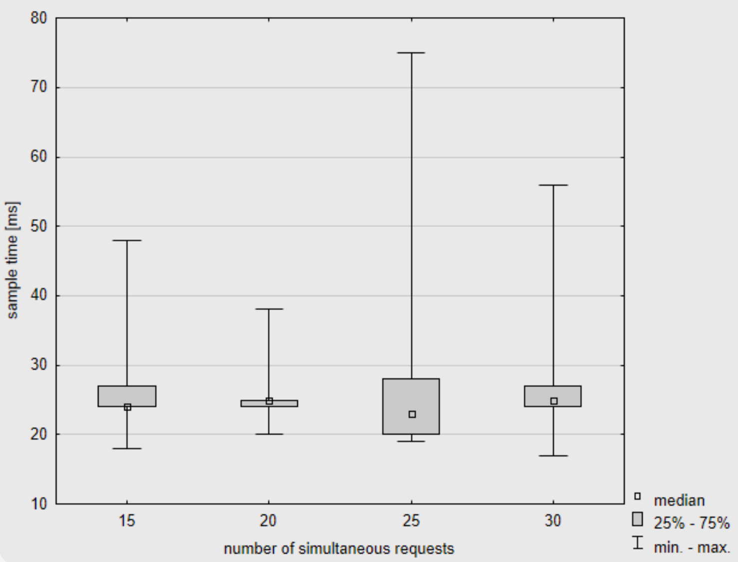
Testing Scene 3



Description of 3D scene	Textured 3D model of terrain and an interactive volume visualization of a storm cloud
Mode of movement used	Turntable
Number of HTML files and their total size	1, 1208.320 kB
Number of texture files (JPEG) and their total size	1, 2260.992 kB
Number of raster (PNG) files for volume visualization and their total size	1, 831.488 kB
Total number of data files and their size	**3, 4300.800 kB**

Performance

over different numbers of simultaneous requests



overall statistics

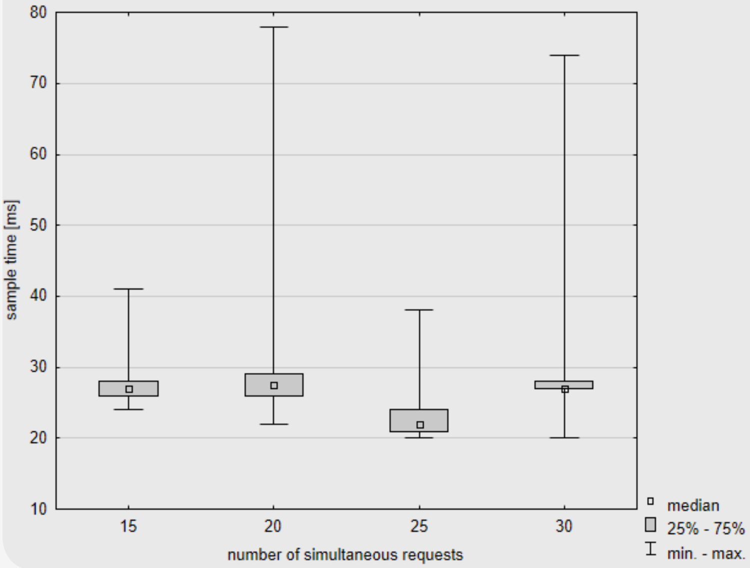
mean	25.9 ms
stdv	7.7 ms
maximum	75.0 ms
Q_3	26.0 ms
median	25.0 ms
Q_1	23.0 ms
minimum	17.0 ms

Testing Scene 4

Description of 3D scene	3D model of a classroom interior
Mode of movement used	Look around
Number of HTML files and their total size	1, 8.192 kB
Number of binary (BIN) files and their total size	12, 5730.300 kB
Total number of data files and their size	**13, 5738.500 kB**

Performance

over different numbers of simultaneous requests



overall statistics

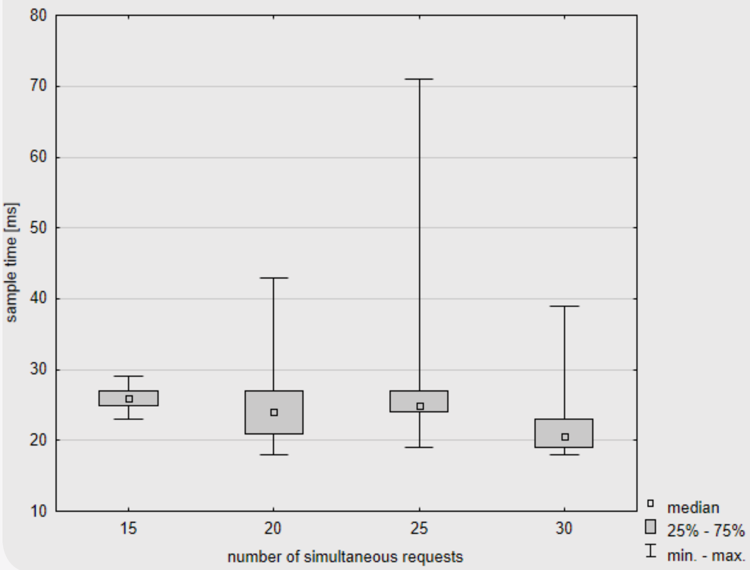
mean	27.7 ms
stdv	9.1 ms
maximum	78.0 ms
Q_3	28.0 ms
median	27.0 ms
Q_1	23.0 ms
minimum	20.0 ms

Testing Scene 5

Description of 3D scene	Textured 3D model: one block of buildings
Mode of movement used	Fly
Number of HTML files and their total size	1, 8.192 kB
Number of X3D files and their total size	1, 5853.184 kB
Number of texture files (JPEG) and their total size	57, 376.832 kB
Total number of data files and their size	**59, 6238.208 kB**

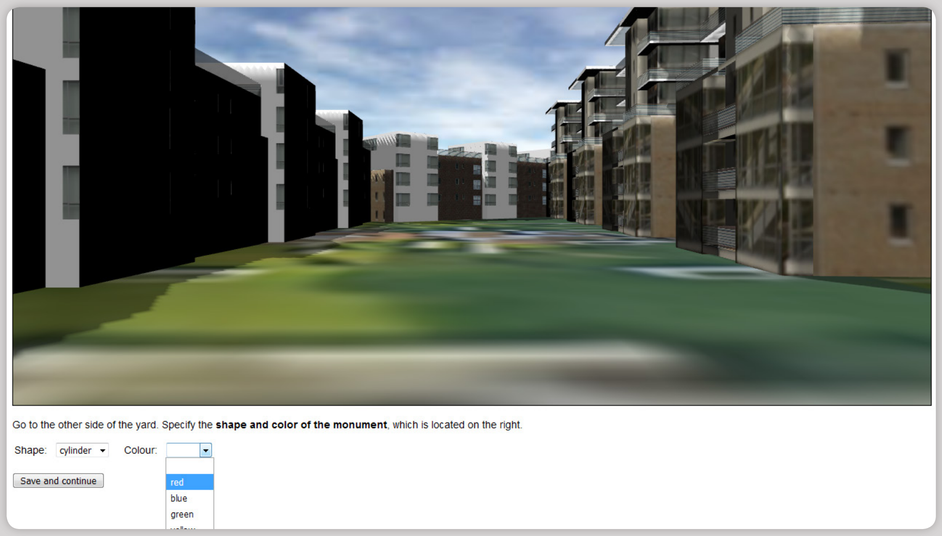
Performance

over different numbers of simultaneous requests

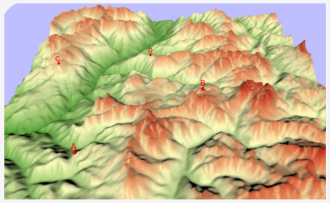


overall statistics

mean	24.8 ms
stdv	6.7 ms
maximum	71.0 ms
Q_3	26.0 ms
median	24.0 ms
Q_1	21,0 ms
minimum	18.0 ms

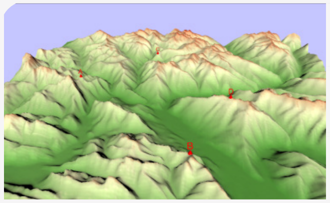


Video 3. *Click to view a video of 3DmoveR testing scenes.*



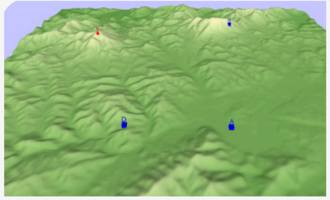
Task 1: Select Which of Four Objects is at the Highest Altitude

		experts					non-experts					comparison	
		mean	stdv	median	Q_1	Q_3	mean	stdv	median	Q_1	Q_3	U	p
response time [s]		22.52	14.73	17.85	9.77	27.35	37.67	24.01	32.05	24.85	43.06	98.0	0.006
length of virtual trajectory [km]		387616.03	322235.59	299815.14	139279.51	530053.75	560245.23	418977.75	428946.70	354801.32	593470.68	138.5	0.099
average speed [km/s]		17760.87	11774.18	14704.03	10099.10	19941.57	14258.18	5661.79	14236.87	10944.27	16516.73	180.5	0.607
total rotation [°]	center angle of the orthodrome	20590.15	15083.81	16862.88	11243.96	28265.65	25613.07	18889.77	24410.70	15513.59	31732.98	164.5	0.344
	horizontal (yaw)	1293.70	2346.06	689.78	393.52	1227.54	1021.89	967.94	902.60	398.53	1129.68	184.5	0.685
	vertical (pitch)	907.10	766.48	725.20	339.17	1224.98	1138.16	860.32	1020.01	891.10	1177.31	151.5	0.194
average height of virtual camera [m]		12132.73	4417.07	11521.61	8550.99	13614.47	12780.00	5608.70	10530.49	9366.25	15163.89	191.5	0.829
total duration of individual types of movement [s]	rotation	12.81	10.99	8.54	5.63	16.40	20.98	17.79	15.61	12.60	19.47	100.0	0.020
	pan	0.59	0.96	0.00	0.00	0.74	1.74	1.92	1.56	0.00	2.54	119.0	0.029
	zoom	1.98	2.32	1.40	0.00	2.59	3.70	3.13	3.16	2.17	4.45	109.0	0.014
	without movement	7.78	3.61	7.79	4.64	9.83	12.30	6.98	10.64	7.96	14.88	108.0	0.013
proportion of individual types of movement [%]	rotation	47.45	19.24	48.96	32.74	56.06	49.05	17.32	50.72	41.99	57.23	181.5	0.626
	pan	1.93	2.86	0.00	0.00	3.23	3.99	4.17	3.65	0.00	6.17	137.0	0.091
	zoom	7.89	6.78	7.36	0.00	12.86	11.15	8.75	9.28	3.88	17.50	156.0	0.239
	without movement	42.73	19.76	40.69	32.37	50.95	25.52	14.49	22.08	16.51	30.88	88.0	0.003
number of delays	total	8.15	6.98	5.50	3.00	10.00	12.70	7.27	13.00	7.50	15.00	114.0	0.021
	one second and shorter	2.10	0.70	2.00	2.00	2.00	2.90	1.22	3.00	2.00	4.00	117.5	0.027
	longer than one second	6.05	6.89	3.00	1.00	8.00	9.80	6.73	10.00	4.75	13.25	124.5	0.042



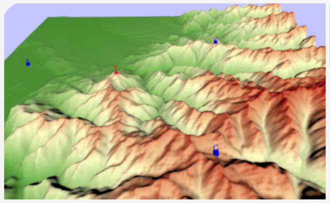
Task 2: Select Which of Four Objects is at the Highest Altitude

		experts					non-experts					comparison	
		mean	stdv	median	Q_1	Q_3	mean	stdv	median	Q_1	Q_3	U	p
response time [s]		20.87	10.55	19.36	12.23	27.58	25.43	14.24	21.71	12.06	39.05	171.0	0.441
length of virtual trajectory [km]		362954.02	232890.30	321146.73	199083.43	456054.47	489037.00	293266.46	526463.87	223026.42	616597.70	138.0	0.096
average speed [km/s]		18012.30	7216.45	16322.07	13286.54	22122.81	19569.11	8564.95	20333.09	14154.65	24498.59	172.0	0.457
total rotation [°]	center angle of the orthodrome	20225.25	14338.46	16409.95	8906.98	28143.82	20361.39	12048.13	17871.38	12868.62	22991.00	183.0	0.655
	horizontal (yaw)	963.68	832.77	748.31	292.62	1368.50	728.16	441.26	640.48	395.85	1165.62	187.0	0.735
	vertical (pitch)	815.77	683.80	642.01	371.18	1103.82	840.83	528.49	692.91	489.69	1070.32	177.0	0.543
average height of virtual camera [m]		10965.02	4677.33	8872.61	7465.60	13553.58	11997.05	5574.37	9789.85	7512.81	16585.37	183.0	0.655
total duration of individual types of movement [s]	rotation	11.51	8.31	7.68	5.76	14.99	14.58	8.82	12.35	8.29	19.28	147.0	0.156
	pan	0.50	0.83	0.00	0.00	0.64	1.24	2.33	0.00	0.00	1.30	173.5	0.482
	zoom	2.25	2.64	1.23	0.00	3.75	2.31	2.47	1.66	0.00	4.08	200.0	1.000
	without movement	6.62	2.94	6.77	4.34	8.12	7.30	4.04	6.60	4.24	9.32	189.5	0.787
proportion of individual types of movement [%]	rotation	51.92	18.50	56.33	34.67	63.03	57.38	17.23	59.29	51.56	68.59	160.0	0.285
	pan	1.95	3.52	0.00	0.00	2.53	3.47	5.69	0.00	0.00	5.04	173.5	0.482
	zoom	10.01	9.28	6.68	0.00	18.21	7.22	7.81	5.03	0.00	11.36	171.0	0.441
	without movement	36.12	14.12	36.18	25.70	42.86	31.93	17.52	29.49	21.44	33.77	138.0	0.096
number of delays	total	7.55	4.82	5.50	4.00	10.00	8.85	5.72	7.50	3.00	15.00	180.0	0.598
	one second and shorter	2.10	0.89	2.00	2.00	2.00	2.35	1.31	2.00	1.00	3.00	179.0	0.579
	longer than one second	5.45	4.52	3.50	2.00	8.00	6.50	4.95	5.50	2.00	12.00	188.5	0.766



Task 3: Determine Which of Four Objects Are Visible from the Top of the Mountain

		experts					non-experts					comparison	
		mean	stdv	median	Q_1	Q_3	mean	stdv	median	Q_1	Q_3	U	p
response time [s]		44.49	38.50	27.20	21.93	48.13	67.52	34.15	60.33	42.32	86.61	96.0	0.005
length of virtual trajectory [km]		365398.15	294464.69	267754.47	187271.72	389153.53	524523.76	317438.31	501026.37	312901.81	646641.01	118.0	0.027
average speed [km/s]		9521.36	4908.81	7567.68	6529.95	9736.52	7921.79	3846.91	8075.16	4949.50	11574.79	179.0	0.570
total rotation [°]	center angle of the orthodrome	27448.73	22687.70	16779.82	13253.43	28914.73	34994.78	21467.64	28278.26	21644.91	41481.30	131.0	0.062
	horizontal (yaw)	1784.36	3213.32	919.61	735.11	1552.51	3760.95	6188.15	1562.56	764.85	4085.47	142.0	0.117
	vertical (pitch)	1385.72	2033.63	788.75	439.59	1189.61	3175.64	6713.97	1207.62	679.76	2987.33	148.0	0.160
average height of virtual camera [m]		6742.18	2200.53	6168.14	5480.06	7640.49	6606.59	2916.03	5783.09	4948.63	6950.52	175.0	0.499
total duration of individual types of movement [s]	rotation	17.05	11.17	13.71	10.58	19.25	23.75	10.71	22.95	17.78	29.95	114.0	0.020
	pan	3.60	4.16	1.77	0.00	5.37	5.58	5.09	4.83	0.00	9.68	162.0	0.310
	zoom	9.59	14.17	3.09	1.65	14.12	17.80	15.65	13.19	4.68	26.69	127.0	0.050
	without movement	14.26	10.72	11.61	7.38	14.81	20.40	9.87	18.75	14.01	24.55	109.0	0.014
proportion of individual types of movement [%]	rotation	44.32	13.95	43.52	32.46	54.04	37.57	16.70	35.23	28.72	44.48	153.0	0.208
	pan	6.46	5.71	6.77	0.00	11.19	8.13	8.31	7.23	0.00	11.28	187.0	0.735
	zoom	14.95	11.46	11.86	5.37	23.91	21.54	13.06	24.04	11.74	29.60	139.0	0.102
	without movement	34.27	6.44	34.78	29.91	36.80	32.77	16.73	27.71	26.04	35.29	136.0	0.086
number of delays	total	16.15	12.85	11.50	9.50	21.75	28.25	20.26	28.00	10.25	34.25	126.0	0.045
	one second and shorter	3.40	2.11	3.00	2.00	4.00	3.95	2.38	3.00	2.75	5.00	130.0	0.060
	longer than one second	12.75	11.32	8.00	6.75	15.50	24.30	19.36	25.00	7.00	30.25	164.5	0.337



Task 4: Determine Which of Four Objects Are Visible from the Top of the Mountain

		experts					non-experts					comparison	
		mean	stdv	median	Q_1	Q_3	mean	stdv	median	Q_1	Q_3	U	p
response time [s]		24.23	11.30	22.38	14.57	28.01	37.26	23.72	29.04	22.31	43.63	132.0	0.068
length of virtual trajectory [km]		432882.50	201879.71	431519.76	303970.42	497045.34	608652.16	353636.54	568537.13	408162.35	708239.24	122.0	0.036
average speed [km/s]		20961.34	11681.90	17669.57	11704.23	24735.09	18653.08	10211.66	15855.65	12539.40	22450.48	192.0	0.839
total rotation [°]	center angle of the orthodrome	24860.48	10417.11	23453.87	18713.07	28273.48	32330.64	17017.83	28764.02	20428.52	40418.34	140.0	0.108
	horizontal (yaw)	1628.39	1849.11	888.70	528.92	1487.33	2435.74	2731.97	1138.63	688.96	2720.21	160.0	0.285
	vertical (pitch)	1204.74	701.64	957.30	784.12	1407.87	1526.16	1113.99	1155.74	794.95	1875.01	169.0	0.409
average height of virtual camera [m]		10853.51	2115.60	9927.47	9032.31	12577.84	13417.67	5906.54	11992.20	9315.54	16691.45	160.0	0.285
total duration of individual types of movement [s]	rotation	8.72	5.62	7.07	5.54	8.48	13.01	7.64	11.56	7.62	17.33	117.0	0.026
	pan	1.17	1.19	0.92	0.00	2.17	2.74	3.36	2.22	0.00	4.09	153.0	0.208
	zoom	5.06	4.59	4.06	1.78	6.03	8.30	9.76	3.94	2.27	10.89	185.0	0.695
	without movement	9.28	3.55	8.65	6.71	10.93	13.22	7.84	10.78	8.79	16.59	137.0	0.091
proportion of individual types of movement [%]	rotation	36.85	13.43	34.90	29.44	48.08	37.78	16.52	33.45	28.57	48.08	193.0	0.860
	pan	4.48	4.28	5.09	0.00	6.92	6.22	6.02	5.64	0.00	10.59	169.0	0.409
	zoom	17.85	12.76	17.83	9.92	22.46	17.28	11.51	15.01	7.62	26.98	195.0	0.903
	without movement	40.82	9.22	40.11	36.29	46.56	38.72	16.57	35.14	29.96	39.68	145.0	0.140
number of delays	total	12.85	5.29	12.00	9.50	17.25	19.55	13.49	18.00	10.00	25.00	141.5	0.117
	one second and shorter	2.35	1.42	2.00	2.00	2.00	3.20	2.73	2.00	1.75	4.00	141.5	0.116
	longer than one second	10.50	4.81	10.50	7.50	13.00	16.35	11.61	15.50	5.50	21.50	169.5	0.417

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Building a Foundation for a Digital Maps Collection

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Western North Carolina has many treasures, including some buried underwater. Among these subaquatic resources are the vestiges of former communities, hidden by acres of mountain lakes. Homesteads, bridges, roads, churches, schools, and other physical remnants of these communities disappeared as dams were built across the region for both hydroelectric and recreational purposes. One such lake is Lake Lure in Rutherford County, North Carolina, created primarily for recreational uses in 1925–1926. An inquiry from representatives of the town of Lake Lure spurred our academic library's foray into developing a digital collection of historic and regional maps. Town representatives wondered whether Hunter Library, serving Western Carolina University in the Appalachian Mountains, had an interest in historic maps of the Lake Lure area before dam construction. The authors of this paper, the Maps Librarian and the Special Collections Librarian at the institution, took on this project.

Figure 1. North Carolina Portion of Great Smoky Mountains National Park, *Combs and Sloan, North Carolina Park Commission, 1928.*

The majority of these maps, beautifully rendered by Earle Sumner Draper in the early part of the twentieth century, outlined a planned community—complete with subdivided lots—meant to be marketed to potential summer residents from across the Eastern Seaboard. The community was never realized, however, and the maps became a historic record. We were keenly interested in these maps and suggested digitizing them. When our potential partners pressed for details and examples, however, we lacked a comparable digital collection to demonstrate how the digitization would be realized. Creating a pilot digital project for area maps seemed the best option, as this approach would enable us to encounter and manage issues internally before engaging with external partners. We highly value local, unique content and recognized that maps have special value for many reasons. These include documenting place names, family names, and changes to landscapes over time. We hoped that this pilot would allow us to build partnerships and preserve materials throughout the region.

We began the pilot project by defining the collection's scope. We selected and prioritized maps in our collection that were of local interest or of regional importance, allowing us to create a framework for inclusion that was reasonable in scale for a pilot project. We first determined that the digital collection would be limited to Western North Carolina, which is made up of the twenty-four westernmost counties of the state. Due to its proximity, we also chose to include the Great Smoky Mountains National Park, which straddles both North Carolina and Tennessee. Those limitations still included a surprising number of maps, so we further narrowed our efforts to maps unique in subject and likely to be either the only copy in existence or one of a very few copies. The final framework gave us a diverse collection from which to draw, one that was interesting yet not overwhelming in number. The final pilot collection included old plans of our university, orthophoto maps illustrating development around the university and local area, hand-drawn maps relating to the area's Eastern

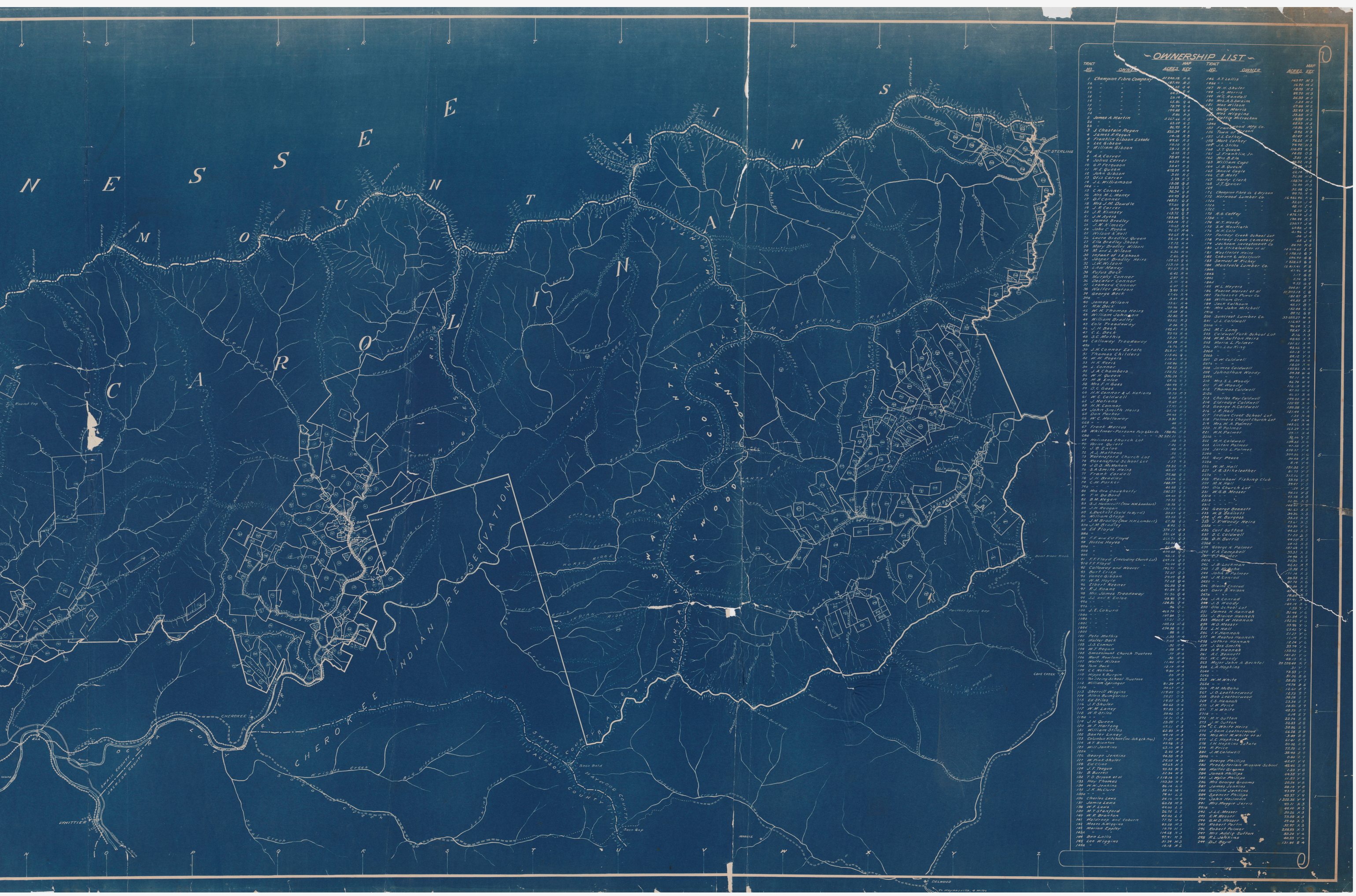

Figure 1 (continued).

Band of Cherokee Indians, and maps indicating historic family holdings or defunct place names.

The next step was to determine how to make the maps as accessible as possible. We knew we wanted to include each map in both the library's traditional catalog (part of our integrated library system [ILS]), as well as the digital collections platform, CONTENTdm. Each platform offered unique strengths. For example, including an ILS catalog record for the maps provided more visibility, as the library catalog is often the first point of contact for patrons doing research. Information in the catalog record included the title, publisher, date, subject headings, and a link to the map in the digital collection. The digital collection's strengths included a high-resolution version of each image that users can scroll, zoom, or view in full screen. It also allowed us to perform optical character recognition on each record, meaning that, in addition to any information provided in the description of the item, any printed text on the map itself was searchable. Therefore, information about the map not captured in the official description was still findable and provided an additional access point.

Since maps would be made available through both platforms, it was important that descriptive information created by the library's cataloging unit accommodated the different requirements of each. This descriptive information, called metadata, was outlined in a schema that detailed how maps should be described in both the ILS and in CONTENTdm. The document detailed each field that patrons would see when viewing a map in the digital collection. This schema also ensured that the descriptions adhered to library cataloging best practices, as well as the two most widely used descriptive standards in libraries, MARC and Dublin Core. For example, the field name that displays as "Date Depicted" within the digital collections correlates to MARC field 050 and Dublin Core field "Coverage-Temporal." Finally, we also decided which fields would be hidden or searchable within the digital collections.

Considerable thought was given to supplemental metadata that provided information about what the map depicted rather than about the map itself. To increase findability, we included a list of places depicted in each map if that information was not already provided in the description. For example, if a map of Jackson County included symbols indicating the presence of mines, we might add the

Author Cox, Thomas A. (Thomas Augustus), 1863- cartographer
Title Jackson County, North Carolina : compiled from original surveys and USGS data / by Thomas A. Cox, Reg. Engr. and land surveryor ; K.E. Cox and F.J. Johnson dels
Edition Scale approximately 1:65,000
Publication Info Sylva, N.C. : [publisher not identified], 1924
Red Oak, Iowa : Thos. D. Murphy Co

Map

Available online:
VIEW WEB VERSION

LOCATION	CALL #	STATUS
WCU SPEC COLL	G3903.J2 1924 .C6 Nearby on Shelf	LIB USE ONLY

Send via Text Message

Description 1 map : color, linen oilcloth ; 88 x 88 cm
Content cartographic image
Media unmediated
Carrier sheet
NOTE Relief shown by hachures, and spot heights
Shows towns, highways, roads, trails, railroads, public schools, churches, natural features and the Indian Treaty Line, i.e., the Meigs-Freeman Line
"August 1924."
"Copy Right Thomas A. Cox, Sylva N.C."
Topical Subject Roads -- North Carolina -- Jackson County -- Maps
Trails -- North Carolina -- Jackson County -- Maps
Church buildings -- North Carolina -- Jackson County -- Maps
Public schools -- North Carolina -- Jackson County -- Maps
Geographic Subject Jackson County (N.C.) -- Maps
OCLC # 917157381

Figure 2a. *ILS record.*

Description

Title	Jackson County, North Carolina : compiled from original surveys and USGS data
Creator	Cox, Thomas A. (Thomas Augustus), 1863-
Medium of Original	maps
Date Depicted	1924
Date Published	1924
Place of Publication	Sylva, N.C.; Red Oak, Iowa;
Publisher	Thos. D. Murphy Company;
Description	Shows towns, highways, roads, trails, railroads, public schools, churches, natural features and the Indian Treaty Line, i.e., the Meigs-Freeman Line. "August 1924." "Copy Right Thomas A. Cox, Sylva N.C."
Features	Relief shown by hachures, and spot heights
Subject	Roads -- North Carolina -- Jackson County -- Maps Trails -- North Carolina -- Jackson County -- Maps Church buildings -- North Carolina -- Jackson County -- Maps Public schools -- North Carolina -- Jackson County -- Maps Jackson County (N.C.) -- Maps
Location	Jackson County (N.C.)
Local Subject	roads or highways buildings
Scale	Scale approximately 1:65,000
Size	35.75" x 35.25"
Call Number	G3903.J2 1924.C6
Source Institution	Western Carolina University Hunter Library
Collection	Maps - Special Collection
Inventory Number	HL_3_0470_0789862_B
Copyright Information	All rights reserved. For permissions, contact Hunter Library Digital Collections, Western Carolina U, Cullowhee, NC 28723
Digital Publisher	Hunter Library Digital Collections, Western Carolina University, Cullowhee, NC 28723
File Format	jpg

Figure 2b. *CONTENTdm record.*

Western North Carolina Regional Map Collection
(Example info based on map record b59051590)

Field Names In CONTENTdm	MARC Tags	Dublin Core Map	Hide	Field Values	Example
Staff Notes		None	Yes		
Title	245 $a $b	Title			General Plan for development of campus of Western Carolina Teachers College, Cullowhee, N.C. Not $c – nothing after /
Creator	1xx	Creator		Controlled	Draper, E. S.; do not include $e
Contributor	7xx	Contributor		Controlled	
Medium of Original		Format-Medium		Controlled-shared	Maps
Type		Type	Yes	Controlled-shared	Still Image
Date Depicted	050 (take from call no./situation no.)	Coverage-Temporal			1927

Figure 3. *Metadata schema.*

word “mines” to the description, even if the map’s focus was not mining. We also developed a list of terms to provide a more intuitive way of browsing than official Library of Congress Subject Headings. These terms are specific to our institution, location, and interests, and are considered locally authoritative rather than broadly applicable to other libraries. Examples used were “advertisements,” “cemeteries,” “mountain range,” and “tourist maps.”

To include the maps in the library’s ILS and to provide high quality descriptive information for each, a part-time cataloger dedicated to the project began working on the selected maps. After an initial meeting to determine the metadata schema, the cataloger and the Maps Librarian discussed other cataloging practices unique to the collection. This discussion included determining when to catalog maps as a single bibliographic record with items attached

Figure 4. Orthophoto Map of Jackson County, North Carolina, *L. Robert Kimball, 1980.*

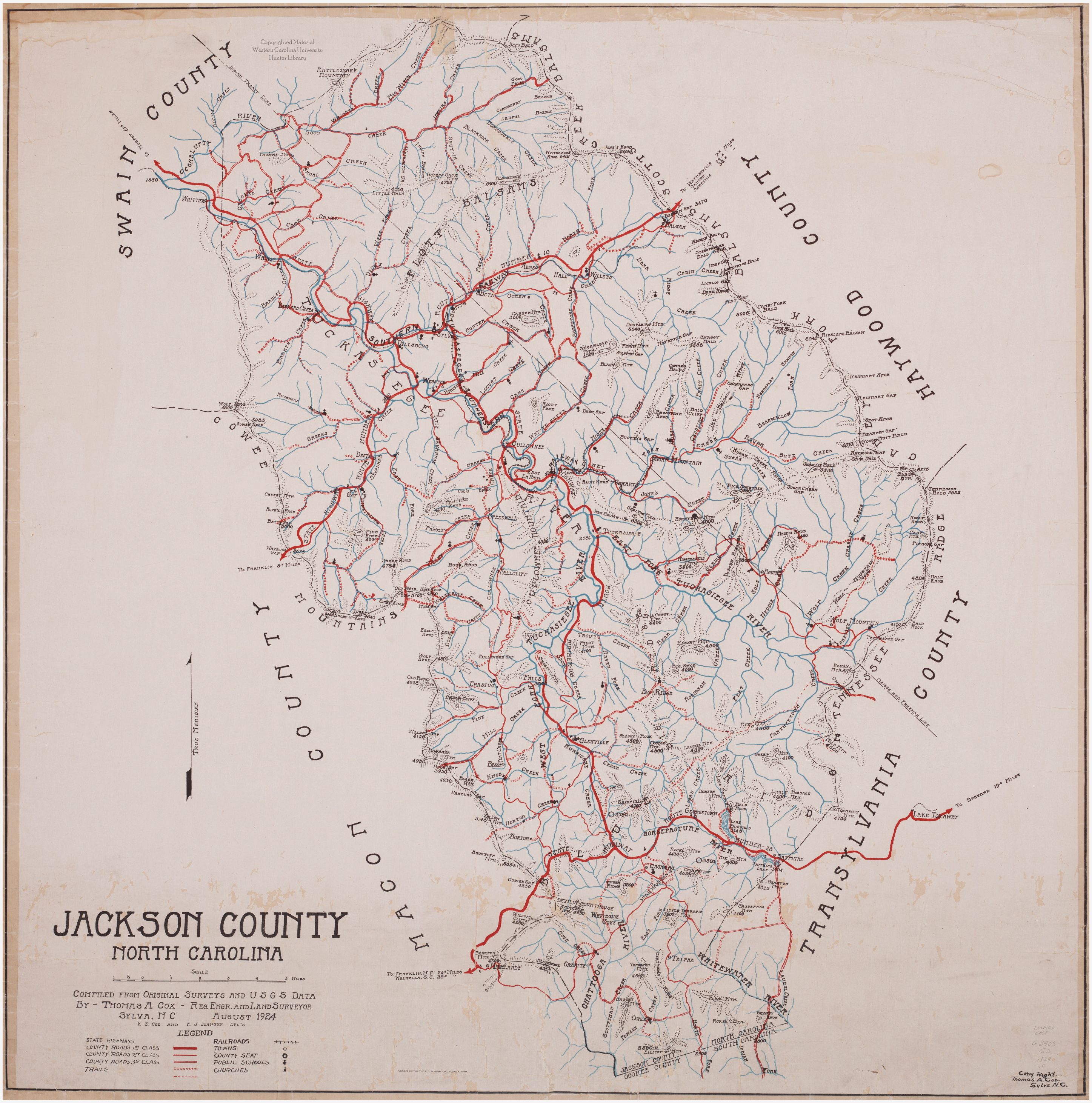

Figure 5. Jackson County, North Carolina, *Thomas Cox, 1924.*

(one catalog record with multiple maps listed for that record) and when to catalog maps separately. For example, if Jackson County has multiple years of highway maps produced by the state's Department of Transportation, would those maps be cataloged as a single set of Jackson County maps with varying years, or would each be cataloged separately? We generally leaned towards cataloging maps in sets. This option seemed to make the most sense from the perspective of a library patron (related maps are found together) while also minimizing catalog clutter. However, as a trade-off, cataloging in sets meant that individual items received less descriptive detail.

Determining the appropriate level of description also posed a challenge for individually catalogued maps. The Maps Librarian and the cataloger agreed on what might be too much detail for most maps, such as comprehensive lists of family or place names for particularly detailed maps. They also determined what marks and information were important enough to note, such as the Meigs-Freeman Line (surveyed in 1802 as part of the Treaty of Tellico, this demarcation served as a boundary line until 1819 between the United States and the Cherokee).

Once descriptive guidelines were set, we began scanning the maps. As the library has limited in-house resources for scanning very large or fragile materials, the first batch of maps was scanned by the North Carolina Digital Heritage Center at the University of North Carolina at Chapel Hill. Thirty-three maps were sent, representing highlights from both Hunter Library's Special Collections and its general map collection. For maps small enough to be scanned in-house, we primarily used an overhead Bookeye 4 scanner. Maps were scanned at 600 dpi and saved as TIFF files,

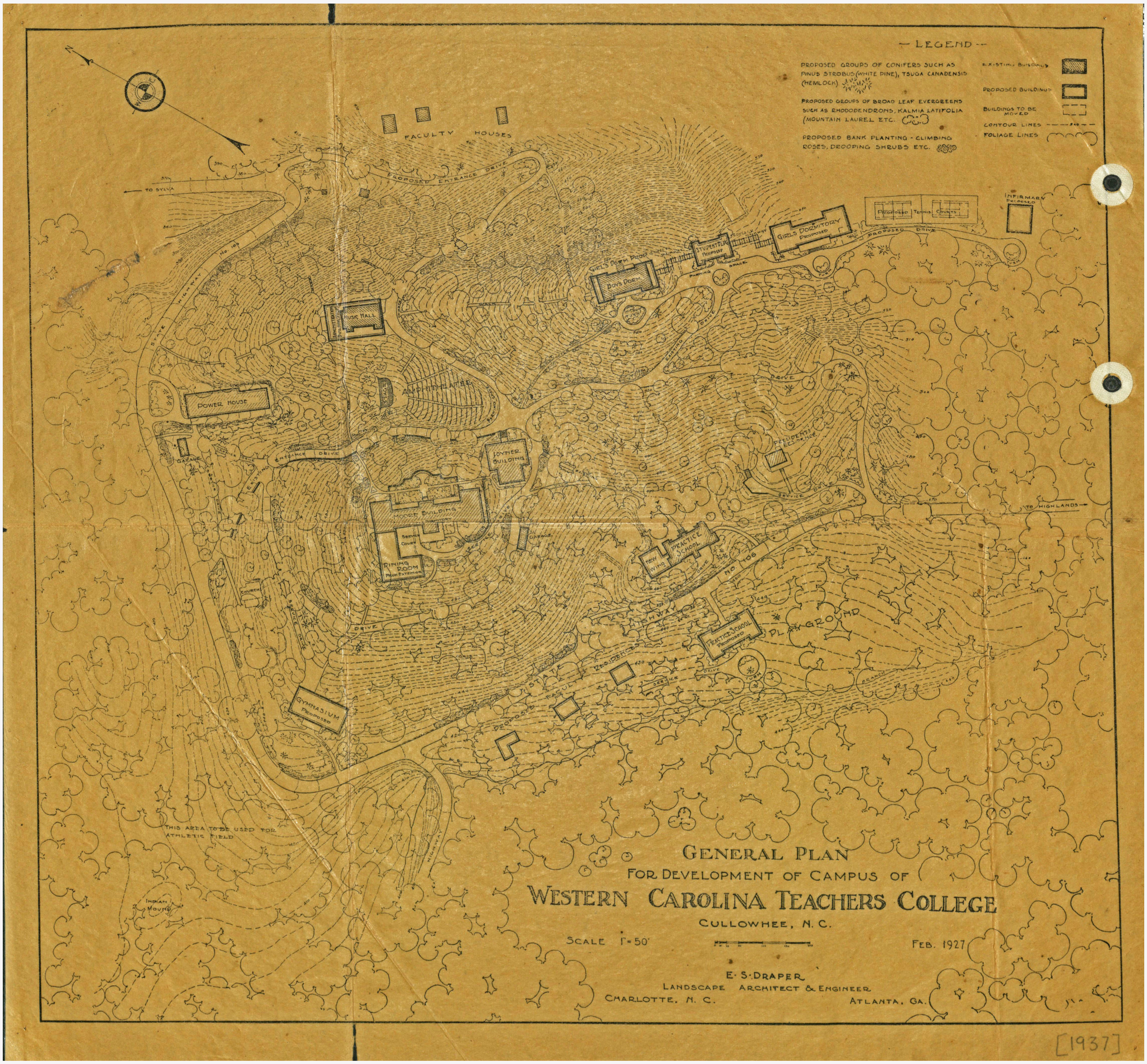

Figure 6. General Plan for Development of Campus of Western Carolina Teachers College, Cullowhee, N.C., *E. S. Draper, 1937.*

which captured a high-level of detail, facilitated zooming, and allowed us to print high-quality reproductions. The 23" × 34" scan bed allowed maps to be laid out and scanned from above, ensuring material safety.

The digital collection debuted four months after the project began, with seventeen of the thirty-three maps chosen for the pilot. To date, there are 130 maps in the collection and those maps have received nearly 4,000 online views. The maps have been used in a variety of student and faculty projects; for example, many maps featured prominently in an upper level history course that focused on some of the region's historic communities that once appeared on maps but no longer do. The 1924 Thomas Cox map of Jackson County served as a foundation for the project and students used it to show where former schools, churches, and post offices once existed.

This project has benefited the library in numerous ways including allowing our patrons to engage more deeply in the region's history and raising awareness of the library's map collections throughout the university and region. As the library looks forward, we intend to develop this collection of unique maps, extend its the scope, and solicit local and regional partners including the town of Lake Lure, with whom discussions are ongoing. In the meantime, we will be adding maps from the 1930s of the Pisgah National Forest, mid-twentieth-century maps from the Blue Ridge Parkway, and more maps of interest from the library's manuscript collections.

A final note to other institutions considering similar projects: we found the most useful steps to be those of the planning process. We defined the scope of our project narrowly enough to be accomplishable, while also being scalable. We also defined the intended audiences for such a collection to help guide selection and prioritization, and determined best methods for describing materials to ensure consistency and aid in browsing and findability. Thanks to this careful planning, the project did not seem overwhelming for any member contributing to the project, yet the work still resulted in a robust and meaningful collection. We are very pleased with these first steps and look forward to building this unique bridge between the university and local communities.

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The Power of Appearances

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I make most of my maps with Adobe Illustrator, a program that provides a wealth of powerful styling abilities. Despite years of familiarity, I'm still finding new ways to use the software to automate complex styling. The circle in Figure 1, for example, has feathering, dashes, and two different colors separated by a gap, and yet, from the software's perspective, it is only a simple vector path with a single style applied to it. In this article, I intend to walk you through how I made this particular style, not because I expect you'll want to reproduce it exactly, but because it serves as an excellent demonstration of some of the software's capabilities, and because it may inspire your own future efforts.

Before we can get into how it's made, we need to cover two background concepts in Illustrator: *appearance attributes* and the *Knockout Group* setting.

APPEARANCE ATTRIBUTES

As anyone who has ever watched me work in Illustrator will attest, I am a big fan of the Appearance panel. This thing is the heart and soul of the program. I really think it should be introduced on day one of Illustrator 101, but most people I know only encounter it, as did I, much later on in their career.

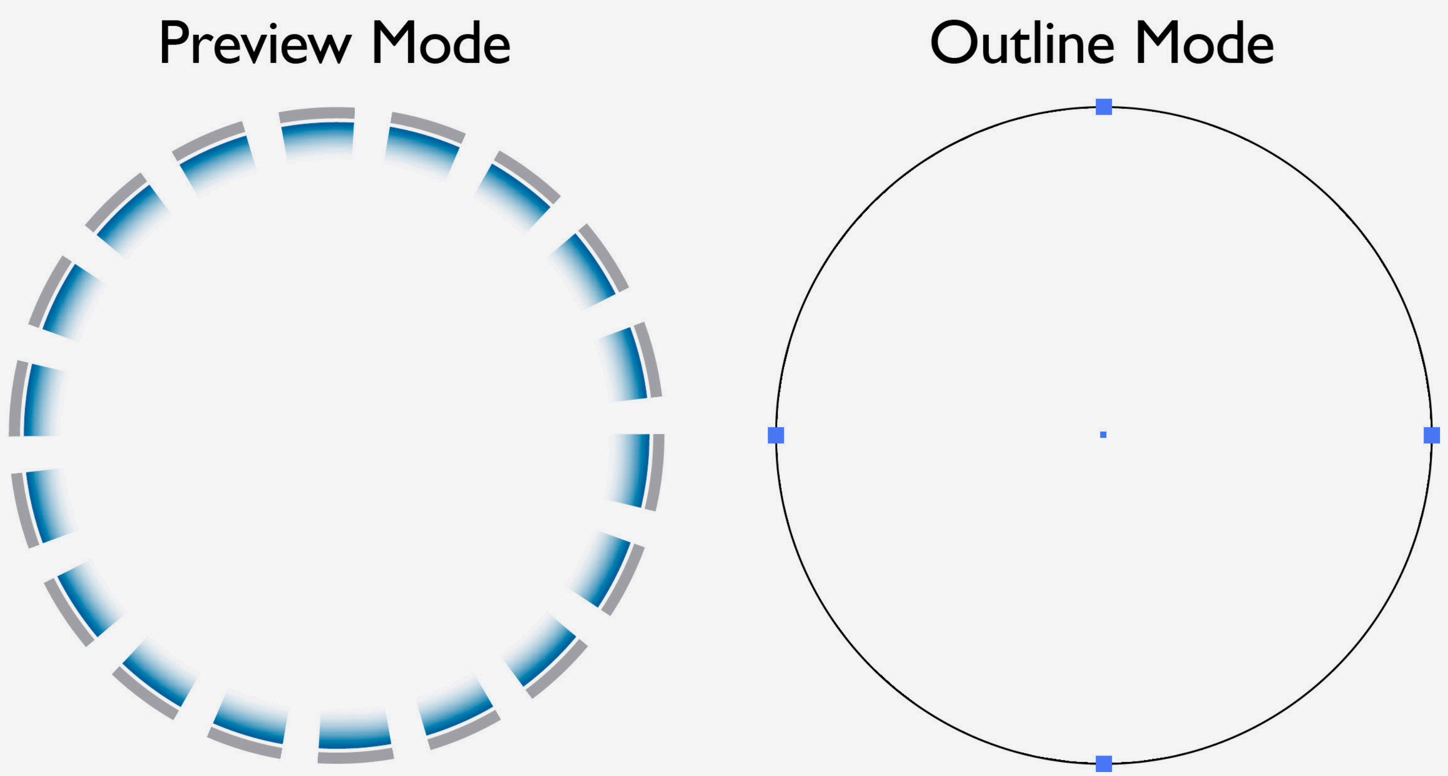

Figure 1. *A circle with complex styling. Switching to Illustrator's Outline Mode reveals that it is a simple vector path.*

All artwork in Illustrator has appearance attributes. Fills and strokes are the most common, but there are many other possibilities: drop shadows, transparency, blurs, etc. Anything that affects how your vector paths *look* is an appearance, and you'll see it listed when you select something in the Appearance panel (Figure 2).

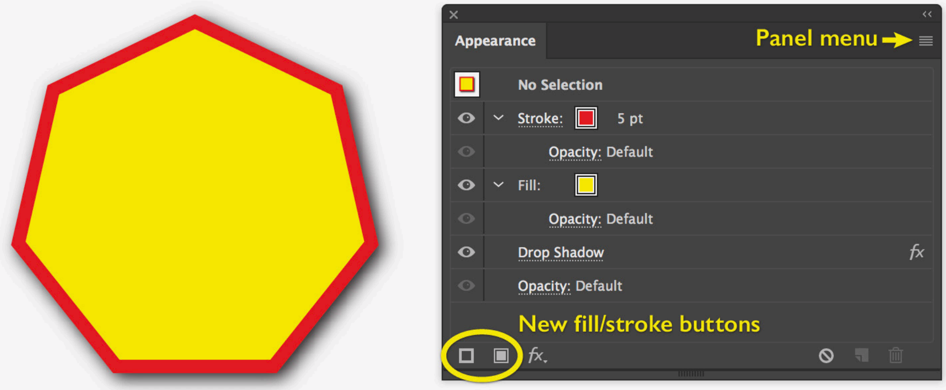

Figure 2. *A path with three appearance attributes: a fill, a stroke, and a drop shadow.*

This panel lets you do a variety of useful things: first, you can *rearrange* the order of appearance attributes. An object's stroke, for example, could go behind its fill. This is done simply by clicking and dragging it down in the list, just as you would change the order of layers in the Layers panel. Secondly, you can use this panel to easily add new appearance attributes. For example, you can add a new fill or stroke to your object by using the buttons along the bottom of the panel, or by clicking on the panel menu (the icon with the parallel lines in the upper right). Figure 3 shows the attributes of a line with *two* strokes: one is thick, grey, and solid, while the other, on top of it, is thin, yellow, and dashed.

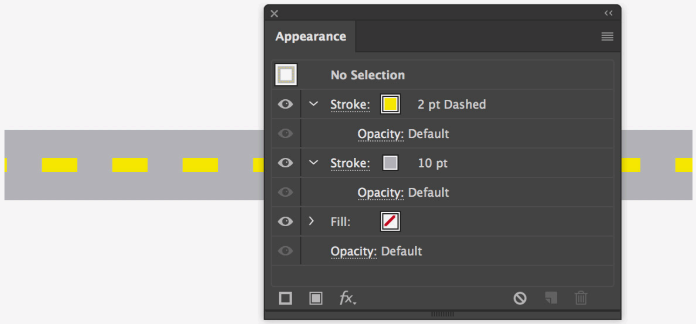

Figure 3. *A simple road style built from two strokes applied to a single path.*

Thirdly, you can use this panel to *alter* any of the appearance attributes you've applied. In Figure 2, the shape I have drawn has a drop shadow, and you can see the Drop Shadow effect listed in the panel. I can click on those words to adjust the shadow's color or other settings without having to recreate it. I could also drag it to a new position in the list hierarchy so that the effect only operates on particular attributes of the shape, such as on the fill or the stroke. I can also remove the shadow completely using this panel.

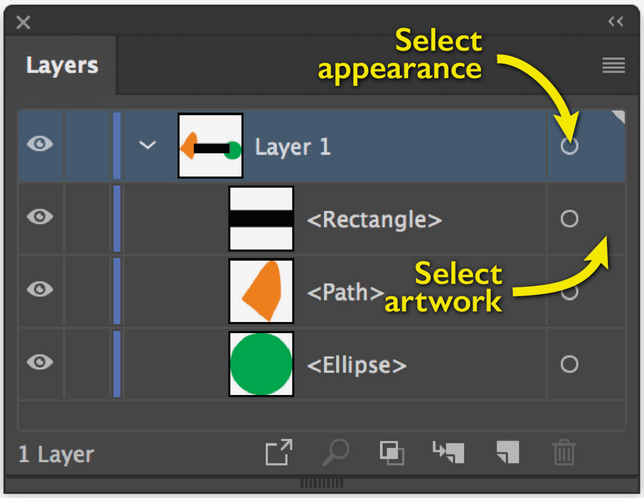

Figure 4. *Circles for selecting appearances, and zones for selecting individual artwork elements.*

Perhaps you've seen those little circles in the Layers panel, the ones next to each object and layer? I've highlighted one of them in Figure 4. I was originally taught that you should click on the circle next to an artwork element to select it, but this is not strictly correct. It turns out that the little blank spaces directly to the *right* of the circles are what you should click to select artwork. In truth, clicking the circle or the blank space for an *individual object* is basically the same thing. When we are talking about *layers*, however, the place you click makes a big difference.

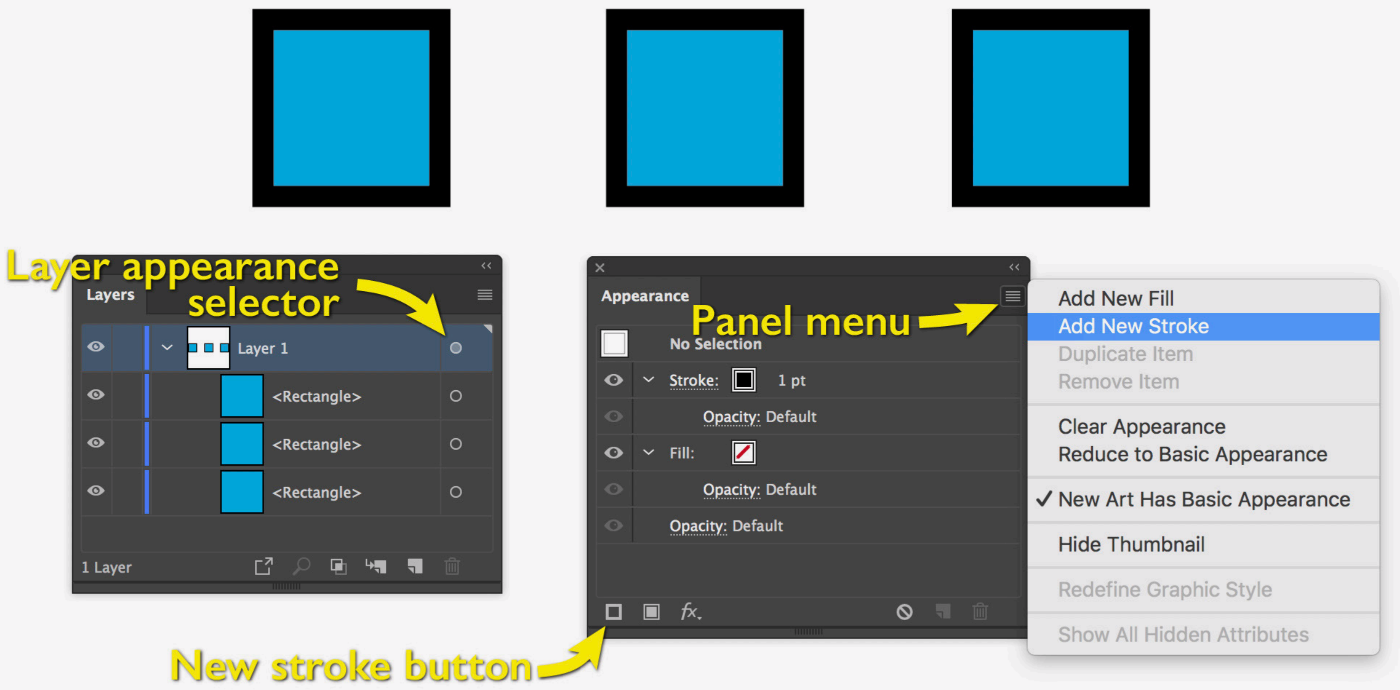

Figure 5. *Applying a new stroke to a layer of squares.*

The reason there's one circle for the layer and one for each object is so that you can apply appearance attributes to an entire layer, in addition to whatever attributes the individual elements might have. For example, I could, on a single layer, draw a series of squares, and give each a blue fill with no stroke. By then selecting the appearance circle for the layer, I can then add a new stroke to all the elements on that layer. This is done by choosing **Add New Stroke** from the Appearance panel menu in the upper right, or by using the equivalent button on the bottom of the panel. As a result, all my squares inherit the stroke that I applied to the layer (Figure 5). Yet, if I select an individual square, Illustrator will say it doesn't have a stroke—because, in fact, the individual objects do not. It is the *layer* that has the stroke, and that stroke is applied on top of whatever style is already applied to objects in that layer. The squares get a blue fill from their individual appearance, and then they pick up a black stroke from the layer appearance.

This distinction of applying appearance attributes to objects vs. layers is super useful once you get the hang of it. It all relies on clicking in the right place: clicking on the circle by the layer name will let you alter the layer's appearance. Clicking on the space nearby will instead select the individual appearances of each piece of artwork in the layer. I've given one more example of the distinction in Figure 6. On the left, a drop shadow was applied to each object. On the right, a drop shadow was applied to the whole layer.

This is why it's important to be careful when making selections by clicking on the circles. You may end up in a situation where you want to apply a shadow, or perhaps some transparency, to every object in a layer. But by selecting the circle next to the layer name, you'll actually be applying it to the layer as a whole, rather than to each object. We won't be making any use of this distinction between object and layer appearances for our example dashed line style, but it's a common source of confusion when using the Appearance panel, and a bit of clarity here can unlock a great deal of versatility.

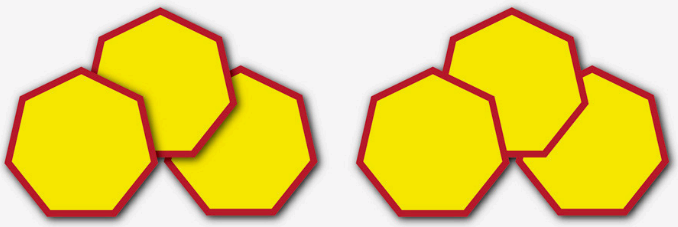

Figure 6. *Drop shadows on individual objects, vs. on an entire layer.*

KNOCKOUT GROUP

Perhaps you've seen the little Knockout Group checkbox on the Transparency panel in Illustrator (Figure 7) and wondered what it did. If you've never seen it before, try clicking a couple of times on the icon directly to the left of the word "Transparency" to get it to appear. This button changes how many options are shown in the panel.

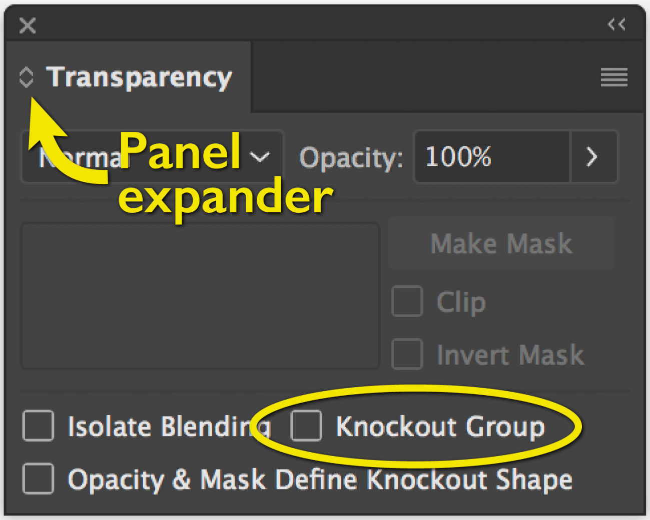

Figure 7. The Transparency panel in Illustrator.

Whenever a graphic has two overlapping objects, Illustrator has to figure out which parts can be seen, and which are hidden. So, in Figure 8, we don't see the entire red square because the blue circle is covering part of it. Illustrator has *knocked out* (made invisible) part of the red square. Remember, we're not dealing with real physical objects, so for one thing to hide another, Illustrator has to make a decision for each pixel on the screen (or page): "do I show red, blue, or some combination?"

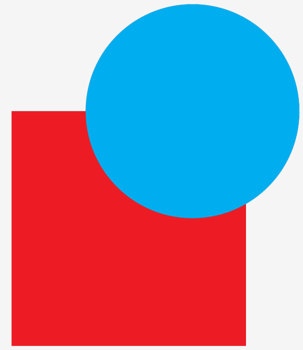

Figure 8. The blue circle hides the red square.

If, as in the top half of Figure 9, I turn the blue circle partly transparent, Illustrator figures that some portion of the red square should show through, and does some math to determine what color the resulting overlap should be. If I turn the blue circle completely transparent, Illustrator realizes that the red square should entirely show through.

The order of operations Illustrator follows here is: (1) look at the blue circle's transparency setting, and (2) use that

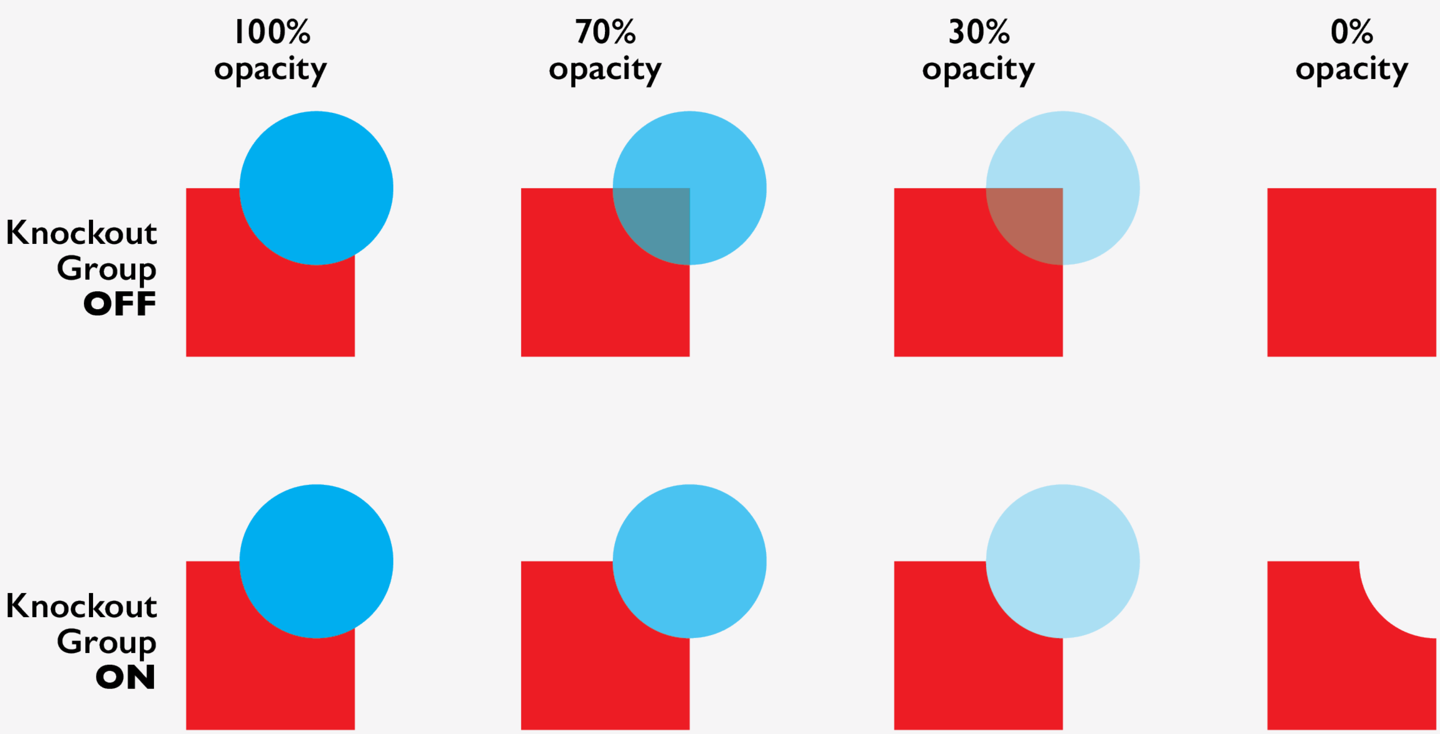

Figure 9. The Knockout Group setting affects how the blue circle interacts with the red square. When combined with transparency, the difference can be significant.

information to decide what parts, if any, of the red square need to be hidden (if the blue circle happens to be totally opaque) or to change color (if the blue circle is partly transparent). Turning on Illustrator's Knockout Group setting reverses this order of operations. First, Illustrator decides that the blue circle should hide part of the red square because they overlap. And *then* it looks at blue circle's transparency settings. So, if we made the circle completely transparent, Illustrator first hides the overlapped part of the red square, and then it makes the blue circle vanish. The end result, as seen in the bottom half of Figure 9, is that the red square can end up being hidden by something that's invisible.

I must credit Illustrator guru Mordy Golding (**twitter.com/mordy**) for my understanding of how this stuff works. I don't remember if it was a blog post or one of his **Lynda.com** tutorials that taught me this, but thanks to him I've been getting a lot of mileage out of the Knockout Group setting for years.

If you're tempted to try this out, there are two things to note: first, you'll need to click the checkbox next to Knockout Group more than once. The first time you click, the box turns to a dash, and then on the second click it turns to a checkmark. The dash indicates the "neutral" setting and the check mark activates the behavior I have been discussing. I'm not going to lie: I have only a *very* fuzzy understanding of what the neutral setting does and why you'd use it. To the best of my understanding, it basically stops the Knockout Group setting on your artwork from interfering with the Knockout Group setting on any group or layer that encloses your artwork. As I mentioned before, Illustrator has so many capabilities that it can take an entire career to master them, and the neutral setting is one I haven't quite had occasion to figure out just yet.

The second thing to note is that Knockout Group only affects things that are hierarchically below it. So, if you apply Knockout Group to a layer, it causes the top objects in that layer to knock out those underneath. If you apply Knockout Group to an object, it causes individual pieces of the object to knock each other out (such as the stroke of an object knocking out part of its fill), but the individual objects themselves don't affect each other—the effect is confined to that object. So, if you draw a bunch of circles in a layer, then turn on Knockout Group for all of them, nothing will happen. Instead, you'd want to first select the appearance of the whole layer that those circles sit in, and then turn on the Knockout Group setting. This is one of those cases where the distinction between layer appearances and object appearances is critical.

BACK TO THE LINE STYLE

With this background, we can begin making our complex dashed/feathered/two-color line style. I originally created this style while working on an ecological atlas for a client. Many of the maps showed the ranges of various species: either their annual range or their ranges in different seasons (Figure 10). The client also wanted a way to show areas where the boundary of the annual range was coincident with the boundary of a seasonal range. My solution was the style seen in Figure 11, the anatomy of which I'll break down here.

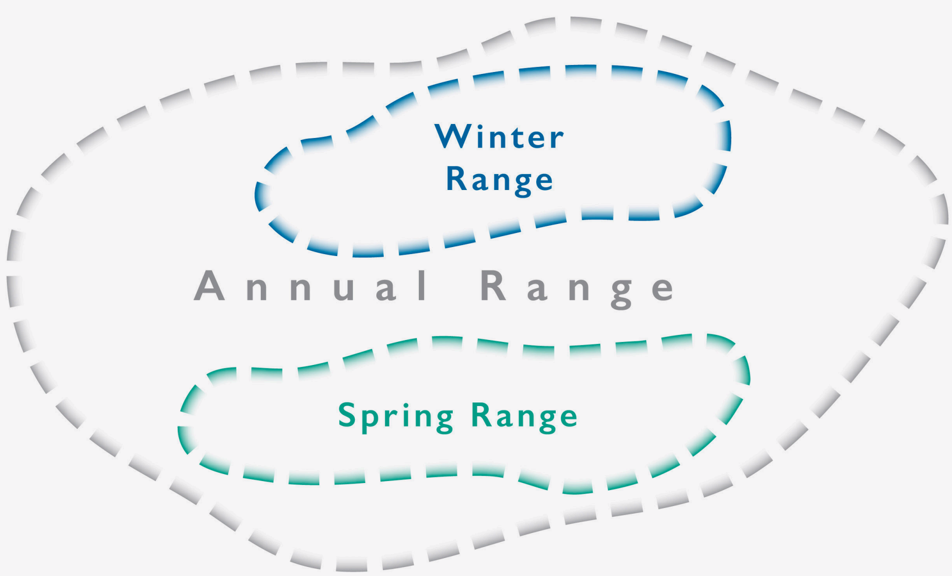

Figure 10. *Range styles.*

Let's start with a blue dashed stroke. In my case, it has a 16pt line weight, with 10pt dashes and

5pt gaps. If you've got Illustrator set to use inches or centimeters by default, you can easily change it in the Unit preferences, which you can reach by hitting the **Command** (or **Control**, if on a PC) and **comma** keys. Or, you can keep Illustrator in your preferred unit and simply type, for example, **16pt** in a dialogue box and it will automatically convert that to the appropriate number of inches/centimeters.

In Illustrator, I've set the dashes to align to corners and ends so that they look a little tidier (Figure 12). I really only need an inside stroke here, rather than one that goes on both sides of my path. But, for some reason you can't do an inside stroke in Illustrator if you're also using the *align dashes* setting. And I *do* want to keep the dashes aligned,

Figure 11. Combined range style.

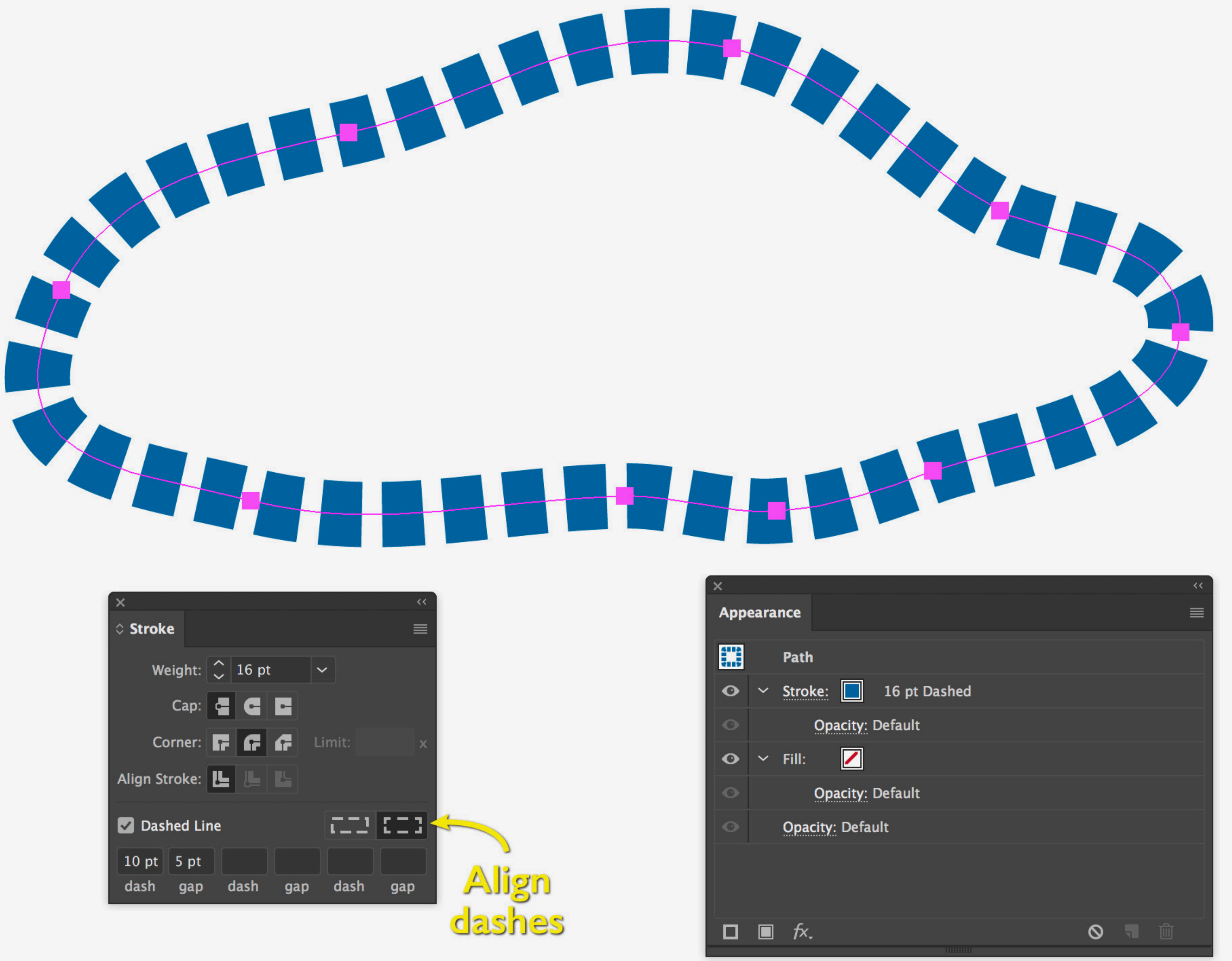

Figure 12. Creating a simple blue dash, aligned to corners.

because they tend to look a little more deliberate and even.

So, to work around that, I will add another 9pt stroke *on top* of the blue one, but this one will be solid and set to only go on the outside of the path (Figure 13). Again, you can use the handy button on the bottom of the Appearance panel to add this extra stroke. Notice also that each individual stroke (or fill) has its own Opacity settings. I can make any particular one transparent, or I can apply the effect to the object as a whole. In this case, I'm going to select the new stroke I just made and set its opacity to 0%. Then I go to the bottom of the appearance listings and select the opacity for the *whole object* and click **Knockout Group** (Figure 14). Remember to click twice, so you go past the neutral state. Now the outside portion of our dashed line is gone. The top stroke is being made invisible, but it still knocks out part of the blue stroke.

If you're playing along at home, it's quite possible that nothing happened when you followed these steps. Check to make sure that you've got your line selected. If you don't have anything selected, none of these appearance adjustments will have any effect. This happens to me *constantly*, no matter how many years I've been doing this; I will accidentally deselect the object I was planning to work with and then I wonder why none of my appearance changes are doing anything.

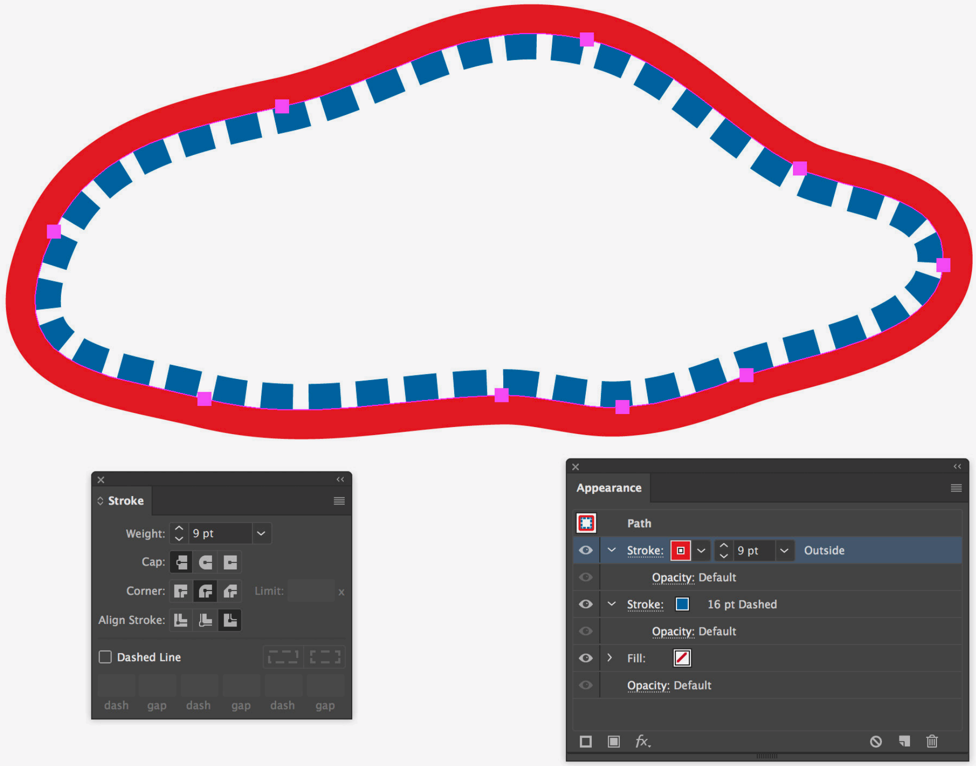

Figure 13. *Adding a second stroke on top of the first.*

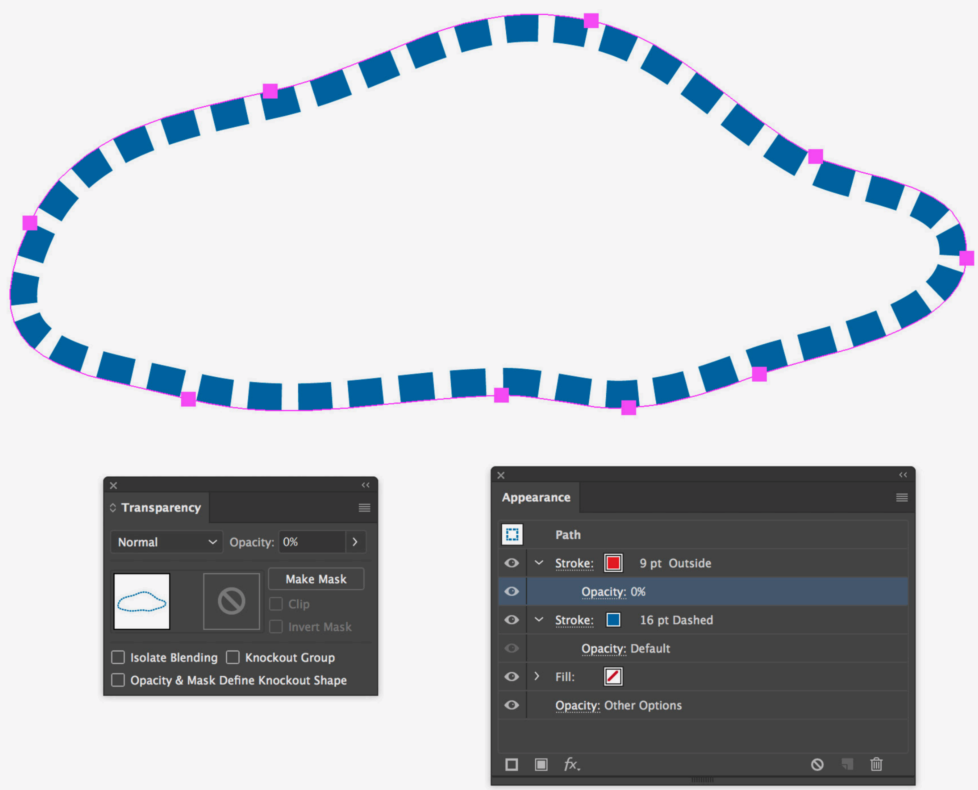

Figure 14. *The top stroke has 0% opacity, and the entire object has Knockout Group turned on.*

Thanks to those first two steps, I've got the blue portion of the stroke finished. Now let's add the grey portion on the outside. I'll add another stroke, this one grey, 4pt wide, and with the same dash pattern (10pt dash, 5pt gap). Notice that only the portion that's inside the path shows up in Figure 15. The outer portion gets knocked out by that outside stroke we have already set up, above. This is assuming you've ordered the strokes the same way I have: with the 9pt outside stroke on top, then the grey and blue ones. You can try changing the order, and exploring the effect that the invisible outside stroke has: it only hides what's underneath it.

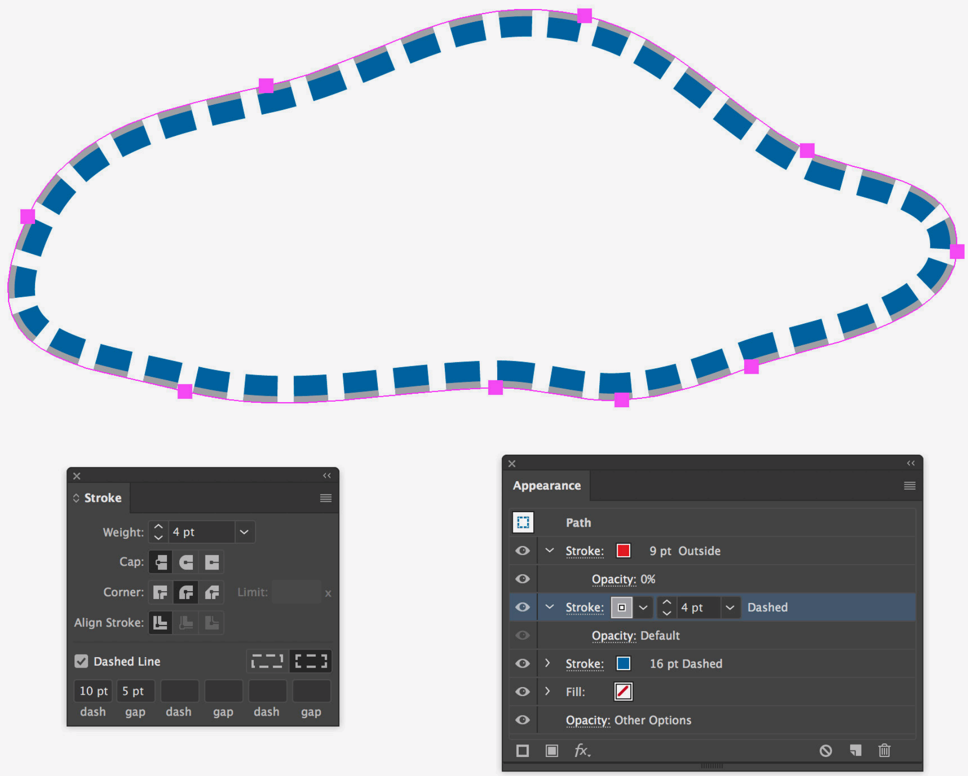

Figure 15. *Grey stroke added.*

Next, we need to create a small gap between the two strokes. This will also require a knockout. We'll start by creating a new, 0.5pt stroke. Color doesn't matter, but I'll make mine red to stand out. This is going to knock out parts of the grey and blue strokes, so put it on top of both of those. Then, I will apply an Offset Path effect to it. You can find this by first clicking either the **fx** button on the bottom of the Appearance panel or the **Effects** menu on the top of the screen, and then looking for it under the **Path** submenu. Use Offset Path to shift this new stroke inward by 1.75pt, as in Figure 16. Notice that I applied the Offset Path to just the new stroke, not anything else. Appearance *effects* (like glows and shadows, for example) can be applied to individual appearance *attributes* of objects (such as this new stroke). In the

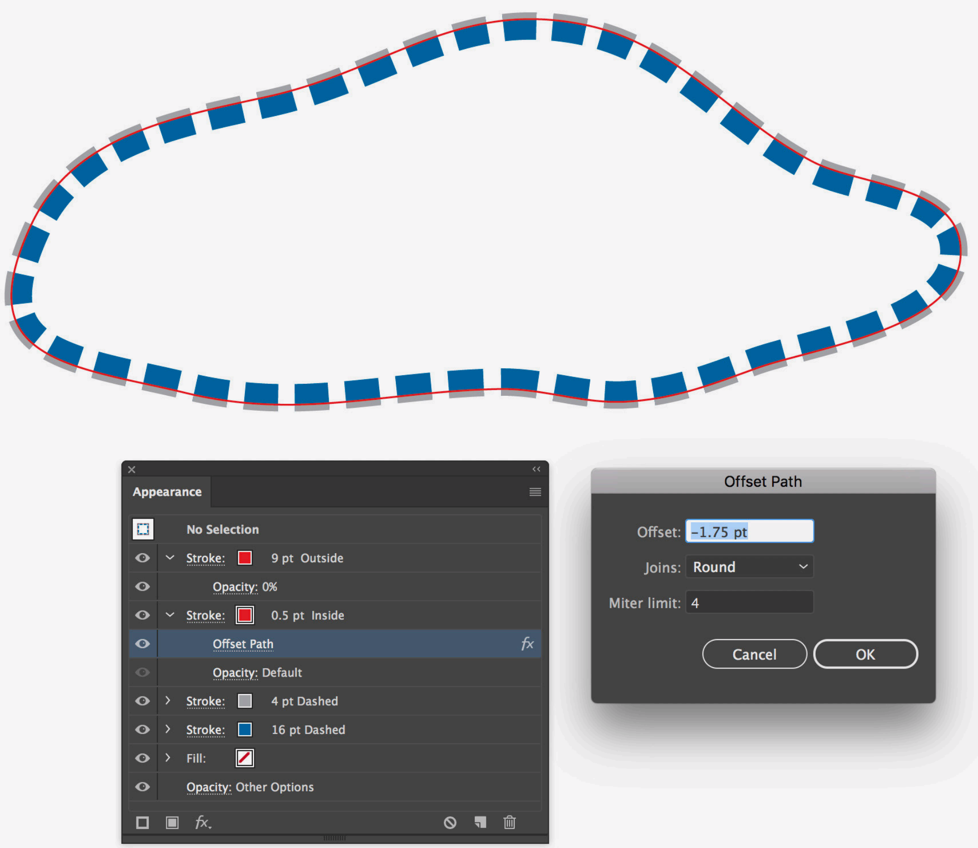

Figure 16. *A new, thin path is put on top of everything else and then offset inwards.*

Appearance panel, if you first click on the red stroke to highlight it, anything you choose from the Effects menu (such as Offset Path) will be be applied only to that stroke. If you applied Offset Path to the wrong thing, you can always click and drag to move it around.

Finally, I take that thin stroke and I set it to 0% opacity. Since we've got Knockout Group on, it knocks out the stuff underneath, leaving a 0.5pt gap between our grey and blue strokes, as seen in Figure 17. We're nearly done.

Finally, I want to make these dashes fade away as they get toward the center of the shape. I like the softness of the look, and to me it also imparts the idea of "this species stays on *this side* of the line," which is important when the shape is large enough that the reader might not always be looking at the whole thing at once. To create this effect, I start by adding a new fill on top of everything else, and offset it inward (2pt in this case). This means the fill doesn't start until just after the gap, and it will cover the blue stroke. Next I apply a 4pt feather effect to the fill to cause it to fade at the edges. Make sure to add this feather *after* the Offset Path effect—that is, below the Offset Path in the order of appearance layers (Figure 18).

At this point, you might be able to predict the next step: I set the fill to 0% opacity. Because of the Knockout Group setting, the blue stroke fades out as the

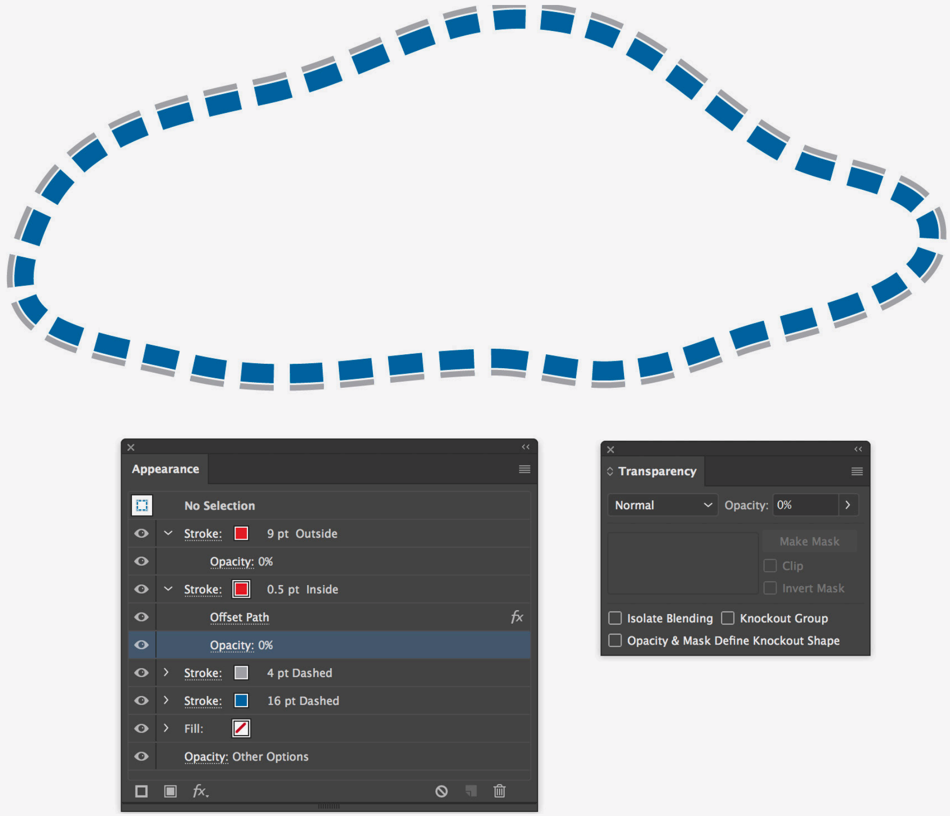

Figure 17. *The thin stroke is now invisible and knocks out everything below.*

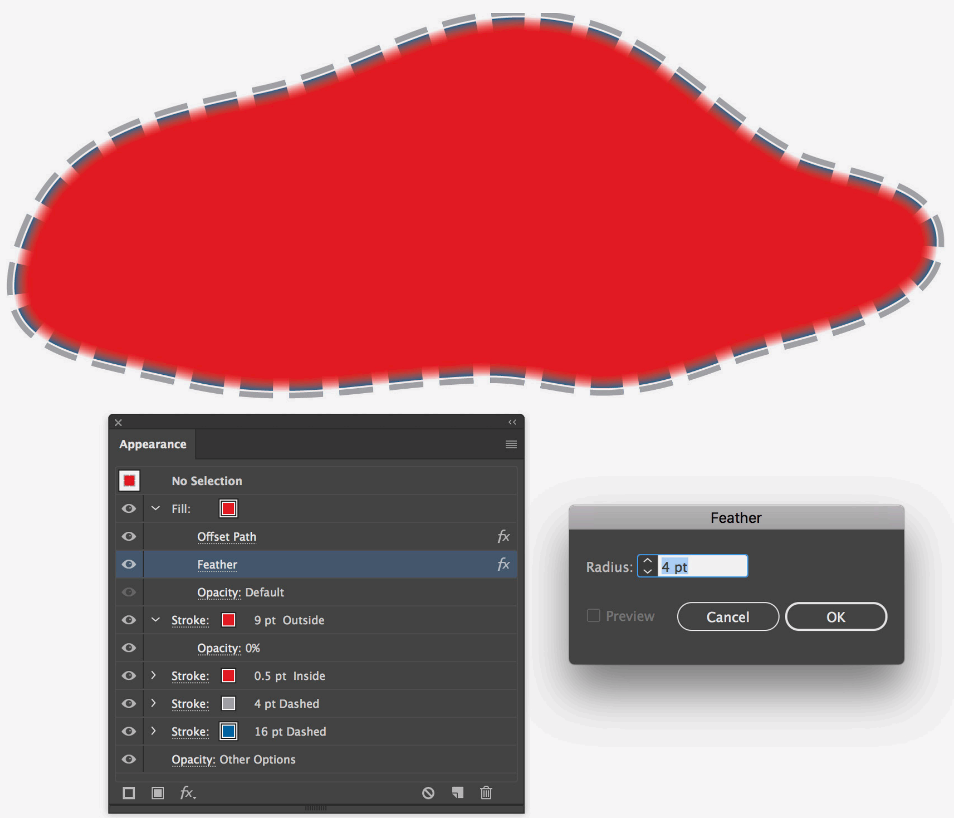

Figure 18. *A new fill, offset inward 2pt and feathered 4pt.*

invisible fill fades in. We're left with the finished product, which can be seen in Figure 19. Figure 20, meanwhile, shows it in use on an actual map.

This particular effect does not always look great when going around hard bends or corners (Figure 21), but I don't generally have those in the situations where I'm using it, so I don't mind. Dashes often get pretty tricky in those situations, no matter how simple or complex your style is.

The nice thing about this style is that it is all one object. You could achieve a similar look by creating multiple paths all stacked on top of each other, but it is far more flexible to do it all on one object. If the shape needs to change, you don't need to

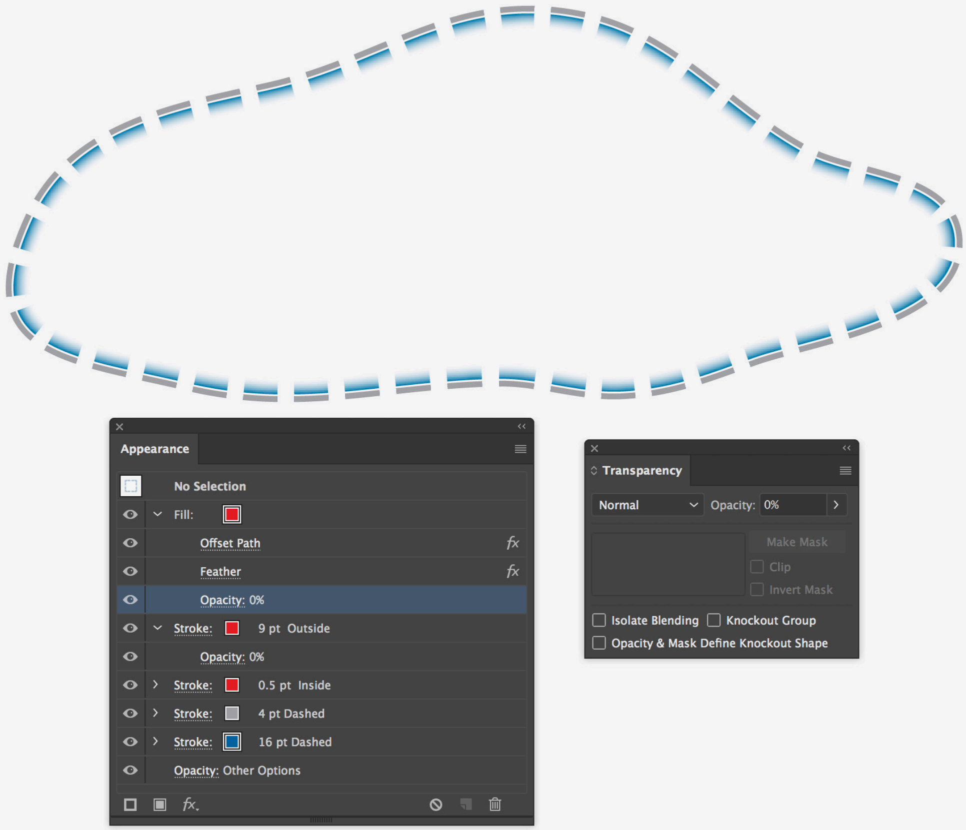

Figure 19. *The final line style.*

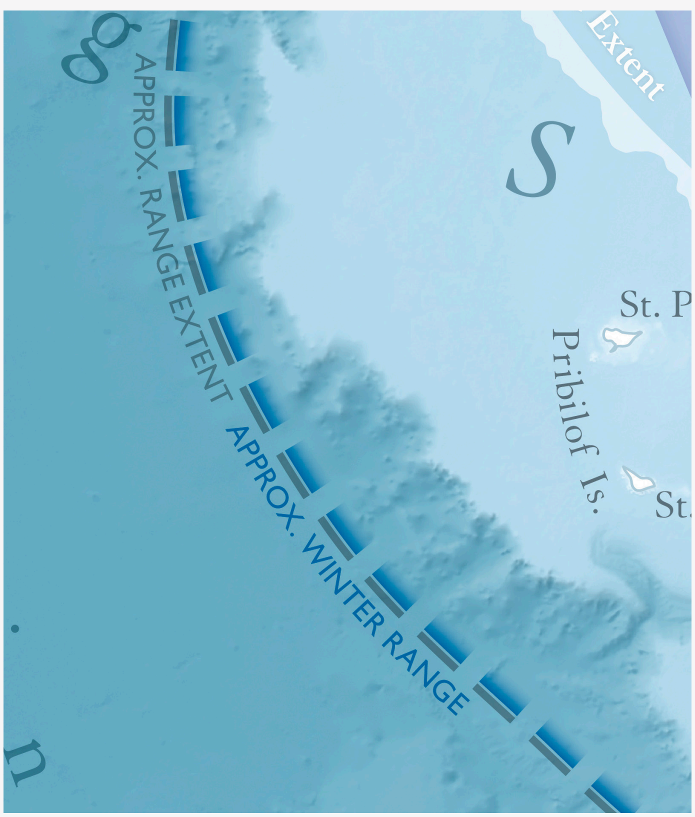

Figure 20. *The line style in use on an ecological map.*

Figure 21. *Corners and bends can cause issues.*

update multiple copies, each with its different stroke style. You simply redraw your shape, and everything updates.

After doing all this work, it's also important to know that styles can be saved. Opening up the Graphic Styles panel will give you options to save styles and to apply them to other paths, so you don't need to keep recreating this over and over again (though some practice can't hurt).

Again, I imagine that you probably won't need to reproduce this *exact* style (though you're welcome to if you find it useful). But, I hope this step-by-step breakdown gives you some ideas as to what is possible when using appearance attributes, knockouts, and effects. You can accomplish quite a lot by styling a single path, and, once you get the hang of it, Illustrator makes it fairly straightforward to take your work to another level.

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A Freelancer's Approach to Teaching Cartography

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While I mostly make my living as a freelance cartographer, over the past several years I've also had the privilege to serve intermittently as a lecturer for an introductory cartography course at the University of Wisconsin–Madison. Through my simultaneous development as both an educator and a practitioner, I've slowly changed my classroom approach to better reflect my experiences in the real world of mapmaking. Although I cover the typical roster of topics in my course, it is structured in a way that is informed by my own hands-on perspective. This paper includes an à la carte selection of some elements that reflect this practical approach, and which I have found successful in helping students learn. Perhaps the ideas I explain here will inspire a more enterprising instructor to put them to a formal test.

First, a quick bit of background on the course, which is titled "Introduction to Cartography," and enrolls anywhere from 30 to 80 students depending on the semester. I give two 75-minute lectures per week, which cover broad mapmaking fundamentals, including typography, projections, colors, visual variables, etc., as well as the critical thinking skills needed to make good cartographic choices. Students also meet once a week in smaller (15 to 20 person) lab sections, which are conducted by a graduate teaching assistant who guides students in learning hands-on technical skills in ArcMap and Adobe Illustrator. Students also complete mapmaking assignments during and outside of lab. No prior knowledge of GIS or mapping is required to take the course. My objective is to see students come out of the course with the capacity to make basic maps on their own, and to critically assess maps they encounter in their daily lives.

EMBRACING SUBJECTIVITY

In my freelance work, there is no single, absolute, right way to make a map. Any two people may disagree on what works and what looks good, and whatever pleases one of my clients (or colleagues) may displease another. Likewise, grades on mapping exercises are, in essence, *opinions*. The person assigning the grade gives their opinion on how well the student has addressed a problem that has a virtually infinite range of possible solutions, and that opinion may vary among graders. I long struggled with the subjectivity inherent in assessing students' work before I decided to simply embrace this fact and own it in front of my students.

It's important to me to begin the course by telling students that their grades are based on my opinion and on the opinions of the teaching assistant(s). I tell them to think of us as their clients: the work they do has to make us happy and conform to what *we* think is good practice. I acknowledge that they may disagree with us at times, but that they need to set aside their view and make the client's perspective the priority, just as I do in my freelance practice. At the same time, I empathize with students, telling them how my work often requires me to shelve some of my preferred ideas in favor of the wishes of others.

I do not pretend to them that cartography is objective, or that it has absolutely correct answers; instead I explicitly state the opposite at the beginning of the course and in the syllabus. I want students to understand that it is not automatically wrong to go against the ideas I present in lecture. At the same time, I acknowledge the reality that it is my course, and we need to do things my way (even if it is not the *only* valid way). In this way, I sidestep fruitless arguments about our individual subjective preferences.

Subjectivity is also reflected in the way grades are assigned. Rather than using a system of points, all assignments simply receive letter grades. To me, it seems rather clearer to tell a student that they got a B than to tell them that they got 10 out of 14 points on an assignment: this helps them realize better where they stand. With a simple number grade, it can be difficult at first glance for a student to tell if they've done a good job, or failed to meet expectations. Given how subjective grading can be, points also carry an inappropriate air of precision. At the end of the semester, the university requires that I summarize a student's entire course performance in a single letter grade, which represents my opinion on how well the student has learned mapmaking. If students have been seeing letter grades on their assignments all along the way in the course, then the end result is less surprising to them. Since instituting this system, I have indeed seen fewer students push back against their final course grades.

I do have to use point values internally for practical reasons, so that I can average or add together assignment grades. I convert letter grades to numerical grades using the university's four-point scale (A = 4, AB = 3.5, B = 3, BC = 2.5, etc.). To make the process easier for students, I provide them with an online grade calculator. They can enter the letter grades from each of their assignments, and it calculates their current course grade in letter format.

NO MORE EXAMS

Probably the boldest move I've made as an educator is to eliminate quizzes and exams from my course. My freelance clients evaluate me solely on what I produce, and I have come to believe that my students should likewise be graded on the quality of the maps they make, rather than how well they can parrot the content of my lectures. My goal is to give students the skills to independently *practice* cartography. Either what I teach them will help them make better maps during their lab assignments, or they shouldn't be asked to remember it.

My lectures have value: I teach fundamental concepts, discuss good practices, and lead students in group critiques of published professional maps. They then get a chance to demonstrate, via their graded lab exercises, that they've absorbed that material—or at least picked it up from somewhere else. I primarily want to see what the students can *make*; I am less concerned with how they learned it, whether from listening to me, or browsing cartography blogs, or intuiting good practice on their own. However it works out, I believe their grade in the course should primarily reflect their ability to create maps. Over half of students' grades come from their five lab assignments, and another third comes from a final project map that they complete at the end of the semester.

SECOND CHANCES

In my freelance work, I make many drafts. A client will ask me to create something, I will show them an initial attempt, and then I will make revisions based on their feedback. Often I'll even do a revision or two *before* clients see the work, in response to critique from colleagues. The first version I make is rarely the final, and there is generally no penalty for not getting it right on the first try.

I think students deserve the same chance to revise their work. Having their final grade depend on a first effort is not reflective of how cartography (and many other pursuits) works in the real world. Therefore, after a student has received their graded map, they can revise and resubmit it within two weeks for a new grade. About a third of all lab assignments are revised under this system; for the rest, the students are sufficiently content with their grade that they don't make a second attempt. In my first semester, I limited students to a single revision per lab assignment. The second time around, I gave them a total budget of five revisions for the semester (so that they could revise a lab multiple times while leaving others untouched); however, I have only seen one student revise a map a second time.

There is an incentive to do better on the first try: if a student's initial this grade was a C or worse, then their final grade for the lab will be the average of the revised grade and the initial grade. If their initial grade was better than a C, then their final grade will simply be the grade of the revised map, and the old one will be discarded. This minimizes a possible abuse of the system, in which a student might use a revision to give themselves a deadline extension on an assignment by first turning in an incomplete map, then finishing it and turning it in as their revised copy later on.

This system of lab revisions not only allows but *encourages* students to learn from their mistakes, and it has been successful in doing so. In my two most recent semesters of teaching Introduction to Cartography, the average lab received 3.4 out of 4 points (so, about an AB in our letter-to-number conversion). In the two semesters prior to that, in which lab revisions were *not* allowed, the average lab grade was 3.0 points (a B), 13% lower. To be fair, these numbers don't come from any controlled study: these courses took place at different times, with different teaching assistants grading the labs, and so on. But, I think the results are quite encouraging, and suggest that students are indeed coming out of the class with a better ability to make maps.

I originally added lab revisions to compensate for the fact that I eliminated exams. Since students' course grades now depend primarily on their lab assignments, they have a lot of eggs in one basket. There are only five labs, and a misstep on any one could do real damage to someone's final grade. Giving students a second chance minimizes that impact, letting them correct a stumble here or there. I do not wish to overly penalize students as they make mistakes on their way to developing skills; I only care that they develop them.

BEHIND THE SCENES

A number of my students each semester have an interest in continuing on professionally in mapmaking; yet it can be difficult for them to get a sense of what cartographers actually *do* in the structured and controlled environment of a college course. So, I try to offer glimpses into my freelance career by taking a few minutes during lecture to show them projects I'm working on. In the past I have shown them how I interact with clients, and how, in my own work, I implement the the good practices I demonstrate in lecture. In addition, I show them how my work must sometimes change in response to client requests (again, trying to empathize with them regarding the need to please others), as well as feedback from colleagues, showing how the process of improvement doesn't stop once you become a professional.

When I take these side detours into my freelance work, I get more questions and engagement from the students than almost any other time in the course. They want to know more about what it's like to have a cartography job: How much do I make? How do people find me? How do I figure out how much to charge for a project? How long does it take me to make a map? Do cartographers have meetings? What other kinds of jobs are there in cartography? These are important questions, and they're ones that don't always fit into my normal lecture content, which focuses more on the details of how to make a proportional symbol map or on how to make good typographic choices. I have seen how eager the students are to know how mapmaking works out there in the real world.

During the final lecture period of the semester, instead of talking at the students, I do a live demo. I make a simple map, from start to finish, over the course of about 70 minutes, so they can see my own personal mapmaking workflow. When I go to conferences or read articles in *Cartographic Perspectives*, I learn a lot from watching my colleagues show their processes and share their tips and tricks. Through this demo day (and in smaller demos throughout the semester) I likewise want students to see how a practicing cartographer solves problems. While it reinforces some of the skills students have already been taught (but may not have absorbed), it more importantly demonstrates how I, as a professional, make use of the same ideas and technical skills that they have learned. I call this live demo "Bob Ross Day," after the host of *The Joy of Painting*, who taught many people how to paint by simply letting them watch him do it.

PRACTICAL TUTORIAL ASSIGNMENT

As a freelancer, I benefit greatly from the fact that the cartographic community is built upon a culture of sharing knowledge. Mappers are always figuring out new tools and techniques, and then using social media, articles, or conference presentations to teach colleagues about them. I want my students to participate in this spirit of sharing by teaching something useful to their lab colleagues. Late in the semester, I require them to turn in a simple one to two page practical cartographic tutorial. The assignment is pretty open: they need to produce a document that will teach their fellow students something that is useful for mapmaking, and that we haven't talked about in class. It could be a data source, a tool in Adobe Illustrator, a trick in ArcMap, etc., as long as it's novel (to them) and practical.

When I first introduced this assignment, I was a little concerned that students wouldn't know what to do. After all, if I was asking them to learn something new, but not saying exactly what that was, might not some of them get lost? I have, however, been pleased to find that almost every student manages to produce something useful and interesting, with no guidance. They have been very good at exploring the wider world of cartography and bringing back useful knowledge. Their tutorials are later shared on the course website, so that everyone can benefit. It's especially encouraging to have a student ask a question in class and then have another student respond, "I wrote a guide about that recently; have a look and let me know if you have any questions!" I draw satisfaction from seeing them engaged in the kind of culture of mutual assistance that I benefit from in my own professional work.

ONLINE DISCUSSION

Whenever I get stuck on a project, or have a technical question, I ask colleagues for help. Wanting to replicate that experience for my students, I set up an online discussion forum using Slack, which is a group chat application popular with a number of cartographers and GIS professionals. While there are public Slack chats on the wider internet, the one I established was accessible only by members of the course. I then encouraged students to post their questions and solicit feedback on their work, so that other students could log in and offer help and advice.

Results with the Slack chat have been mixed. The first semester I tried it, students were fairly engaged with each other, responding to each other's queries a few times per week. Not a great deal of traffic, but the site was definitely seeing regular use throughout the semester. It was very satisfying to see students helping each other out, and becoming teachers of the material they had learned. I and my teaching assistants also chimed in from time to time, to help out on questions that weren't being answered, or suggest alternatives to students' answers.

Unfortunately, the following semester, the Slack chat lay mostly empty. Almost no questions were asked, and any engagement was mostly between myself and the students, rather than peer-to-peer. There were 38 students in that course, as compared with 59 in the prior semester, so perhaps there is some minimum number that's necessary to achieve critical mass. Whatever the cause may be for the decline in use, I think the idea still has merit; however, it may require further experimentation to find a successful formula, and perhaps it is not as sustainable in smaller classes.

A WORK IN PROGRESS

I hope that these examples will be of some value to you, and perhaps inspire you to iterate upon them. I think these elements combine to produce a course that teaches not only the basics of cartography, but also some of the basics of being a cartographer. Just as with my freelance work, the course is a work in progress, going through multiple drafts: each semester I make small changes, trying new things and adjusting or discarding old ones. In the end, my goal is to ensure that students leave my course ready to be practicing cartographers. I think I'm moving in that direction.

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That Map You Love, That Saved Your Life

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My maps, prints, and photographs are responses arising from an effort to stop and listen to the place. I make direct contact with, and in one Body, the experience of being awake and embracing the event. I make artist-editioned maps, prints, artist books, and broadsides in small numbered editions using a variety of matrices: relief, stone & plate lithography, intaglio, collagraph, silk screen, and letterpress. I make responses directly using both dry and wet drawing materials. My lithographic stones are over 100 years old and still in use. Printing, involving multiple matrices, hand-mixed inks, and fine papers that include blind embossing, chine-collé, and trial and error, is done using the two luddite presses: a Gordon Oldstyle letterpress and a Griffin lithograph & etching-intaglio press.

I stop and listen
I stop and observe
I return back and stop
    again, and again
I count
I measure
    I breathe in
    and I breathe out
AND I sing like Walt and Kabir and Lorca

I experience the place itSelf
this, this drug of song and dance and colour

I touch and feel and enJOY
    and get wet
    and get dirty
    and get cold and hot and hurt and healed
    sun-cloud-water exposed

STOP, OBSERVE, EXPERIENCE
Did I say this?

And when the place speaks
And I hear the Voice

    MAKE
    to Make a mark
    to Respond
a response arising from the place itSelf
    I-Thou, the Other
    Listening
I can no longer make maps

These are given to me,
    Gifts that saved my life

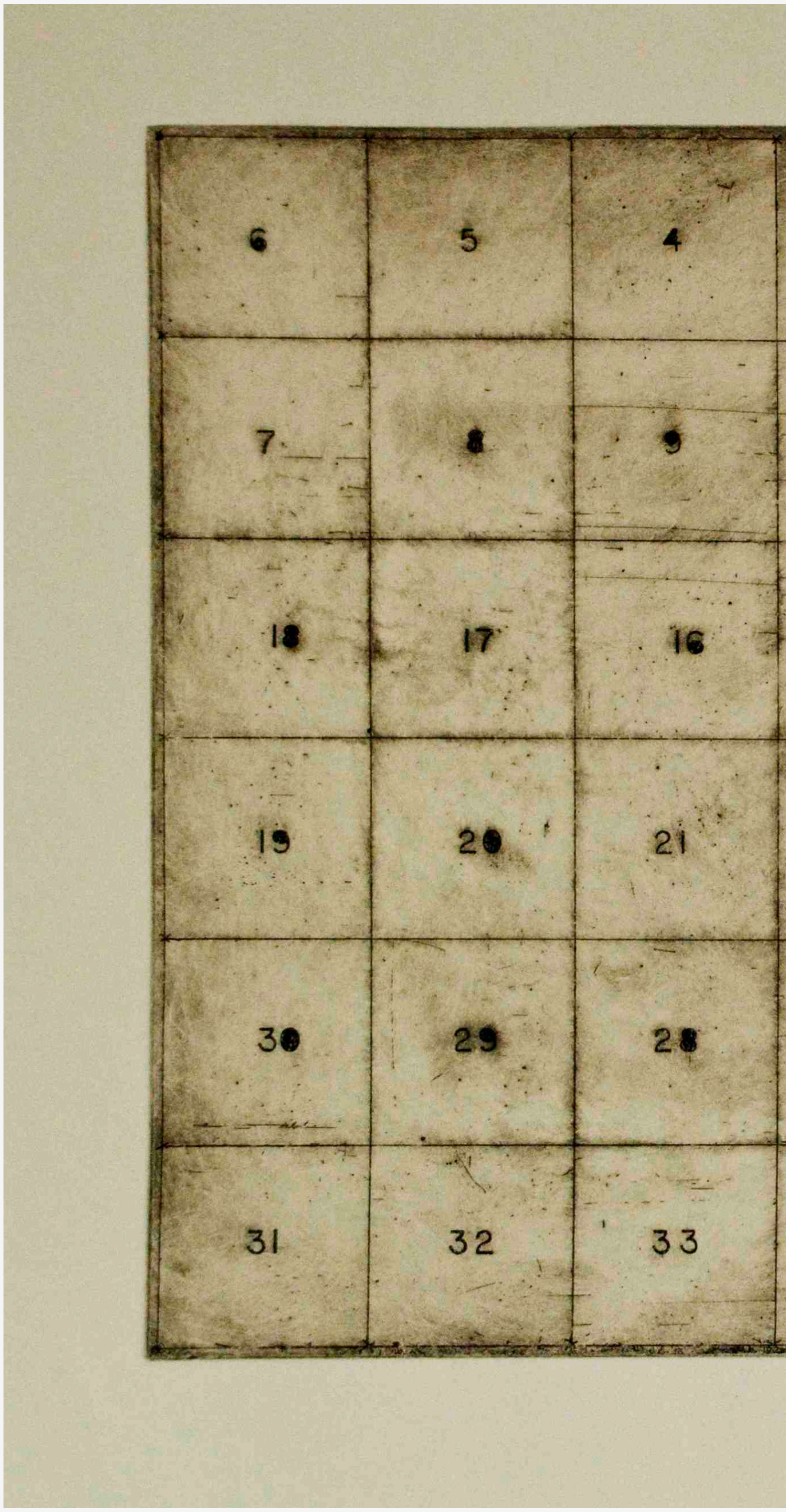
Next page:
Stopping to Observe & Experience the Other, *North Shore of Lake Superior, Minnesota, 2012.*

After the Indian Wars
    the new King placed a grid like a blanket
    heavy and suffocating EVERYwhere
    a permanence of his pleasure
    and power
AND did what he wanted

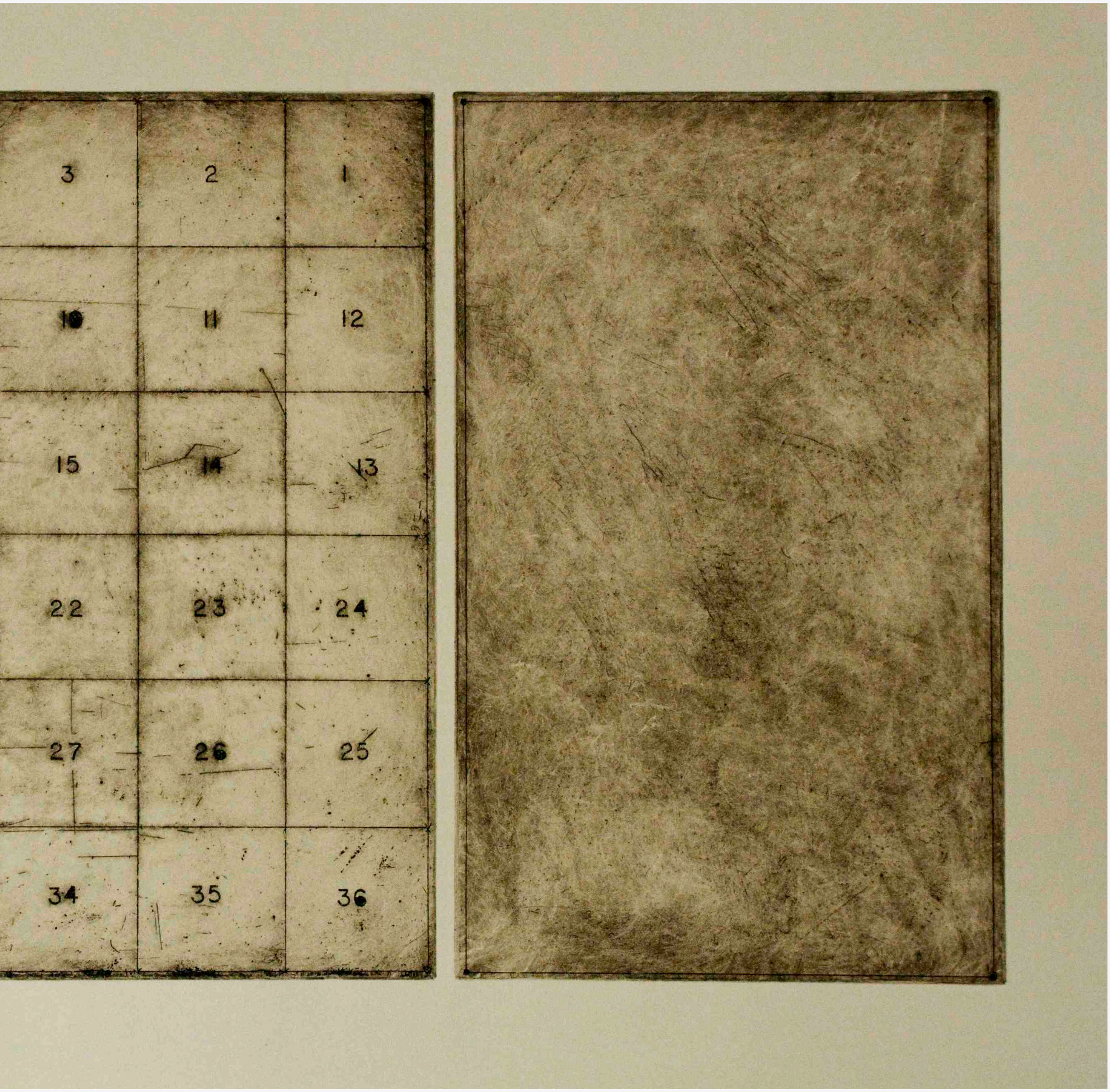
Gave the land to those in his favor
    a medal with his image to those he defeated

And thus began
    the great extractions
    the steel ribbons
    the cutting and fencing and
the endless concrete
    the draining & covering of the swamps
    the terrible stagnation of the dams

And the poisoning of ki-o-te
    I-IT. I-IT. I-IT.
    ME ME ME they shouted
    MINE. I WANT. MINE.



Mapping the World, *Intaglio 25 by 38 in. on Sakamoto Aiko, 2009.*



Mapping the World, *Intaglio 25 by 38 in. on Sakamoto Aiko, 2009 (continued).*

Muddy flooding of the Nile
    Rising and falling of the Ganges
    the great Tigris-Euphrates, rich valley of mudwater moving life-stuff
    Missouri-Ohio-Mississippi, Columbia-Kootenay, Amazon Basin of life
Muddy waters rising and falling
Bearing Witness
    the dark walls of Chauvet Cave in the valley of the Ardèche
    paintings, engravings and drawings bearing witness
    hand prints; I too was here bearing witness with you

And the event at BodhGaya on the Phalgu-Ganges
the Earth bearing witness, mud-waters rising up
    his right hand touching the earth,
    the waters rising and bearing witness
And Mara disappeared.

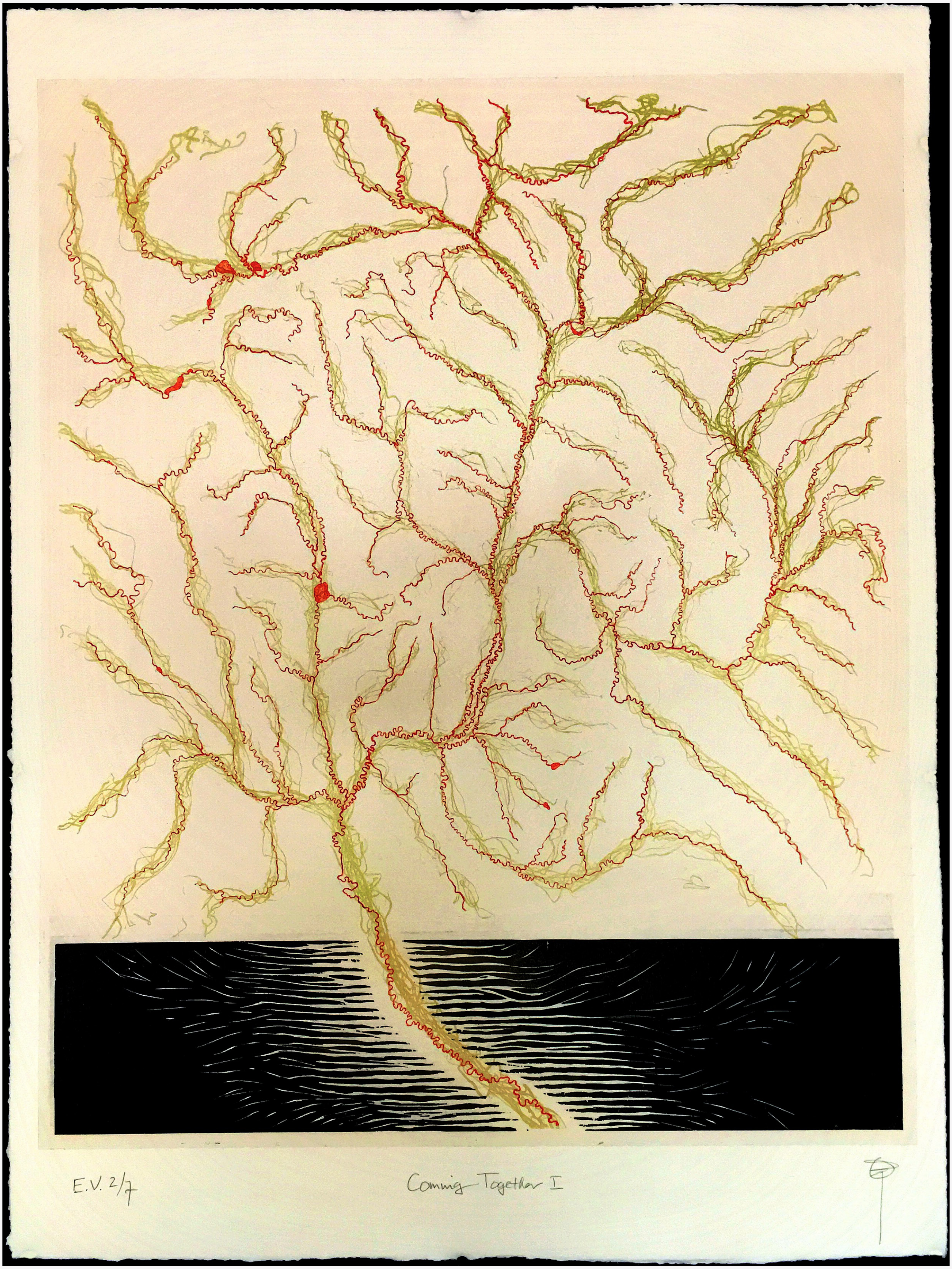
Next page:
Map of the Waters Bearing Witness (When Buddha Touched the Earth on the Phalgu–Ganges Rivers at BodhGaya, India), *37 by 25 in. Stone lithograph on Sakamoto, 2010.*


MAP OF THE WATERS BEARING WITNESS
F.V. 4/12

Stopped here
the Place called Three Forks of the Missouri
witness to a coming together
    in winter, in spring, in summer
Watersheds polyphonic, water in song & in dance
An assembling and mixing and transporting of
    My DNA. Your DNA. The DNA.

    As in a flood all jumbled together. Coming Together.
Did we come together as these rivers
    without effort
    joining without dispute or judgment
How lucky I am
    making a mark on a cave wall
Marks that saved my life
Marks
    to make things that
Disrupt and Disturb and Awaken me
    In spring and in summer and in winter and autumn.

Next page:
Coming Together I (Three Forks of the Missouri, Montana), *41 by 30 in. Lithograph, Flocking, Blind embossing, Relief, Chine-collé on Kozo mounted on Arches, 2015.*

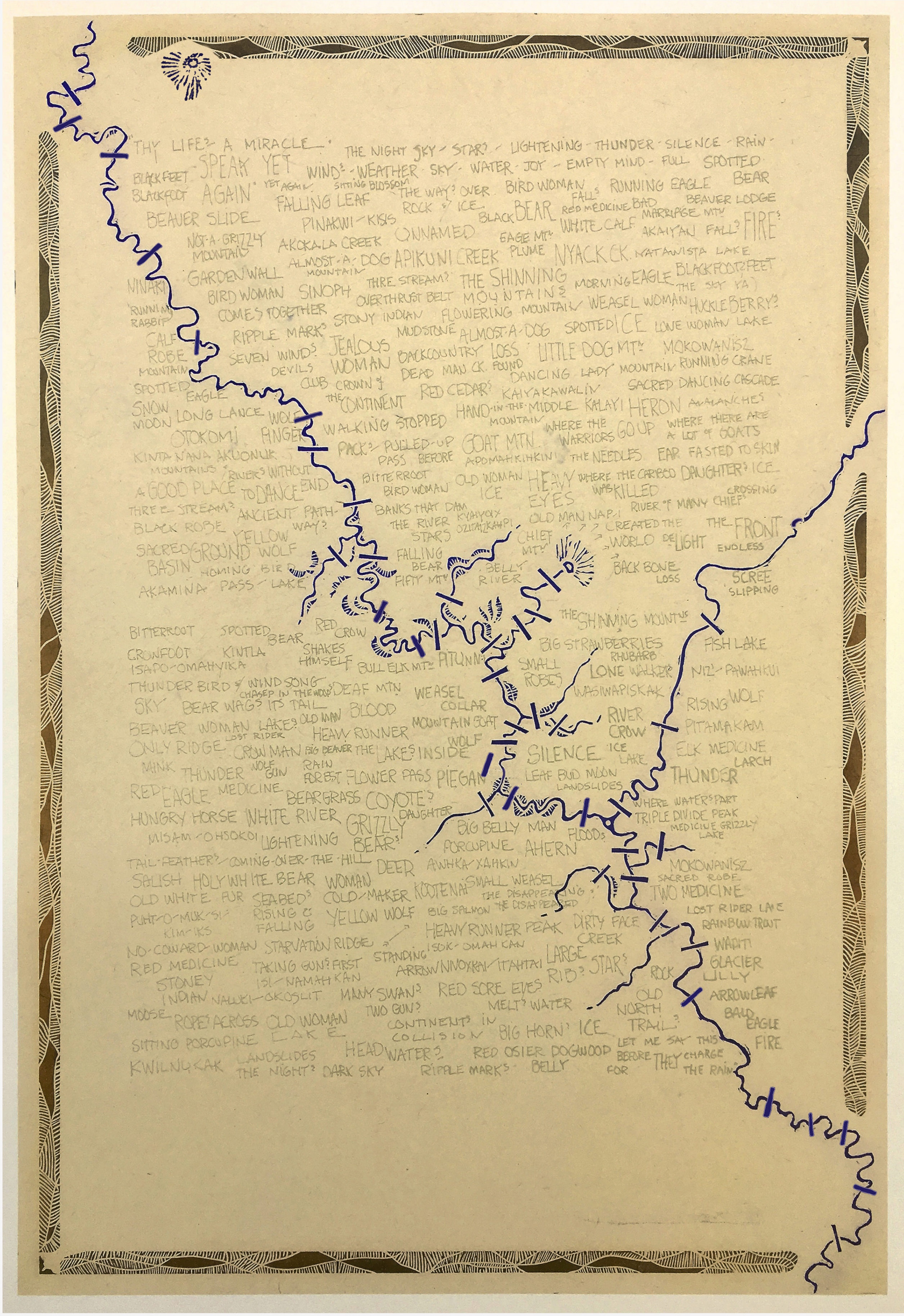

E.V. 2/7
Coming Together I

How to cross east to the buffalo people
How to cross west to the salmon people
    This is all you need to know
    the way across. Leave all the rest to the crossing itself.

To cross the Shining Mountains, Crown of the Continent . . .
    Crowsnest, Tent Mountain, Ptolemy, North Kootenay, Middle Kootenay, Sage and Kishinenai,
        Akamina, Boulder, Brown, Jefferson and Kootenai
    There is Fifty Mountain, Stoney Indian, Gable at Chief Mountain on the Front,
        and Ahern, Red Gap, the Tunnel called Ptarmigan and Swiftcurrent
    And Logan, Piegan and Siyeh, Hidden Lake, Comeau, Lincoln, Gunsight,
        Red Eagle, Cut Bank, Surprise, Triple Divide by the Peak, Pitamakan
        Then Dawson, Two Medicine, deSanto, Firebrand, Marais,
        Muskrat, Badger, Gateway, Teton

Crossings without end. Mountains and Rivers without end.
The WAY across.

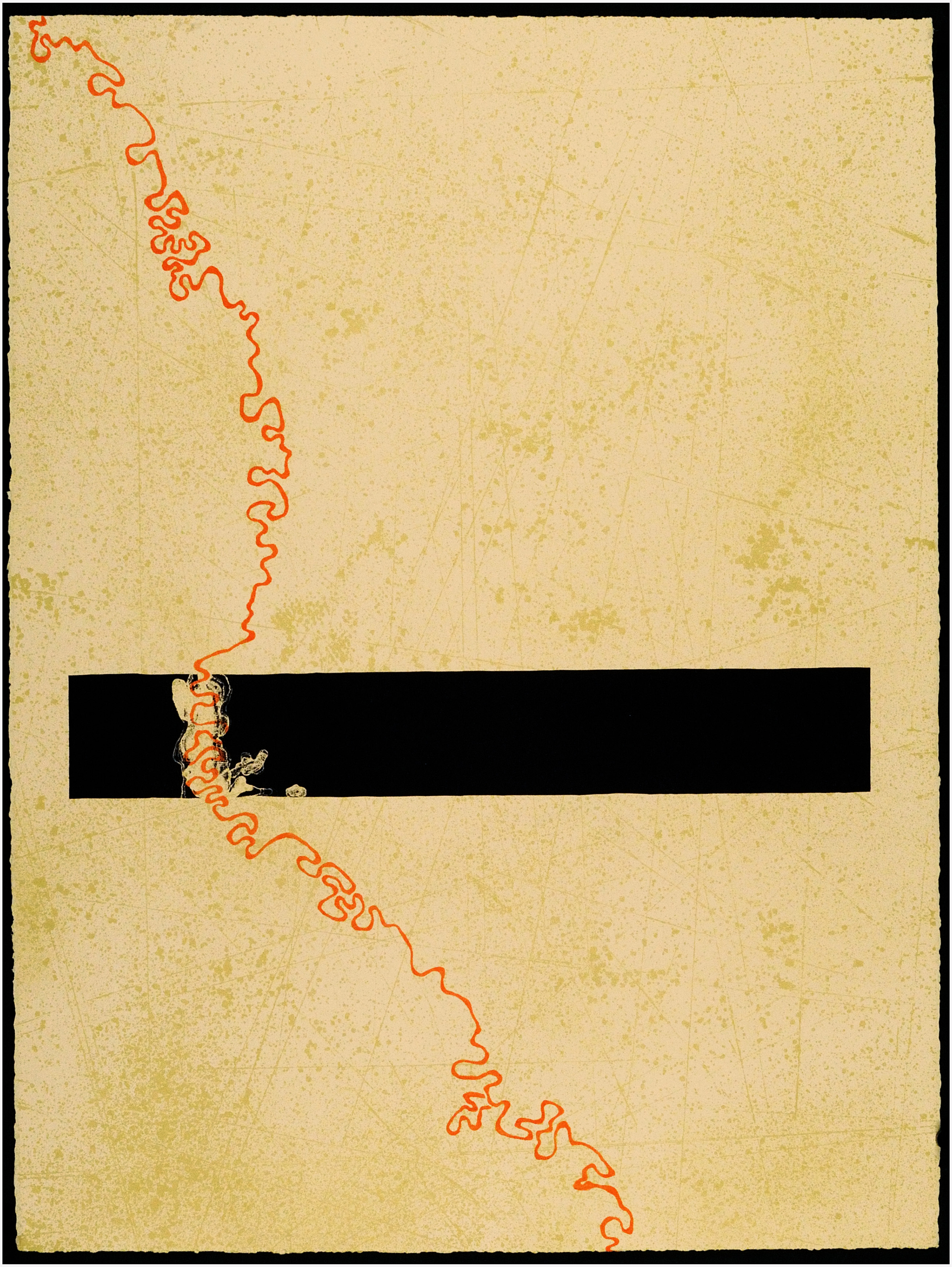
Next page:
The Way Across (Northern Rocky Mountains roadless areas, passes & continental divides, British Columbia, Alberta & Montana), *42 by 31 in. Lithograph, Flocking, Relief & Chine-collé on Kozo mounted on German Etching, 2017.*


THY LIFE'S A MIRACLE
THE NIGHT SKY - STARS - LIGHTENING - THUNDER - SILENCE - RAIN
SPEAK YET AGAIN
WIND'S - WEATHER SKY - WATER - JOY - EMPTY MIND - FULL
SPOTTED BEAR
BLACKFEET
BLACKFOOT
SITTING BLOSSOM
THE WAY'S OVER
BIRD WOMAN FALLS
RUNNING EAGLE
FALLING LEAF
ROCK & ICE
RED MEDICINE BAD MARRIAGE MTN
BEAVER LODGE
BEAVER SLIDE
PINAKWI - KISIS
BLACK BEAR
WHITE CALF
AKAIYAN FALLS
FIRES
NOT-A-GRIZZLY MOUNTAIN
AKOKALA CREEK
UNNAMED
EAGLE MTN
ALMOST-A-DOG MOUNTAIN
APIKUNI CREEK
PLUME
NYACK CK.
NATAWISTA LAKE
NINAKI
GARDEN WALL
THREE STREAMS
THE SHINNING MOUNTAINS
MORNING EAGLE
BLACKFOOT'S FEET
THE SKY YA
BIRD WOMAN
SINOPH
OVERTHRUST BELT
WEASEL WOMAN
HUCKLEBERRYS
RUNNING RABBIT
COMES TOGETHER
STONY INDIAN
FLOWERING MOUNTAIN
CALF ROBE MOUNTAIN
RIPPLE MARKS
MUDSTONE
ALMOST-A-DOG
SPOTTED ICE
LONE WOMAN LAKE
SEVEN WINDS
JEALOUS WOMAN
BACKCOUNTRY LOSS FOUND
LITTLE DOG MTN
MOKOWANISZ
RUNNING CRANE
DEVILS CLUB
DEAD MAN CK.
DANCING LADY MOUNTAIN
SPOTTED EAGLE
CROWN of THE CONTINENT
RED CEDARS
KAIYAKAWALIN
SACRED DANCING CASCADE
SNOW MOON
LONG LANCE
WOLF FINGER
HAND-IN-THE-MIDDLE MOUNTAIN
KALAYI
HERON
AVALANCHES
WALKING STOPPED
WHERE THE WARRIORS GO UP
WHERE THERE ARE A LOT of GOATS
OTOKOMI
PACKS
PULLED-UP PASS BEFORE
GOAT MTN.
APOMAHKIHKINI
THE NEEDLES
EAR FASTED TO SKIN
KINTA NANA AKUONUK MOUNTAINS
RIVERS WITHOUT END
BITTERROOT
OLD WOMAN ICE
HEAVY EYES
WHERE THE CARIBOU WAS KILLED
DAUGHTERS ICE
CROSSING
A GOOD PLACE TO DANCE
BIRD WOMAN
RIVER of MANY CHIEF
THREE-STREAMS
ANCIENT PATH-WAYS
BANKS THAT DAM THE RIVER
KYAHYOIX OZITAIIKAHPI
OLD MAN NAPI CREATED THE WORLD
THE FRONT
BLACK ROBE
YELLOW
STARS
CHIEF MTN
DE LIGHT
ENDLESS
SACRED GROUND WOLF
FALLING BEAR
BELLY RIVER
BASIN
HOMING BIRD
FIFTY MTN
BACK BONE LOSS
AKAMINA PASS - LAKE
SCREE SLIPPING
BITTERROOT
SPOTTED BEAR
RED CROW
THE SHINNING MOUNTAINS
CROWFOOT
KINTLA
SHAKES HIMSELF
BIG STRAWBERRIES
RHUBARB
FISH LAKE
ISAPO-OMAHYIKA
BULL ELK MTN
PITUNN
SMALL ROBES
LONE WALKER
NIZ' PAWAHKUI
THUNDER BIRD & WIND SONG
CHASED IN THE WOOD
DEAF MTN
WEASEL COLLAR
WASIWAPISKAK
RISING WOLF
SKY
BEAR WAGS ITS TAIL
BLOOD
RIVER CROW
BEAVER WOMAN LAKES
OLD MAN
HEAVY RUNNER
MOUNTAIN GOAT
PITAMAKAM
ONLY RIDGE
LOST RIDER
CROW MAN
BIG BEAVER
THE LAKES INSIDE
WOLF
SILENCE
ICE LAKE
ELK MEDICINE
LARCH
MINK
THUNDER
WOLF GUN
RAIN FOREST
FLOWER PASS
PIEGAN
LEAF BUD MOON
LANDSLIDES
THUNDER
RED EAGLE
MEDICINE
BEARGRASS
COYOTES
DAUGHTER
WHERE WATERS PART
TRIPLE DIVIDE PEAK
HUNGRY HORSE
WHITE RIVER
GRIZZLY BEARS
BIG BELLY MAN
FLOODS
MEDICINE GRIZZLY LAKE
MISAM-OHSOKOI
LIGHTENING
PORCUPINE
AHERN
TAIL-FEATHERS
COMING-OVER-THE-HILL
DEER
AWHKA-XAHKIN
MOKOWANISZ
SACRED ROBE
SALISH
HOLY WHITE BEAR WOMAN
KOOTENAI
SMALL WEASEL
THE DISAPPEARING
THE DISAPPEARED
TWO MEDICINE
OLD WHITE FUR
SEABEDS
COLD MAKER
BIG SALMON
LOST RIDER LAKE
PUHT-O-MUK-SI-KIM-IKS
RISING & FALLING
YELLOW WOLF
HEAVY RUNNER PEAK
DIRTY FACE CREEK
RAINBOW TROUT
NO-COWARD-WOMAN
STARVATION RIDGE
ISOK-OMAH KAN
WAPITI
RED MEDICINE
TAKING GUNS FIRST
STANDING ARROW
NINOYKAI/ITAHTAI
LARGE RIBS
STARS
ROCK
GLACIER LILLY
STONEY INDIAN
ISI-NAMAH KAN
NALUKI-OKOSLIT
MANY SWANS
RED SORE EYES
OLD NORTH TRAILS
ARROWLEAF
MOOSE
ROPES ACROSS
OLD WOMAN LAKE
TWO GUNS
MELTS WATER
BALD EAGLE
CONTINENTS IN COLLISION
BIG HORN ICE
LET ME SAY THIS BEFORE THEY CHARGE FOR THE RAIN
FIRE
SITTING PORCUPINE
LANDSLIDES
HEAD WATERS
RED OSIER DOGWOOD
KWILNUKAK
THE NIGHTS
DARK SKY
RIPPLE MARKS
BELLY

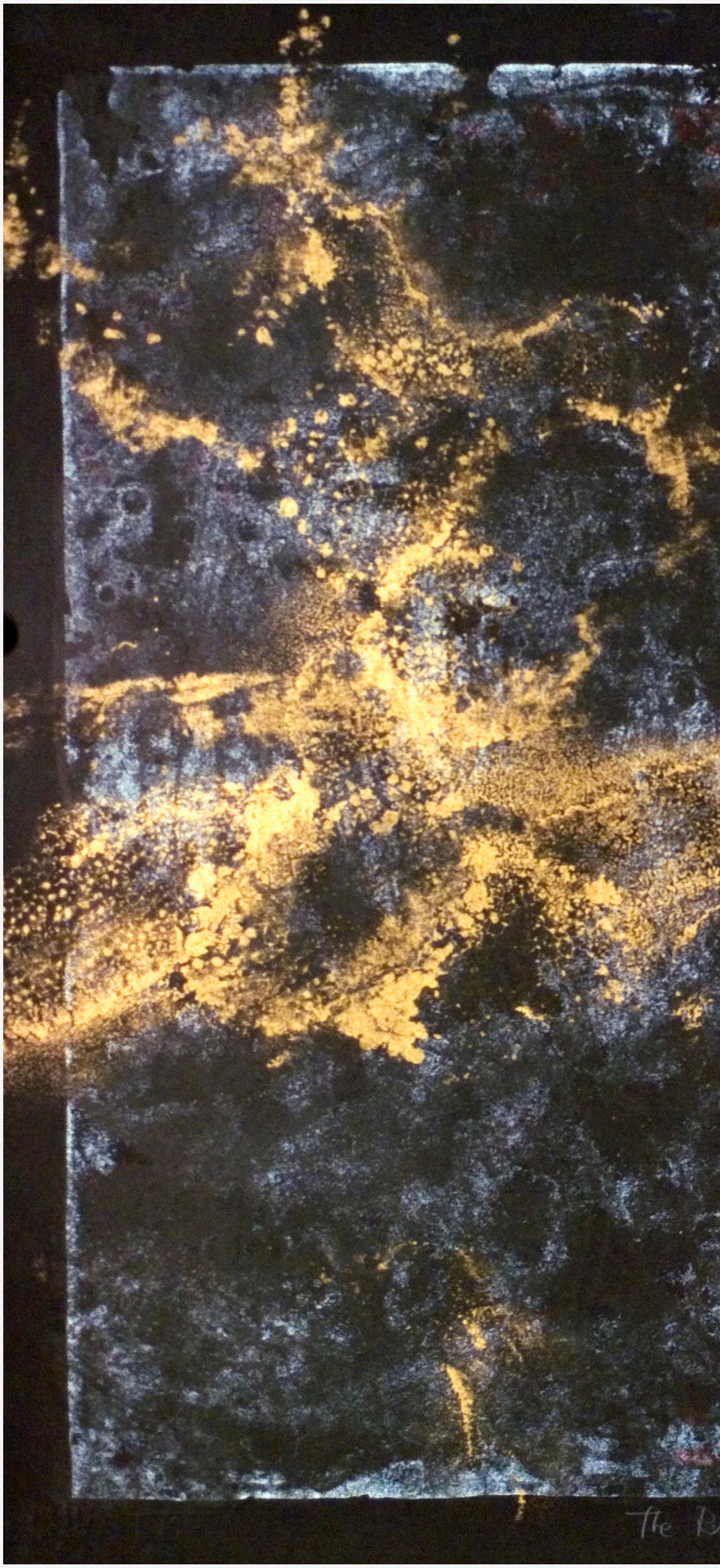
ALL DAY PERMANENT RED

All Day Permanent Red: The First Battle Scenes of Homer's Iliad*, rewritten by Christopher Logue, 2003.*

Next page:
Something Happened Here (Little Bighorn Battlefield & River, south central Montana)*, 30 by 22 in. Stone lithograph on Somerset Velvet, 2009.*



At night the river is an inky blackness, the bottom of which I cannot locate, more than a shadow, an eclipse of sorts, a doorway that invites me in. I stand back and look out now, and the song of the night is shimmering awake. Above, on the surface, gold reminds me of something. I cannot distinguish between the night and the shimmering gold. At this moment the gold has no price and cannot be sold.



The River Awakens at Night (Missouri River at the junction of the Arrow, Montana), *22 by 30 in. Stone lithograph on Somerset Velvet Black, 2004.*

The River Awakens at Night (Missouri River at the junction of the Arrow, Montana), *22 by 30 in. Stone lithograph on Somerset Velvet Black, 2004 (continued).*

And the heron, in its constant dance,

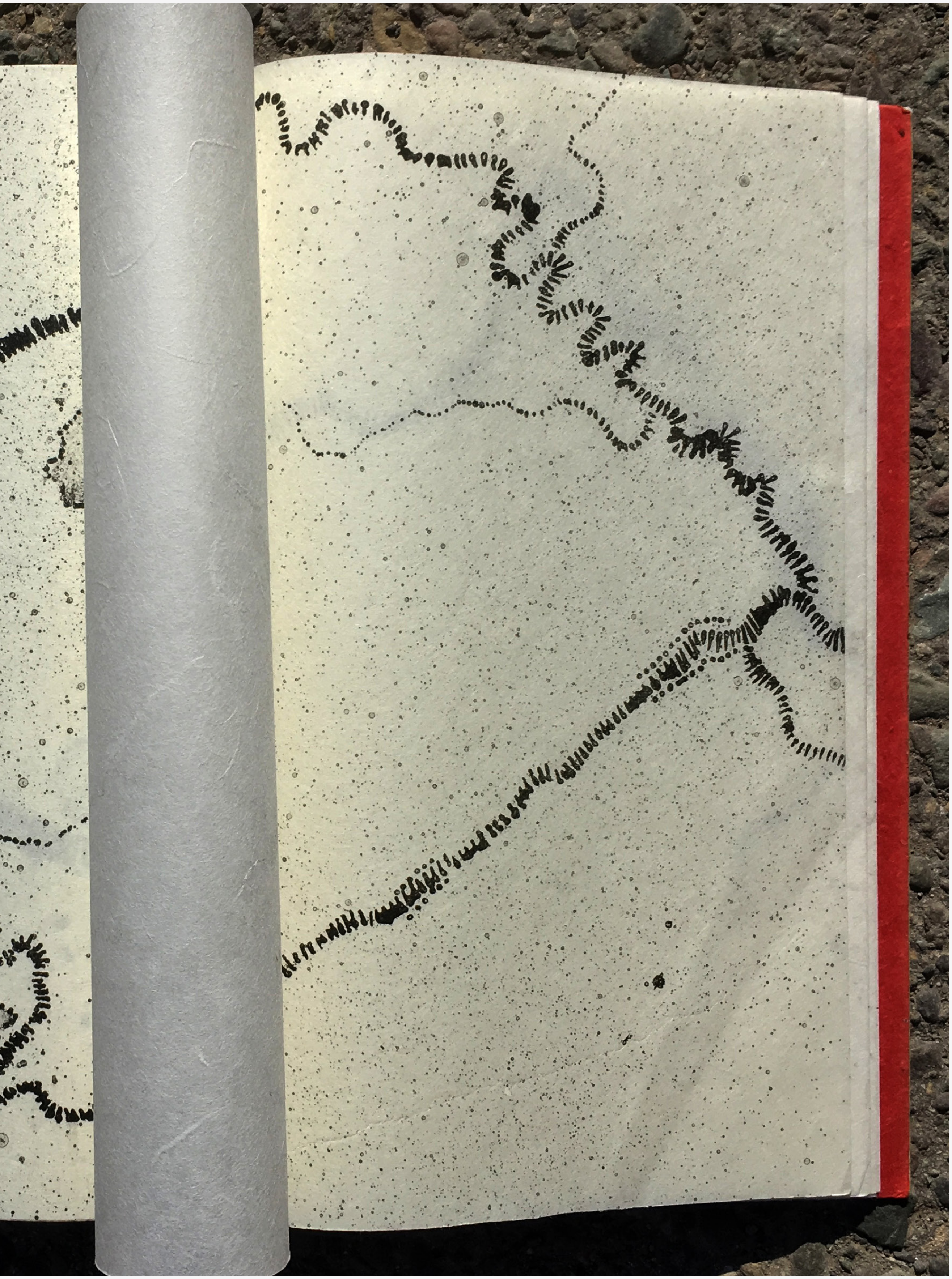
its thinking, along the Vermilion River links
    as the poem, the map—poem,
    everything together,
    everything interwoven,
    interconnected, changing, song and dance.

Every morning, in the wild rice shallows
I look for the heron and wonder what it has dreamed.

In what sense can a map,
    the domesticated map,
    ever know the dreams of the heron in flight,
    in stillness.

The river is the place where your voice came into song.

Flight Path of the Heron (Vermilion River & tributaries, Vermilion Lake to Crane Lake, Minnesota), *11 by 8 in. hand bound. Artist Book & Lithograph, 2007.*



Flight Path of the Heron (Vermilion River & tributaries, Vermilion Lake to Crane Lake, Minnesota),
11 by 8 in. hand bound. Artist Book & Lithograph, 2007 (continued).

Weightless
The tide, its waters in and out from the sea
The currents, swirling in the bay
The wind, the sun, the waves, the spray
    I am swimming within all these now
    and between the sky and the salty water.

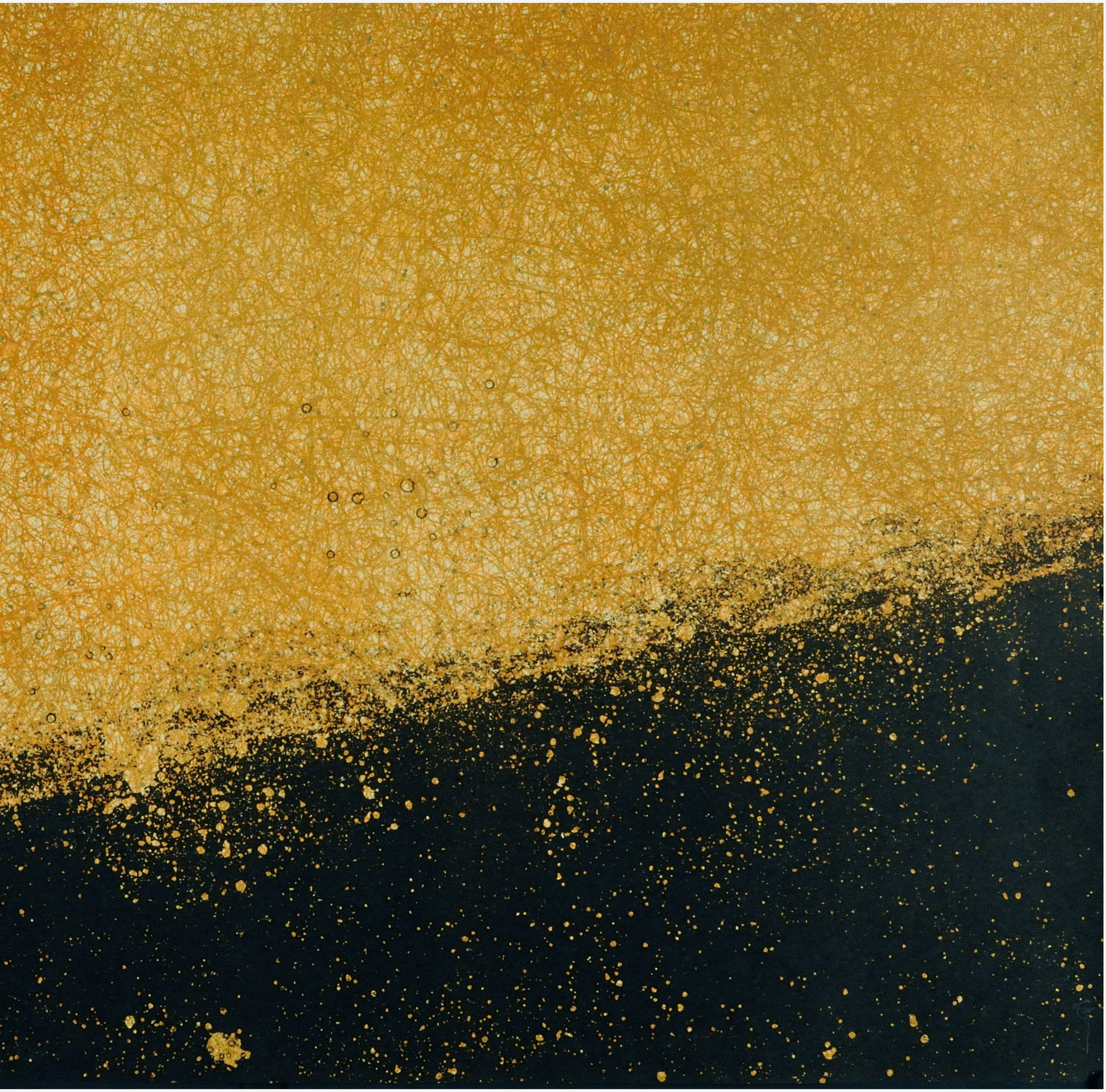
The pilot boat is nowhere
    then suddenly everywhere and nowhere to be seen
    rising and falling in the waves
we are in the water, we are so very small
swimming the Golden Gate under power of arms, lungs, legs
    being lifted by this, an immense Body
    being lowered now, into this Body.

Stroke, Two, Three . . . breathe right, sight for the landing
Stroke, Two, Three . . . breathe left, sight for the pilot
    suddenly beside me, their eyes looking high above
    I press against the side of the boat
    & push myself away, turn and look

falls the shadow.
I am swimming in the space between light & shadow
I am swimming in the moving waters; ahwō
All the while I am being carried
    everything unstoppable
    everything dancing
    everything moving, moving out to sea.

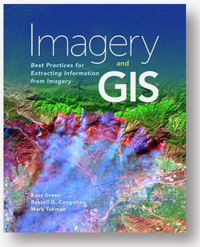
Falls the Shadow (The Golden Gate & the shadow of the Golden Gate bridge, California), *25 by 38 in. Stone lithograph on Sakamoto, 2008.*

Visual Fields focuses on the appreciation of cartographic aesthetics and design, featuring examples of inspirational, beautiful, and intriguing work. Suggestions of works that will help enhance the appreciation and understanding of the cartographic arts are welcomed, and should be directed to Section Editor Matt Dooley: **mapdooley@gmail.com**.



Falls the Shadow (The Golden Gate & the shadow of the Golden Gate bridge, California), *25 by 38 in. Stone lithograph on Sakamoto, 2008 (continued).*

IMAGERY AND GIS: BEST PRACTICES FOR EXTRACTING INFORMATION FROM IMAGERY



By Kass Green, Russell G. Congalton, and Mark Tukman

Esri Press, 2017

437 pages, $99.99, softcover.

ISBN: 978-1-58948-454-2

Review by: Jörn Seemann, Ball State University

Aerial photos and satellite images are fascinating sources for mapmakers since they can make the invisible visible and allow the extraction of important data for maps and GIS databases.

One of my first encounters with the literature on remote sensing and image processing was the second edition of *Remote Sensing and Image Interpretation* by Lillesand and Kiefer (1987). I eagerly wallowed through the more than 700 pages and jotted down notes on how to process, enhance, and classify satellite images step-by-step. That book contained mainly black-and white illustrations, but in the mid-section, the authors included about two score of color plates. Among these was one that drew my attention: the comparison between a panchromatic and an infrared image of Camp Randall Stadium at the University of Wisconsin–Madison. The IR film photo revealed the treachery of images: the turf of the football field was synthetic and not real grass.

For both of these reasons—their utility and the treachery—the production of maps frequently requires practical knowledge of how to prepare images.

There is no shortage of introductory textbooks about image processing on the market. Classic remote sensing texts such as *Fundamentals of Remote Sensing and Airphoto Interpretation* (Avery and Berlin 1992) and *Introduction to Remote Sensing* (Campbell and Wynn 2011) have been published in multiple editions, and specialized uses of satellite images in archeology (Forte and Campana 2016), the environment (Jensen 2013), urban planning (Yang 2011), and other fields, have also received book-length studies.

Imagery plays an essential part in a wide variety of geospatial projects involving GIS, GPS tracking, databases, online apps, and, of course, cartography.

Imagery and GIS proposes to teach readers "about the many ways that imagery brings value to GIS projects and how GIS can be used to derive value from imagery" (3), and the book provides useful insights into successfully preparing and integrating images into GIS and maps, and in support of analysis. Each of the the three authors: Kass Green, Russell Congalton, and Mark Tukman, can look back on decades of professional experience and research on the application of remotely-sensed imagery to real-world situations.

The authors mention three principal utilizations of imagery in a GIS environment: "as a base image to aid the visualization of map information," "as an attribute of a feature," or "as a data source from which information is extracted through the process of image classification" (21).

The latter use type—the preparation of images for applications—is the focus of this book.

The book is divided into four sections that correspond to the common sequence of a typical imagery project workflow: selection, processing, information extraction, and effective management. In the four chapters of the first section, entitled "Discovering Imagery," the authors present general ideas about the structure of images, fundamentals of remote sensing (electromagnetic spectrum, sensors, resolution, platforms, etc.), and some tips and checklists to help users select appropriate images for their specific projects.

Section 2 ("Using Imagery") has two long chapters that deal with the basics of image manipulation, including discussions of formats and properties, image enhancement, mosaicking, radiometric correction, and georeferencing. "Extracting Information from Imagery" is the third section, and discusses the information extraction process. Its five chapters provide an emphasis on diverse interpretation strategies, classification methods, and modeling techniques that help readers interpret and compare data in different space settings and time frames. The last section is made up of three chapters dedicated to the management of imagery and GIS data; accuracy issues, ArcGIS mosaic datasets; and the storage, publishing, and sharing of images in cloud platforms.

A final chapter, "Concluding Thoughts," offers "some nuggets of wisdom" (385) that the authors have gathered over their long experience in remote sensing research and their participation in many mapping projects. The twenty tips, laid out in bullet point format, address topics like the need for a well-crafted classification scheme; the best uses of high-resolution, hyperspectral, and lidar imagery in GIS projects; the importance of scripting in facilitating workflows; and the advantages of web technologies and services.

The text of the more than 400 pages of *Imagery and GIS* is printed in a generously spaced, easy-to-read sans-serif font that is interspersed with more than 150 figures and over a dozen tables. There are a large number of examples from different places in the United States, including an ArcGIS swipe map comparing before and after the 2016 flooding in Louisiana (315), woody debris monitoring in Vermont's Great Brook (81–83), and a very detailed look at the Sonoma County Vegetation and Habitat Mapping Program. The authors tell us that "over 30 of these figures are linked to external interactive applications, which allow you to explore the concepts in more depth" (9). Many of the URLs in the book lead to examples compiled for the Esri Landsat Explorer web app (landsatexplorer.esri.com). "Imagery and GIS Web Apps" is a set of Esri story maps, hosting fourteen different applications that allow interactive exploration and comparison of resolution, filters, temporal sequences, radar imagery, and many other topics discussed in the book. Most of these interactive maps include action buttons that allow the user to engage and "play" with the imagery by selecting a filter or defining a mask, or actively switching and "swiping" between two images from different periods. In their book, the authors provide information on how to explore these images. In addition to this, the web app hosts continuously updated versions of tables 4.2 and 4.3 from the book, which list and compare current and future commercial high- and very-high spatial resolution satellite products.

Besides these web resources, the reader is informed about other features and applications such as the Collector for ArcGIS tool (detailed use guidelines for which are included in the book). There are a lot of examples in the book and on line, but more detailed explanations, additional questions or even a few exercises would further enrich the experience.

While the numerous online resources are useful, they are not always convenient to access. It would be preferable to bring more of this material into the book itself. In the case of the Sonoma County study, however, the inclusion of 28 pages of text defining vegetation type hierarchies and listing dozens of Sonoma County plant and tree species with their botanical characteristics, habitats, and Latin names might not be absolutely necessary to illustrate "the importance of developing a robust classification scheme" (190).

This is a light and easy read that gently introduces the reader, who may not be very familiar with the world of satellite images, to basic concepts of image processing and enhancement for GIS. In addition to this, the 150-plus entry glossary is a useful aid to understanding the very specific terminology of remote sensing. However, it must be said that the book is mainly about the preparation of images *for* GIS use and not specifically about the use of imagery *in* GIS projects. The emphasis is on the creation of image data rather than its practical application. This is not a workbook with hands-on exercises, but a decision-making aid and an introduction to concepts, methods, and processes.

In comparison to other publications on the market, *Imagery and GIS* is far less technical and detailed than, for example, *Elements of Photogrammetry with Applications in GIS* (Wolff, DeWitt, and Wilkinson 2014) or *Image Processing and GIS for Remote Sensing: Techniques and Applications* (Liu and Mason 2016). At the same time, it is less practical and engaging than *Making Spatial Decisions Using GIS and Remote Sensing* (Keeranen and Kolvoord 2014), and less visual and popular than *The ArcGIS Imagery Book* (Brown and Harder 2016). None of this implies that this book is inferior to the others, but rather that it finds a useful kind of middle way approach. *Imagery and GIS* is an introduction to the fascinating world of spatial imagery for those readers who want to get a basic idea about remote sensing, image processing, and how images are prepared for GIS projects. Keeping in mind this limited aim, the authors deliver their message clearly and in a very comprehensive manner. Images are gaining increasing importance in mapping projects and GIS databases and these pictures can, literally, be worth more than a thousand words when it comes to mapmaking.

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ECOLOGICAL ATLAS OF THE BERING, CHUKCHI, AND BEAUFORT SEAS, SECOND EDITION

Edited by Melanie A. Smith, Max S. Goldman, Erika J. Knight, and Jon J. Warrenchuk; Cartography by Daniel P. Huffman

Audubon Alaska, 2017

332 pages, 100+ maps, and 100+ illustrations; $105, softcover.

Free PDF download: ak.audubon.org/conservation/download-ecological-atlas-bering-chukchi-and-beaufort-seas

Review by: Daniel Cole, Smithsonian Institution

This handsome book begins with an invitation to imagine various scenes of human-wildlife interaction in the Arctic. The editors, led by Melanie Smith of Audubon Alaska, want the readers to explore these and other Arctic marine scenes. Their goal, as set out in the opening paragraphs of the Introduction, "is to create a comprehensive, trans-boundary atlas that represents the current state of knowledge on subjects ranging from physical oceanography to species ecology to human uses" (2). This review will evaluate whether or not the atlas, and especially its maps, has achieved this goal.

The rest of the Introduction addresses a range of basic issues, including how the Arctic is managed, both nationally and internationally. It also provides a review of historic cartographic endeavors by the National Oceanic and Atmospheric Administration (NOAA) and by Audubon Alaska, followed by a discussion of mapping methods and challenges that includes issues of data quality and knowledge gaps. The section Use of Traditional Knowledge and Subsistence Datasets tells how the atlas content was reviewed by Bering Strait tribes, and is a critical inclusion.

The first map in the atlas is on page 9, and is a map of North America made in 1812 that shows the Bering and the southern Chukchi Seas, but nothing at all of the Beaufort. An accompanying inset of a Google Earth-like image of the region suggests how much we have learned about the geography of the area in the past two hundred years. One criticism that must be noted is that while the editors mention the David Rumsey Map Collection, neither a cartographer nor a map issuer is credited for the 1812 map. This lapse is unfortunate and inexplicable.

Daniel Huffman's well-rendered two-page base map completes the introductory chapter. This map provides topographic and bathymetric relief, political boundaries, the Arctic Council boundary, roads, rivers, ferry routes, villages, and cities, plus a line indicating the extent of Alaskan submerged lands. While the map is effectively and properly labeled, the addition of a legend would help the reader.

Following the Introduction are two chapters focused, respectively, on the Physical and Biological Settings, followed by four chapters that concern the Fishes, Birds, Mammals, and Human Uses of the region. Things are wrapped up with a six-page Conservation Summary.

All of the chapters except the Introduction and Conservation Summary open with a table of topical sections, with each entry represented by a small map. Each section, however, contains numerous other one-quarter to full-page maps as well as a number of satellite images, and because there is no comprehensive map index, finding any particular map requires the reader to peruse the atlas.

Chapter 2, Physical Setting, opens with maps of ocean currents in the three seas, with notations on flow direction, upwelling, stream discharges, summer and winter ice extents for 2006, and interpolated measurements of carbon depletion in marine sediments. A look at sea ice follows, with maps of old ice (ice that has survived at least one melt season) and of ice concentrations for 2016. A pair of two-page maps shows long-term changes in seasonal ice advance and retreat over the period from 1850 to 2015. Varied line symbols include a dotted line for 1850, dashed lines for 30-year monthly medians from 1980 through 2010, and thick, fuzzy lines for 10-year monthly medians between 2006 and 2015. Polygons symbolize the presence of polynyas, landfast ice, and mixtures of the two. There are also maps of marine ecoregions, Arctic air temperature differences, and sea ice concentration anomalies at the 2016 annual Arctic sea ice area minimum (September) and the 2017 annual Arctic sea ice extent maximum (March). Forty-five-year averages of shallow and deep-sea water temperature, sea ice concentration, ice phytoplankton concentration, micro- and macro-zooplankton concentrations, and benthic infaunal biomass concentration are placed side by side with maps of the same topics showing projections for 2040. These maps are appropriately colored either in light-to-dark tones or in diverging colors above and below zero, depending on the data. The last map in this chapter effectively combines mean sea level air pressure in diverging colors with a three-class set of arrows indicating wind speed.

The third chapter, Biological Setting, begins by addressing primary productivity. A Landsat 8 image shows a phytoplankton bloom around the Pribilof Islands. On the next two pages is a map of maximum integrated chlorophyll contoured with values from 2 through 900 milligrams per square meter. Sampling points are indicated, along with lightly shaded mean sea ice extents for March, May, June, July, and September. An inset of a satellite image that lacks a caption or any geographic connection to the text is provided, and seems to be of the Nunivak Island area. Logically following this is a section on zooplankton with a two-page contour map of average annual total zooplankton carbon mass, measured in milligrams of carbon per cubic meter. The lightly toned ice extents are again provided, but the sampling points are not. Next is another two-page map depicting the relative benthic biomass for the three seas, with both ice extents and lines indicating the limits of contributing surveys, plus point locations for documented coral and sponge gardens in the Aleutian Islands. This chapter is completed with distribution maps of several crab species, based primarily on trawl density.

Chapter 4 maps eight different fish types, including the *Osmeridae* forage fish family (which includes capelin, eulachon, and smelt), Pacific herring, walleye pollock, various cods (Pacific, Arctic, and saffron), Atka mackerel (which are limited to Aleutian waters), yellowfin sole, Pacific halibut, and Pacific salmon (Chinook, sockeye, coho, pink, and chum). Factors of interest illustrated include distributions and concentrations; wintering, feeding, spawning, and nursery grounds; nesting sites, and Essential Fish Habitat (EFH) areas, plus winter and summer migration routes. Some terminology is used inconsistently across the maps; for example, I question the use of the label "Regular Use" on the Pacific herring map as opposed to "General Distribution", which was used on some of the other maps. If there is a reason for using the different term, it is not obvious.

No one should be surprised that the 94-page Chapter 5, Birds, is the longest chapter in this Audubon atlas. The first map concerns Marine Bird Colonies across the three seas and uses pie chart point symbols with population size graduations and proportional species sectors. The six size classes range from fewer than twenty thousand to over five hundred thousand birds, and the pies are divided into up to five species categories (puffins, murres, auklets, storm petrels, and other). The ten largest colonies have a heavy black line around the pies and have small numeric tags indicating their size (from over six hundred thousand to over five million). With only four pies that are of the largest size but that are untagged, and given the numeric tags, I doubt that the black line is necessary. Wisely, the smallest circles are not shown as pies, and the vast majority, but not all, of the points are pulled away from their often densely clustered locations using leaders. However, nine of these leaders near the bottom of the page, including one associated with one of the larger colonies, point to indeterminate locations lost in the page binding. The locations are obscure even in the PDF version of the atlas, since that area of the map fades into a white "Incomplete Data" zone in the Gulf of Alaska. Overlaying the pie areas with the vector shorelines allows both the charts and the map to work independently without being too visually noisy.

This map is immediately followed by four half-page dasymetric maps of foraging guilds (surface planktivores, surface piscivores, diving planktivores, and diving piscivores) that use an effective yellow-to-red color scheme progressively indicating birds per square kilometer, along with small black dots indicating colony locations. Next is a two-page map of Important Bird Areas (IBAs) throughout the three-sea region. This map depicts IBAs as significant at the global (light red), continental (light orange), and state (light greenish-yellow) levels. Given that the vast majority of IBAs are in the global category, presenting the continental and state areas in brighter colors would have been warranted. This map is followed by two half-page maps, the first of annual bird density in shades of red over land and light yellow through shades of green over water, and the second of the number of surveys made at locations across the study area. These two maps together nicely illustrate how density estimates are based on collecting effort, and should not be confused with simple presence-absence. On the facing page are four one-eighth-page maps illustrating winter, spring, summer, and fall bird densities.

After these general studies, the atlas authors tackle individual species maps: starting with the King Eider, followed by the Spectacled Eider, Common Eider, Steller's Eider, Long-tailed Duck, Yellow-billed Loon, and the Red-throated Loon. Each of these two-page maps depicts regions of breeding, wintering, staging, and molting (the Loon maps do not include this last category) in four colors, fall and spring migration routes, plus approximations of the range extents over the Bering Sea and Arctic Ocean. General Marine Areas are also shown.

These give way to a series of half-page maps of the Red-faced Cormorant, Red-necked Phalarope, Red Phalarope, Aleutian Tern, Red-legged Kittiwake, Black-legged Kittiwake, Ivory Gull, Common Murre, Thick-billed Murre, Horned Puffin, Tufted Puffin, Parakeet Auklet, Crested Auklet, Whiskered Auklet, Least Auklet, Short-tailed Albatross, and Shearwaters. Most of these maps include five-class graduated circles for colony sizes, with major colonies emphasized, overlaying areas of regular use and concentration, plus dashed lines of approximate range extents. Colony size circles are not shown on the maps of the Phalaropes, but these maps do depict areas of breeding and non-breeding habitats by regular use and concentration along with the approximate range extents and spring and fall migration routes. The Ivory Gull, Albatross, and Shearwater maps are much the same except that they do not include any differentiation between breeding and non-breeding habitats. A few extra small maps illustrate the at-sea utilization distributions of the Kittiwakes, and the Pacific-wide seasonal migration routes of the Short-tailed and Sooty Shearwaters.

Chapter 6 deals with twelve species of mammals, beginning with seven maps about polar bears. Four half-page maps deal effectively with the intersection of the bears' seasonal marine habitat selection (in light-to-dark green tones) with the outlines of their three annual subpopulation core areas, and their ranges for hunting and denning.

Pinnipeds are next, opening with two large Summer/Fall and Winter/Spring seasonal maps on the Pacific walrus. The first depicts areas of regular use, concentration, and high concentration overlaid by four classes of graduated circles of current (2000—present) and historic (1850s—1990s) haul-outs (places they haul themselves out of the water), while the second shows only areas of use. The color scheme for areas of use changes from pale yellow-to-brown to light-to-dark purple between the two maps.

Bearded, ribbon, ringed, spotted, and northern fur seals each earn a half-page map, but the Steller sea lion merits a two-page map illustrating adult female foraging ranges, seasonal migration, critical habitats, and three classes of graduated diamonds for rookery populations.

Cetaceans finish off this chapter, beginning with two maps of the beluga whale counts, ranges, and migration. Curiously, the larger of the two includes an independent beluga population in Cook Inlet, which is outside the atlas study area. Bowhead whales are given four half-page maps, and gray whales a single half-page map. The humpback whale map is supplemented by a world map from NOAA showing humpback distinct population segment (DPS) groups with their respective breeding/wintering grounds and northern feeding areas, and indicating their population status as endangered, threatened, or "not at risk." It is not clear why world humpback populations, including southern hemisphere stocks, are shown, but not their Antarctic and sub-Antarctic feeding grounds.

The seventh chapter centers on human use of the areas in and around the three seas. Power plant locations and capacities, roads, sub-sea cable routes, airports, and ferry routes all feature. On the Transportation and Energy Infrastructure map, which uses graduated circles for power plants and points for airports, what looks like significant infrastructure exists around Kodiak Island, but the symbols are largely obscured as the map data gradually fades off. This is very much like the faded map data on the Marine Bird Colonies map, and raises the question of why these data are included at all. Either Kodiak Island is outside the study area, and should be excluded, or Kodiak's infrastructure is important contextual information and should be included: giving faded data sets is just a tease.

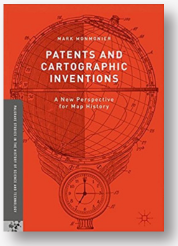
A simple and informative one-third page map of oil and gas infrastructure (roads, pipelines, gravel pads, and gravel islands) of the Alaskan northern shore is followed by a large map of the three seas showing petroleum exploration and development—depicting active and expired leases, planning areas, areas with petroleum potential, and current offshore and onshore wells. Factors concerned with vessel traffic are introduced with a small map helpfully showing the locations of emergency resources: Coast Guard bases, spill response equipment, and towing capacity. Two, colorful, two-page maps that deal with vessel traffic density and movement patterns differentiated by tanker, cargo, towing/tug, and fishing vessels in the three seas and the northern Gulf of Alaska present a spatial picture of a very busy maritime area. Also included are locations for shipwrecks and Coast Guard facilities, as well as the route of the first passenger cruise ship that traversed the Northwest Passage in 2016, the *Crystal Serenity*. Twelve small, monthly maps of vessel traffic are accompanied by a half-page total traffic density map. This last map duplicates one that appeared four pages earlier, with the addition of Areas to be Avoided—a topic that was discussed four pages earlier as well. The overview of vessel traffic is wrapped up with a closer look at the situation in and around Unimak Pass and the Bering Strait, described with bar graphs and a small map of each area.

The map of Fisheries Management Conservation Areas requires a bit of study, since this one map of all three seas covers areas of trawling restrictions, commercial fishing restrictions, prohibitions on bottom contact gear, and Steller sea lion protected areas, along with commercial fishing ports, the Alaskan state water boundary, and the average annual observed catch (in metric tons) in the central and eastern Bering Sea. Seven half-page maps cover the subsistence harvest of six major types of maritime produce—birds and eggs, fishes, marine invertebrates, polar bears, seals, walruses, and whales—followed by a two-page map of total subsistence harvest for six coastal Alaskan areas. The sheer amount of data on this last map required presenting it as regional graphs with one dot equaling ten pounds per capita of annual subsistence harvest of each produce type. The last map of this chapter covers conservation areas, classed by status as strict nature reserves, wilderness areas, national parks, national wildlife refuges, and protected areas with sustainable use of natural resources. It also includes nearby protected areas outside the Arctic boundary.

The atlas finishes with a conservation summary that includes discussions of climate change and other pressure points, and specifically addresses nine conservation themes and their management implications. Within each chapter, map data sources are given for all of the maps produced by Huffman, and a mapping methods subsection is provided to describe the rationale for all of the indexed major maps. Each section of every chapter has separate authors and independent reviewers. Legends and photos are effectively integrated into the maps with background base map data that fades away underneath. Moreover, each chapter has its own reference section; typically quite extensive.

While I have noted some quibbles in this review, they are all really quite minor complaints. Audubon Alaska, and especially Daniel Huffman, have achieved the goals laid out in the Introduction, and they can all be proud of this beautiful atlas.

PATENTS AND CARTOGRAPHIC INVENTIONS: A NEW PERSPECTIVE FOR MAP HISTORY



By Mark Monmonier

Palgrave Macmillan, 2017

267 pages, $109.99, hardcover.

ISBN: 978-3-319-51039-2

Review by: John J. Swab, University of Kentucky

Mark Monmonier makes a significant contribution to the contextualization of recent cartographic history with his new book *Patents and Cartographic Inventions*: *A New Perspective for Map History*. Focused on cartographic innovations approved for patents by the United States Patent and Trademark Office, the book weaves together the fascinating stories of the individuals who developed new mapping technologies from the mid-nineteenth century to the pre-digital twentieth century. Monmonier sees cartographic patents as a little-explored, "parallel literature" to academic cartographic scholarship (6). He proposes that the patent system, with a similar peer-review-like process conducted by patent examiners, provides both a methodological and metaphorical lens through which to understand cartographic innovations over the past century and a half.

The book is organized around thematic chapters examining innovations in identifying locations, wayfinding systems, map folding systems, map projections, novel globes, and a variety of other pre-digital cartographic topics. It examines how the inventions in each of these subthemes built upon both real-world challenges and previously submitted patents, while also detailing the larger stories behind the individual inventors and their adventures navigating the patent application process. As Monmonier's research uncovers, many of these patented innovations were useful and innovative technological developments, even if most were commercially unsuccessful.

While it may be common to believe that georeferencing technologies were only developed recently, as part of the geospatial revolution, an examination of patent records finds antecedents throughout the early twentieth century. For example, multiple patents addressed wayfinding systems that provided nuanced geographic information to aid travelers to reach their destination. Rolled strip maps, advanced by the revolution of car wheels or by hand, were among the first GPS-like technologies. Rural homestead finding systems, developed and sold from the 1910s to the 1930s, provided specially designed maps to aid visitors in locating specific farmsteads down poorly marked country roads.

Other types of inventions, such as those related to map projections or folding systems, were often far less commercially successful. Here, Monmonier contends, it was often more effective to simply use copyright law than to struggle through the patent application process. The important role played by patented paper folding machines (in developing novel ways to fold maps) is touched upon as an example of how innovations in other technologies can lead to new patentable inventions in the cartographic realm. Patent applications for new globes often stressed their educational qualities, with patents filed to protect innovations in mechanical globes highlighting atmospheric phenomena or orbital patterns. With the vast majority of patent applications filed by men, it is notable how the gendered nature of education played out with a relatively large number of globe patents issued to female inventors.

As the book recounts in example after example, winning approval from the United States Patent Office was (and still is) an arduous, time-consuming affair. Applications often languished for years, as examiners, inventors, and lawyers haggled over the meaning of descriptions, redrew poorly executed drawings, and bickered over sweeping technical claims. In practice, this often meant that applications took long periods of time, involving multiple rounds of revisions before finally receiving approval. Occasional grandstanding on the part of the inventor, the patent lawyer, and/or the patent examiner often led to ultimatums, fraught responses, and desperate appeals for leniency.

However, since Monmonier studied only approved patents it is difficult to understand how often and in what ways this review process may have failed. Normally, the approval process was a game of persistence and patience, in which the patent examiner and inventor would spar over individual claims until one side conceded (or modified the claims) and the patent was approved. Monmonier jokingly compares the patent process to the standard academic writing process in which "a stubbornly unwavering author can wear down a reluctant editor" (17).

In some regards, the importance of these patents to the historical cartographic record is questionable. Ultimately, most of the patents filed were never commercially viable, and generally very few physical examples have survived, arguably indicating a lack of widespread use. While some, such as the patented Van der Grinten projection used for the National Geographic Society's logo or the circular route indicators for early automobiles, were widely used, the broader impact of these patents is not always discussed. This is not due to any shortcoming in Monmonier's research, but rather to two specific factors. The first deals with the limited importance of the innovations—in other words, not all patents were commercially feasible and thus were limitedly distributed. The second involves the motives and circumstances of the inventor themselves—an inventor could patent any innovation, but the process of financing large-scale production and marketing held back ideas that could have been profitable under the right circumstances. Certainly the patent literature, especially that discussed in the book's last chapter on the transition to digital mapping, provides some inspiration for future inventors. However, except where there are direct citations of earlier patents in a new application, tracing this intellectual history is difficult.

While patents have long been a vehicle for financial gain (either through manufacture or by selling the intellectual rights to someone who can build the product), in recent years other tactics have provided an increasingly lucrative means of profiteering from inventions. *Patents and Cartographic Inventions* touches on the practices of individuals who file or purchase patents solely for the purpose of keeping innovations out of the hands of competitors and on actual patent trolls who purchase patents merely to bring litigation against competitors. Monmonier's brief discussion in the final chapter opens the door to a much deeper analysis that will be needed to fully understand the impacts of this relatively recent phenomenon.

Although one can argue that cartographic patents are a parallel literature to academic and professional literatures, the linkages between the two are not very clear. Addressing this Monmonier discusses the "theory of multiples," in which multiple, unconnected individuals develop similar innovations in a short time period (14). A key concept in the field of patent studies, the theory connects concurrent innovations with the emergence of similar solutions to different problems to contextualize why similar innovations cluster together temporally while often being dispersed geographically. Most of the chapters include one or more specially designed diagrams classifying patents by their primary technical aims and approval date. Although these diagrams are fascinating, and show the near-constant filing of cartographic patents, the text itself does not fully tie the body of patent literature to mainstream cartography during the nineteenth and twentieth centuries. Apart from an extensive, seven-page discussion of map folding methods in twentieth-century cartographic literature, most other developments are not well connected with applied cartography.

The National Science Foundation grant that Monmonier received to undertake this research placed particular emphasis on how inventors ultimately conceive and patent their innovations. The end result of this research is a wealth of biographical information on individual inventors. Unsurprisingly, the vast majority of examined inventors were Americans, although relevant international connections are made throughout the book. The volume of biographical detail can be a bit excessive at times—as are some of the liberties taken in making connections between different events (a point readily addressed by Monmonier in the Preface). Additional information regarding the biographical details of cartographic innovators—including many not covered in *Patents and Cartographic Inventions*—can be found in the recently published companion book entitled *A Directory of Cartographic Inventors* (Monmonier et al. 2018).

In terms of its construction, *Patents and Cartographic Inventions* is put together well. Illustrations are numerous and are often pulled from images available in the individual patent applications located in the National Archives or from the *Official Gazette of the United States Patent Office* —the government publication documenting newly issued patents since 1872. The images themselves are of high quality and are full page when needed, which greatly assists in making the details of the drawings legible.

Interestingly, the book is organized for individual chapter downloads directly from the publisher's website which means that citations are located after each chapter, a practice which makes searching for references easier. The end matter is similarly well constructed with a comprehensive index and a very informative appendix on how to search for patents. The only limitation in book construction is the lack of a comprehensive list of figures and diagrams, which can make searching for a specific image time consuming.

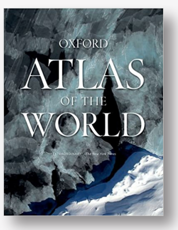
Coming in at a whopping $109.99 for the printed book, $84.99 for the eBook version, and $29.99 for individual eChapters, this is by no means an inexpensive book (although, as of writing, the printed book can be purchased for just over half-price on Amazon). However, for its niche topic, and in view of the dearth of other literature on cartographic patents, it is sure to become an essential read for those interested in this area of cartographic history. As such, it is an important acquisition for map libraries, those interested in the history of cartography, and scholars in science and technology studies.

In the end, Monmonier's book provides a much-needed, in-depth, and deeply researched analysis of cartographic patents. *Patents and Cartographic Inventions: A New Perspective for Map History* is recommended for those interested in understanding how cartographic innovations have developed over the past century and a half.

REFERENCE

Monmonier, Mark, Adrienne L. Atterberry, Kayla Fermin, Gabrielle Marzolf, and Madeline Hamlin. 2018. *A Directory of Cartographic Inventors: Clever People Awarded a US Patent for a Map-Related Device or Method.* Syracuse, NY: Bar Scale Press.

OXFORD ATLAS OF THE WORLD, TWENTY-FOURTH EDITION



Oxford University Press USA, 2017

448 pages, $89.95, hardcover.

ISBN: 978-0-19-084362-5

Review by: Tanya Buckingham, University of Wisconsin–Madison

The blurb on the back cover of the *Oxford Atlas of the World* boasts that it is "the only world atlas to be updated annually," which, incidentally, means that this review of the twenty-fourth edition, copyright 2017, should appear just barely before the twenty-fifth is released. The review begins with an inventory of the twenty-fourth edition, and is followed by a comparison with the 2016 (twenty-third) and 2014 (twenty-first) editions. A comparison to last year's offering was an obvious choice, and a look back at the twenty-first was added for two reasons: first as a point of reference as to how much the atlas has changed, and second because that edition had also been reviewed for *Cartographic Perspectives* (Denil 2016).

The physical copy of the atlas provided for this review is a solid, hard cover book containing 448 thick, glossy, pages. It weighs 7.4 pounds, measures 14.6 inches × 11.4 inches and is 1.4 inches thick. This edition of the *Oxford Atlas of the World* was published on November 1, 2017.

Opening the front cover, the reader is greeted with a world map on the endpapers. The cool color scheme of greens, blues, and greys in the twenty-fourth edition is quite different from the corresponding maps in the twenty-first and twenty-third editions, which sported a wider range of hues. The colors employed to indicate the extent, scale, and page number of each of the various atlas maps remain in the same groups, but are now tertiary, rather than primary, colors. One would expect that their brightness, in contrast to the new, more subdued background, would make them stand out better than they did in the previous edition, where they had more visual competition. I don't find this to be the case, myself, but perhaps the change was made to accommodate users with color vision impairments (a condition I lack). The legends to the world, city, and physical maps are all found on the opening endpaper as well.

The atlas maintains a consistent format across its recent editions, opening with a two-page "Foreword" spread, then a "User Guide," followed by the "Table of Contents." "World Statistics" comes after that introductory material, and provides an alphabetical listing of countries along with data on their area, population, national capital, and annual income in US dollars. Ranking each country in each data category would make comparisons easier and enhance the utility of the list. The same is true of the "World Statistics for Cities" found on page 7.

The opening subject for the thematic content section, which follows the listing of countries and cities, differs from the earlier editions. Recent editions opened with "The Future of the Oceans and Seas," followed by a pair of two-page spreads of issues and facts facing the world's water. In the current edition, the section "A Divided World: Land and Maritime Boundaries" begins with a timely photo of a rusty border wall crawling over an arid landscape, with a cactus situated near the center of the image. The text explains: "In areas where conflict is in the past and people on both sides of the fence can benefit from the free flow of goods and people, a boundary marker may be no more than a ceremonial sign. In more contentious areas, where it is seen necessary to control movement, formidable and physical barriers may be erected. The fence shown in this image marks the division between the United States and Mexico" (9). The four pages that follow are full of maps depicting boundaries cutting through land and water. This opening section feels like a challenge to the many countries currently taking action to become more insular, and makes an interesting start to an atlas that, at its core, relies on just these sorts of boundaries to frame and classify its contents. Arguably, one purpose of an atlas is to explore geographic relationships and the context of phenomena, yet this section leaves the reader to wonder what the world might be like if "artificial constructions" like national boundaries—so sharply portrayed in the atlas—were not so definite. Certainly, the boundaries that are depicted uniformly on the atlas' maps might actually exist in many different forms on the ground. These range from "very 'closed' boundaries, such as North Korea" which restrict the movement of both people and goods, to the more fluid boundaries of the European Union, and we can see that while some states have an adversarial view of their neighbors, other "countries are willing to surrender a degree of individual sovereignty in exchange for greater collective economic or military power." This is one of many times in the course of reviewing this book that I wondered how other people consume an atlas. I know that I rarely read the front matter, and if I had not read it for this review, I would not likely have considered viewing the atlas through this lens.

The next section, "Images of Earth," displays seventeen cities around the globe. Not only is the raw, majestic beauty of the Earth's physical landscape revealed in the images, but so too is the way human existence flows around those features. The images seem to convey an empathy with the human experience that reference maps of these same places are not able, and not typically intended, to display. Adding a scale reference to these images could help the reader grasp the extent of the built human landscape, which ranges from the iconic shapes sketched by the streets of Paris to the artificial palm and world-shaped islands rising from the sea off the coast of Dubai. From the barely perceptible human habitations of Kochi, in south India—where it is the natural features that stand out and the human settlements look almost like static—to the teeming life of the twin national capitals Brazzaville and Kinshasa facing each other across the Congo River, to the linear fields of Bangkok: these images help us see both the different ways that the land impacts human life, and the similarities in patterns of human habitation arising from our dependence on the natural world.

The "Gazetteer of Nations," which follows, is a concise profile of each country's geography, climate, history, politics, and economy, and has ready-reference tables illustrated with flags and location maps. It provides about as much information as one would expect, with variables that seem to make logical sense in summing up each country, as disparate as they may be.

The "World Geography" section is, in my opinion, the best part of any atlas, and this one hosts forty-two pages on a variety of thematic topics, supported by maps, charts, graphs, and diagrams. They are heavy on text and generally follow a three-column layout, with margin vignettes. While the *Oxford Atlas of the World* attempts to teach through text and small graphics, in the end this section comes across as less engaging than is necessary to succeed. My preference is for an atlas that is visually captivating—one that draws the reader in, and inspires deeper learning. Much like a classroom lecturer, an atlas no longer needs to convey all of the available information to the pupil. There is room for this atlas to become more visually striking in a way that would encourage the reader to ask questions that require additional research and inquiry.

"World Geography" opens with a spread entitled "The Universe." The presentation of this material incorrectly situates our known human existence at the center of the universe, arguably failing one of the purposes of an atlas: to place the reader within the context of *where*. Cartographers have a responsibility to consider the impact of their representations, and, without additional knowledge, one could gather from the information presented here that our solar system is actually at the center of everything.

The "World Geography" segments then move through "The Solar System," "Seasons, Time and Motion," "Geology of the Earth," "The Atmosphere," "Climate," "Climate and Global Warming," "Water and Vegetation," "Oceans and Seas," "Biodiversity and the Natural World," "Population," "Cities," "The Human Family," "Conflict and Co-operation," "Energy," "Minerals," "Employment and Industry," "Trade," "Health," "Wealth," and "Standards of Living"; all are, for the most part, full of standard explanations that can be found in introductory texts on the subject. There are some striking oddities in the treatment of graphics, such as inconsistencies in how bar and pie charts are shown: some are in three dimensions, others in two; some have drop shadows, others do not. Similarly, the various maps in the "Conflict and Cooperation" spread display inconsistent coastlines, and three of them sport coastlines much too heavy and dark for their detail. The complicated graphic of air circulation on page 76 is cluttered by a topographic image, which is not only irrelevant but also out of character with the style of the other thematic maps.

Several of the maps struggle with colors that are hard to differentiate, particularly when the authors use a single hue sequential scheme; adding a second hue, or increasing the differences between class colors would help. Furthermore, there are some maps here that would cause some persons with color vision impairments a real struggle to interpret.

There are a few curious projection decisions. Just as Denil (2016) critiqued in his review of the twenty-first edition, pseudocylindrical projections are still portrayed as rectangular, where the curved edges of the water are replaced with straight edges that meet at 90° angles, and indicate only the Prime Meridian and Equator. We might also ask why the Peirce projection was chosen for the "Tourism and Travel" map on the "Employment and Industry" spread, given that it emphasizes the area with the least data by placing it in the center.

The particular themes of the section differ slightly from recent editions of the atlas. "Oceans and Seas" was added in the twenty-fourth edition, pulling content from "The Future of the Oceans and Seas," which was the opening section of the previous editions. The oceanic conveyor belts map would be slightly more visually effective if the projection were centered at a location where the belts were not interrupted. To make room for this new spread, the old "Food Supply" spread is no longer part of the atlas.

As one would reasonably expect, there are modest changes to the data on these maps when compared to the earlier versions considered here. Some photos were also updated, as are some minor data categories; for instance, "Renewables" was added to the "Energy Consumption" graph in the twenty-fourth edition, and the map of inflation on the "Wealth" spread acquired "Negative Inflation" as a category. This "World Geography" theme also contains the biggest change within an existing spread. The bottom half of the second page in the previous editions had focused on Goal 1 of the United Nations Sustainable Development Goals, with a map showing "Growth in GNI" and a chart supporting some text for "Tackling Poverty – Millennium Development Goal 1." These are no longer present, and in their place are icons representing each of the seventeen UN Development Goals. The icons are large and heavy, without much content, and what information they do convey could have been communicated more efficiently.

Following the thematic spreads are maps of seventy urban areas around the world, described as "useful for planning trips around the world, and comparative studies." The city maps include an overview of the city extent with a locator map, and some of them include a closer look at the "central" part of each city. There are varying color bars for the titles, but it is not clear what the color bars are supposed to indicate. A better use of color would have been to link the different maps of same cities together.

The bulk of the atlas, 179 pages of general physical & political reference maps, displays Philip's (**philips-maps.co.uk**) cartography with relief shading and stepped hypsometric tints, starting with two world maps on a Winkel Tripel projection, centered just east of the Prime Meridian. The colors of the physical map could have been improved by using shades of the underlying hypsometric tints to represent the hillshade shadows rather than the black overprint, which muddies the color. Also, the weights of the elevation color steps are not even—the yellow and orange are quite close, as are the two greens.

After making stops at the Poles, the Atlantic Ocean, Greenland, and Iceland, we dive into the continents. The coverage starts with Europe and follows a zig-zag pattern: first to Asia, then Africa, to Australia, through the Pacific Ocean, over to North America, and ending in South America. One criticism here is that the North America map shows the United States and Canada with states/provinces delineated, whereas there are no other continental maps showing equivalent sub-national administrative boundaries. Even Mexico, which appears on the same North America map, does not have its states included.

The "Geographical Glossary" fills over one hundred pages, and contains an 86,000-name index, giving latitude, longitude, and grid references for geographic features, towns, and cities. Geographic indices like this obviously play a large role in the utility of the atlas, are no small task to create. At the close of the book, the endpapers show a guide to the European maps, in the same style as the reference map of the world with which the atlas opened.

The cover of the *Oxford Atlas of the World* proudly displays praise from a number of reputable sources, including *The New York Times*, which remarked: "Extraordinary." The same supportive comments appear on each of the three editions at which I looked, making me wonder how long ago it earned the praise, though for the most part the changes to the atlas through editions twenty-one, twenty-three, and twenty-four are modest data updates. If you are simply wondering whether to update your copy with the latest edition, you may want to consider how much time has passed since your last purchase, and how much the data may have changed. If, on the other hand, you are looking to add a world atlas to your collection, the compact size and introductory coverage of topics in the twenty-fourth edition of the *Oxford Atlas of the World* make it useful for a number of general purposes. This atlas is neither flashy nor dramatic, but it is a sturdy and reliable product that seems to convey a good range of information in straightforward manner.

REFERENCE

Denil, Mark. 2016. "Review of Oxford Atlas of the World, Twenty-First Edition." *Cartographic Perspectives* 83: 35–39. doi: **10.14714/CP83.1349**.

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ABSTRACT: An abstract of 250 words or less should summarize the purpose, methods, and major findings of the paper.

KEYWORDS: Five to ten keywords should be listed at the end of the abstract.

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The general format is: Name of author(s). Year. *Title in Italics*. City of Publication: Publisher Name.

Robinson, Arthur H., Joel L. Morrison, Phillip C. Muehrcke, A. Jon Kimerling, and Stephen C. Guptill. 1995. *Elements of Cartography, 6th Edition.* New York: John Wiley & Sons.

Articles in Periodicals: Author's or authors' names as in *Books,* above. Year. "Title of Article." *Title of Periodical,* volume number, page numbers, DOI if available. Follow punctuation and spacing shown in the following example.

Peterson, Michael. 2008. "Choropleth Google Maps." *Cartographic Perspectives* 60: 80–83. doi: 10.14714/CP60.237.

Articles in edited volumes: Name of author(s). Year. "Title of Article." In *Title of Edited Volume*, edited by [Editor's or Editors' names, not inverted], page numbers. City of Publication: Publisher's Name.

Danzer, Gerald. 1990. "Bird's-Eye Views of Towns and Cities." In *From Sea Charts to Satellite Images: Interpreting North American History through Maps*, edited by David Buisseret, 143–163. Chicago: University of Chicago Press.

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Cartography Associates. 2009. "David Rumsey Donates 150,000 Maps to Stanford University." *David Rumsey Map Collection*. Accessed January 3, 2011. http://www.davidrumsey.com/blog/2009/8/29/david-rumsey-donates-150-000-maps-to-stanford.

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A Plan of the City of New York and its Environs. P. Andrews, sold by A. Dury in Dukes Court, St. Martins Lane, surveyed by John Montressor, 1775.

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