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IN THIS ISSUE

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ABOUT THE COVER: *Detail from Mercury, part of the Atlas of Space by Eleanor Lutz. To read more about her work, check out the Practical Cartographer's Corner, beginning on page XX, or visit her website, tabletopwhale.com.*

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LETTER FROM THE EDITOR

It feels a bit strange to be sitting here in my home office penning this letter to you, the readers of *CP*. I would hazard a guess that few of us would have imagined our current circumstances as the year turned over into a new decade, but here we are. The speed of modern transportation networks aided the quick spread of the novel coronavirus, but modern communication technologies have also helped us to more efficiently spread information that can reduce the human costs of the virus. Unfortunately, they have also led to the faster spread of misinformation, but that is a topic for another day.

Maps have been important to investigating and curbing disease outbreaks long before we were able to identify their causal agents through imaging techniques like microscopes or through cell cultures, assays, and DNA testing (Koch, 2005; 2011). They have been ubiquitous in devising responses to coronavirus in different parts of the world. Everyone connected to the internet must by now have seen some form of the **Johns Hopkins dashboard** that tracks cases across the world, and every major news outlet has their own set of maps and information visualizations about the outbreak. Even in my own household, I cannot escape coronavirus mapping because one of my family members is on the team that makes daily maps of cases to update decision makers here in Australia. Looking at too many of these maps can make you wonder how we will get through these times.

But maps are much more than technocratic tools for supporting decision making. They can also be used to give us joy, pleasure, and hope. For those of us who need something along these lines, I can point to a few ways that maps can give us moments of enjoyment in the upcoming weeks and months, during which many of us will be sheltering at home, with our normal activities curtailed or redirected. First, Anton Thomas's long-awaited, hand-drawn map of North America is now in print. Even if you're not lucky enough to have a copy of your own to hang on the wall, you can get lost in it for a while through some of the presentations he's given on its construction at past NACIS Annual Meetings (**2017**; **2019**). Second, Volume 5 of the ***Atlas of Design*** is currently being put together by editors Nat Case, Brooke Marston, Caroline Rose, and Vanessa Knoppke-Wetzel. This is definitely something to look forward to poring over later this year. For those of you who need a pick-me-up far sooner than that, there is the **#mapsathome** hashtag that Ken Field started a few weeks ago on Twitter, where you can find a daily dose of mappiness. If it's interpersonal interaction with fellow map nerds that you're missing, you can check out **How to do Map Stuff**, an online streaming conference started by Daniel Huffman, being held on 29th or 30th of April (depending on your location). Finally, I can now offer you this new volume of *CP* to peruse.

In *CP 94*, you will find two *PEER-REVIEWED ARTICLES*. In the first, Georgianna Strode and colleagues revisit Bruce Trumbo's ideas from the 1980s on bivariate choropleth map design. They offer a set of focal models that illustrate how bivariate choropleth maps can be designed to answer one of three types of questions. In the second article, Chelsea Nestel combines insights from cartographic semiotics and experiential graphic design to analyze the maps and signage at the ancient site of Troy. Her work underscores the importance of good design in enhancing the user experience at cultural heritage sites, especially those at which maps can help visitors to imagine landscape features that are now present only as remnants of their former structure.

At a time when many of us might like to escape planet Earth (or maybe only your housemates!), you can travel to the Moon with Eleanor Lutz's piece in *PRACTICAL CARTOGRAPHER'S CORNER*. It describes how she created the *Geologic Map of the Moon* that she displayed in the 2019 NACIS Annual Meeting's Map Gallery.

In *VISUAL FIELDS*, Darin Jensen shows it is possible for people from all over the world to quickly collaborate to create something together in his piece on Guerrilla Cartography's Atlas in A Day project, which took place in October 2019.

Four book *REVIEWS* complete CP *94*. Michelle Church reviews *Wild Migrations: Atlas of Wyoming's Ungulates*, a thematic atlas produced through a collaboration between several Wyoming-based scientists and science communicators, and cartographers at the University of Oregon's Infographics Lab. Allan Mustard, the banquet speaker at the 2019 NACIS Annual Meeting, draws on his past experience as diplomat posted to the USSR to ably provide a perspective on John Davies and Alexander Kent's *The Red Atlas: How the Soviet Union Secretly Mapped the World*. Daniel Cole summarizes the strengths and weaknesses of *GIS for Science: Applying Mapping and Spatial Analytics*, a recent Esri Press book edited by Esri's Chief Scientist, Dawn Wright, and Christian Harder, which profiles interesting scientific projects that make use of mapping technologies. Finally, Jenny Marie Johnson compares the contents of three recent volumes penned by Edward Brooke-Hitching, an English writer and map collector, that tell the story behind a selection of historic maps. Each volume uses a different lens through which to view its selection of maps.

Please take care of yourself and each other. I hope *CP* 94's contents provide you with a few hours of mappiness in these uncertain times.

Amy L. Griffin *(she/hers)*
Editor, *Cartographic Perspectives*

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Operationalizing Trumbo's Principles of Bivariate Choropleth Map Design

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Trumbo's (1981) ideas on bivariate choropleth design have been underexplored and underutilized. He noted that effective map design (including color selection) is directly informed by the intended goal or use of the map (i.e., what questions might the map answer), and he identified three common spatial relationships that can be displayed by a bivariate choropleth map: inverse relationships, a range of one variable within another, and direct relationships. Each is best suited to answering different map readers' questions. Trumbo also suggested sample color palettes to focus the map reader's attention on pertinent data. In consultation with Trumbo, we extended his ideas, first by creating focal models *that illustrate his three spatial relationships. We then constructed sample maps to examine each of the focal models, and finally compared each model by mapping the same two data sets (of obesity and inactivity). We investigated the visual differences in each of the resulting maps, and asked spatial questions regarding the relationships between obesity and inactivity. Our work validates Trumbo's ideas on bivariate choropleth map design, and we hope our focal models guide cartographers towards making color choices by linking their map purpose to the appropriate focal model.*

KEYWORDS: Bivariate choropleth map; sequential color scheme; diverging color scheme; color selection

> "Confusion and clutter are failures of design, not attributes of information. And so the point is to find design strategies that reveal detail and complexity — rather than to fault the data for an excess of complication. Or, worse, to fault viewers for a lack of understanding."
>
> Edward Tufte, Envisioning Information, 1990

BIVARIATE CHOROPLETH MAPPING

While univariate maps, which represent one thematic variable at a time, are both standard and widespread (Jin and Guo 2009; Brewer 1994), bivariate maps have the potential to reveal spatial relationships and patterns between two variables on a single map more effectively than by using two side-by-side univariate maps (Carstensen 1986). Bivariate maps can make use of a variety of symbol strategies, such as color combinations (as we explore in this paper), shaded proportional symbols, shaded cartograms, split symbols, shaded isolines, or star plots (Friendly 2008; Kimball and Kostelnick 2017). Though they can represent any pairing of thematic variables, they are typically employed to examine the relationships between socioeconomic variables, such as elderly populations and ethnic minorities, or levels of educational attainment and household income. A well-constructed bivariate map displays both the distributions of its individual datasets and their degree of interaction, and—at least for some visual variable combinations— variation in one thematic variable does not impair the ability to read the other (Ware 2009).

The alternative to bivariate mapping is to compare two univariate maps side-by-side; often inconvenient and inefficient (Leonowicz 2006; Wainer and Francolini 1980;

Bernard et al. 2015). In order to keep information cost to a minimum, the type of data classification, symbol choices, and scale must be comparable across all maps in the series (Wickens, Gordon, and Liu 2004). Yet even when mapmakers use consistent visual communication techniques, human judgment can be shaped by the user's experience in map reading, familiarity with the subject matter, and the limitations of human visual perception. We adhere to the hypothesis that given the difficulties of creating comparable univariate maps, pursuing methods to visualize multiple phenomena on a single map is worthwhile (Leonowicz 2006).

Frequently, bivariate maps produce ambiguous representations that convey information poorly (Dunn 1989). A common method for creating bivariate maps is to superimpose two choropleth maps. This technique, called the overlay, crisscross, merge, or crossing, combines two maps along with their color schemes to produce a new map with a new set of colors (Monmonier 1989). An early example of overlays is the US Census Bureau's 1970s *Urban Atlas* map series, which contained sixteen-color, mass-produced maps showing various pairings of data variables. Although the maps were aesthetically pleasing, they were strongly criticized as difficult to interpret (Fienberg 1979; Wainer and Francolini 1980; Dunn 1989), as cartographers had no literature to guide their interpretations and relied on their own judgment and that of colleagues (Halliday 1987). More recently, techniques for drawing bivariate choropleth overlays have improved, and studies have demonstrated that effective color schemes can greatly enhance their readability (Eyton 1984; Robertson and O'Callaghan 1986; MacEachren et al. 1999; Rheingans 1997; Leonowicz 2006). Nevertheless, they still lack sophistication for the interrogation of data relationships.

Bivariate choropleth mapping is a relatively recent cartographic method, dating to 1974, when the US Census Bureau saw value in combining two data sets into one map. A suggestion was made for "two choropleth maps of different variables to be 'crossed'" or overlaid (Meyer, Broome, and Schweitzer 1975, 102). This melding became colloquially known as the overlay. The overlay is constructed by combining two univariate choropleth maps and their color schemes through transparency, by overprinting, or by manual color adjustments (Stevens 2015). The overlay scheme is considered a method of convenience and is not necessarily the best choice (Trumbo 1981). Although the overlay scheme works well in some instances, critics of bivariate choropleth mapping note that the overlapping color schemes can become muddied and indistinct, especially the farther they are from the legend's x- and y-axes. The information cost for a map can be unnecessarily high when a less-than-ideal bivariate choropleth mapping method, such as the overlay, is utilized. This can force map readers to refer to the legend more often than necessary.

In the mid 1970s, the Census Bureau developed an automated mapping system and began creating a series of bivariate maps for mass distribution. The overlay scheme was used to merge yellow-to-red on the x-axis and yellow-to-blue on the y-axis. The resulting color scheme was a confusing mixture of colors. "Considerable practice" was required to discriminate among the colors in the legend and to organize data relationships (Fienberg 1979, 176). A study by Wainer and Franconi (1980) found difficulties in map comprehension, and they concluded that the Census maps did not meet Bertin's (1973) elementary level of inquiry as it was difficult to answer a question such as, "what is the median family income at this spot?". Tufte (2001) termed the maps "puzzle graphics," because users had to run phrases through their minds to aid comprehension. Olson's (1981) study on users of the bivariate maps concluded that participants could recognize order, but judging correlation between two variables was more difficult than using two side-by-side univariate maps.

Figure 1 offers an example of the difficulties of the overlay method. It shows the percentages of education and income. Unfortunately, this scheme produces ambiguous mixtures across the blue-to-violet range that are difficult to distinguish visually and could require users to view the legend too often.

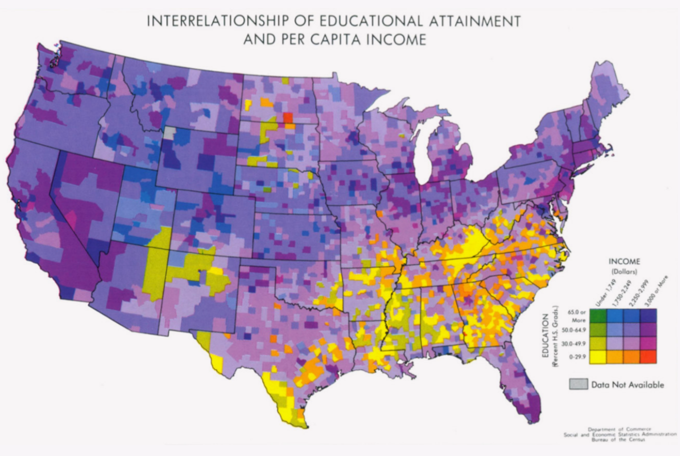


Figure 1. *Bivariate map from the 1970s* Urban Atlas *from the US Census Bureau.*

TRUMBO'S THREE RELATIONSHIPS

Both univariate and bivariate choropleth maps can answer a variety of questions. For example, assume a thematic variable pair of income and education level. Univariate maps are limited to proximity queries about a single data variable, and restrict interrogation to questions such as: Do low income tracts occur mainly in the center of the city? Are tracts with highly educated populations mainly in the suburban areas with an especially heavy concentration in the northern suburbs? (Trumbo 1981, 223). In contrast, bivariate choropleth maps answer more complex questions involving thematic variable pairs: Are all of the districts with both low income and low education near the center of the city? Are there tracts with high education and low incomes? What is the range of educational attainment among high earners? Is there a positive association between the two variables? Or what spatial patterns are formed by exceptional cases? (Trumbo 1981, 223).

For Bruce Trumbo, effective design (including color selection) is directly related to the map's purpose, as expressed in these sorts of questions (Trumbo 1981). "My personal motivation . . . was to improve on the bivariate color scheme adopted by the U.S. Bureau of Census. In my view, there are many ways to do that, including ones I suggested" (personal communication, July 2, 2019). However, a review of the literature suggests that the creation of bivariate maps does not necessarily begin with a conscious articulation of each map's purpose (Nyerges 1991; Caquard 2015). Trumbo's 1981 paper identified principles to facilitate the comprehension of statistical maps and identified several color schemes appropriate for different map purposes. Our paper focuses on map purposes, or types of questions that a bivariate choropleth map can answer, as identified by Trumbo, rather than upon his specific color scheme suggestions.

Trumbo identified three common data relationships that together cover many of the questions that a reader might ask of a map. These are seen in Table 1: inverse relationships, a range of one variable within another, and direct relationships. Each corresponds to a different map purpose and facilitates its own range of questions. Trumbo also suggested sample color palettes to focus the attention of the user on data pertinent to the map's purpose (Trumbo 1981). Each question uses a statistical emphasis to place focus on specific types of interactions between variables. One method, the inverse relationship, explores the highs and lows of the two variables. A sample question is "where are high foreclosures within low-income areas?" The corresponding bivariate choropleth map design should highlight the areas with high and low values for both inputs while de-emphasizing the areas where values are normal or average. A second method focuses on a range of values within a specific category. A sample question is "what is the range of foreclosures within areas of high income?" The corresponding bivariate choropleth map would first identify the various categories, and second, show the progression of values within each category. A third method shows the relationship between the two variables. A sample question is "what is the relationship between income and foreclosures?" The corresponding bivariate choropleth map displays the correlation between the variables.

Type of Question	Inquiry Formula	Sample Questions
Inverse relationship	low/high of __ and/or low/high of __	Where are high elderly populations with low income?
Range of one variable within a category of another variable	range of __ within low/high of __	What is the range of education among high earners?
Direct relationship	relationship of __ and __	What is the relationship between income and education?

Table 1. *Three types of questions a bivariate choropleth map can answer based on Trumbo's data relationships.*

TRUMBO'S FOUR PRINCIPLES

Each of these three types of questions places emphasis on different interactions between data variables, and each can be supported by the thoughtful use of color. To that end, Trumbo articulated four principles of color usage to distinguish similarity and dissimilarity. Principle I is **order:** for data ordered quantitatively, the colors should preserve the order, i.e., they should show a progression of hue, saturation, and/or lightness (whether individually or in combination) that can be detected by the human eye. Principle II is **separation,** in which important differences in values are represented by colors that are equally different. Colors are spaced comfortably apart, or separated, from others. Principle III refers to **rows and columns:** in a bivariate legend, each row or column represents a univariate dataset and should be in a visual sequence, with colors that are distinct enough that the corners of the bivariate legend stand out. Lastly, Principle IV relates to the legend **diagonal**. If the interaction between variables is critical, then the principal diagonal is the focal point and it should be visually separated from colors on either side. Both univariate maps and bivariate choropleth maps use Principles I and II, but Principles III and IV are formulated specifically for the latter.

Trumbo's four principles provide theoretical insights into how color can communicate data changes and relationships using bivariate choropleth maps. The first two principles involving color sequences have been successfully applied within GIS largely due to efforts of Brewer (1994; 2005) and Brewer et al. (2015). The gradient formation of Principle I is represented by Brewer's sequential color scheme, and the mutually distinguishable colors of Principle II are represented by the diverging color scheme (Brewer 2005). Principles III and IV combine multiple color schemes in various ways to direct focus to specific portions of the data to address the map's original question. Principles III and IV have not been widely transferred to GIS color schemes. Univariate map makers often start with a clear purpose for a map and correspondingly design their maps to communicate a specific idea or theme. In this sense univariate maps may be seen as more often confirmatory in purpose and for public consumption (MacEachren 1995; Tukey 1980). However, bivariate map makers construct more complex maps (multiple variables), which are often exploratory in purpose and not necessarily for the public consumption (Tyner 2010).

THE ROLE OF DESIGN IN FOCAL MODELS

Focal models are illustrations that show how to translate Trumbo's three spatial relationships into specific color choices that adhere to his four principles of color usage. Figure 2, for example, illustrates three color schemes and how they highlight specific data. The sequential and diverging color schemes from Brewer (1994) align with Trumbo's Principles I (order) and II (separation). Sequential schemes order sequences from low to high to illustrate linear progressions of values (Brewer 2005; Slocum et al. 2005). Sequential schemes are characterized by words such as "range," "progression," and "gradient." They minimize low values while emphasizing high values. Diverging color schemes show separation by emphasizing the extremes with complementary colors and de-emphasizing the central areas. They minimize statistical descriptions such as "average," "common," "normal," "regular", "expected," and "unchanged" while emphasizing high and low values, changes, distinct values, differences, and standard deviations. In effect, diverging schemes are two complementary sequential color schemes joined at the center, designed to highlight the extremes and minimize the expected values. Qualitative schemes represent differences in data categories and do not use ordered colors because mathematical operations are meaningless on nominal data (Brewer 1994).

Trumbo's original color scheme examples were designed for the Ostwald and Hickethier solid cube color models that are no longer used today. Both color models are "uniform color spaces" as they are known within the field of

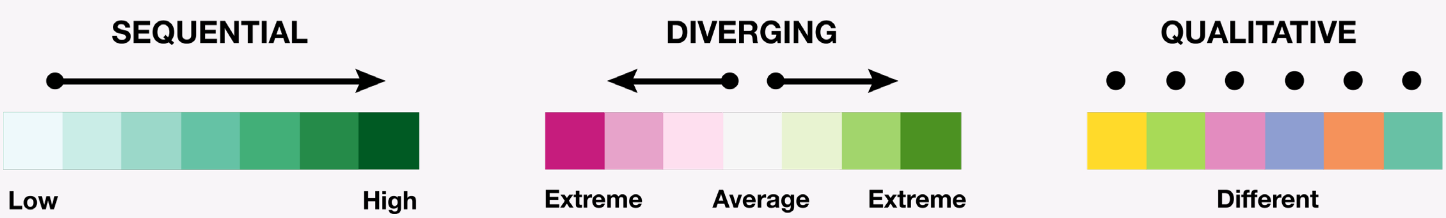


Figure 2. *Sequential, diverging, and qualitative color schemes (Brewer 1994).*

color science (Wyszecki and Stiles 1967). Uniform color spaces are based upon a geometric shape such as a square or cone and use a consistent, measurable metric, making perceptive color differences more intuitive. Validation of color similarity and difference can be achieved through examination of the color metrics (Robertson and O'Callaghan 1986; Bujack et al. 2017). Robertson and O'Callaghan demonstrated that Trumbo's principles are achieved through uniform color models. Principles I (order) and II (separation), used for both univariate and bivariate maps, are easily achieved through the consistent measurable metrics of the model. For bivariate maps, Principles III (rows and columns) and IV (diagonal) can also be satisfied through differing schemes. The diagonal is achieved through a square model that highlights the diagonal, and rows and columns are successful using a conical model that preserves linearity within a group (Robertson and O'Callaghan 1986).

Trumbo (1981) proposed his principles for bivariate choropleth mapping prior to mapmaking software being generally available outside of governmental agencies and labs (Waters 2018). He had limited opportunities to test his theories before publication (Trumbo, personal communication, July 2, 2019). Uniform color models are independent of any particular display device, and for reproducibility on different display devices, it may be necessary to adjust the hue, saturation, and lightness—a process known as "device modeling" (Robertson & O'Callaghan 1986). For example, Ware (2009) notes differences between types of monitors where some colors have more luminescence than others, which can alter the visual output. As Trumbo writes,

> there are more difficulties rendering these schemes on screen and in color printing than I had supposed. Color settings on a monitor have to be just right in order to show strong association to best effect (with my schemes), and the usual precision of color printing in popular magazines is not sufficient to represent some color schemes to good effect. (personal communication, July 2, 2019)

Color settings on monitors have advanced significantly, allowing for a greater and broader use of color in cartography (Monmonier 2006). Modern computer graphics use one of several RGB color spaces defined by the primary colors of red, green, and blue in the X, Y, and Z axes. Color scheme parameters such as color separation, the logical arrangement of colors, and a zero-saturation diagonal can be automated by symbology tools available today in most GIS software.

BERTIN'S INFLUENCE

BERTIN'S (1973) *SEMIOLOGIE GRAPHIQUE* introduced an ambitious and comprehensive theory to formalize graphic language. His concept of visual variables (e.g., size, shape, value, orientation, color, texture) serves as a guide for map symbology in cartography textbooks. In addition to his contribution of visual variables, Bertin described three levels of reading possible in map comprehension:

- **Elementary level**: Direct translation from the perceived graphic variable to a quantitative component. For example, "what is the median age at this location?"

- **Intermediate level**: Trends between two variables are related and understood. For example, "what is the relationship between median education and distance from the inner city?"

- **Superior level**: The entire structure of one variable is compared with that of the other. For example, "how does the geographic distribution of median family income relate to that of the percentage of college graduates?"

Robertson and O'Callaghan (1986) concluded through their color evaluations that Trumbo's principles and suggested color schemes supported Bertin's vision of the levels of comprehension that maps should support. The definitions of the intermediate and superior levels require multiple thematic variables, thus suggesting that Bertin may have envisioned bivariate and multivariate maps as readily achievable. The focal model that supports seeing the range of one variable within a category of another variable successfully addresses the elementary level because a perceived variable can be translated into a quantitative value. The model focusing on direct relationships can support

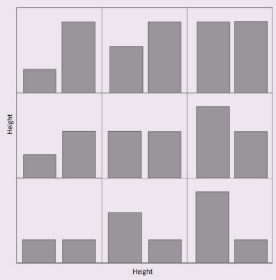
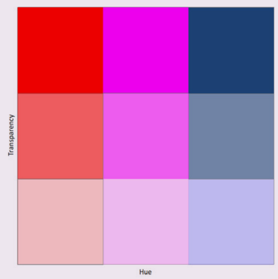
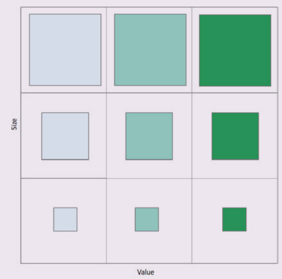
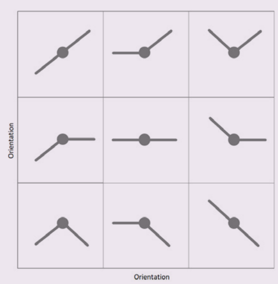
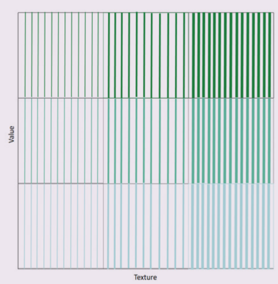
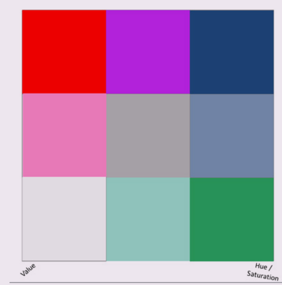
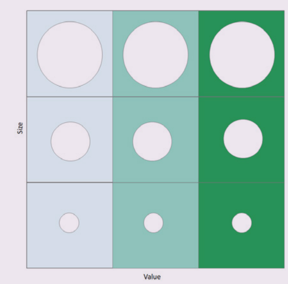
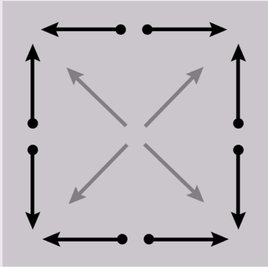
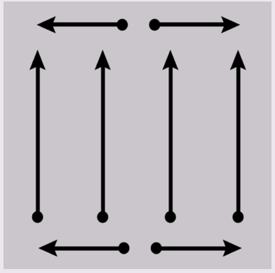
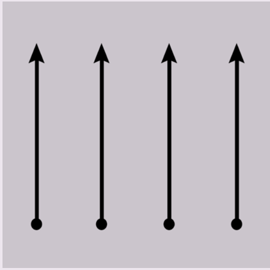
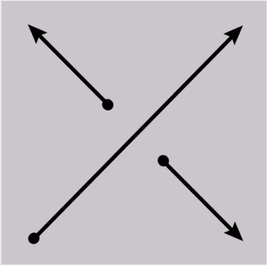
Selective Attention Concept	Configural	Asymmetrical	Integral	Separable
Definition	Addresses an emergent dimension when variables are "in agreement."	Addresses unique or conditional interactions between two visual variables.	Addresses an emerging dimension, but inhibits reading of the original variables.	Addresses the original variables with minimal perceptual interference from other visual variables.
Examples	Bar Chart 	Value by Alpha 	Rectangle Map 	Shaded Cartogram 
	Spoke Glyph 	Shaded Texture 	Bivariate Choropleth 	Choropleth w/ Graduated Symbols 
Trumbo's Equivalent Concepts using Color (Focal Models)	Corners 	Range  	Diagonal 	Not addressed in Trumbo's original color scheme but can be achieved by incorporating size and/or shape symbology (see Figure 3).

Table 2. Relationships between Elmer's (2013) discussion of selective attention for bivariate maps and Trumbo's color concepts. Charts adapted from Elmer (2013).

the intermediate (local distribution) and superior levels (global distribution) of map comprehension by revealing the relationships between two variables (Robertson and O'Callaghan 1986).

Bertin also introduced the concept of "selectivity" of graphic variables, which is related to the idea of selective attention (MacEachren 1995; 36): the ability of a map reader to focus on one visual variable while simultaneously ignoring others. The concept of selective attention was first developed in the field of psychology, and has since been applied by cartographers to further the understanding of thematic maps (Carswell and Wickens 1990; Nelson 2000; Elmer 2013). Selective attention concepts of configurality, asymmetry, integrality, and separability describe the perceptual aspects of the combination of two visual variables.

Table 2 shows the relationships between selective attention concepts, using combinations of visual variables identified by Elmer (2013) and Trumbo's equivalent concepts using color. The focal models are based on Trumbo's color concepts, and will be addressed in detail in the next section. This chart serves to situate Trumbo's ideas on color within the cartographic literature regarding selective attention concepts. Configural relationships show highs and lows of data values as does Trumbo's corners method. The asymmetrical concept and the range method reveal ranges of data values within categories with unique interaction effects. The integral and diagonal methods both show the emerging dimension where two variables interact while inhibiting reading individual variables.

Trumbo's original color scheme does not address the selective attention concept of separability, in which a reader can attend to one visual variable with minimal interference from others. However, this can be achieved by combining color with other visual variables, such as the example in Figure 3, which combines color with symbol size. The corners method uses color to show how the population

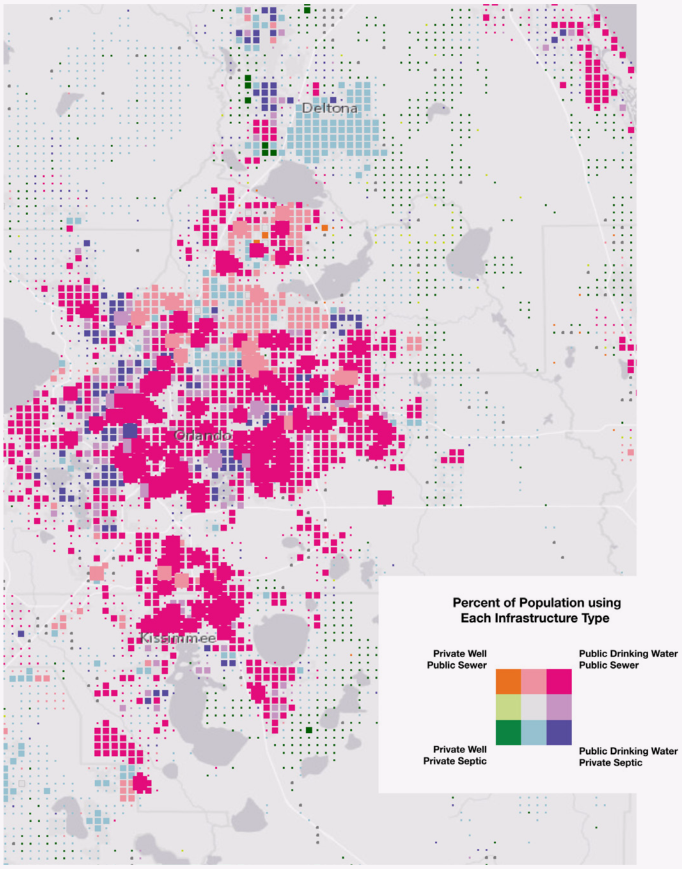


Figure 3. *Bivariate map showing population using public and private water infrastructures for drinking and wastewater in Orlando, USA. Water infrastructure data from the Florida Department of Health, 2016. Data were gridded to 1km cells, with larger squares representing higher population and smaller grids showing lower population.*

in each area meets their wastewater and drinking water needs using private infrastructure, public infrastructure, or a combination of the two. By aggregating water infrastructure and population data at the property parcel scale to a 1km grid, we can use a graduated symbology, where population data are clearly separable from water infrastructure information. Applications of this map include planning new sewer lines or identifying areas without electricity to operate private wells for planning for disaster management.

METHODOLOGY

The reprisal of Trumbo's work that we present here began by consulting with Trumbo, and both extends and demonstrates his 1981 ideas. We created *focal models* that illustrate how Trumbo's three spatial relationships above can be translated into bivariate color schemes that adhere to his four principles of color usage. We then constructed three sample maps to illustrate each of the focal models. Most sample maps are standard choropleth maps, but two used 1km grids. Finally, we created three maps using the same socioeconomic data variables (obesity and inactivity)

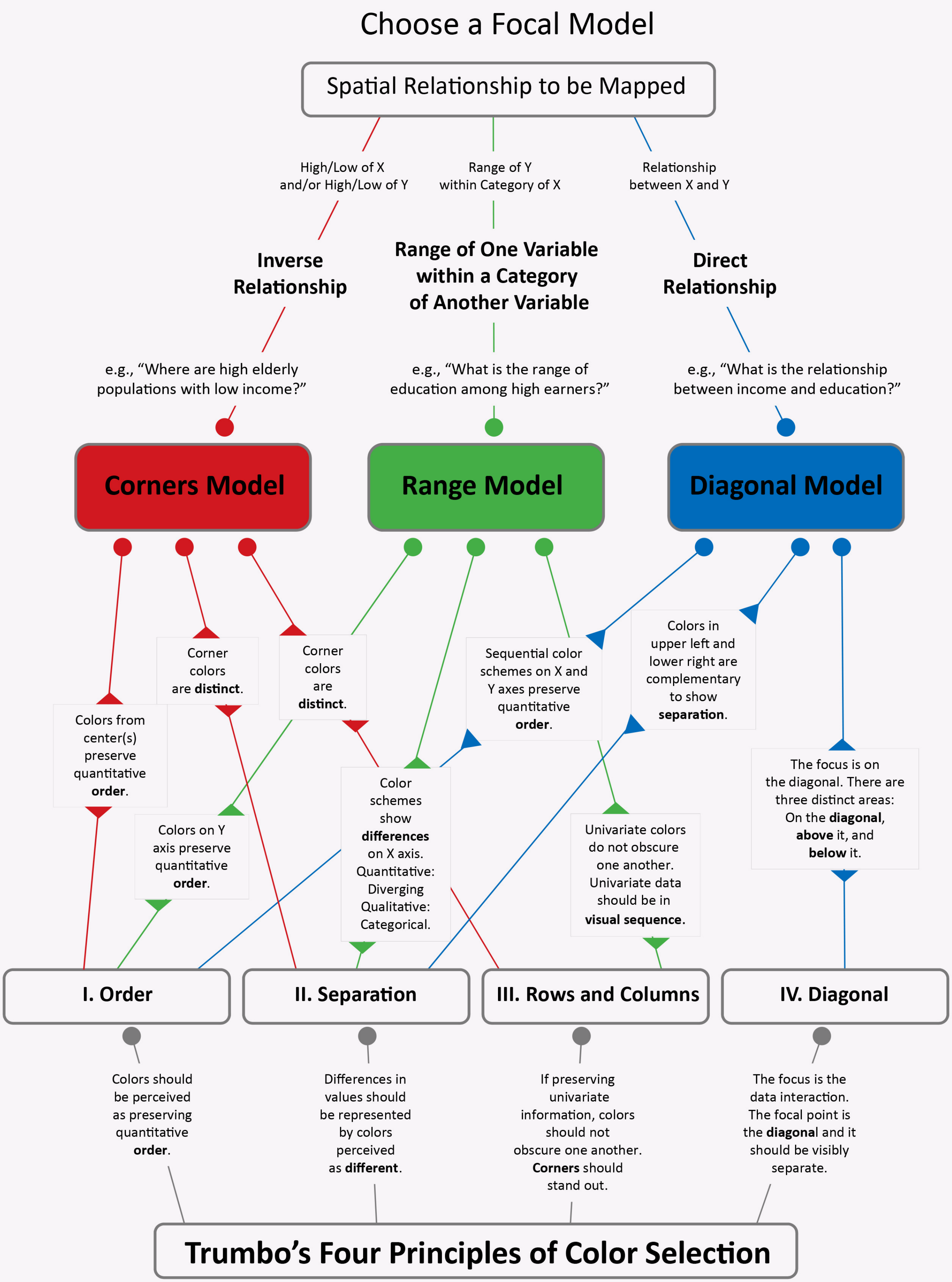


Figure 4. Relationship between Trumbo's four principles and the three focal models for bivariate choropleth maps.

for each of the models to determine if the final maps were visibly different and if each can be used to successfully answer questions about relationships between obesity and inactivity. In doing so we explored the following questions: Do the focal models produce different maps using the same data? Is there a noticeable relationship between the stated map purpose and the resulting emphasized data? Can the focal models guide color choices by associating their map purpose with the appropriate color scheme? Can the focal models be converted into reproducible symbolization guidelines suitable for a GIS?

To clarify the relationships between the four principles suggested by Trumbo and the three types of questions, Figure 4 presents an overview of our ideas. The diagram shows Trumbo's four principles of order, separation, rows and columns, and diagonal as foundational knowledge. The principles are shown in relation to our three focal models, each of which derives from one of the three types of questions that the cartographer is trying to answer. This diagram can also be used as a decision-making flow chart for cartographers. Each focal model draws attention to the data that appropriately address the purpose of the map (Table 3).

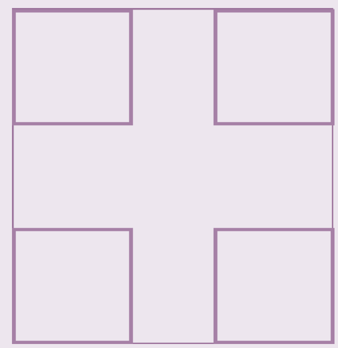
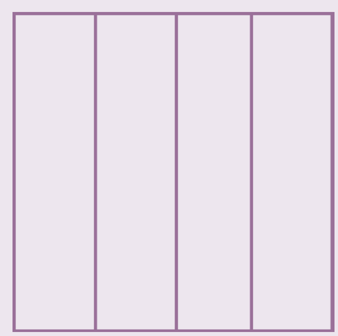
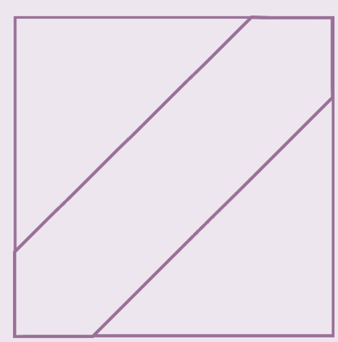
Relationship Type	Inquiry Formula	Model Name	Visual Focus	Visual Focus Diagram
Inverse relationship	low/high of x and/or low/high of y	Corners	Corners	
Range of one variable within a category of another	range of y within low/high of x	Range	Distinct x and sequential y	
Direct relationship	relationship of x and y	Diagonal	3 distinct categories: on or near diagonal, on one side, or the other	

__Table 3.__ Overview of the three focal models and their attributes.

Below, we'll examine each focal model by constructing a diagram of a bivariate choropleth map legend, and we'll illustrate how its design conforms to Trumbo's four principles of effective color choice for bivariate choropleth maps. These diagrams illustrate the areas where the reader's focus is directed, and the combination of sequential, diverging and qualitative schemes that produced the data emphasis. For each model, we'll also look at an example map and legend.

THE CORNERS MODEL

The corners model, shown in Figure 5, deals with the exploratory questions of low/high of x and low/high of y. It uses multiple complementary diverging color schemes designed to highlight the distinct corners while minimizing the interior. The corners model succeeds because the complementary diverging color schemes draw attention to the extreme areas. It is meant to address questions such as: Where are the areas of high income and low education? Where are the areas of low population density and high crime? Where are the areas of high public transportation and high food deserts? Perdue (2013) successfully used the corners model to highlight differences between population density and crowding in urban environments.

The map and legend in Figure 6 offers an example of the corners model, highlighting areas where the rates of home ownership or of education are either high or low. The legend uses multiple diverging color schemes around the

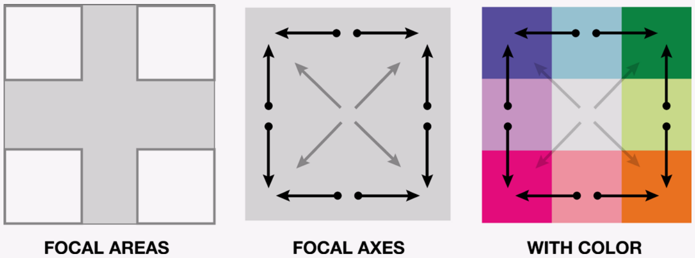


Figure 5. The corners model.

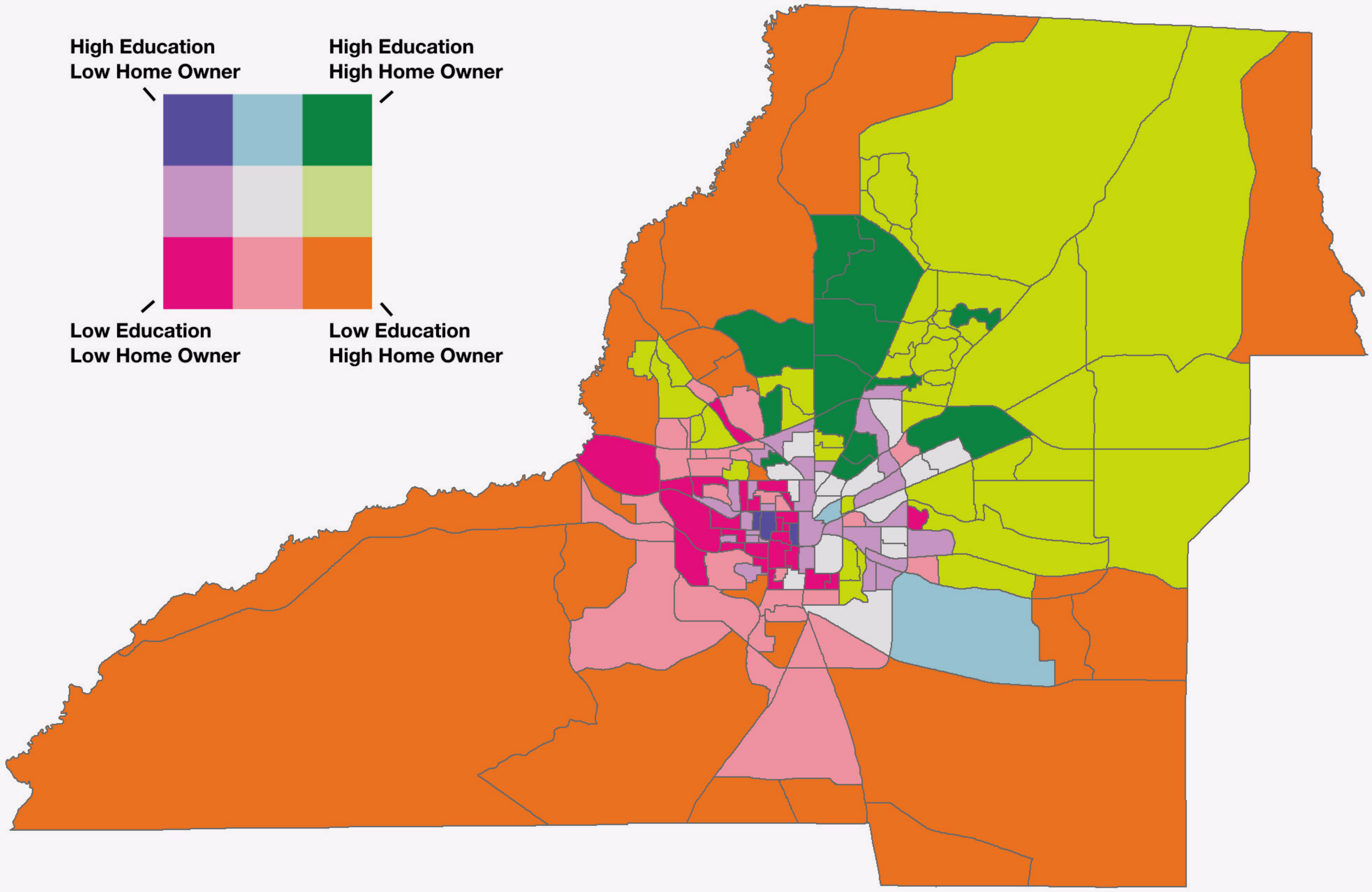


Figure 6. Corners model highlighting areas of either high or low rates of education and home ownership for Leon County, Florida. Data from 2010 US Census.

exterior walls to emphasize the contrast between the four corners and minimize the interior areas. The effect is to draw attention to geographic areas where extreme percentages of those with advanced education and home ownership are very similar or very dissimilar. The geographic areas with less extreme values of the two population categories are minimized through representation with lighter colors. The goal of this map and legend is to allow quick and easy identification of areas with very low or very high values of either variable without distraction from areas with intermediate values.

Trumbo (1981) called for a 4×4 grid, but we demonstrate a 3×3 grid in Figure 6. In critiquing this palette, Trumbo asked about the 4×4, as it offers more gradation (personal communication, August 2016). Trumbo's sample color palettes used the Ostwald and Hickethier uniform color models that could achieve his goals (Robertson and O'Callaghan 1986). In constructing a sample corner palette for our demonstrations, we were unable to blend 16 colors with sufficient distinctness and order. We are unsure if the problem is a change in color model or our limited color blending skills. Thus, we have chosen to use colors similar to Brewer's (1994) "diverging/diverging" 3×3 scheme to overcome issues with color distinctiveness.

Further, an anonymous reviewer of this article aptly noted that the 3×3 grid colors can be adjusted to achieve different purposes. For example, if it is important to emphasize high and low values, the interior five colors could be lightened so that the corner colors are more prominent. If it is important to emphasize certain highs and lows (e.g. emphasis on low/high, low/low, high/high, or high/low), the two corners representing these values can be left saturated and the other two corners can be muted slightly to call less attention.

There are limitations to the corners model. It may require map readers to consult the legend more often than other models due to the lack of color gradation that reminds readers of data values. Additionally, it is important to select colors that are appropriate to the data type to avoid misrepresentation (e.g., qualitative vs. quantitative) interpretation. Finally, it is worth noting Eyton's (1984) and Dunn's (1989) designs for highlighting high and low data values as shown by Figure 7. Both of these models are alternatives to Trumbo's corner and diagonal methods. These models perform the tasks of a corner model by highlighting high and low data values by the use of pure colors in the upper-left and lower-right cells with easily distinguishable colors in the other two corner cells. These

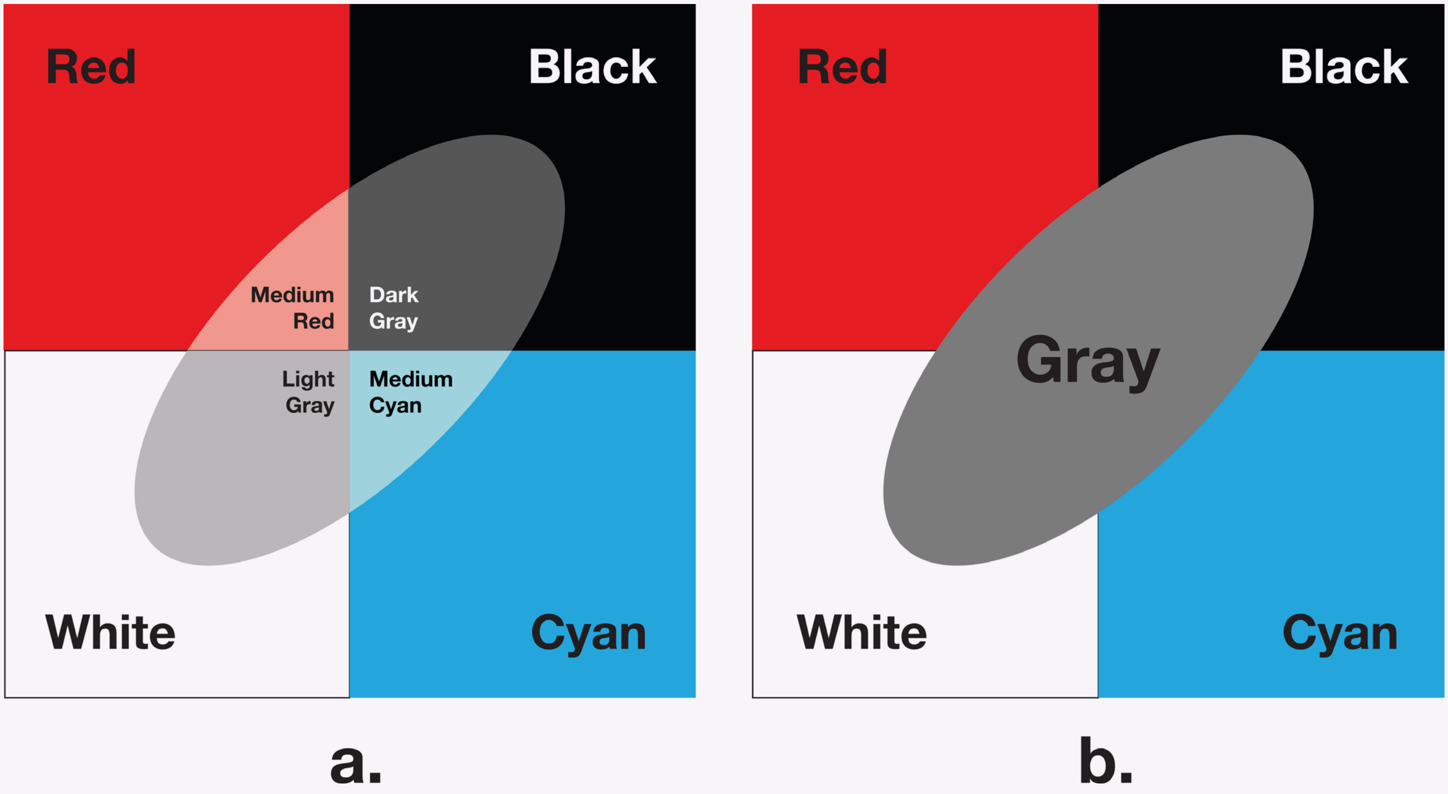


Figure 7. (a) Adapted from Eyton (1984) and (b) Dunn (1989). Both diagrams are alternatives to the corners and the diagonal focal models.

models perform the task of Trumbo's diagonal model (discussed later) with the lower-left and upper-right cells using a progression of light-to-dark shades of the same color hue to show the data relationships along the diagonal. Eyton (1984) demonstrates eight classes of data and Dunn (1989) uses five. Data along the diagonal can be represented using a single color or multiple colors to show gradation. Both models can represent correlated data as well as outliers.

THE RANGE MODEL

The range model, shown in Figure 8, illustrates the range of y within the low/high of x. The primary focal axis consists of a qualitative color scheme that provides an organizing structure to separate data into visually distinct categories, resembling ribbons. The secondary axes are sequential interior schemes that show the progression of values from low to high within each category. Users can select a category of interest along the x-axis, and then see the range of values distributed throughout. Our diverging color schemes vary somewhat from Brewer's (1994). While she describes hers as having steps of lightness, our involve colors that fall along gradients that diverge from a quantitative midpoint, but do not necessarily require a change in lightness.

The range model addresses questions such as: What are the ranges of education among those with high incomes? About how many votes were cast in areas with strong Obama support? What are the income levels in areas of high foreclosures? The map and legend in Figure 9 show both the degree of support for political candidates as well as a general idea of the number of votes cast. For example, populated areas with strong Obama support are shaded dark blue and rural areas with strong Romney support are shaded light pink. Rural areas with relatively equal voting for each candidate are shaded light purple. Instead of choropleth enumeration units, the map uses a 1km grid system. The colors along the x-axis create categories showing the percentage of support for each candidate. Within each category, a sequential scheme along the y-axis indicates the number of votes within each region.

Trumbo (1981) used specific color codes to achieve color gradations. However, we were unable to successfully select colors that achieved both order and separation in a visually appealing manner. Instead, we found that the value-by-alpha symbolization of Roth, Woodruff, and Johnson (2010) worked very well.

It is worth noting that the range model is the only focal model that can map qualitative data. Categorical colors can represent the different types of data in the x-direction

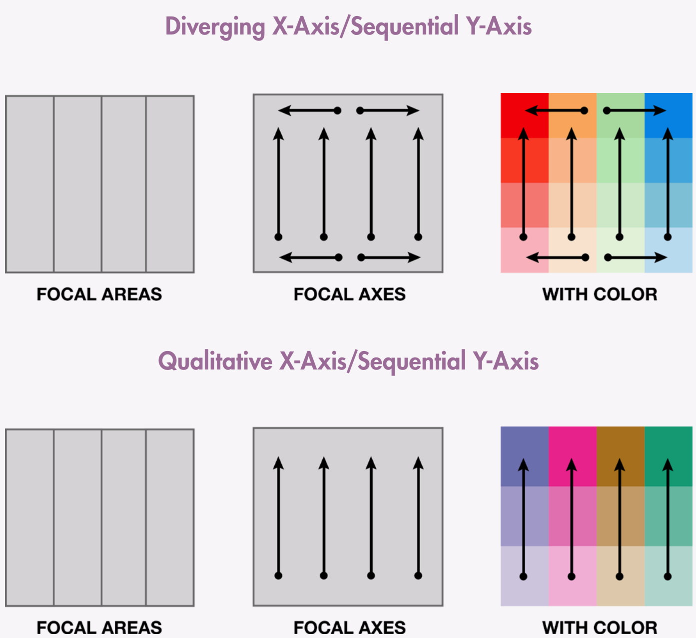


Figure 8. *Two versions of the range model, with either diverging or qualitative colors along the x-axis.*

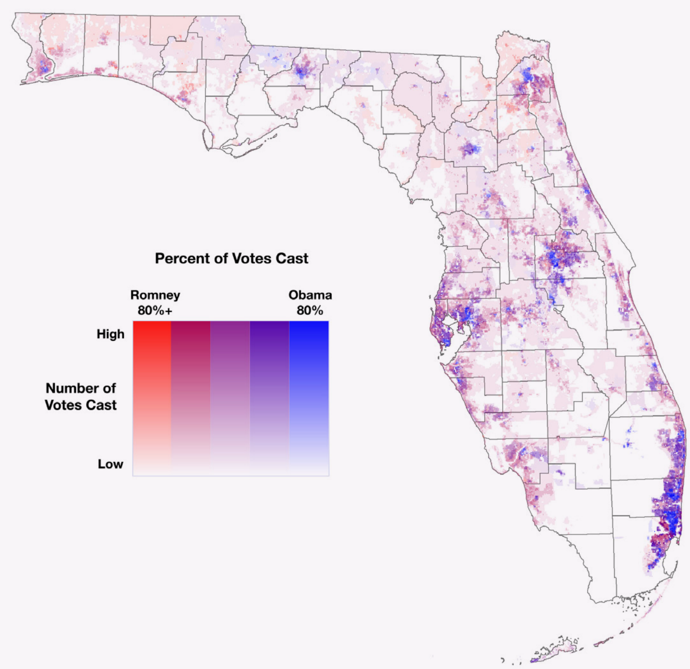


Figure 9. *An example of the range model, showing the number of votes cast in areas with a given level of support for a candidate. Data are 2012 precinct-level election results reported to the Florida Division of Elections, disaggregated to census blocks (spatial interpolation weighted for population 18 years and older), then disaggregated to a 1km grid.*

while quantitative values are mapped in the y-direction. An example of a qualitative map could be one of predominant agricultural production by county. For each county, the main agricultural product (e.g., corn, wheat, soy) could be represented along the x-axis through columns, while the total amount harvested (quantitative) could be represented along the y-axis using a transparency gradient. Another example map could show income and education, where income distributions are along the y-axis and categories of education (e.g., no high school, high school, associate degree, bachelor's, etc.) comprise the columns along the x-axis. Brewer (1994) provides variations on the range model. One, a bivariate example, uses a qualitative scheme for presentation of nominal data. The second, a binary model, presents the range (y-axis) of values within a categorical variable (x-axis) while maintaining a binary status (e.g., members vs. non-members).

THE DIAGONAL MODEL

The diagonal model answers exploratory questions about the relationship bewteen x and y, as shown in Figure 10. It consists of a sequential color scheme at a 45-degree angle, to show progression of correlated data, and a diverging color scheme on the opposite diagonal, which highlights the differences between areas on either side of the main diagonal. These two color schemes, at right angles to each other, succeed in dividing the data into three categories (Carstensen 1984). Correlated data are shown on the diagonal sequence while non-correlated data are shown in complementary colors at their respective corners. This is similar to the overlay method used by the 1970s Census maps; both attempt to show data correlation along the diagonal.

The diagonal model can answer questions such as: What is the relationship between income and education? Are tobacco sales and food deserts correlated? Is there a relationship between population density and public transportation? The example map and legend in Figure 11 show the relationship between elderly and minority populations using the diagonal model. The complementary colors in the diverging color scheme produce a white-gray-black sequence along the diagonal. The resulting effect divides the data into three categories: correlated data appear in a grayscale sequence, while non-correlated data are shown using gradients of complementary colors. In the example map, there are few greyscale areas, as the data themes feature little correlation. However, the complementary blue and

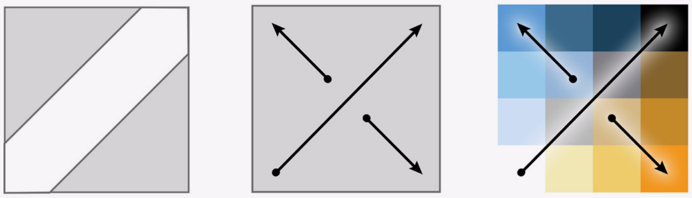


Figure 10. *The diagonal model.*

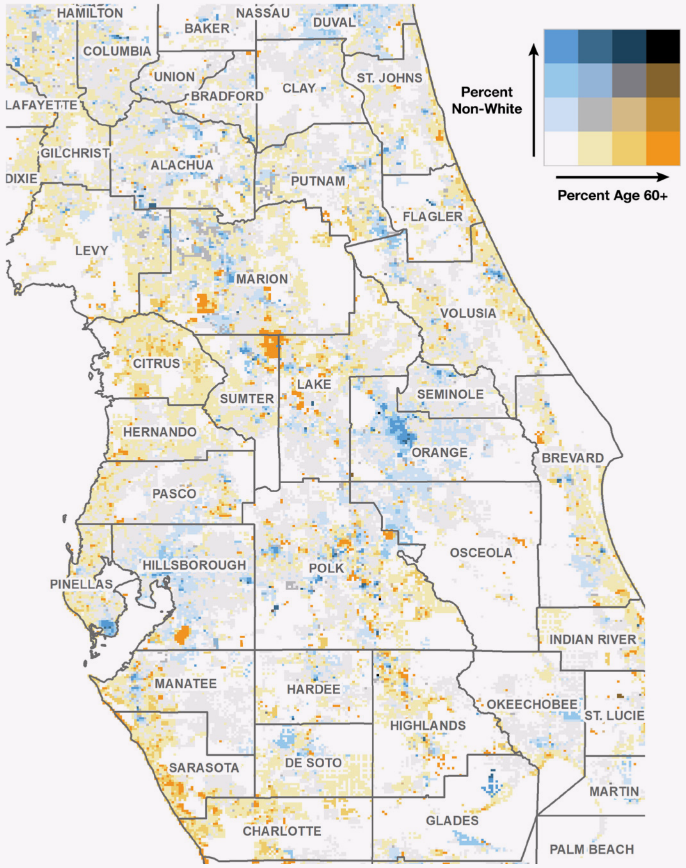


Figure 11. *Sample map using the diagonal model. Data are from the 2010 US Census.*

orange colors show clearly whether an area's population is predominantly elderly or minority. The internal progression of color preserves the degree of population differences (e.g., high elderly populations are a darker orange than areas with low elderly populations).

Figure 11 clearly shows the locations where one of the two variables has a much higher percentage than the other. The data do not need to be correlated to use this model, as the diagonal model shows data to be above, on, or below the diagonal. Contrast Figure 11 with Figure 1, which used the overlay method. Recall that Figure 7 presents an alternative version of the corners and diagonal models.

RESULTS

In order to compare the focal models in detail, we created three maps, one per model, of the same two datasets: the percentages of obese and of physically inactive persons per county, from the US County Health Rankings & Roadmaps Program (University of Wisconsin Population Health Institute 2016). Figures 12–14 illustrate the results.

In the corners model (Figure 12), the diverging complementary colors in each corner separate high values from low values. Since this model focuses on high and low values, a 3×3 grid is sufficient, with intermediary shades working only to separate the corners. This map can answer the following questions: Where are areas of high obesity and high inactivity? Where are areas of high obesity and low inactivity? Where are areas of low obesity and low inactivity? Where are areas of low obesity and high inactivity?

The range model (Figure 13) shows a diverging color sequence along the obesity axis, with sequential colors representing the range of inactivity in each obesity category. This map could be used to answer the following questions,: Where are the areas of highest inactivity and highest obesity? What is the range of inactivity in the counties with the highest obesity? Note that in this map, counties with the highest inactivity, regardless of obesity category, have a high saturation. This shifts the readers' focus strictly to the activity levels rather than how activity relates to obesity, which should be considered when categorizing data and designing a color scheme.

The diagonal model (Figure 14) shows both obesity and inactivity with sequential colors. The diagonal, representing a correlation between the two, follows a grayscale sequence, while the more saturated blue and orange corners

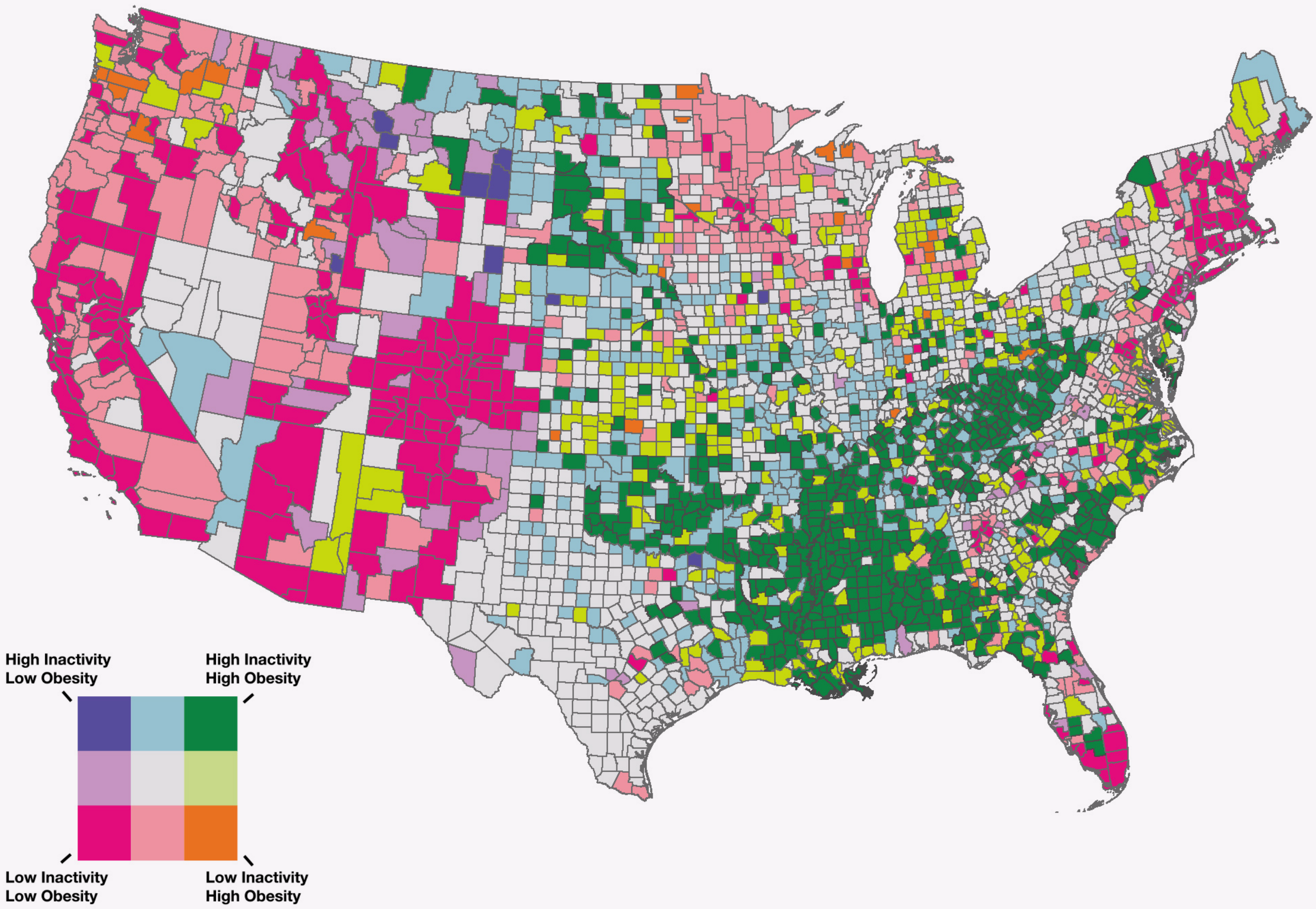


Figure 12. Corners model of obesity and inactivity in the lower 48 states.

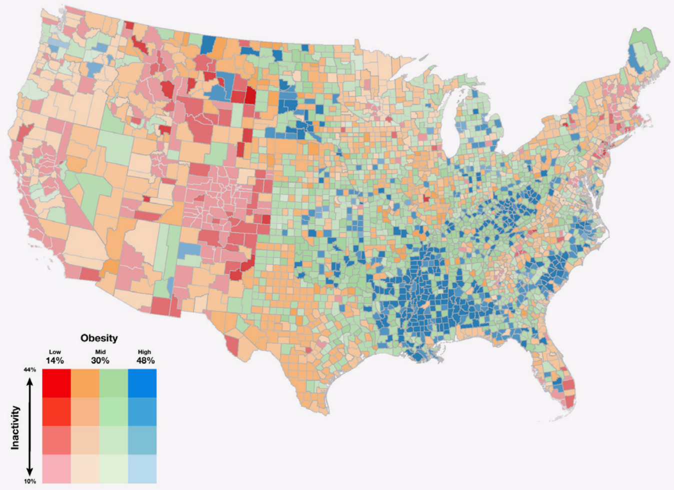


Figure 13. *Range model of obesity and inactivity in the lower 48 states.*

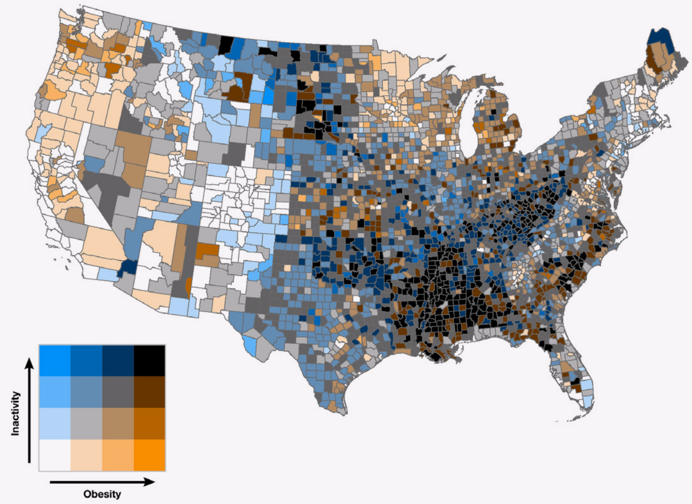


Figure 14. *Diagonal model of obesity and inactivity in the lower 48 states.*

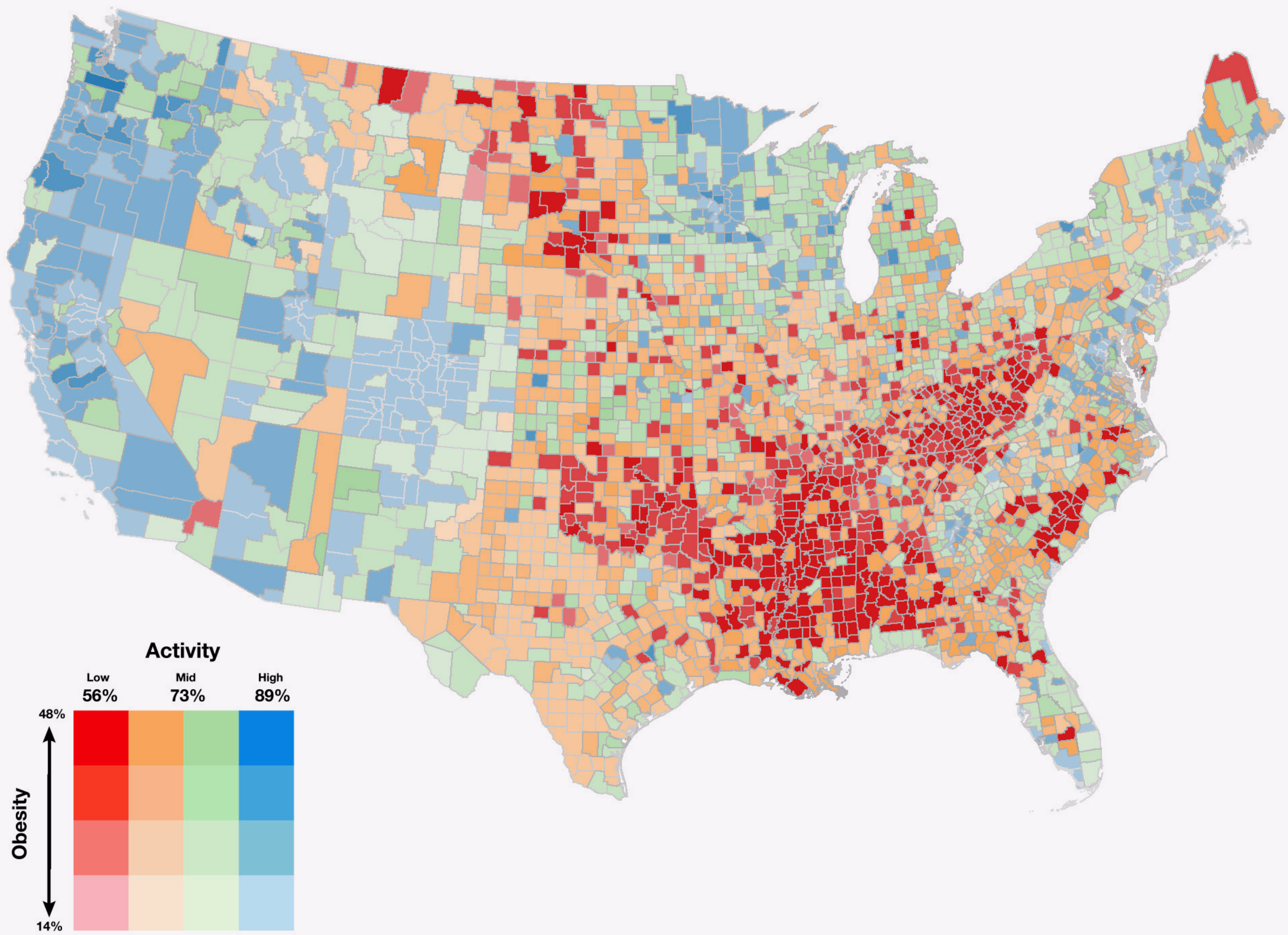


Figure 15. *Inverted range model of activity and obesity in the lower 48 states.*

represent non-correlation. The map could answer the following questions: Where are obesity and inactivity positively correlated? Where do obesity and inactivity differ? The most attention is drawn to the black areas of the map, which represent areas with high, correlated values of obesity and inactivity.

To illustrate how changing the color scheme can affect the outcome of the data interpretation, we inverted the "inactivity" dataset to an "activity" dataset for Figures 15–16, and switched the axes while keeping the color scheme the same. Now, the range model in Figure 15 illustrates activity levels on the x-axis with diverging colors, while a sequential scheme shows obesity along the y-axis. In contrast to Figure 13, this reclassification of inactivity to activity provides a more intuitive understanding of how activity levels may relate to obesity levels. Rising activity would seem to indicate lower obesity, rather than lower inactivity indicating lower obesity. This allows readers to answer questions such as: Where are the areas of lowest activity and highest obesity? What is the range of activity in the counties with higher percent obesity?

Figure 16 shows that a reclassification from "inactivity" to "activity," though beneficial for the range model map, is detrimental for the diagonal model map, whose color scheme now represents an entirely different purpose. The new diagonal emphasizes any correlation between increased activity and increased obesity, which is both a very different perspective on the datasets than before, and a correlation that mostly doesn't appear on the map. However, the map can answer questions such as: Where are high activity levels and high obesity levels? Where are low activity levels and high obesity levels? Is there positive correlation between increased activity and increasing obesity? Is there lack of correlation between increased activity and increasing obesity?

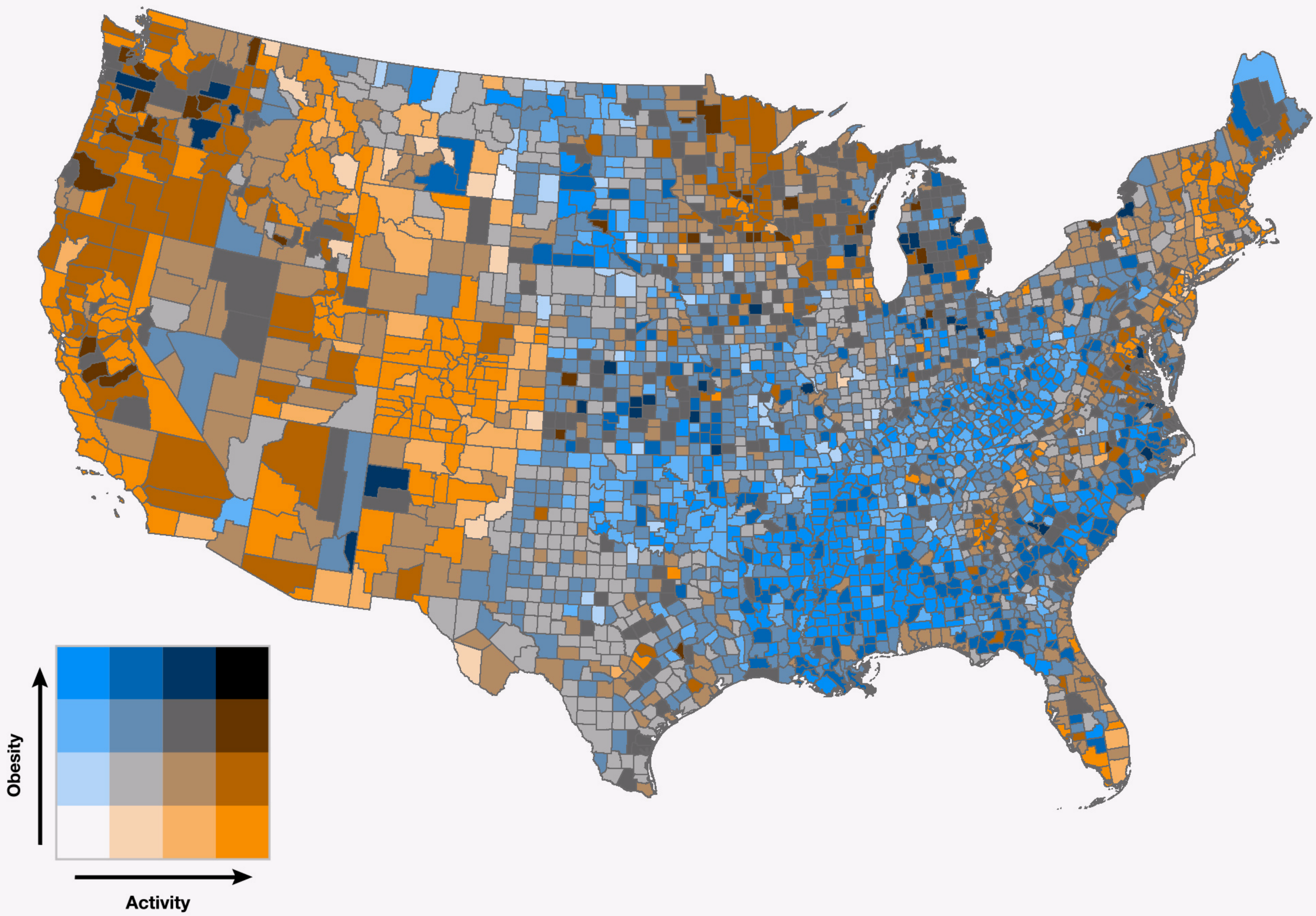


Figure 16. Inverted diagonal model of activity and obesity in the lower 48 states.

CONCLUSIONS

To be effective, maps must be designed for their intended use. Bivariate and univariate maps share many of the same design challenges, but the multidimensional aspect of the former adds extra complexity. To address this, Trumbo (1981) proposed three types of bivariate choropleth maps, each with unique purposes and goals. Our work, under the guidance of Trumbo, extends his ideas by producing focal models, sample color palettes, and sample maps (Table 4). The three resulting focal models offer mapmakers bivariate choropleth options other than the single-purpose overlay scheme, and they lead to design choices that support a map's intended purpose by highlighting the appropriate data. The focal model diagrams, and our sample materials, provide guidelines for the production of

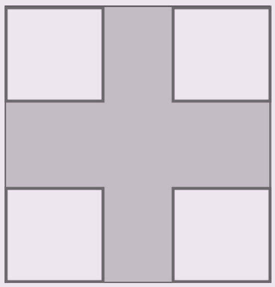
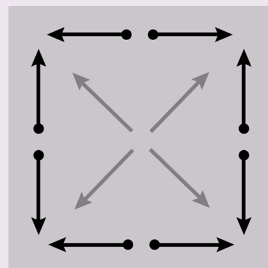
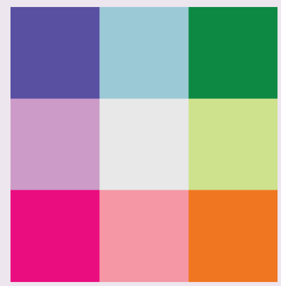
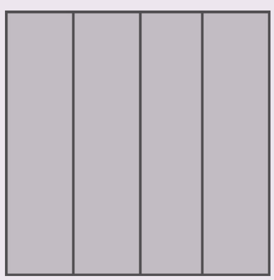
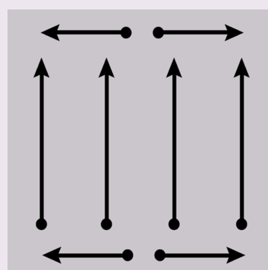
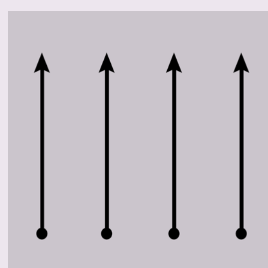
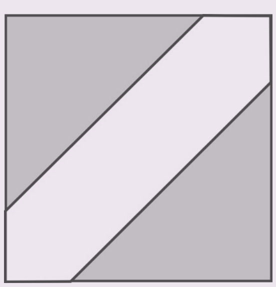
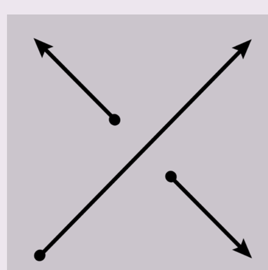
Focal Model	Inquiry Syntax & Sample Question	Focal Areas	Focal Axes	Sample Color Palette
Corners	low/high of x and low/high of y *Where are areas of high income and low education?*			
Range	***Diverging*** range of y within low/high of x *What is the range of education among high earners?*			
	Qualitative range of y within category *What is the range of education within each category?*			
Diagonal	relationship of x and y *What is the relationship between income and education?*			

Table 4. *Summary of focal models and their attributes.*

bivariate choropleth maps in a GIS production environment. We also presented a methodology to relate typical map user questions to the appropriate focal model, which can be used for cartographic decision making.

There is more work to be done to improve the design of bivariate choropleths, and future work could explore color palette selection, the role of color saturation, classification choices, the value of statistics in revealing data relationships, and mapping data uncertainty. We also urge researchers to consider external factors that could contribute to the clarity of these maps, including the size of geographic areas, display devices, and the user's knowledge and experience with the data.

In this paper, we have provided a framework for linking types of bivariate maps with focal models, and thereby operationalized Trumbo's (1981) principles of bivariate map design. Using this framework, GIS practitioners have a practical outline for how to create bivariate choropleth maps.

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Designing an Experience: Maps and Signage at the Archaeological Site of Ancient Troy

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Maps and signage are essential for visitors to understand and appreciate the cultural, historical, and natural importance of a heritage site. Unfortunately, the on-site maps and signage at the archaeological site of ancient Troy near Çanakkale, Turkey, create a poor visitor experience. A UNESCO report found that the site suffered from "poor and confusing wayfinding" and "visual clutter and chaos" (Riorden 2009, 9–10). To understand how the maps and signage failed to help visitors, I completed a content analysis of the maps and signage found at Troy in the summer of 2014, based on recommendations from cartographic semiotics and the field of experiential graphic design. The analysis uses a case study of the archaeological site of Ancient Troy to derive insights into user experience design at preserved sites of cultural or historical significance.

KEYWORDS: experiential graphic design; semiotics; signage; archaeology; wayfinding; environmental graphic design; information design; historical site; maps; cultural heritage

FROM "GREAT EXPECTATIONS" TO "GREAT DISAPPOINTMENT": WHY SIGNAGE SYSTEMS MATTER

When we arrive at a historic site, how do we understand what we see? Maps can do much of the heavy lifting of explaining the environment, but rarely do so on their own. Frequently, *wayfinding systems* comprising installed signs (described as *signage*) and maps (both portable and installed) help travelers understand where they are and what is around them. A growing industry, *experiential graphic design* (XGD; formerly known as environmental graphic design), exists to manage the experience of place through signage systems. However, relatively minimal attention has been paid in cartographic research as to how signage and maps interact with each other in a well-functioning wayfinding system.

Historic sites present a special wayfinding design challenge because visitors arrive with preconceptions of what they are about to see. Media consumed before the trip build an imaginary idea of what the place will be like (Urry and Larson 2011) and set expectations for the visit (Skinner and Theodossopoulos 2011). On site, tourists become "semioticians" of the landscape, looking for classic "signs" that "signify" the identity of the place (Culler 1981). For example, the Eiffel Tower signifies the identity of Paris, France. When the place itself is highly complex, such as an archaeological site with overlapping strata, the wayfinding system is relied upon to help the visitor find these "signs." If the wayfinding system is unable to translate the environment for the visitor, the result is a disappointing visitor experience. For historic sites, which often rely on the public for their funding, a good visitor experience is critical to the site's popularity and continued preservation.

My research examines the wayfinding system used at ancient Troy, an archaeological site laden with visitors' expectations, and featuring a poorly functioning signage system that has contributed to negative visitor experiences. I conducted a quantitative content analysis of the maps and signage available on-site in 2014 using research and recommendations from cartographic semiotics and XGD. Both cartography and XGD are focused on depicting places; joining them creates an approach that combines a scientific, semiotic understanding of how maps work (cartography) with practical knowledge of signage and wayfinding best practices (XGD). To date there has been little cross-pollination between the fields, despite their significant potential to enrich each other through shared interests in maps and wayfinding. The XGD field is expanding and presents an opportunity for cartographers to contribute their ideas and insights on the design and function of maps in the environment.

Herein, I discuss how the signage system at ancient Troy fails to meet the current best practices of XGD, and I set forth guidelines for improving wayfinding signage at Troy that would also apply to other historic sites.

SIGNED IS NOT DESIGNED: THE EXPERIENCE OF TROY

> "As ruins go, this site is seriously ruined."
>
> "I was hoping for the movie story… so I guess the bar was waaaay too high!"
>
> "The horse at Çanakkale is more authentic."
>
> Quotes on TripAdvisor (n.d.) from tourists without a tour guide

Many tourists report that their experience at Troy is a disappointment. A number of factors contribute to this negative perception. First, many of the visit Troy after having seen the better preserved ruins of Pompeii or Herculaneum, or the reconstructed monuments of Ephesus. Second, because of Troy's complex history and its sheer size, it is difficult for tourists to navigate and understand what they are seeing without informative guides. During its 3,500-year history, Troy was destroyed multiple times due to war and earthquakes, resulting in successive layers of ruins that are difficult for tourists to read within the landscape. Third, the on-site maps and signage at Troy have been designed in an inconsistent and ad hoc manner, resulting in Troy's two greatest challenges, according to UNESCO: "poor and confusing wayfinding" and "visual clutter and chaos" (Riorden 2009). The tourist path is poorly marked with wayfinding signage, causing visitors to miss important structures or vistas. Due to constraints imposed by the Turkish Ministry of Culture, existing signage has an inverted hierarchy: caution signage (such as that which forbids smoking or offers other warnings) is emphasized over directional and informational signage. Most visitors arrive by bus and are on site for only 90 to 120 minutes, making the lack of efficient wayfinding and concise informational signage particularly problematic under the tight time constraints.

Finally, the maps and signage provided do not meet the standards of good cartographic design and XGD. The mapping and color conventions used in the signage are derived from maps featured in archaeologist Wilhelm Dörpfeld's 1902 book *Troja und Ilion*. These standards violate contemporary cartographic design conventions by using color hue to depict quantitative information (Figure 1). The current signage was developed by archaeologists and stakeholders managing on-site research during the period of 1988–2012 (William Aylward, pers. comm., 2014). This group was trained in neither cartography nor XGD, and is not involved with managing Troy today.

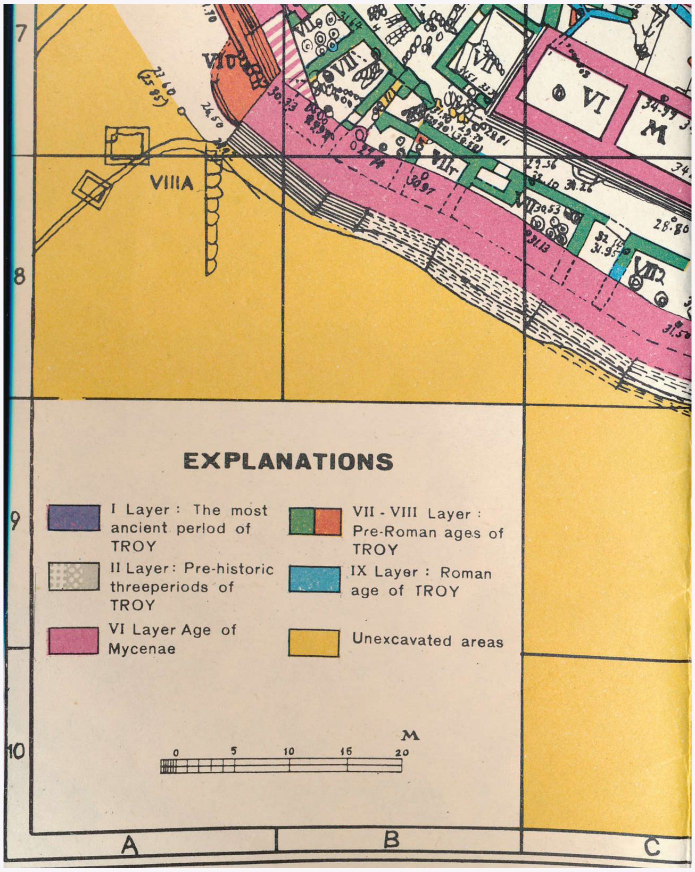

Figure 1. Legend from Wilhelm Dörpfeld's (1902) map of Troy, from which color conventions were derived for the site's signage. The layers have been organized chronologically but represented with a qualitative color scheme. The cartographic solution is to assign a sequential color scheme.

SEMIOTICS

I DRAW FROM TWO BODIES of knowledge to inform my analysis of Troy's wayfinding system: cartographic semiotics and experiential graphic design. Beginning with the first, modern semiotics is influenced by two dominant models of signs: *dyadic* (developed by Ferdinand Saussure between 1907 and 1911) and *triadic* (proposed by Charles Sanders Peirce in 1867; Hoopes 1991; Nöth 1990). Saussure's dyadic model consists of a representation (*signifier*) such as the letter "H" on the map, and a concept (*signified*), which could be "Hospital" on some maps, or "Helicopter" on others. The ambiguous meaning in this example indicates the importance of carefully considering real-world context in the design of maps and signage. Peirce's triadic model of the sign includes (using Morris's 1938 terminology) the *sign vehicle* (equivalent to Saussure's *signifier*) and the *interpretant* (equivalent to Saussure's *signified*), while adding the *referent,* or the real-world object or phenomenon (Figure 2). The same "H" map mark, using the triadic model, consists of (i) representation—the letter "H" on the map, (ii) the concept of "Hospital" or "Helicopter," and (iii) the real-life object to which the sign refers—the actual hospital or helicopter pad. The advantage of the triadic model over the dyadic model is that the former allows for additional consideration of the real-world phenomenon—the referent—which is the primary visual signal and point of confusion. The ruins of an archaeological site like Troy are difficult for visitors to comprehend because they're mostly no longer present and therefore do not visually match up to the sign vehicles or interpretants used in on-site signage, which are usually of more complete structures. The referent, while always relevant to design, is particularly important when looking at wayfinding systems and the interplay of maps and signage.

Ogden and Richards (1923) visualized Peirce's triadic model in a triangle to put the emphasis on the interpretant's mediation of the sign vehicle and referent (Figure 3), but each axis of the semiotic triangle can mediate "between what is seen and what is known" (MacEachren 1995, 221). Thus, "spinning" this semiotic triangle provides different ways of looking at the interplay among the referent, interpretant, and sign vehicle, resulting in three different dimensions for assessing the maps and signage at Troy. A *referent-as-mediator* approach acknowledges that there are many kinds of representations possible for a given real-world object and that congruence should be maintained between characteristics in the design of the sign vehicle and the referent the sign describes. An *intepretant-as-mediator* approach acknowledges that a sign serves as shared knowledge between the designer and the

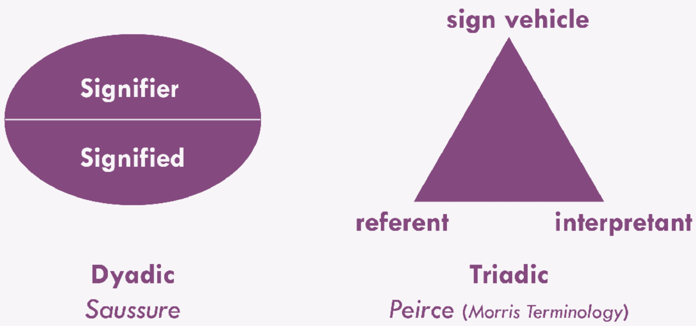

Figure 2. *Dyadic and triadic sign systems. The dyadic system consists of the signifier (the symbol) and the signified (the concept). The triadic system adds the referent, or real-world object or phenomenon.*

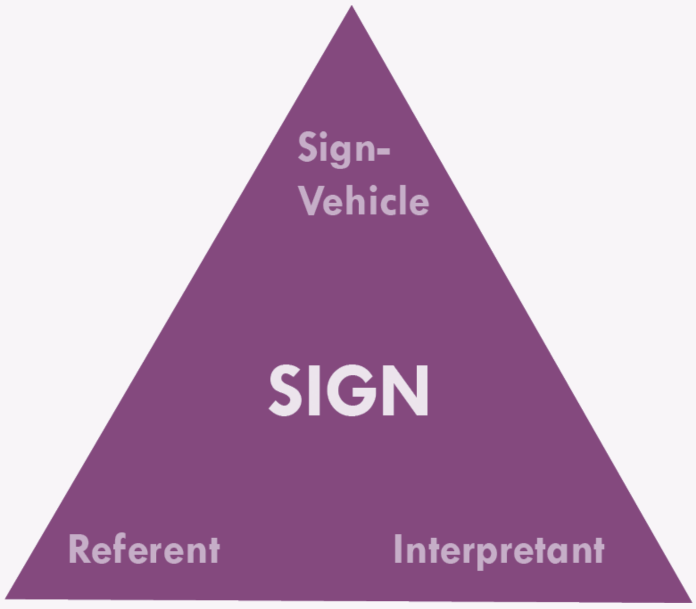

Figure 3. *Ogden-Richards Triangle. "Spinning the triangle" shows different aspects of semiosis: sign-vehicle-as-mediator focuses on the connection between a real-life object and its meaning. A referent-as-mediator approach focuses on the different kinds of possible representations and emphasizes congruence between characteristics for the design and referent. An interpretant-as-mediator approach focuses on shared knowledge between the designer and visitor.*

visitor. Finally, a *sign-vehicle-as-mediator* approach acknowledges the sign vehicle as the connection between the real-life object and its meaning. Using each axis as mediator allows for a multifaceted examination of how maps and signs generate meaning using different visual variables or other design dimensions. Each of these three semiotic approaches was the basis for a portion of my analysis of the design of maps and graphics at Troy.

From the *referent-as-mediator* perspective, we can examine the type of information and embedded knowledge about the referent that is contained in the representation. Below, I analyzed the *information content* that can be found in wayfinding systems at Troy, placing that content into three categories following geographic information theory (Peuquet 1994): attribute information, geographic information, and temporal information. Archaeological sites are unique in their emphasis of temporal, or *historical* information, which puts events and artifacts in historical context.

I also examined the embedded knowledge content of the signs. *Embedded knowledge* is expert knowledge that enhances the interpretation of the sign vehicle and surrounding environment. Three forms of embedded knowledge have been formalized by research on spatial cognition (Golledge and Stimson 1987, 94): *declarative* knowledge that organizes information about phenomena with their meanings, *procedural* knowledge that organizes information about how to complete a task or move from place to place, and *configural* knowledge that organizes information about the spatial arrangements of objects. Although declarative and procedural knowledge are helpful for wayfinding, configural knowledge draws declarative and procedural knowledge together to help form a knowledge of place. An example of configural knowledge at Troy is the spatial layout of ruins at a vista.

The *interpretant-as-mediator* perspective focuses on the ambiguity in the sign, and typically is treated in cartography as the degree of arbitrariness in the representation. Most signs fall on a continuum somewhere between abstract and iconic (MacEachren and Ganter 1990). To further classify the iconicity of signs I used the Robinson taxonomy, which classifies symbols as pictorial, geometric, and associative (Robinson et al. 2005). The Robinson taxonomy does not account for the realism now possible beyond pictorial representations; I have appended a category to account for this.

Many commonly encountered symbols in maps and signage are part of sign libraries. Two of the most common sign libraries used at cultural heritage sites are the AIGA /DOT symbol library developed by the American Institute for Graphic Arts in collaboration with the US Department of Transportation (AIGA, n.d.), and the ISO 7001 (International Standards Organization) symbol library for depicting information in public areas (ISO 2007). Because these symbols are widely used, they have a greater potential to be recognized by visitors and thus limit confusion while promoting wayfinding.

The *sign-vehicle-as-mediator* approach evaluates the use of *visual variables*, the perceptual dimensions that can be varied to encode information in the sign, according to their effectiveness for depicting information at a given level of measurement (Bertin 2010; MacEachren 1995). The *sign-vehicle-as-mediator* approach also applies to the text in the wayfinding system, as the visual characteristics of text can be designed to encode meaning.

EXPERIENTIAL GRAPHIC DESIGN

In addition to semiotics, my analysis of Troy's wayfinding systems draws upon ideas from experiential graphic design. In XGD, signage in the environment is frequently classified by function, e.g., road warning signage (Smitshuijzen 2007). Sign designers generally list six overarching sign types (Mollerup 2013; Katz 2012; Gibson 2009; Smitshuijzen 2007): (i) *identification*, (ii) *directional*, (iii) *informational*, (iv) *regulation*, (v) *ad-hoc*, and (vi) *indirect* (Table 1). Signage can also support multiple functions at one time, such as an identification sign that also provides directions (Figure 4). Identification signage, in particular, is important at Troy because the features of the ruins are not easy to identify in the landscape (e.g.,

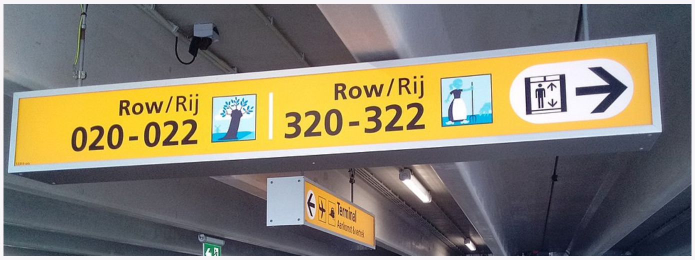

Figure 4. *An example of a sign that supports multiple functions at once. This sign is an identification sign (you are at Row 020-022) and a directional sign (elevators are to the right). Photo by Donald Trung Quoc Don, 2019 (CC-BY-SA). bit.ly/3aqe12K.*

compare the library of Celsus at Ephesus to the Sanctuary at Troy; Figure 5). Signage needs to communicate that the vistas "are indeed extraordinary, even though [they do] not seem to be so" (Urry and Larson 2011, 16).

Signs can also be classified by their shapes. Variation in shape can reflect the function that the sign serves. Certain shapes are commonly used for signs, primarily derived from road signage. Circular signage typically provides instruction or regulation; rectangular signage, including square signage, identifies or provides directions; triangular or diamond-shaped signage serves as a warning (Federal Highway Administration 2012; UNECE 2006).

Signage and maps installed outdoors are often affected by environmental conditions, and I considered some of these factors in my analysis. Lighting can drastically change the legibility of a sign, and its effect is mediated by the finish used on the sign. A *glossy* surface will reflect direct sunlight, while a *semi-matte* or *matte* surface will reflect less light (Mollerup 2013; Calori 2007). Furthermore, while a sign may be well-designed, its physical placement in the environment can decrease its effectiveness. Like the concept of the visual hierarchy in cartography—that the most important information should be the most prominent in a map's design—the sign hierarchy necessitates that the most important signage be the easiest to discern in the environment (Mollerup 2013). Signage that violates this rule cause confusion.

Sign systems can include wayfinding enhancements to assist visitors in navigation. Readers experience a lower cognitive load when interpreting maps or sign systems that follow certain naming conventions. Place names should

Signage Type	Definition
Identification	Identifies a location or important object; signals to the viewer that they have arrived at a location.
Directional	Provides navigation instruction.
Informational	Provides information about a place or object.
Regulation	Prescribes visitor behavior.
Ad-hoc	A handwritten sign; ad-hoc signage indicates a failure of the formal signage system.
Indirect	Something in the environment that communicates information without a formal sign. Common example: barbed wire = "keep out!"

Table 1. *Signage classification types.*

Figure 5. *The library of Celsus at Ephesus (left) and the Sanctuary at Troy (right). Although both sites would benefit from the inclusion of identification signage, the scene on the right would benefit the most. Left: Photo by Behn Lieu Song, 2010. bit.ly/39kmQLn. Right: Photo by Jennifer Tanabe, 2006. bit.ly/2vDNm3s.*

include procedural directions (Mollerup 2013), and names should be the same between maps and signage, because synonyms for place names (e.g., "Main Street" versus "Downtown") can cause confusion (Mollerup 2013; Calori 2007; Smitshuijzen 2007; Arthur and Passini 1992). Abbreviated place names can be easier for visitors—especially if using an abbreviation will help avoid a hyphenation—but should not replace descriptive place names (Mollerup 2013).

Lastly, there are a number of wayfinding considerations affecting the design of maps. Designers should consider the direction that the visitor will be facing when making a map for installation in the environment, instead of always using the traditional "north-up" alignment of paper maps. A "heads up" display that orients the map in the direction that the visitor is facing does not require mental rotation to understand the environment (Katz 2012). Occasionally a designer may choose to distort distance or geography in the interest of simplicity, such as in a schematic map of a subway. On map installations, the *You-Are-Here* mark is used with an arrow indicating the direction that the person is facing rather than a dot that does not inform the visitor of their orientation (Katz 2012). The entirety of the sign system should follow common patterns to speed up visitors' processing of information.

Taken together, insights from cartographic semotics and XGD provide a basis for the design of wayfinding systems, and thus critical assessment of existing wayfinding solutions, toward the end of improving the visitor experience. Next, I apply these reviewed guidelines through a quantitative content analysis of maps and signage at Troy.

HOW TO READ THE "SIGNS": METHODS

Quantitative content analysis (QCA) describes the process of generating quantitative information from a sample by counting and comparing different qualities of the artifacts studied (Muehlenhaus 2011a). The requirements of QCA are (1) a sample of artifacts and (2) predetermined codes that can be applied to an artifact. The codes represent an artifact's traits; if the artifact is a map, for example, those traits could be the use of color, or the presence of a north arrow. The traits themselves can be qualitative, quantitative, or even a Likert-scale rating (Kessler and Slocum 2011). Each trait can be considered a dimension of an artifact, and each artifact receives a binary code that indicates whether it possesses that trait or not. Traits need not be mutually exclusive. Variations of QCA have been used in cartography to study journalistic mapping (Monmonier 1989), persuasive maps (Muehlenhaus 2011a; 2011b), web mapping technologies (Roth et al. 2014), and journal publications (Kessler and Slocum 2011).

The general advantages of QCA include the speed of analysis (compared to qualitative content analysis) and the ability to compare many traits over time across a large sample. The inherent subjectivity of qualitative work often means that researchers cannot build on previous analyses, but in QCA, a future researcher could pick up the codes and replicate previous work (Muehlenhaus 2011a). QCA offered other advantages for this study, specifically: it enabled data collection without requiring a research visa, as would be necessary for other kinds of analysis that require access to non-tourist areas of the site (e.g., redesigning the tourist path to better view archaeological features). QCA also allowed me to derive a list of specific ways that maps and signage at Troy were not functioning well from a single analysis. Finally, QCA was cost-effective, as it could be conducted on the basis of photographs of maps and signage, which were free to take.

In this analysis, common design pitfalls are flagged by a selection of codes representing best practices derived from cartographic scholarship and XGD. The coding scheme was particularly useful for understanding how Troy's signage system could be improved, because "violations" of conventional mapping recommendations (e.g., using color hue to represent quantitative information) revealed specific design shortcomings. Generally, a single instance of ineffective design was enough to suggest that a sign be redesigned, because the codes represented significant design limitations, as determined by prior research in cartography and XGD. Furthermore, because the sample consisted of a signage system designed using common rules, an ineffective design on one sign was commonly repeated on other signs of that type. For example, illogical numbering found on one identification sign was found on most other identification signs as well. Thus, a single ineffective design decision could have compounding effects. In addition to signage violating cartographic standards, I also noted underutilization or total absence of design elements whose use is considered best practice in cartography and XGD (e.g., using a heads-up map orientation). Thus, the results of the QCA identified specific ways that individual signs, and the sign system itself, could fail the viewer.

To conduct my analysis, I collected geocoded images of signage at the Troy site from July 15th to July 16th, 2014 creating a census of every sign a visitor could encounter while on the tourist path. Images were excluded from the analysis if they were duplicates, blurry, contained an unusual lighting condition, were not a permanent installation, or were outside the bounds of the site. After this filtering, 108 total artifacts remained for the quantitative content analysis. Of those, 86 artifacts were signage without maps and 22 were signage with maps.

60 unique codes were applied to each artifact (Tables 2–5). The codes were grouped into categories. The first three were derived from spinning the Odgen-Richards Triangle: referent-as-mediator, interpretant-as-mediator, and sign-vehicle-as-mediator. Recommendations from XGD were included in a fourth category. The codes were binary—either an artifact received the code or it did not—but the codes were not mutually exclusive, so artifacts could receive multiple codes from the same category. The final coding scheme enabled an analysis of how the maps and signage functioned across broad semiotic categories through the spinning of the Ogdens-Richard Triangle, and by individual semiotic codes. Inferential statistics were not included because the sample size was low and did not include a control group. However, a researcher could collect another sample in a few years to note improvements. The final result was a table of design imperatives, organized by code categories, which includes recommendations for all signage, as well as for specific types of signage (e.g., directional signs; see Table 6).

IMPROVING THE TOURIST GAZE: RESULTS AND RECOMMENDATIONS

I analyzed and interpreted the results using the code themes for the referent-as-mediator, interpretant-as-mediator, sign-vehicle-as-mediator, and XGD perspectives. Some codes are omitted from discussion because the results were not directly relevant to this analysis, such as sign type.

REFERENT-AS-MEDIATOR

Information Content

Geographic information (56.5%) was found on more than half the signs. But, only 22 of 108 on-site signs (20.4%) included geographic information in the form of maps

Referent-as-Mediator	Definition & Source	Number of signs	Percentage of total signs
Information Content	Peuquet 1994		
IC1. Attribute (temporal)	Artifact contains historical information.	50	46.3%
IC2. Attribute (other)	Artifact contains non-historical information.	79	73.1%
IC3. Geographic	Artifact contains geographic, non-attribute information.	61	56.5%
Type of Knowledge or Instruction Provided	Golledge and Stimson 1987		
K1. Declarative	Knowledge about objects, attributes, and places.	69	63.9%
K2. Procedural	Knowledge about how to complete a task.	40	37.0%
K3. Configural	Knowledge about spatial relations between objects.	22	20.4%

Table 2. *Referent-as-Mediator results.*

Figure 6. A directional sign at Troy indicating the way to archaeological layers IX, VIII, and VIIb that could be improved by the inclusion of a map depicting the relationship of the archaeological layers to the surrounding environment.

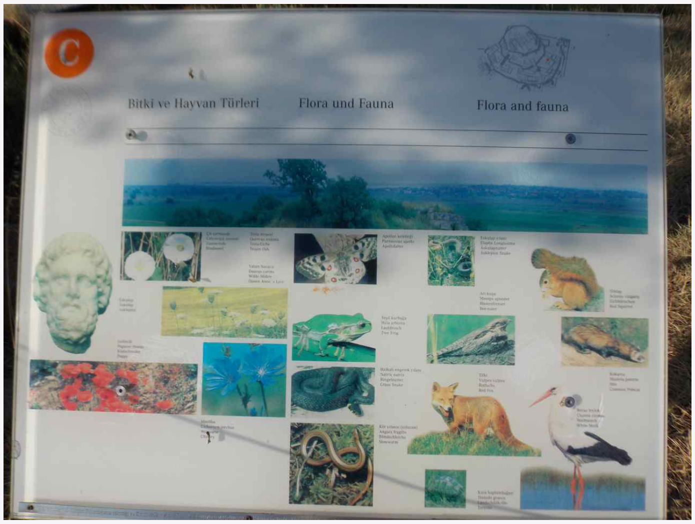

Figure 7. Flora and Fauna of Troy. The small text describes the name of each species in Turkish, German, and English. A description of the historical context of these species (rather than just these generic photographs) would improve this sign.

(Table 2, IC3 & K3). Geographic information was found on many examples of directional signage in the form of spatial navigation procedures indicating the direction to a particular layer of the site (Figure 6), but such directional signage was text-based and included no map visuals. An opportunity was thereby missed to pair identification and directional signage with maps, which would provide both procedural and configural knowledge within a single sign.

Seventy-nine signs (73.1%) contained attribute information and 50 signs (46.3%) contained historical information. The relative lack of historical information across signage was particularly problematic for Troy: as a UNESCO World Heritage Site, knowledge of Troy's history is critical to the visitor experience. For instance, the sign "Flora and Fauna of Troy" (Figure 7) included pictures of plants and animals at Troy but did not describe their historical context, thus leaving visitors to speculate as to whether these plants and animals were found in Ancient Troy as well as in the modern day.

Knowledge or Instruction Provided

Declarative knowledge was the most common form (63.9%) of embedded knowledge found in the sample (Table 2). Identification signage often contained declarative knowledge in the form of POI identifications (see Figure 8, identifying the location of Layer III). While such identification is essential for confidently locating features at Troy—and thus getting a full sense of the

Figure 8. An identification sign showing the location of layer III provides no other declarative knowledge such as its date. Including the date would make the sign more useful.

complexity of the Troy site—declarative knowledge is not limited to superficial identifications. Declarative knowledge broadly imbues objects with meanings and significance. Troy could use declarative knowledge in a deeper way by including interpretative information about cultural or physical significance to enrich the visitor experience.

Procedural instructions were found in 40 instances (37.0%) of the on-site signage. All directional signage (100%) contained procedural knowledge in the form of navigational instructions to a point of interest, such as a given layer of the archaeological site or the location of the bathrooms. Unfortunately, signs directing visitors to specific layers were likely to be confusing, because the signage used the letter and roman numeral labels assigned to the site over the years by archaeologists for research purposes (e.g., VIIb). Thus the procedural knowledge embedded in informational signage often failed cartographically.

Informational signage is encountered in a sequence as visitors walk the tourist path, and each sign has a sequence number in an orange circle (Figure 9). Unfortunately, as seen in Figure 10, the sequence uses a confusing mix of letters and numbers that is only somewhat ordered (1A follows A, C follows 3, etc.). This makes navigating the sequence difficult, and visitors might be led to believe they had made a wayfinding error when in fact they were on the

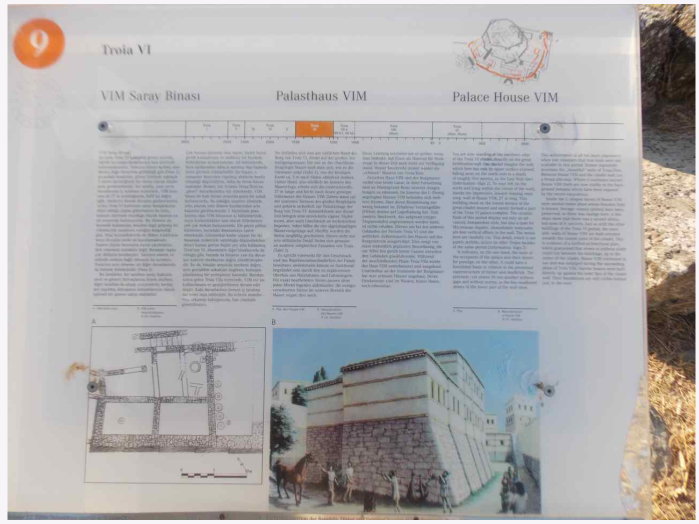

Figure 9. Procedural information on an informational sign (orange circle in upper-left-hand corner) found on the tourist route.

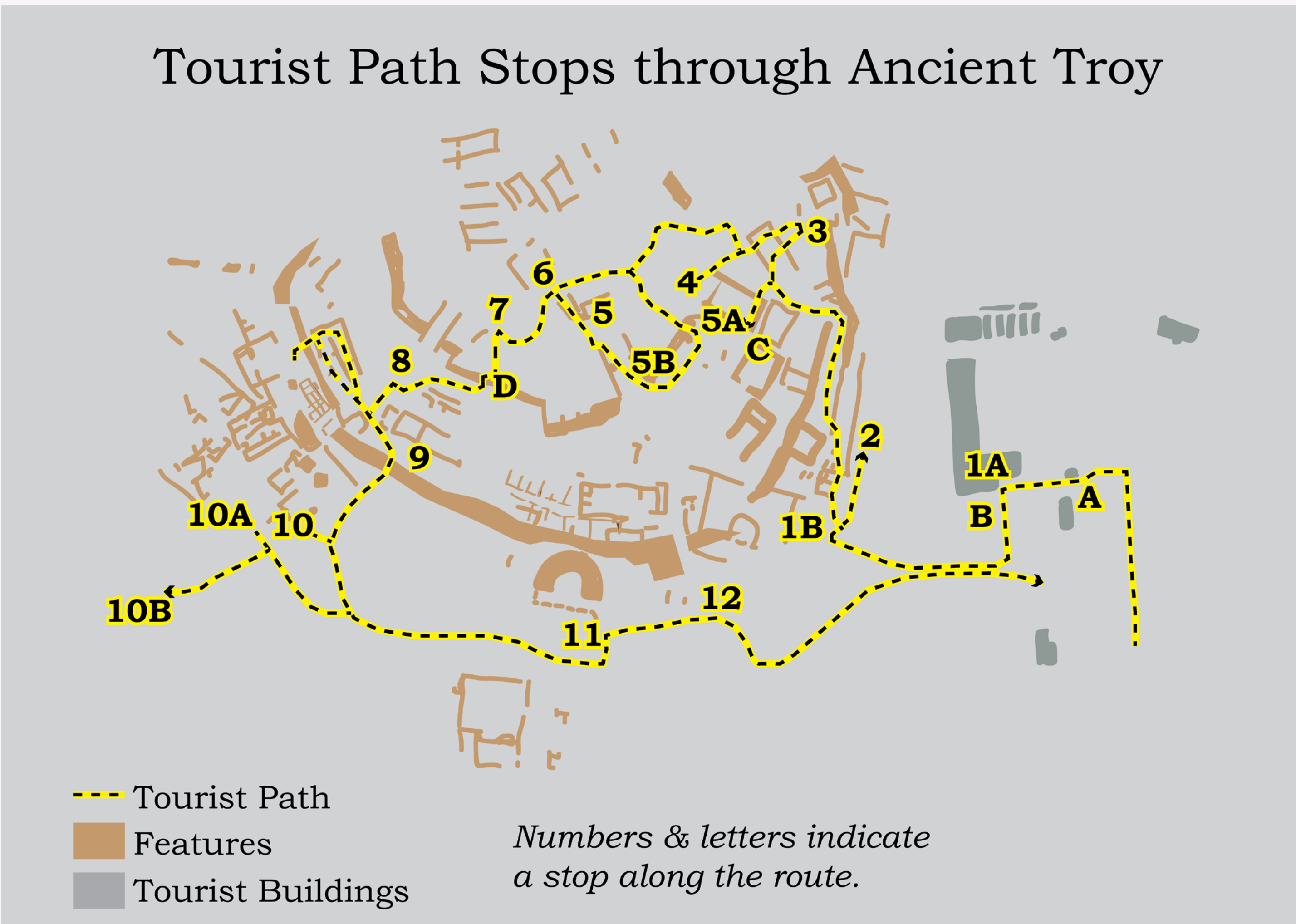

Figure 10. The order of informational signage along the tourist path at Troy. The numbers attempt to provide procedural information; however, this information does not follow a logical linear sequence. In a walk-through of the Troy loop from the visitor center, a visitor would experience the following sequence of procedural directions on informational signage: A, 1a, B, 1b, 2, 1b, 3, C, 3, 4, 5a, 5b, 5, 6, 7, D, 8, 9, 10, 10a, 10B, 11, 12. Map based upon Korfmann & Mannsperger (2013).

correct path. This issue is likely exacerbated by the short amount of time tourists spend on-site when visiting with a tour bus. A comprehensive redesign of the procedural wayfinding strategy is needed to clearly mark recommend tourist routes in a logical and informative order using color coding or a logical sequence of numbers.

Finally, configural knowledge, or knowledge of spatial relationships, was embedded in the form of small inset maps with the layer(s) of interest colored on a gray basemap (Figure 11). Configural knowledge was found exclusively on informational signage, or signage that provides information about a phenomenon (20.4% of signs at Troy; Table 2). Unfortunately, these representations were limited because they lacked an indication of directionality to help visitors understand the configural information in the context of the current vista.

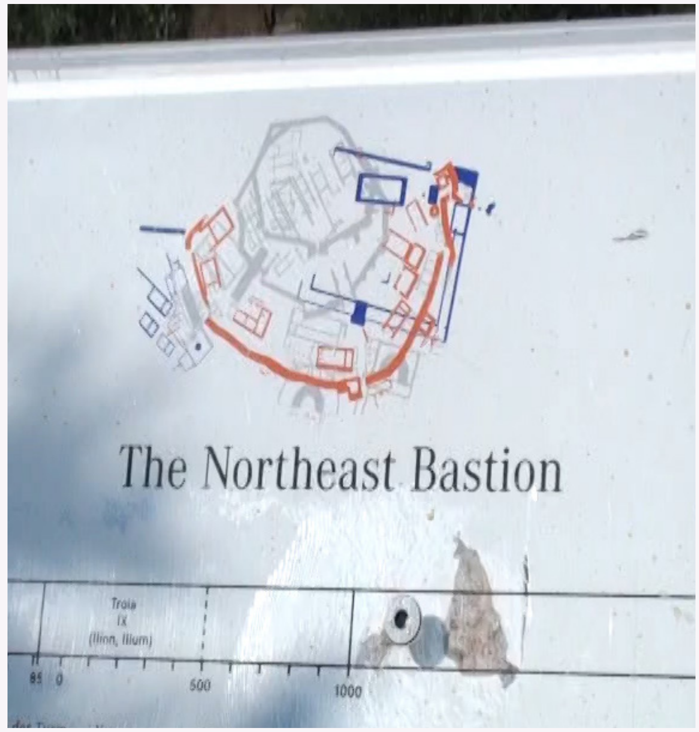

Figure 11. *An example of configural information present on informational signage. The map, intended to function as a locator map, does not include a You-Are-Here symbol or match the perspective the visitor faces. Changing to a heads-up display and including a You-Are-Here symbol will make this map more effective.*

INTERPRETANT-AS-MEDIATOR

Iconicity

The least common representation strategy at Troy was to utilize an associative / iconic solution (9.2%; Table 3). Meanwhile, pictorial / iconic solutions were found in only 15 signs (13.9%). Pictorial or associative representations are helpful at Troy because these representations present information in a readily understandable format, although with the drawback of potentially relying on culturally specific meanings. An example of a pictorial solution would be to depict the site's Trojan Horse replica as a simplified icon. However, a drawback is the difficulty in creating an effective pictorial or associative solution for display at map scale, given the complexity of the archaeological features at Troy. One way to solve this problem is to go beyond pictorial / iconic solutions to the level of image or realism. Unfortunately, this approach was not taken in an effective matter, as discussed later in this section, and this remains a missed opportunity at Troy.

Figure 12. *Extremes of abstraction (left) and realism (right) found on an informational sign at Troy. The abstract designs are difficult for a visitor to understand without a background in archaeology, especially given the lack of a legend. The realistic designs are so detailed that visitors may be overwhelmed by excess detail and lose connection between the map and the environment. The mismatched representation would be improved with consistency in iconicity. Note also the reflection on the signage that impedes legibility, which will be discussed later.*

Geometric / abstract designs (55.6%) were the most common symbol solution at Troy (Table 3). These designs can be useful as conventional symbols, but they require prior knowledge on the part of the visitor or a consistent legend in order to be understood; otherwise, immediate communication of complex meaning is difficult or impossible. For instance, Figure 12 shows an abstract representation of the layers of the archaeological site (see the left-hand arrow), but without a background in archaeology a visitor will not

Interpretant-as-Mediator	Definition & Source	Number of signs	Percentage of total signs
Iconicity (Modified Robinson Taxonomy)	MacEachren 1995		
I1. Associative / Iconic	Artifact's relation to the referent is via association.	10	9.2%
I2. Pictorial / Iconic	Artifact physically resembles the referent.	15	13.9%
I3. Geometric / abstract	Artifact's relation to the referent is arbitrary or conventional.	60	55.6%
I4. Image / Realism	Artifact's relation to the referent is photorealistic or near photorealistic.	21	19.4%
Part of a Symbol Library	ISO & AIGA		
SL1. ISO	Part of ISO library of symbols.	3	2.8%
SL2. AIGA	Part of AIGA library of symbols.	12	11.1%
Sign Type	Berger 2005; Smitshuijzen 2007; Calori 2007; Mollerup 2013		
ST1. Informational	Artifact provides information about a place.	28	25.9%
ST2. Identification	Artifact identifies a place, location, or object.	9	8.3%
ST3. Directional	Artifact indicates the direction to an object or location.	39	36.1%
ST4. Regulatory	Artifact regulates or prohibits behavior in a space.	16	14.8%
ST5. Ad Hoc	Handmade or graffiti sign used when a sign system fails.	0	0.0%
ST6. Indirect	Not a formal sign, but provides information about the environment.	16	14.8%

Table 3. *Interpretant as Mediator results.*

Figure 13. *Left: Signage with a realistic map (bottom left) and an abstracted map (top right). Right: Vista. It is difficult to relate the map to the environment because it doesn't show salient landmarks.*

__Figure 14.__ A prohibition sign (left) that could be improved with the use of symbols, such as a modified AIGA symbol for "no entry" (center) or the ISO symbol for "no access" (right). Typically, a second symbol is placed behind the ISO prohibition symbol to specify the type of prohibited access.

be able to understand how the shapes correspond with the actual features they are looking at in the landscape. Geometric / abstract map symbols and signage are particularly important at Troy because the landscape provides few landmarks that are recognizable without the presence of a sign to help the visitor connect maps and signage to the surrounding environment.

Image / realism was the second most common iconicity strategy at Troy: 21 signs (19.4%) utilized this approach (Table 3). Realism was presented in the form of artistic interpretations of the city during different time periods (Figure 12). Because Troy is a ruin, the "true to ancient life" visual interpretations of ancient Troy are difficult to match with the modern environment (Figure 13). Including realistic images of the environment as it appears to the contemporary viewer, emphasizing salient landmarks, will help the viewer associate the information on the sign with the present vista.

Notably, 29 artifacts could not be coded for iconicity: 12 signs contained only text and 16 signs were indirect, using neither text nor pictures. The all-text signs were prohibition signs or identification signs (Figure 14). As signage at Troy is written in some combination of Turkish, German, and English, additional visual content would help the signs communicate with visitors who are unable to read these languages.

Sign Libraries

Of the 108 signs in the analysis, 15 (14.1%) used standard symbols for *Parking*, *Bathroom*, and *No Smoking* (Table 3). Of these signs, 4.6% took symbols from the ISO library, and 9.5% were symbols from the AIGA sign library (Figure 15). An opportunity was missed to leverage the ISO and AIGA symbol libraries more consistently to standardize the visitor experience at Troy. The use of so few standard symbols led to a reliance on text across Troy's signage, and inclusion of custom abstract or realistic symbols when text was supplemented with visuals.

Sign Type

While Table 3 gives the quantities of each sign type (e.g., regulation, directional), the results of this content analysis cannot suggest whether increasing the number of signs of one type or another is appropriate. Many of these signs are necessitated by the particular shape of the tourist path, and so suggestions on changing them would first require an analysis and possible redesign of the path. That would

__Figure 15.__ Associative ISO symbol for "bathroom" as used in a sign at Troy.

be a viable future direction for this project, but for now, I can only comment on the *design* of the signs, not their quantity.

SIGN-VEHICLE-AS-MEDIATOR

Symbolization

Color hue was the most frequently used visual variable to represent quantitative differences (36.1%; Table 4), despite recommendations from semiotics to reserve color hue for depicting qualitative differences. On maps and signage, color hue was used primarily to show a temporal difference between the historical layers at Troy (following color conventions established by Dörpfeld [1902]), or to highlight positions along a timeline (Figure 16). The symbolization of historical information would be clearer if the spectral color scheme relying solely on color hue was replaced with a sequential scheme modifying color value in addition to color hue.

No artifacts at Troy used the visual variable of size to communicate quantitative differences, though it is the strongest variable for this purpose. This is due to the site's focus on reference mapping rather than thematic mapping to support the user experience at Troy. There is an opportunity to add statistical archaeological information to the maps and signage in addition to the map-based wayfinding information, such as quantities of artifacts found.

While only color hue was used in quantitative representations, color hue, color value, texture, and orientation were used qualitatively (Table 4). Color hue (12%) was used to highlight features of interest on maps and signage or to indicate categorical differences in Troy's features, though individual hues were unfortunately not used consistently across identification signage (Figure 17). Also, several signs used hues that contrasted poorly with their surroundings (Figure 17, center image) and engraved or embossed signs had text which contrasted poorly with the sign's background (Figure 17, left image). The poor contrast decreased the legibility of the signage and indicated that color value variation within a color hue, or outer framing may be needed to increase contrast within a sign or account for variable environmental conditions.

The qualitative use of orientation was found in all directional signage (100%). Here, a triangular symbol found

Figure 16. *An informational sign showing the strata throughout Troy. Color hue is used to show quantitative data in the timeline, when a sequential scheme relying on color value would have been an improvement. Cross-section maps such as this one would have been useful in other locations throughout the archaeological site to help the visitor understand the complicated strata.*

Figure 17. *Various styles of identification signage at Troy. The inconsistent choice of color hue requires visitors to read these signs in order to know their function rather than inferring it from the qualitative use of color hue alone. Using color hue consistently will enhance the function of these signs.*

Sign Vehicle-as-Mediator	Definition & Source	Number of Signs	Percentage of Total Signs
Color Hue	Bertin 2010; MacEachren 1995		
H1. Hue Quantitative	Hue used to show a quantitative difference.	39	36.1%
H2. Hue Qualitative	Hue used to show a qualitative difference.	13	12.0%
Color Value	Bertin 2010; MacEachren 1995		
V1. Value Quantitative	Value used to show a quantitative difference.	0	0.0%
V2. Value Qualitative	Value used to show a qualitative difference.	1	0.9%
Texture	Bertin 2010; MacEachren 1995		
T1. Texture Quantitative	Texture used to show a quantitative difference.	0	0.0%
T2. Texture Qualitative	Texture used to show a qualitative difference.	2	1.9%
Shape	Bertin 2010; MacEachren 1995		
S1. Shape Quantitative	Shape used to show a quantitative difference.	0	0.0%
S2. Shape Qualitative	Shape used to show a qualitative difference.	0	0.0%
Size	Bertin 2010; MacEachren 1995		
SZ1. Size Quantitative	Size used to show a quantitative difference.	0	0.0%
SZ2. Size Qualitative	Size used to show a qualitative difference.	0	0.0%
Orientation	Bertin 2010; MacEachren 1995		
O1. Orientation Quantitative	Orientation used to show a quantitative difference.	0	0.0%
O2. Orientation Qualitative	Orientation used to show a qualitative difference.	38	35.2%
Typeface			
TF1. Serif used	Artifact uses a serif typeface.	47	43.5%
TF2. Sans serif used	Artifact uses a sans serif typeface.	34	31.5%
Type Case			
TC1. Normal capitalization rules	Artifact uses normal capitalization rules.	44	40.7%
TC2. All caps	Artifact uses all caps.	36	33.3%
TC3. Small caps	Artifact uses small caps.	0	0.0%
Type Style			
TS1. Roman	Artifact uses roman style.	79	73.1%
TS2. Bold	Artifact uses bold style.	24	22.2%
TS3. Italic	Artifact uses italic style.	0	0.0%

Table 4. *Sign-Vehicle-as-Mediator results.*

on either side of a signpost pointed out the direction to the indicated phenomenon. This effective qualitative use of orientation could also be applied in identification and informational signage to indicate the direction a visitor should look when arriving at a point of interest. However, this orientation cue in some on-site signage contained no obvious meaning, as the triangles pointed at nothing in particular, causing confusion (Figure 18). This "signage to nowhere" should be removed from the site.

The qualitative use of shape—a strong visual variable for depicting categorical data—did not appear in any signage (0%). Shape could have been used to indicate features of interest or to coordinate points of interest across maps and signage. For example, the shape of the signage itself could have provided information about the contents of the signs, enabling the visitor to distinguish between informational signage and regulatory signage at a glance.

Figure 18. Signage using the visual variable of orientation without any clear meaning caused confusion at Troy. This sign should be removed.

Typography

The typography sub-category included codes for type class, case, and style (Table 4). While all materials from the visitor center contained type, 16 on-site signs (14.8%) did not contain text because they functioned as indirect signage, as no text was needed to communicate the information that these signs conveyed (Figure 19).

Nearly half (43.5%) of on-site signage featured a serif typeface (Table 4). However, the typeface was not consistent across the signage, which would have been preferable. It is cartographically conventional to label natural phenomena in a serif typeface, and doing so on signage would increase congruency between referent and sign-vehicle. Like serif typefaces, the sans serif typefaces used for on-site signage were not consistent across Troy. Additionally, sans serif typefaces found in signage were sometimes hand-made (Figure 20), giving the signage a slapdash, unprofessional appearance.

Roman type (73.1%) was the overwhelming choice for signage at Troy (Table 4). No signage included italics, but roman type was paired sparsely with bold type, which occurred on 24 signs (22.2%). The complementary use of

Figure 19. Surveillance placed in a prominent location: an indirect sign indicating the visitor is being watched. No text is needed to explain the function of this sign.

Figure 20. Directional sign with obviously handmade sans serif typography. This sign should be redesigned with a more professional looking sans serif typeface.

Figure 21. Lighting conditions impede the legibility of glossy signage due to reflections caused by bright sunlight (left) and shadows (middle). Compare with the matte signage in bright sunlight (right). The design of the two signs on the left can be improved with using a matte or semi-matte material.

Figure 22. Ambiguous directional signage attempts to communicate the location of Troy I. Where in the environment is Troy I? An opportunity was missed to pair directional signage with maps that explain what the visitor should recognize in the environment.

Figure 23. This prominent "No Smoking" sign is inconsistent with the sign hierarchy. The size of this sign can be reduced.

bold and italics with the roman type can emphasize important or special details in signage and encode additional nominal and ordinal information in maps, thereby improving their effectiveness.

EXPERIENTIAL GRAPHIC DESIGN

Physical Properties

The physical characteristics of the signage at Troy impacted its effectiveness. Nearly half of the 108 signs were semi-matte (46.3%; Table 5), followed by matte (17.6%) and glossy (21.3%). Matte and semi-matte signage did not present legibility problems, but glossy signage was difficult to read in conditions of bright light and dark shadow (Figure 21). This should be replaced with the use of matte or semi-matte signage.

Sign Shape

The majority of signage at Troy was rectangle-shaped (54.6%; Table 5). Only one regulation sign was circle-shaped (0.9%), conforming to ISO sign shape standards. Although a small number of signs were triangle-shaped (9.3%), this triangular shape was not used to carry the conventional semiotic meaning of caution or warning. Some signage combined a rectangular sign with a single triangular edge (20.4%). This signage functioned well when providing general directions to a destination such as a parking lot or a bathroom but was ineffective when indicating a layer of the complex archaeological site, given the ambiguity in relating the direction to a subterranean feature in the landscape without additional interpretive cues (Figure 22). Pairing this directional signage with maps that illustrate stratigraphy would help solve this problem. Solutions such as adding a You-Are-Here

Experiential Graphic Design	Definition & Source	Number of Signs	Percentage of Total Signs
Physical Properties	Calori 2007; Mollerup 2013		
P1. Matte	Sign is not reflective.	19	17.6%
P2. Gloss	Highly reflective sign.	23	21.3%
P3. Semi-Matte	Sign is partially reflective.	50	46.3%
P4. Halation Present	Sign or sign lettering appears to "glow" beyond its appropriate border	0	0.0%
Physical Shape	Calori 2007; Mollerup 2013; Berger 2005		
PS1. Circular	Artifact is circle-shaped.	1	0.9%
PS2. Rectangular	Artifact is rectangle-shaped.	59	54.6%
PS3. Triangular	Artifact is triangle-shaped.	10	9.3%
PS4. Triangular and Rectangular	Artifact is a combination of triangle- and rectangle-shaped.	22	20.4%
PS5. Other	Artifact is neither circle-, rectangle- or triangle-shaped.	0	0.0%
Size & Sign Hierarchy			
SH1. Prominent and Consistent with Sign Hierarchy	Artifact is in a prominent location appropriate to the sign hierarchy.	74	68.5%
SH2. Prominent and Inconsistent with Sign Hierarchy	Artifact is in a prominent location not appropriate to the sign hierarchy.	4	3.7%
SH3. Recessive and Consistent with Sign Hierarchy	Artifact recedes appropriately in the sign hierarchy.	4	3.7%
SH4. Recessive and Inconsistent with Sign Hierarchy	Artifact recedes inappropriately in the sign hierarchy.	10	9.3%
Damaged or Heavily Worn			
D1. Yes	Artifact is damaged.	15	13.9%
D2. No	Artifact is not damaged.	93	86.1%
Occluded or Poor Visibility			
OD1. Yes	Artifact is blocked or partially blocked from the visitor's sight.	11	10.2%
OD2. No	Artifact is not blocked from the visitor's sight.	97	89.8%

Table 5. *Experiential Graphic Design considerations.* *Continued on next page.*

Experiential Graphic Design	Definition & Source	Number of Signs	Percentage of Total Signs
Procedural Directions included in Place Names	Mollerup 2013		
CD1. Yes	Procedural directions are included in place names.	1	0.9%
CD2. No	Procedural directions are not included in place names.	107	99.1%
Coordinated Names	Mollerup 2013		
CN1. Yes	Artifact uses coordinated names.	23	21.3%
CN2. No	Artifact does not use coordinated names.	85	78.7%
Common Patterns Used	Mollerup 2013		
CP1. Yes	Artifact uses common patterns.	65	60.2%
CP2. No	Artifact does not use common patterns.	43	39.8%
Heads-Up Display	Mollerup 2013		
HU1. Yes	Artifact uses a heads-up display.	0	0.0%
HU2. No	Artifact does not use a heads-up display.	108	100.0%
You-Are-Here Symbol Present	Katz 2012		
Y1. Yes	Artifact uses a You-Are-Here symbol.	0	0.0%
Y2. No	Artifact does not use a You-Are-Here symbol.	108	100.0%
If Present, Symbol is Arrow	Katz 2012		
YP1. Yes	Artifact uses an arrow-shaped You-Are-Here symbol.	0	0.0%
YP2. No	Artifact does not use an arrow-shaped You-Are-Here symbol.	108	100.0%
Distance or Geography Distorted	Katz 2012		
GD1. Yes	Artifact distorts distance or geography.	0	0.0%
GD2. No	Artifact does not distort distance or geography.	108	100.0%

Table 5. *Experiential Graphic Design considerations, continued.*

symbol and rotating the top of the map to the visitor's current perspective would further tie these ambiguously shaped directional symbols into the overall map and signage strategy.

Sign Hierarchy

The majority of signage at Troy was prominent and exhibited a consistent sign hierarchy, with more important signs being more prominent (68.5%; Table 5). However, four very large "No Smoking" signs were inappropriately prominent, thereby causing distraction (Figure 23). While smoking poses a fire risk to the site and smoking prohibitions are uncommon in Turkey, visitors to Troy need to gain more from their experience than the knowledge that smoking is prohibited. Raising the prominence of other information in the sign hierarchy may help solve this problem.

Figure 24. *Recessive identification sign, inconsistent with the visual hierarchy. This sign is not readable without a zoom lens. Changing the size or placement of this sign will improve its ability to serve its intended function.*

Figure 25. *Recessive regulation sign, inconsistent with the visual hierarchy. This sign advises that the tourist path ends, but a visitor must walk up to the sign (and thereby leave the tourist path!) to learn this information. The sign will be more functional if moved to a visible location.*

Similarly, ten signs were recessive in a way that was inconsistent with the sign hierarchy (9.3%). They were placed in shaded locations used as waypoints during the hot Troy summers and were difficult to see from the trail. Some of the recessive signage included identification signs (Figure 24) that could cause visitors to become frustrated when they could not confirm that an important vista or point of interest had been reached. Of more concern, visitors failing to see recessive regulation signage could enter a dangerous area off the tourist path, leading to injury or damage to the site (Figure 25).

Damage and Occlusion

Some signage at Troy was ineffective due to material damage (13.9%; Table 5; Figure 26) or occlusion (10.2%) by environmental elements such as foliage (Figure 27). Ineffective signage impairs the visitor experience and contributes to a potentially unsafe situation. The occluded signage demonstrates the importance of maintaining the Troy site in a manner that preserves the signage hierarchy. Also, signage should not be placed in areas where it cannot be regularly maintained, even if the positions are visually salient.

Wayfinding Information

The signage at Troy could have been greatly improved by the inclusion of wayfinding information using best practices from experiential graphic design. Missed opportunities include utilizing a heads-up display to orient visitors to the features in front of them (0%; Table 5), and You-Are-Here symbols (0%). By making better use of wayfinding information, the signage at Troy could have better served the needs of visitors.

Figure 26. *Damaged signage is difficult to read and hurts the visitor's experience of Troy. These signs should be repaired or removed.*

DISCUSSION: DESIGN IMPERATIVES

> Sing in me, O Muse, and *through me* tell the story.
>
> Opening of Homer's *Odyssey*, and a summary of best practices for historic signage design.

In this study, I have explored the ways that signage at Troy could be improved using the principles of cartographic semiotics and best practices of XGD through conducting a quantitative content analysis of the signage found on site at Troy. The results of the content analysis were used to derive a summary table of recommendations for signage at Troy, addressing specific deficiencies in the Troy visitor experience with improved design of maps and signage (Table 6). My analysis revealed new avenues for signage development beyond existing recommendations in the literature. For example, when analyzing the topic of embedded knowledge, it became apparent that on-site signage underutilized maps and configural information. Addressing that broad-level deficiency requires a holistic approach of considering (1) design opportunities for utilizing maps and configural information, and (2) other best practices that Troy's signage does not follow, such as the inclusion of more geographic information and geometric / abstract representations. This specific approach would not have been apparent before conducting the analysis. In other words, the literature provided a framework, but the empirical work identified the design gaps at Troy. The design imperatives in Table 6 aim to take the gaps in the focused study and speak back to the literature. Although the recommendations are specific to Troy, they can also be generalized for use at other archaeological sites.

LIMITATIONS

Limitations to this study include the time period of the analysis, which was a time of transition for Troy. The photos of the artifacts were collected in the summer of 2014. Since then, the maps and signage may have changed at the site. Thus, any revisions to maps and signage at Troy based on the above recommendations need to account for changes to the site, including the opening of a nearby Troy museum in 2019. Relating to the content analysis itself, I did not have a second coder to enhance coding replicability.

There were several aspects of the visitor experience at Troy that I did not capture due to the limited time I had on site.

Figure 27. *Occluded sign. Trimming foliage will improve the visibility of this sign.*

Additional dimensions that I would have liked to have captured included the correspondence of audio guides to vistas, the physical dimensions of the maps and signage, and important landmarks or vistas that were off the tourist path or otherwise not identified with a sign. Regarding the latter, I am unable to identify locations at Troy where additional maps and signage are needed—an important consideration for wayfinding and visitor experience—as the study focused solely on the content of existing signs.

This study focused on the ways in which information was displayed to visitors at Troy but did not focus on the historical content itself, such as the choice of the specific historical information appearing on a given sign. Conducting an interview study to understand the needs of stakeholders such as locals, visitors, and researchers would expose aspects of the historical content missing in the maps and signage as well as capture broader opinions, values, and reactions to maps and signage at Troy. However, the collection of primary information from these stakeholders was outside of the project's scope due to the limited time on-site.

Cartographic Semiotics	
Information content	Iconicity (continued)
Include geographic information in signage to highlight and identify salient landscape features.	Add more pictorial or associative representations to maps and signage.
Make geographic information available throughout the site.	Sign Library
Put more historical information on signs.	Use standard symbols from widely recognized symbol libraries such as AIGA / ISO.
Embedded knowledge	Use standard symbols to reduce the amount of text on signs.
Include maps on identification signs and directional signs.	Use standard symbols to communicate with visitors who cannot read Turkish, German, or English.
Use declarative knowledge to identify and interpret features.	Visual variables
Make configural information on maps relatable to the configuration of the environment.	Reserve color hue, texture, and shape for qualitative differences.
Rotate inset maps to reflect the direction that the visitor is facing when reading the sign.	Keep color hue consistent across the sign system.
Include a You-Are-Here symbol on maps.	Use perceptual scaling for color value.
Deliver procedural information in an understandable format.	Reserve size for quantitative differences.
Iconicity	Utilize orientation to show the strata on-site at Troy.
Use geometric / abstract & "true to ancient life" image / realism representations with landmarks so that visitors can "read" them within the modern environment.	Rely on orientation to indicate the direction a viewer should look when arriving at a point of interest.
Experiential Graphic Design	
Change glossy signs to a matte or semi matte finish.	Ensure that signs are visible because occluded signs impair the experience of place.
Conform signage to ISO sign shape standards.	Include consistent systems of names.
Pair directional signs with maps that illustrate stratigraphy.	Use procedural directions in place names to orient the visitor.
Ensure signage is consistent with the sign hierarchy so that unimportant signs do not cause distraction.	Use a heads-up display to orient visitors as to what is in front of them.
Make sure important signs, such as identification signs, are large enough for visitors to read at a reasonable distance when they arrive at a vista or point of interest.	Make the You-Are-Here symbol an arrow so that visitors can identify on the map the direction they are facing.
Repair or remove damaged signs.	

Table 6. *Design imperatives derived from the content analysis.*

CONCLUSIONS: FROM SIGNED TO DESIGNED

There are several future potential directions for this research. This study could be repeated across multiple historical sites, using the same QCA coding scheme, to produce a cartographic semiotics / XGD checklist for maps and signage that ensures that the signage in the environment is communicating effectively with the visitor. Another valuable direction is to complement this study with an examination of the effects of digital tools, such as audio tours, interactive displays in the museum, and augmented reality via mobile devices. This will enrich our knowledge about designing not only signage, but an entire visitor experience. Lastly, further exploration of the intersection of cartography and XGD would be beneficial for both fields. Each can share their respective insights into the design process, the consistency of representations, and the structure of the visual hierarchy. These insights will result in better maps produced by experiential graphic designers, while giving cartographers a better awareness of the wider environment in which their maps are used.

Improving the user experience by ensuring that Troy has a functional sign system will attract more visitors, which will increase its public visibility and likelihood of attracting funding, thereby furthering its preservation. The outcome of this study is a series of recommendations, grounded in cartographic semiotics and XGD, that will hopefully help future designers transform this legendary UNESCO World Heritage Site from a *signed* experience into a *designed* experience, so that Troy may inspire visitors for generations to come.

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A Geologic Map of the Moon Designed with Open Data

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INTRODUCTION

Over the past couple of years, I designed a collection of ten maps of outer space using open-source data, including an animated map of the seasons on Earth, a map of Martian geology, and a map of asteroid orbits. My goal for the project was to make a set of decorative posters that people from any background could enjoy, whether or not they were scientists.

This article explains my design process for one of the most challenging maps in the project: a geologic map of the Moon. This Moon map was particularly difficult because the geologic data was split into six different datasets. Each dataset had unique labels (and sometimes different data formats) so I spent a lot of time piecing the data together to create a cohesive map. Though it was difficult to make, it was also one of my favorites, because there were so many unique geologic features, such as large impact craters, broad plains, and textured ridges. The Moon has no significant atmosphere, and there is little wind to erode meteorite craters once they have formed. Several huge impacts have created large geologic features still visible today, such as the Orientale basin on the southern far side visualized in bright red on my map.

After finally finishing the map collection, I'm very excited to share with you my workflow for making this particular map with open astronomy data from the **USGS**, **IAU**, and **NASA**. My Github page (**github.com/eleanorlutz**) provides my open-source code, along with more detailed instructions on technical steps, including special instructions for beginners who are new to coding or design. The software I used includes Python, GDAL, Illustrator, and Photoshop (CC 2019), but other open-source design software like Inkscape and GIMP can achieve similar results.

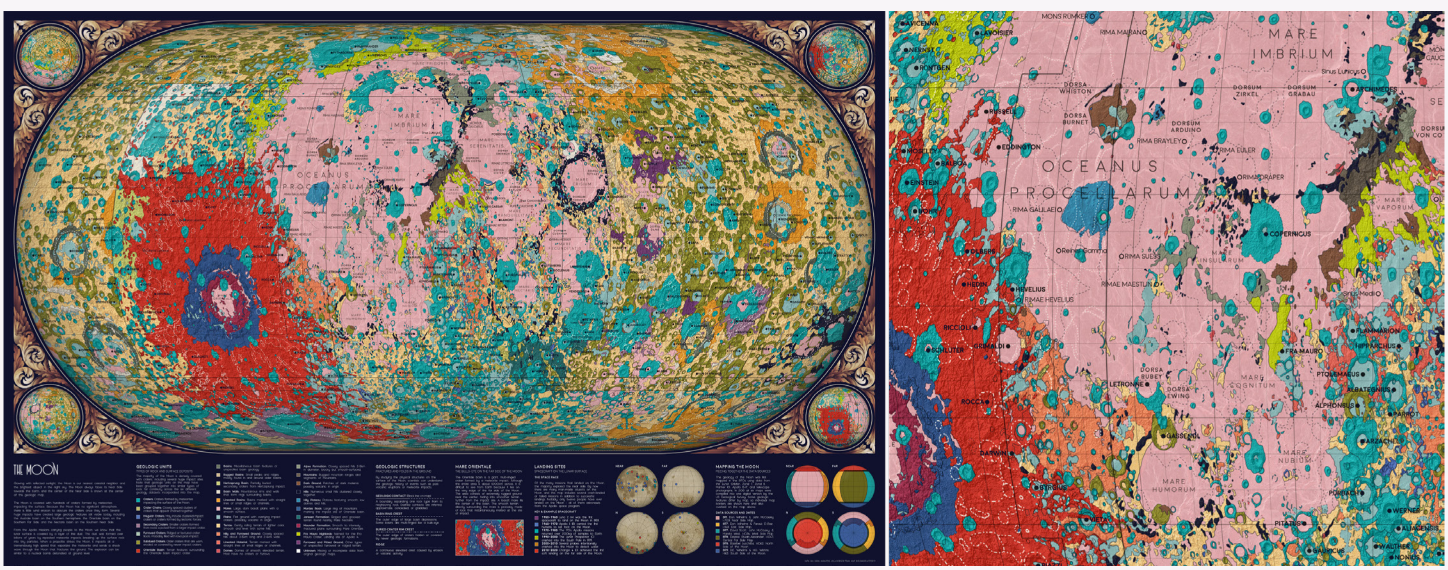

Figure 1. The completed map (left) and a detail section (right) showing Oceanus Procellarum.

GATHERING AND PROCESSING DATA

The main map is composed of three basic elements: geology, elevation, and nomenclature labels. I needed to understand and plot each data type separately before I could incorporate them into one cohesive map.

GEOLOGIC DATA

To give a little context, the geology of the Moon was mapped in the 1970s using data from the Lunar Orbiter program, Zond 7, Zond 8, Mariner 10, Apollos 15–17, and telescope photographs. In 2013 all six of these original maps were compiled into a digital dataset by the USGS. However, the digital version was still separated into six different sections, each with their own folder full of shapefiles, symbology, and metadata (illustrated in Figure 2). Because of this, the geologic data was probably the most complicated dataset to pre-process.

One complication with having six datasets instead of one was that they were sometimes inconsistent. Some geologic categories were described differently between datasets, like "*Basin Material, Rugged*" vs. "*Material of Rugged Basin Terrain,*" The imprecise geologic timescales offered another complication. Some areas were described with uncertainty—for example, some plains were classified as being from the "*Imbrian or Nectarian*" era, which are two periods of geologic time on the Moon. And some geologic categories combined many time periods, like craters from "*Imbrian, Nectarian, and pre-Nectarian*" time periods. These timescale estimates also differed between datasets.

I thought it would be too visually complicated to show all these uncertain aggregations in one map, and I also needed to find a way to reconcile labels across the six datasets. To solve both of these problems, I decided to omit timescale data entirely. I reviewed the descriptions of each feature type in the USGS data, and re-assigned them to 29 colors based on morphology (craters, basins, etc.) without including geologic timescales. This meant that the final map had much less detail than the original data—but the information flowed consistently across the entire planet, instead of fragmenting visually into six sections.

One additional issue with this data was that the shapes in the two polar datasets were encoded in meters, while the rest of the data was encoded in degrees. This was an issue for my particular workflow, which involved using the programming language Python to convert the USGS data files into vector illustrations. The default globe in Python is based on Earth, which has a much larger circumference than the Moon, so data plotted in meters didn't cover the correct amount of space. To fix the issue I created a custom sphere with the Moon's radius:

```
axis = 1737.1 * 1000 # radius of the Moon, in
  meters
```

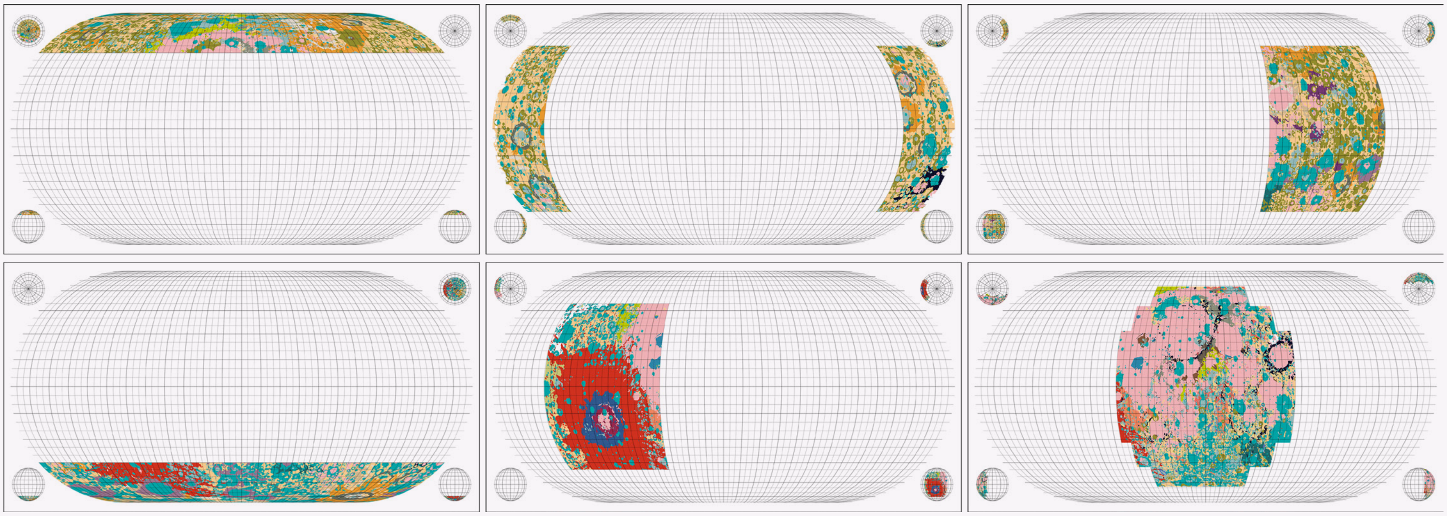

Figure 2. *Each of the six geologic datasets making up the final map. In the design phase of the project I created each of these maps separately in Python, then combined them together in Photoshop. This allowed me to experiment with the order of each layer to see which combinations would show the fewest discrepancies across data borders.*

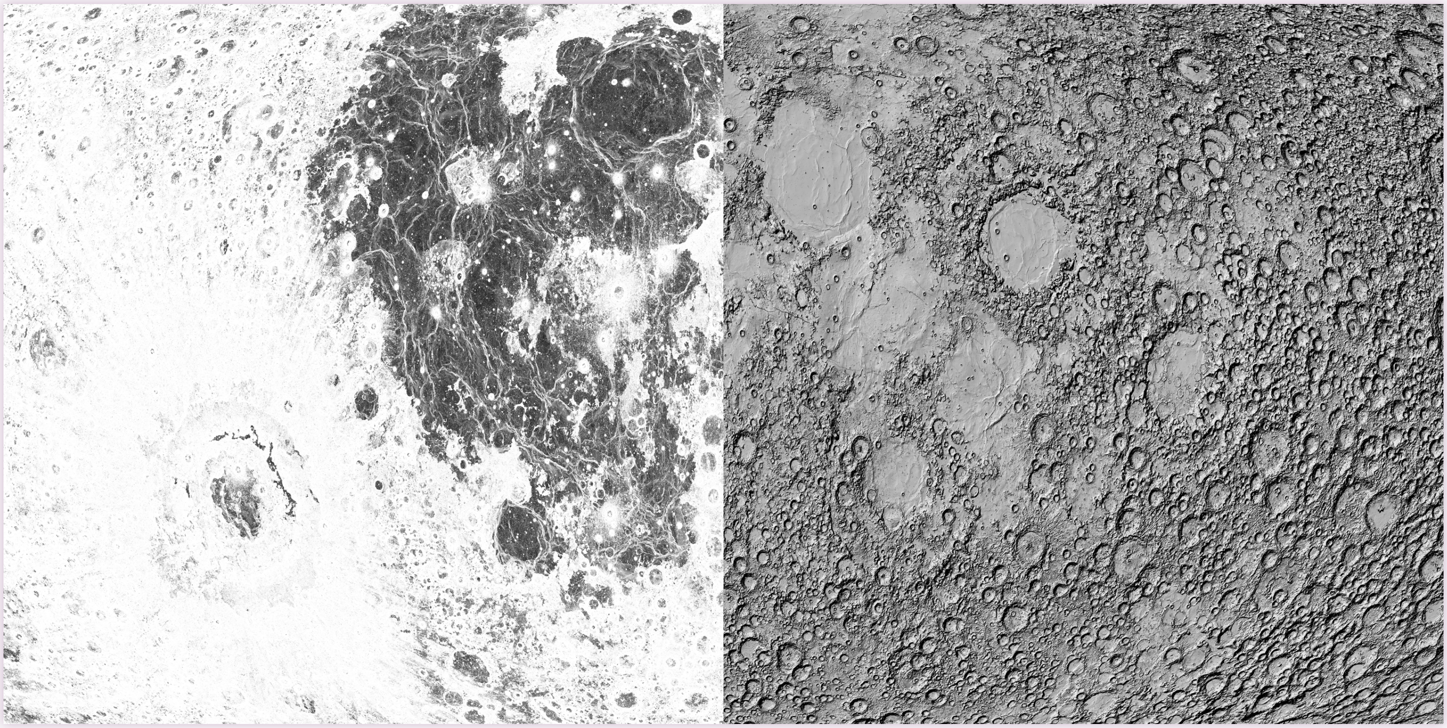

Figure 3. *The slope (left) and hillshade (right).*

```
globe = ccrs.Globe(semimajor_axis=axis,
  semiminor_axis=axis, ellipse=None)
large_proj = ccrs.EckertIV(globe=globe)
```

ELEVATION DATA

To make the hillshade and slope textures for this map I used a **digital elevation model (DEM) from the USGS**. The original DEM file uses a plate carrée projection, which is a fairly simple projection that distorts the area of features across the globe. In this geologic map I wanted to use an equal-area projection, like Eckert IV, so that I could accurately compare the relative areas of each type of geologic feature. To convert the plate carrée map into the Eckert IV projection, I used the command line installation of GDAL. The code below uses the original raster file to create a new file using the eck4 (Eckert IV) projection:

```
gdalwarp -t_srs “+proj=eck4”
  ./path_to_intif.tif ./path_to_outtif.tif
```

Next, I downsampled the file by decreasing the resolution of each pixel to 1500×1500 meters. It's useful to decrease file size to reduce computation times, and it's much faster to downsample at this point than to scale images later on in the process.

```
gdalwarp -tr 1500 1500 -r average
  ./path_to_intif.tif ./path_to_outtif.tif
```

Next, I used the downsampled DEM to generate hillshade and slope maps for each hemisphere of the Moon. For this map I used a particularly high vertical exaggeration, multiplying elevation values by 20, because the map colors would be matched to geologic units instead of topography. This increased visual contrast helps the hillshade show up under all of the other map elements.

```
gdaldem hillshade -z 20 ./path_to_intif.tif
  ./path_to_hillshade.tif
gdaldem slope ./path_to_intif.tif
  ./path_to_slope.tif
```

In addition to the main Eckert IV map, I also mapped the four hemispheres of the Moon (northern, southern, eastern, and western). The Eckert IV map isn't great for visualizing the polar regions (which are flattened excessively), so the northern and southern hemisphere insets were particularly important for understanding these areas. To make the hillshade and slope for each of the four corner maps, I repeated the same code as above, modified slightly for the orthographic projection and specifying the center latitude and longitude for each map. The code for the north pole is shown below:

```
gdalwarp -t_srs "+proj=ortho +lat_0=90
  +lon_0=90" ./path_to_intif.tif
  ./path_to_outtif.tif
gdalwarp -tr 1500 1500 -r average
  ./path_to_intif.tif ./path_to_outtif.tif
gdaldem hillshade -z 20 ./path_to_intif.tif
  ./path_to_hillshade.tif
gdaldem slope ./path_to_intif.tif
  ./path_to_slope.tif
```

NOMENCLATURE DATA

I downloaded the official feature names for the Moon from the **International Astronomical Union**, which is responsible for naming features of extraterrestrial objects. The full data includes about 9000 named features, and in my map I included about 400 of them. Many of the features I omitted were near the landing sites of various spacecraft—in these areas many more objects were named because they could be observed and studied at high resolution from the lunar surface.

To download a CSV file of all features, I used the IAU's **Advanced Search Function** and selected:

- **Target:** Moon
- **Feature Types:** All
- **Approval Status:** Adopted by IAU
- **Columns to Include:** Feature ID, Feature Name, Clean Feature Name, Diameter, Center Lat/Lon, Feature Type, Feature Type Code
- **Output Format:** CSV

MAP DESIGN

After cleaning the data, I switched gears and developed a design style that would be appropriate for both this map and the others in my collection. I wanted to make sure it could tie together each map into a cohesive collection.

OVERALL DESIGN STYLE

Decorative Illustrations

For this project I wanted to combine large datasets with a hand-crafted design style. I was particularly inspired by artists like William Morris or Alphonse Mucha, whose textile designs and Art Nouveau paintings were known for their colorful, detailed decorations. For this scrollwork design I started with a pencil sketch, and tried several iterations of leafy scrolls before finally picking a less botanically inspired design.

When I paint decorations like these in Photoshop, I begin each design as a solid white shape and then gradually break away pieces into detailed chunks. Next, I brush away pieces of each section with the brush eraser tool until the pieces look like a fully-shaded monochrome design. I wait to add color until the very last step, where I use many different colors and overlay layers for a richer effect.

Designing a Color Scheme

The original geologic maps of the Moon—**like this one**—were published in the 1970s, and I loved the bright neon color schemes in these historical maps. I tried to keep as many of the same colors as possible, though I re-arranged the palette to save the more extreme colors for smaller or more unusual geologic formations. The color design was also influenced by the other maps in my astronomy series, as I traded colors between them.

Figure 4. *The completed scrollwork (far left), as well as separate layers from the file including color overlays and the monochromatic segments separated out for painting.*

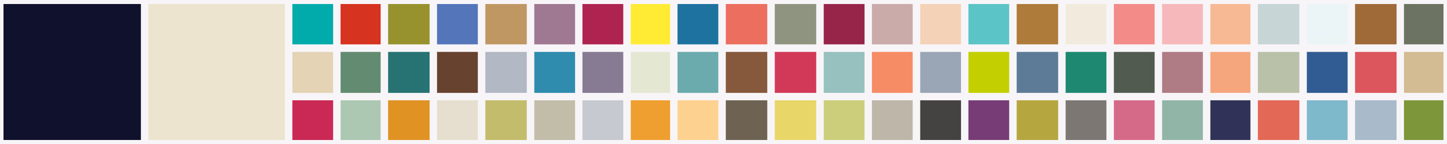

Figure 5. The color map used as a reference for all 10 of the maps in my space atlas project. The two large color blocks on the far left are the two base colors used in every map for the background and text. For the lunar map I used 29 colors, and I tried to choose those that were as different from each other as possible, producing a set that spanned a large range of brightness and hue.

CONSTRUCTING THE MAP LAYERS

To construct the different pieces of this map, I designed five plots in Python to import into Illustrator. I often split up data for plotting so I can easily apply layer-specific effects, such as drop shadows or blurs, in Photoshop or Illustrator.

Layer 1, Geologic units: Geologic units are morphological categories such as plains, basins, or craters. In geologic maps, including this one, each unit is typically mapped in a separate color. In this dataset, each geologic unit is tagged with a code identifying the rock type. I assigned a color to each letter code by making a table of code-color pairs, and referenced this file when plotting each unit in Python. Saving my graphics parameters in a separate file makes it easier to try different color schemes, and compartmentalizes the design from the code. I saved each of the six geologic datasets as a separate figure, because some areas of the six maps overlapped and I wanted to try different layering sequences in Photoshop.

Layer 2, Geologic contacts: In this map, geologic contacts are the boundaries between different colors. Most of these boundary lines are solid black lines, but in some cases where the boundary is hidden underneath the ground or approximate, the contact line is shown as a dotted black line.

Layer 3, Geologic features: Geologic features include fractures and folds such as ridges, buried crater rims, or basin rims. These features don't necessarily mark the boundary between different geologic unit colors. For example, there may be many ridges within a single plain. To map geologic features in a distinct style, I plotted each one in a different color in Python, and then stylized the lines in Illustrator. The geologic features data was particularly different between datasets, so in the end I only included features that were present in more than one dataset.

Layer 4, Nomenclature: I plotted each label with a font sized approximately according to the size of the object. I actually changed the font sizes substantially in Illustrator after plotting them in Python, but this first step helped add a framework for some of the label choices. I also plotted each type of feature in a separate color, so that I could use the *Select Same Color* feature in Illustrator to quickly group and edit feature types like craters, mountains, and plains. For this map I used the **Redflower** typeface for the title, and **Moon** for all of the nomenclature labels.

Layer 5, Gridlines and Data boundaries: I also used Python to plot gridlines for each map projection. I included the borders of each of the six datasets, to give an idea of where geologic contacts and features overlapped. Because

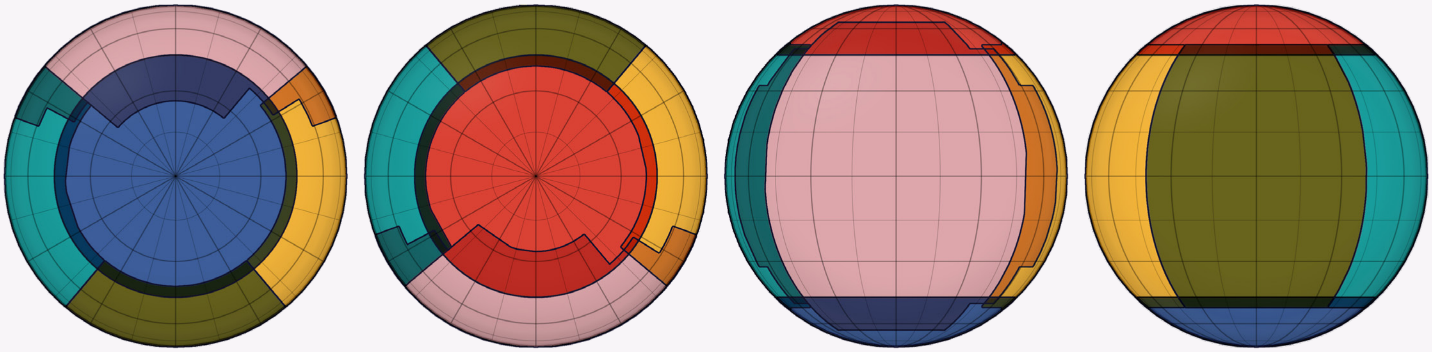

Figure 6. The extent of each dataset mapped on the southern (far left), northern (left), near (right), and far (far right) hemispheres. Each color visualizes one dataset included in the set of six.

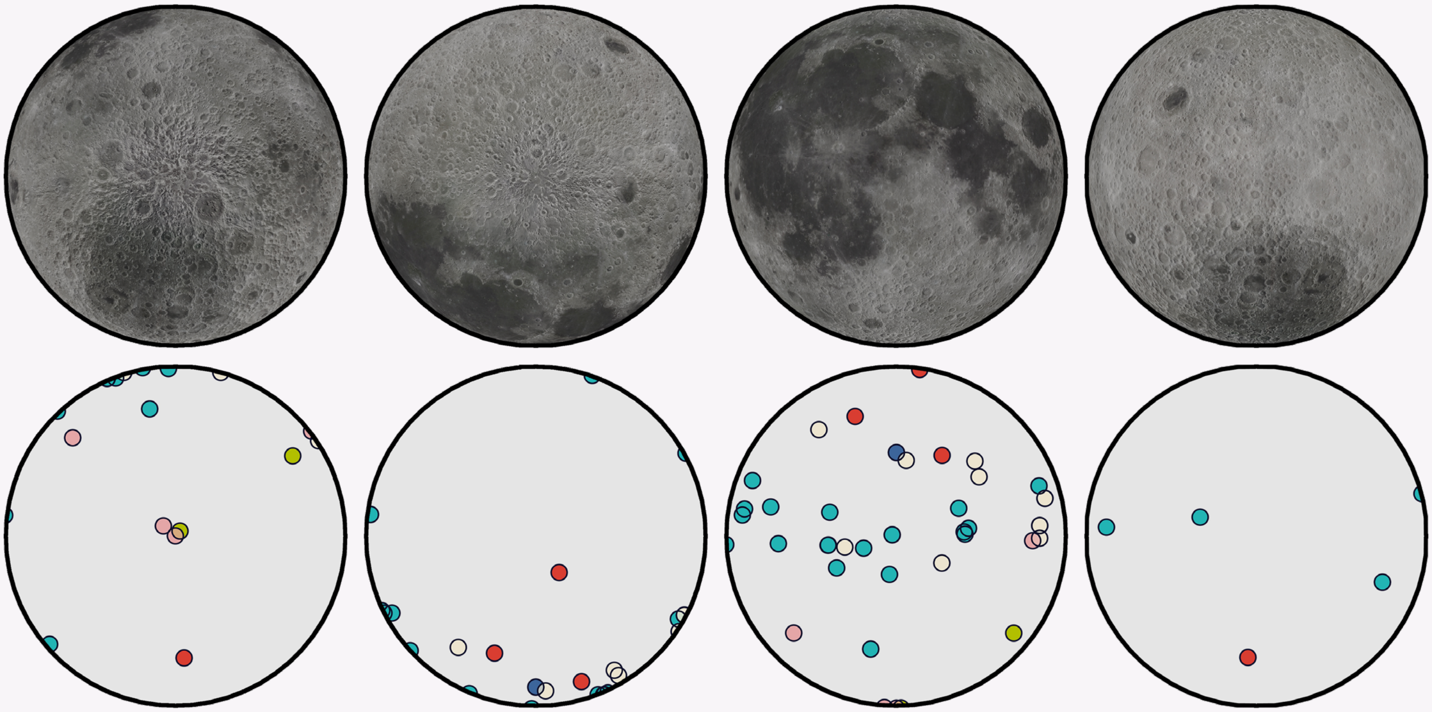

Figure 7. Digitally enhanced Moon images from Stellarium (top) and landing sites (bottom). Left to right: southern, northern, near, and far hemispheres.

there were some visible discrepancies at the borders between the six datasets, I decided to add a more detailed key showing the age and area coverage of each of the six scientific studies used in this map. To make this key I plotted the outlines of each dataset, from the perspective of each of the four hemispheres of the Moon.

Landing Sites

By now there are many human-made objects on the Moon, from crash landings and successful missions alike. I wanted to include a guide to these landing sites to add historical context to the different areas of the Moon. To create the backdrop for the landing site maps, I used a **digitally enhanced image of the Moon** from the open-source astronomy tool **Stellarium** as the backdrop, reprojected into four orthographic projections. To plot the landing sites themselves, I collected a list of successful (and some failed) lunar missions from the **Planetary Society** and looked up their exact landing coordinates. I then plotted each one in Python, using different colors to show missions from different decades.

Saving Figure Files Generated in Python

For most of my maps generated in Python, I save each figure as a PDF so I can edit the text and shapes in Illustrator. There are a couple standard commands I use to export these figures so they're easy to edit:

```
import matplotlib
import matplotlib.pyplot as plt
import matplotlib.backends.backend_pdf as pdf
# Export text as editable text instead of
  shapes:
matplotlib.rcParams['pdf.fonttype'] = 42
# Remove borders and ticks from subplots:
ax.axis('off')
# Remove padding and margins from the figure
  and all its subplots
plt.margins(0,0)
plt.subplots_adjust(top=1, bottom=0, right=1,
  left=0, hspace=0, wspace=0)
plt.gca().xaxis.set_major_locator(
  plt.NullLocator())
plt.gca().yaxis.set_major_locator(
  plt.NullLocator())
# Save the Matplotlib figure as a PDF file:
pp = pdf.PdfPages('./savename.pdf',
  keep_empty=False)
pp.savefig(fig)
pp.close()
```

Figure 8. A finished section of the combined map (far left), as well as some of the individual pieces including the hillshade, slope, geologic unit colors, and geologic structures.

After saving the figure, I edit the PDF file so that each object can be manipulated individually. In Illustrator, I select everything in the file and then go to **Object → Clipping Mask → Release**. At this point the file is ready to edit, allowing me to make changes to line widths, font, or any other effects.

If I don't need to edit vector paths, I save the file as a PNG so I can import it directly into Photoshop. For this particular map, I saved the geologic unit maps in PNG format, because I didn't plan to change the colors or shapes after mapping. To save my figures as a PNG I use this code instead:

```
plt.savefig('./savename.png', format='png',
  dpi=600, pad_inches=0, transparent=True)
```

COMBINING MAP LAYERS IN ILLUSTRATOR AND PHOTOSHOP

After each map layer was finished, I combined them all in Photoshop using layer effects. For this specific map I added the slope over the hillshade layer at 50% opacity. This combination adds some extra detail to steep areas, and softens areas of extreme hillshade. The color layer is duplicated four times, with one layer each set to **Multiply** (100%), **Overlay** (35%), **Soft Light** (50%), and **Lighter Color** (50%), at different opacities. I also add a shadowy blur around the text labels by including a field blur (**Filter → Blur Gallery → Field Blur**). To give a softer effect I usually stack two differently sized blur layers: one small blur close to the text, and another larger blur to soften the edges. In many cases I duplicate layers and apply several different effects, because some Photoshop effects are better for darker colors and others for lighter colors.

Description	Blending Mode	Opacity
Labels	Linear Burn	17
Labels	Linear Burn	85
Gridlines	Normal	100
Hillshade	Lighter Color	15
Hillshade	Color Burn	15
Contacts	Multiply	50
Color	Lighter Color	50
Color	Soft Light	50
Color	Overlay	35
Color	Multiply	100
Slope	Normal	50
Hillshade	Normal	100

Table 1. Layering order and blending information for each layer in the Photoshop file..

CONCLUSION

I really enjoyed working on this project, and learning how to map many different kinds of open data! Overall I was very happy with the design of the final Moon map, but in the future I think it would be fun to redo the map using the original geologic data separated by age. I think this kind of map would require much more careful planning—and perhaps might work best as several maps in a series—but it would be an exciting challenge to visualize the entire dataset. In addition to this Moon map, I also designed a **geologic map of Mars** in a similar style. Other maps in the collection include **topographic maps of the rocky planets**, **constellations from cultures around the world**, and **a map of 18,000 asteroids in the Solar System**. As a final note, I've open sourced **all of my code for this Moon map project**, so if you found this article interesting please feel free to use the code for your own maps.

ACKNOWLEDGEMENTS

Thank you to Henrik Hargitai, Chloe Pursey, and Leah Willey for their helpful advice in working with digital elevation models and designing this map. In addition, thank you to everyone who helped me and gave me advice throughout my entire project of maps of outer space: Oliver Fraser, Michael Ruxton, Nadieh Bremer, Mark van der Sluys, and James Skinner. Finally, thank you to two anonymous reviewers for their time, advice, and helpful suggestions, which made this manuscript significantly better.

FURTHER RESOURCES

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International Astronomical Union (IAU) Working Group for Planetary System Nomenclature (WGPSN). 2019. "Gazetteer of Planetary Nomenclature." **https://planetarynames.wr.usgs.gov**.

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Atlas in a Day Challenge: A Global, Real-time Collaboration

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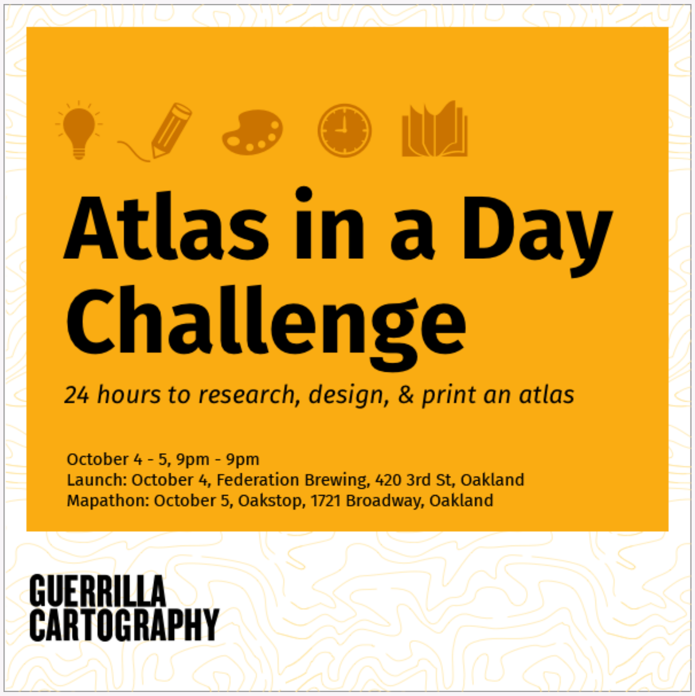
On Saturday, October 5, 2019, more than 50 guerrilla cartographers gathered, in person and online, to collaborate in producing an atlas in a single day on the theme of migration. While researching and designing an entire atlas on a complex theme in the span of 24 hours is indeed a challenge, this volume of maps is a concrete demonstration of the power of global, real-time collaboration.

The mission of Guerrilla Cartography is to promote the cartographic arts widely, and to expand the art, methods, and thematic scope of cartography through community workshops and symposia, public exhibitions, and collaborative projects. We imagined the Atlas in a Day challenge as another such collaborative project, one that could bring a diverse group of ideas and people into the mapping process. After all, we had already figured out how to engage a global community in producing a substantial and beautiful atlas in a few months, so why not see what we could do in one day? We knew there would not be time for comprehensive editing, nor money to finance a fine printing, but our main objective was to build a community around a collaborative mapping project, one that could then say something through cartography about an important theme.



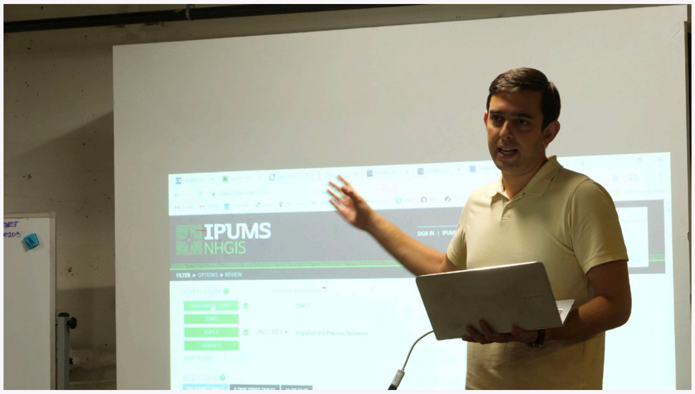
Pre-challenge publicity poster.

The theme of the Atlas in a Day project—migration, broadly defined—was announced to the Guerrilla Cartography collaborative only the night before the challenge, via a livestream at 9 pm Pacific Time, from Federation Brewing in Oakland, California. The following day, some 35 participants met at Oakstop in downtown Oakland, and began sharing ideas and working on maps. Together, we enjoyed invited speakers, food, and collaboration all day long.

Darin Jensen, announcing the theme live on Facebook.

A DAY OF MAPPING

With morning coffee and donuts, we started the day with "Geospatial data from the US Census," as UC Berkeley economics Ph.D. candidate Zach Bleemer offered a practical demonstration of accessing public census



Zach Bleemer.

Diana Negrín and guerrillas.

Jay Mahabal.

Diana Negrín.

GC board vice president Maia Wachtel, Åse Mitchell, Whitney Newcomb.

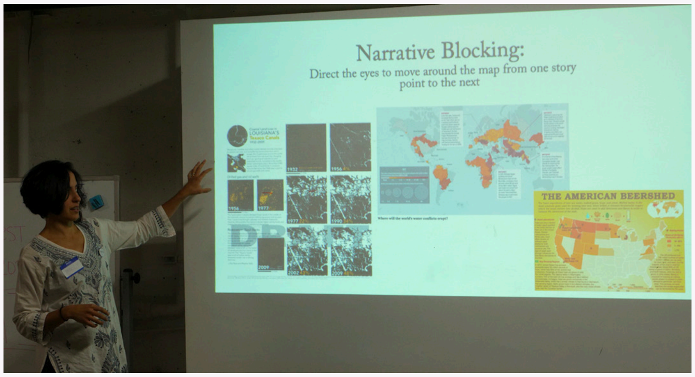
data. After Zach's demonstration, the guerrillas settled in to working on their maps, mining data, and pulling out art supplies.

At midmorning, our Atlas in a Day keynote speaker, Professor **Diana Negrín**, an instructor at UC Berkeley and the University of San Francisco, spoke on the ethics of mapping in her talk, "**Represent, Visibilize, Dignify**." As she described in her abstract,

> The practice of mapping is fundamentally anchored to the act of representing places, peoples, species and the less tangible elements that inhabit the spaces where human and non-human life circulate. These acts of representation transmit worldviews that can ultimately lead to material consequences, be they just or unjust. Just as a map can provide perspective and insight into the otherwise unseen, it can also

J. H. Blakeslee and Molly Roy.

Max Shen and GC board secretary Sydney Johnson.



Molly Roy.

> become a tool that tracks, disciplines and distorts the represented ecosystems and peoples. In this talk, we will contemplate what forms of visual enunciation have the capacity to paint a more just portrait, considering specifically the ability to portray whole narratives and dignity in the practice of writing and visualizing an increasingly bordered world.

The guerrillas continued collaborating and sharing ideas throughout the morning and early afternoon. Guerrilla friend and Atlas in a Day co-organizer and contributor, J.H. Blakeslee, set up a sandwich bar where everyone found something delicious to eat. After lunch, with full bellies and a lot of good information and positive energy, the guerrillas settled back into their individual and team mapping projects.

At midafternoon, Guerrilla Cartography co-founder, former board member, and freelance cartographer, **Molly Roy** spoke on map design. Titled "**Not just a pretty map: How to be an effective visual storyteller**," her talk focused on how to effectively communicate concepts and data on a map, from color theory to data representation to narrative blocking. With all the talks concluded by early afternoon, and a 7:30 pm submission deadline looming, work on mapping continued.

Creating on computers, paper, and boards; using crayons, watercolors, embroidery thread, and other media, the challenge collaborators submitted 43 maps on the theme of migration by the 7:30 pm deadline. A single electronic file was compiled and one rough print on a scrappy printer was attempted by 9 pm, fulfilling the challenge.

THE MAPPERS

Whitney Newcomb's full-time day job is making maps at a computer. Atlas in a Day gave her an opportunity to explore other, non-digital mapmaking options. She said, "I had a canvas and some acrylics in my closet that were just screaming, 'Make me into a map!'" She waited patiently for the theme announcement at 9 pm on Friday night, and then turned to searching the internet to find her eventual subject: the longest migration in the world, that of the Arctic Tern. She spent the rest of the night and into the morning researching and drafting a map on paper, then transposing it to the canvas before heading to Oakland to meet up with a friend and go to the event.

> I spent the day trying to get as little paint on the table and myself as possible while listening to the presenters and the other cartographers around me making incredible maps in all kinds of ways! We all shared paint and stories as this talented and passionate group of people came together to create something more than a map, more than a book—a community of cartography!

While Whitney created her map on her own (but in the company of that "community of cartography"), others worked in teams. Alex Epstein, Joshua Douglas Hubbard,

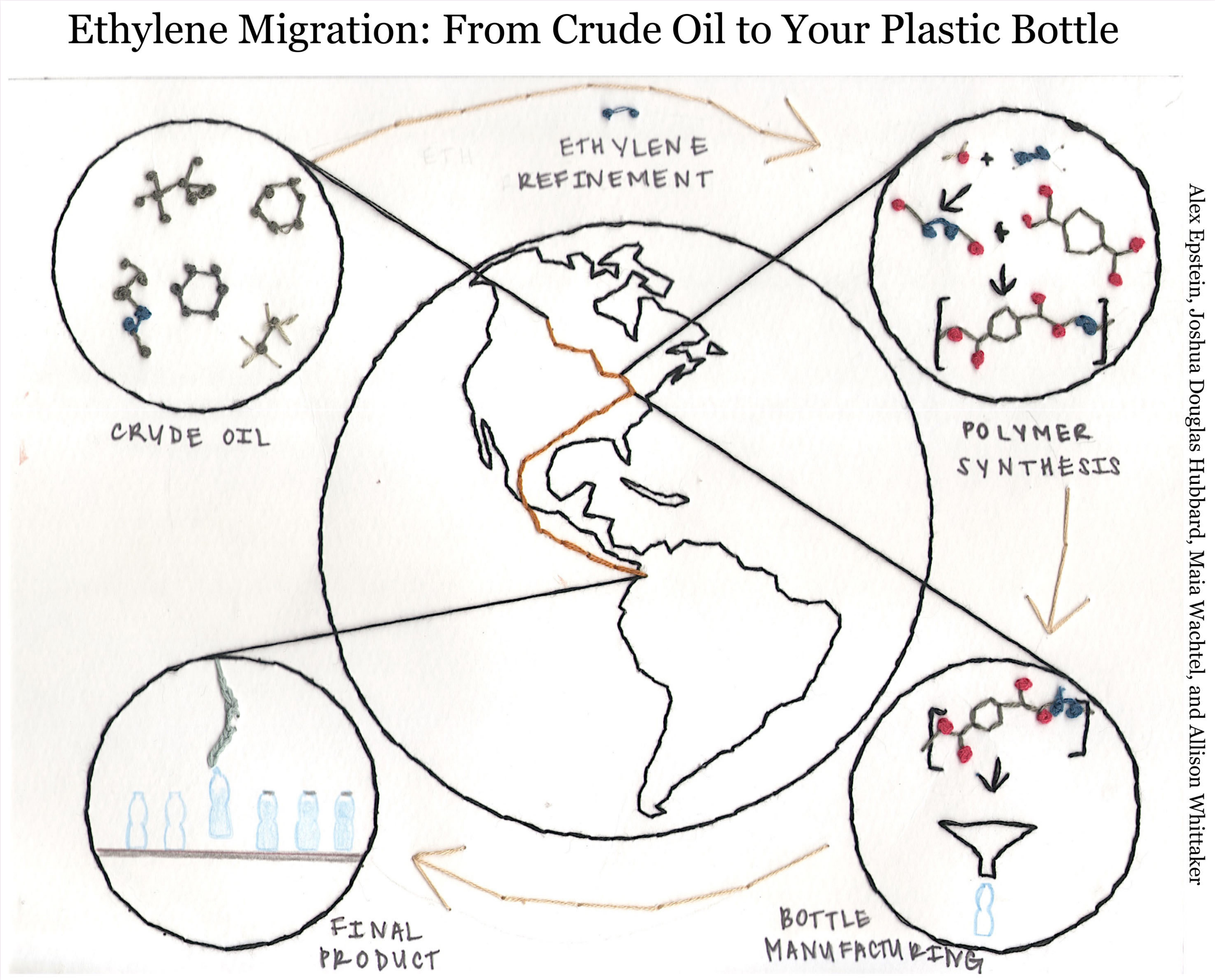
Whitney Newcomb.

Chasing Starlight: The Earth's Longest Migration.

Joshua Douglas Hubbard, Maia Wachtel, and Alex Epstein.

Allison Whitaker, and GC board vice president Maia Wachtel joined their individual expertise to research, draft, and embroider a map.

Alex Epstein had never done any kind of cartography before, but as a graduate student researcher he frequently thinks about how to condense complex information into one meaningful figure. The Atlas in a Day challenge provided him "a new framework to approach that concept, and that was very exciting to me." Epstein studies new materials for recyclable plastics, and believes part of the solution to solving the problem of plastics is reducing our dependence on non-renewable resources like petroleum. He proposed to his team that they trace the "migration" of a petroleum molecule as it is processed into a plastic bottle. Epstein's team chose to embroider their map on card



Ethylene Migration: From Crude Oil to Your Plastic Bottle.

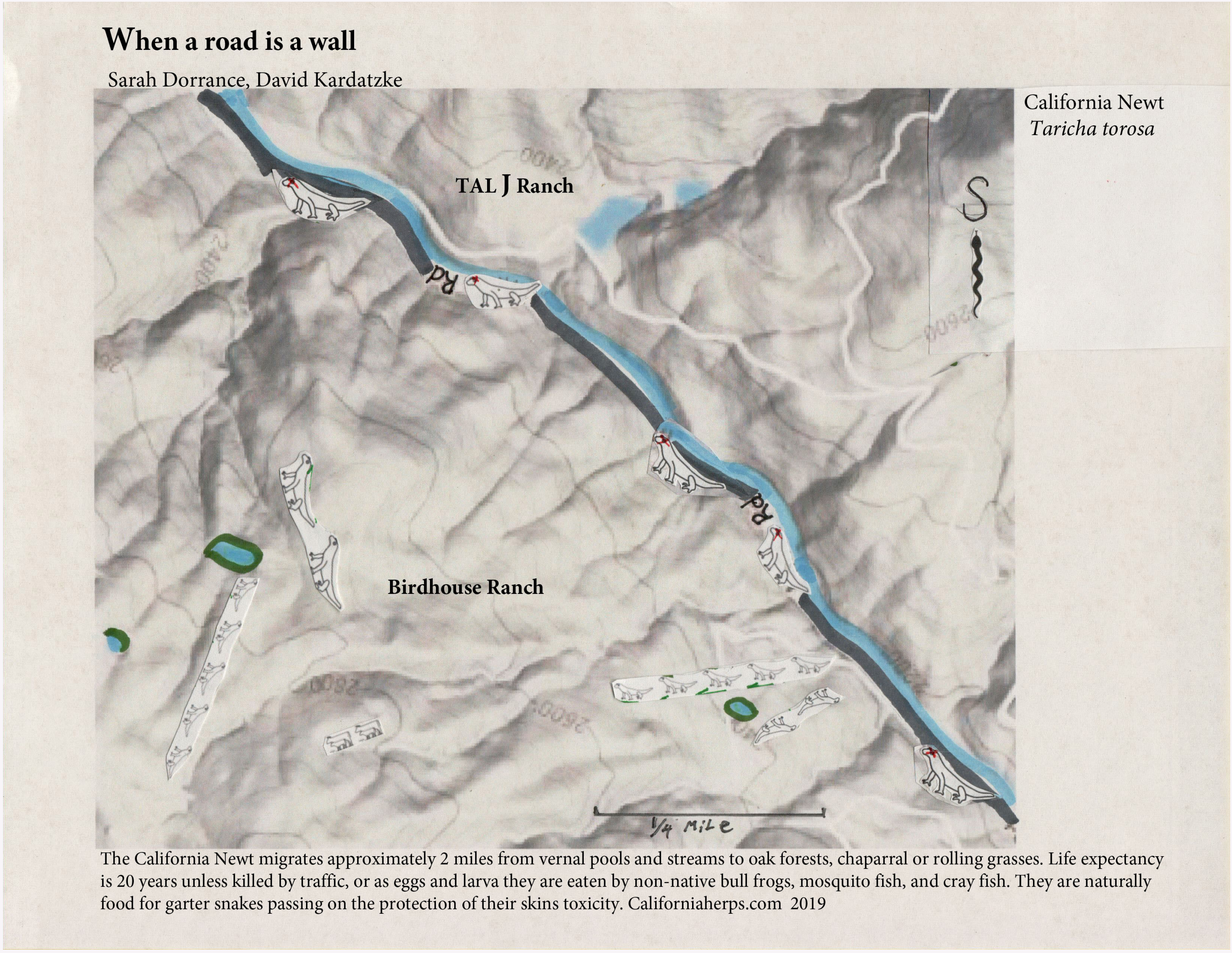
stock. After researching and sketching their design, they spent the bulk of their time embroidering the map.

Also working in a team, Sarah Dorrance and David Kardatzke brought their collective talents to the Oakland event to get started on their map and to hear the speakers, and then went back to San Francisco to finish and submit it. Dorrance, a mosaic artist, previously contributed to Guerrilla Cartography's *Water: An Atlas* and contributed to the GC blog with reflections on her map and experience. She also mounted the first public exhibition of the nascent Guerrilla Cartography group in 2012 when she included ***Mission Possible: A Neighborhood Atlas***, in her art map show, "Maps Only: Radical Cartography in Contemporary Art," at Back to the Picture in San Francisco.

For their map, *When a Road is a Wall*, Dorrance and Kardatzke focused on the California migration of the California Newt (*Taricha torosa*), a creature whose migration they've witnessed multiple times near Livermore, California. Dorrance said, "GC offered us a place to highlight their migration plight and connect it by title to the wall being built on the US southern border to keep migrants out; and possibly 'to keep US citizens in.'"

Another 28 people joined the challenge remotely, many watching all the presentations via a live feed, from 14 other locations in the United States and five locations in Canada, Panama, and New Zealand.

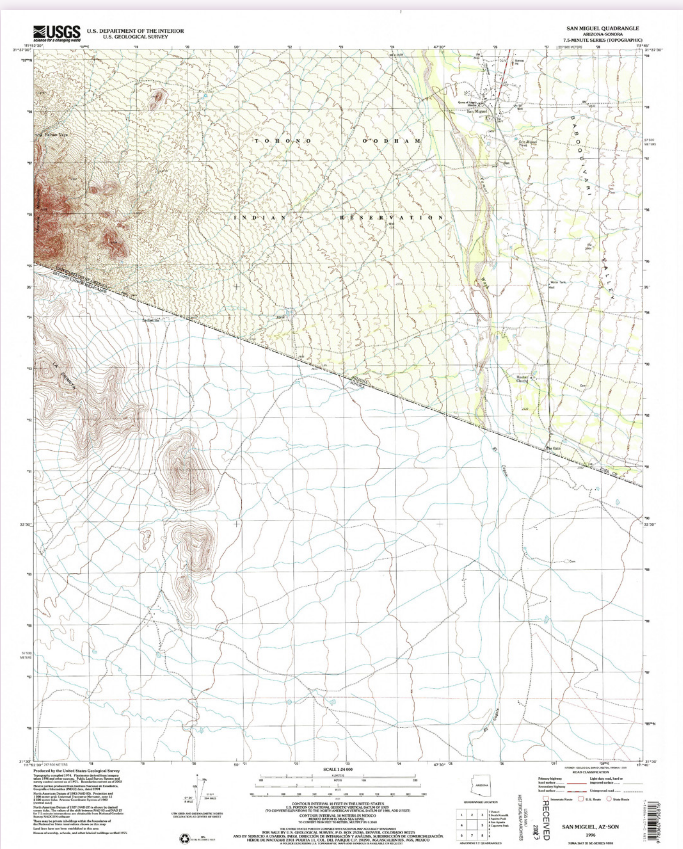
From his studio in Missoula, Montana, Steven R Holloway contributed *The Gate at the Crossing at El Coyote on the*



When a Road is a Wall.

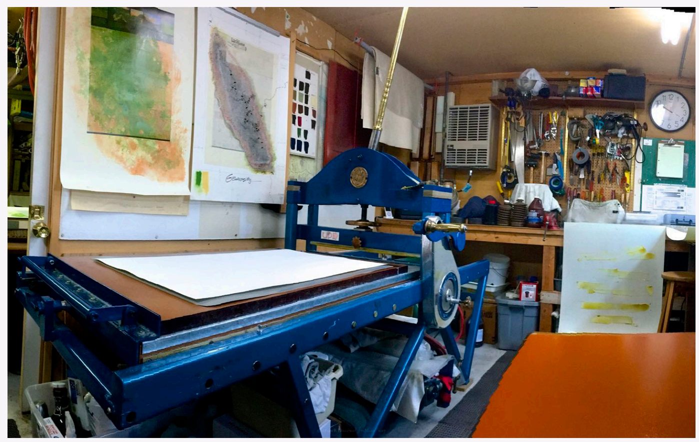
Vamori Wash to Many Dogs Place, an evocative ink-on-crumpled-kōzo map marking a space of crossing between the United States and Mexico—a crossing Holloway has hiked. Reflecting on his journey there, he wrote, "… one day the green border people stop us. Ask to see ID. Demand to search our packs. Stopped. My heart is beating hard. Beneath my feet there is a stream of water. Moving across the border; the Vamori Wash. Cottonwoods. Open the gate. Close the gate. Does it really matter? …"

Hollloway, an artist mapmaker, used a string coated with brown-black ink to snap a line along the US/Mexico border. He blocked out the border gate, and then added it in via letterpress in orange-red. His source materials were many, including a USGS quad map showing where the Vamori Wash crosses the border in the Tohono O'odham Nation, southwest of Tucson, Arizona. The Tohono O'odham Nation is bifurcated by the border, and now reserved to a small part of their original land north of the border. "On all the maps I research there is always this line. This abstract line ... longitude this, latitude that. Sometimes on the maps there is nothing at all on the other side of the line." The ethereal nature of Holloway's geographic representations has inspired Guerrilla Cartography to open its last two atlases with his work.



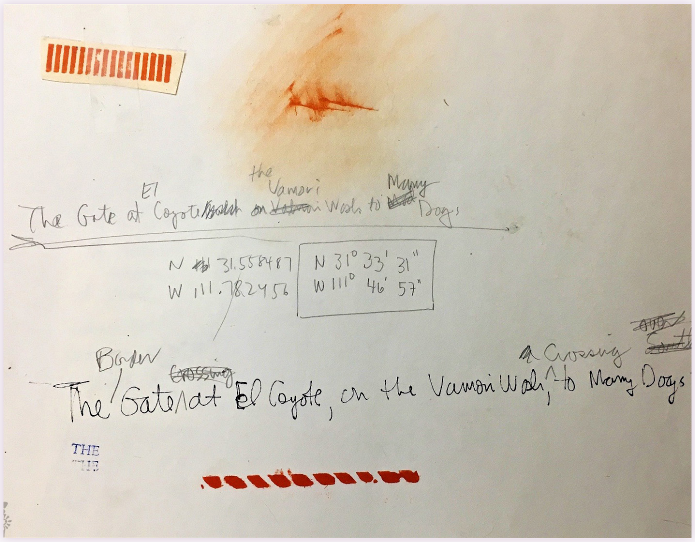
A USGS topographic map used as a source by Steven.

Steven R Holloway.

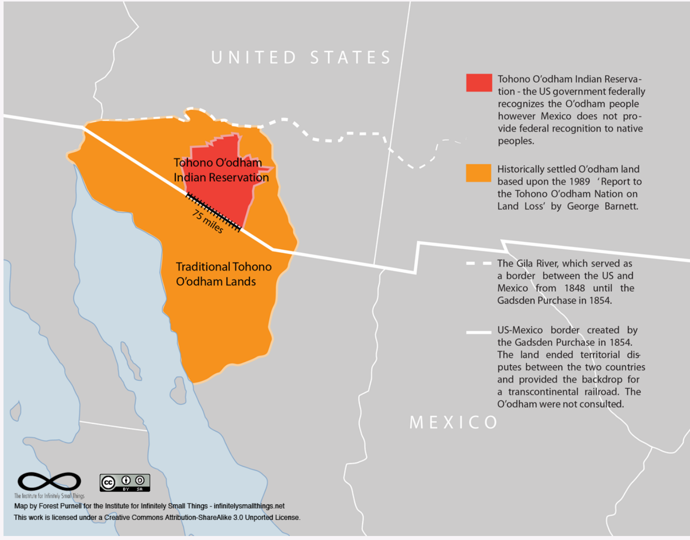


Steven R Holloway's studio.

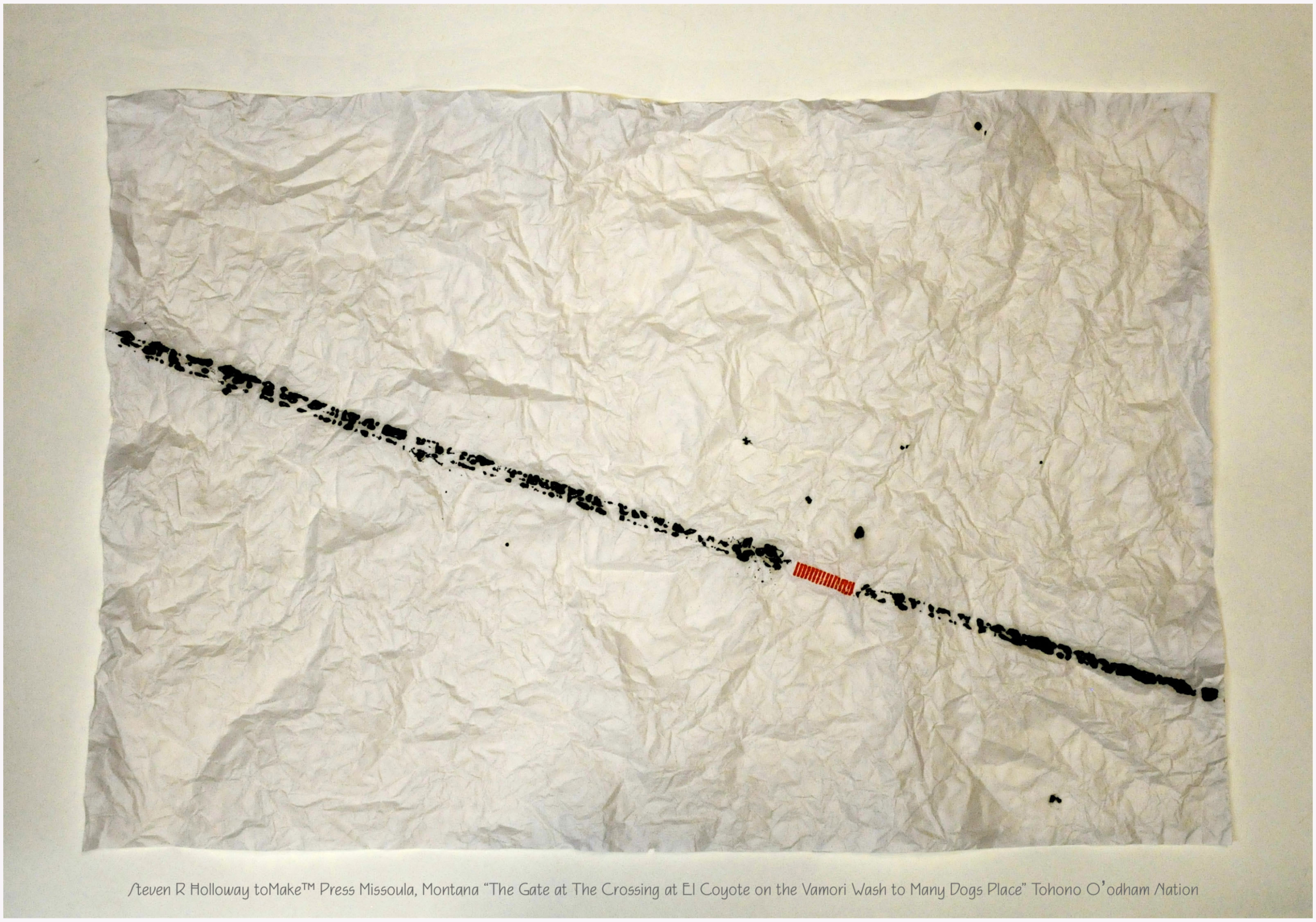
Some of Steven's materials.



Steven's notes.



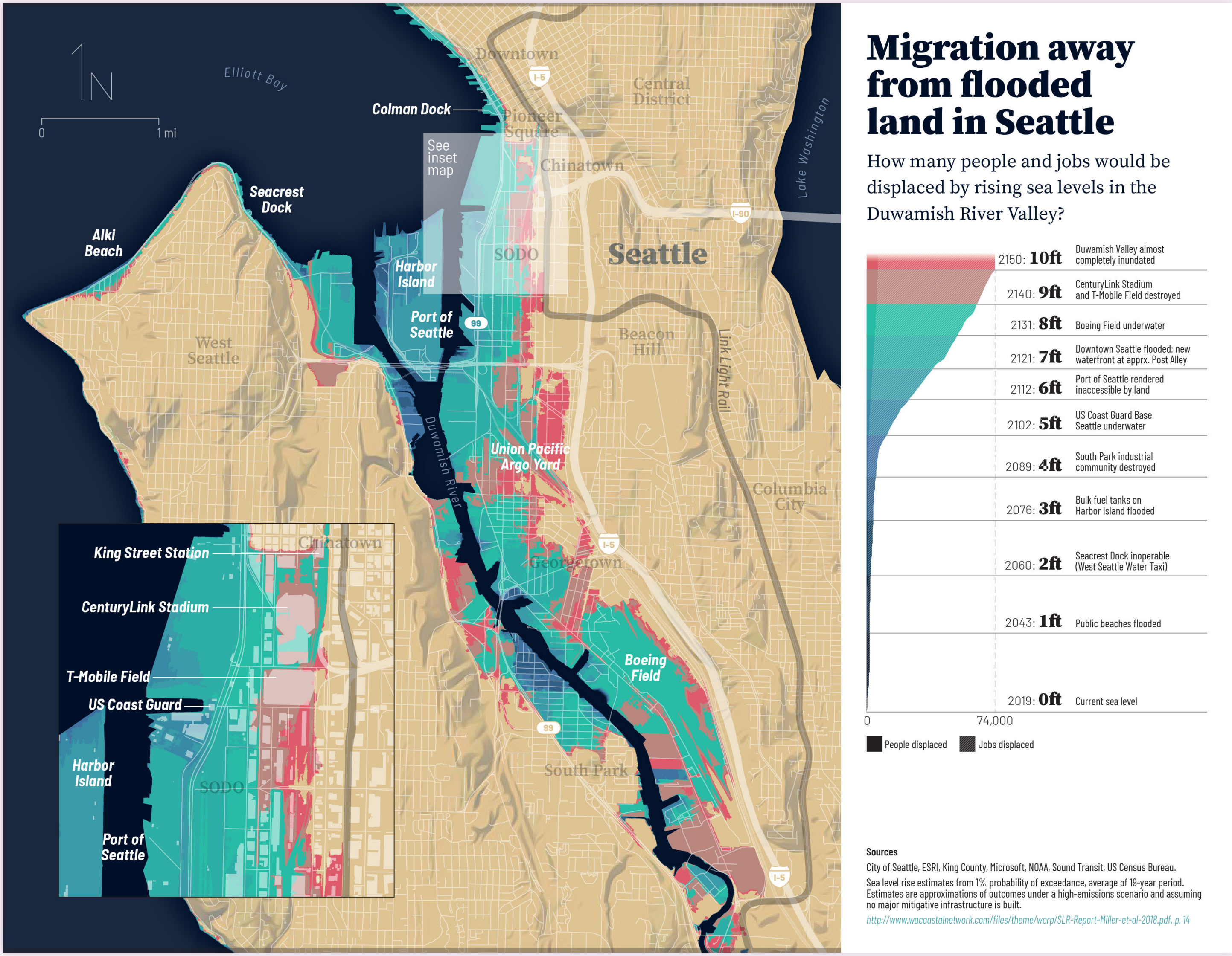
Tohono O'odham Nation. Map by Forest Purnell, CC-BY-SA 3.0.



The Gate at the Crossing at El Coyote on the Vamori Wash to Many Dogs Place.

Joseph Poirier and Brendan Rahman spent the Saturday of the Atlas in a Day challenge in Seattle working together—collaborating as a guerrilla cell—to create the map *Migration Away From Flooded Land in Seattle*, which shows where people and jobs could be displaced by sea level rise over the next 130 years. Colleagues at a transportation planning firm, they spent a large part of their day, "batt(ing) around a number of ideas but struggled to come up with something that we were interested in mapping, was meaningful, could be completed in one day, and was somewhat challenging." With a subject finally chosen and ample, familiar basemap data, they searched out the sea level rise data and, "interrogat(ed) the structure of the data and figure(ed) out how to best represent it."

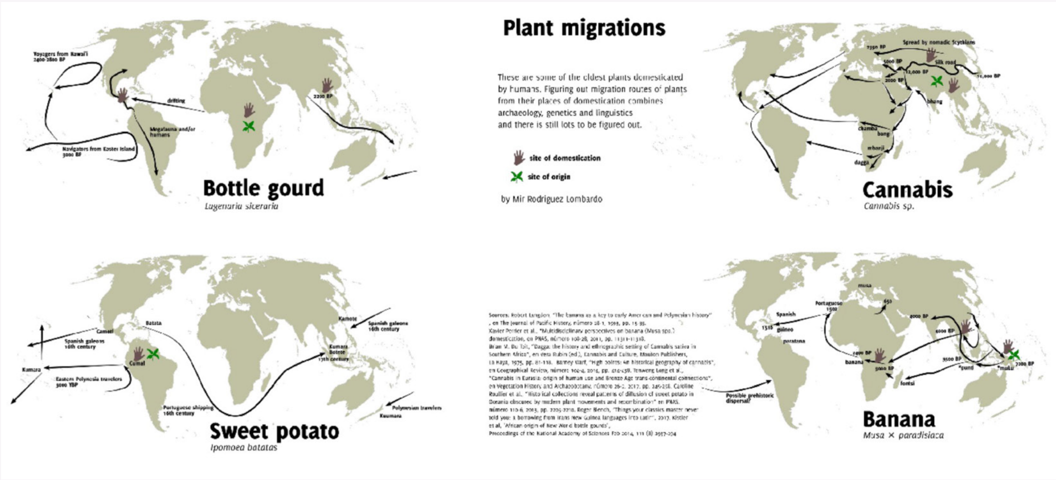
Poirier and Rahman split up the mapping tasks "to play to our strengths." Poirier created the basemap and did the analytical work while Rahman created the design, happy, as Poirier said, "to do some recreational cartography ... It ended up being a great way to spend a Saturday." They were pleased with their final output and appreciated the opportunity to make a one-off map, as opposed to one that needed to adhere to design guidelines so that it could be incorporated into a suite of maps: "[The Atlas in a Day Challenge] allowed us to be more creative with the aesthetics than we often can be for work projects. We're looking forward to next year's Atlas in a Day!" Guerrilla Cartography doesn't plan to make them wait that long for another Atlas in a Day challenge.



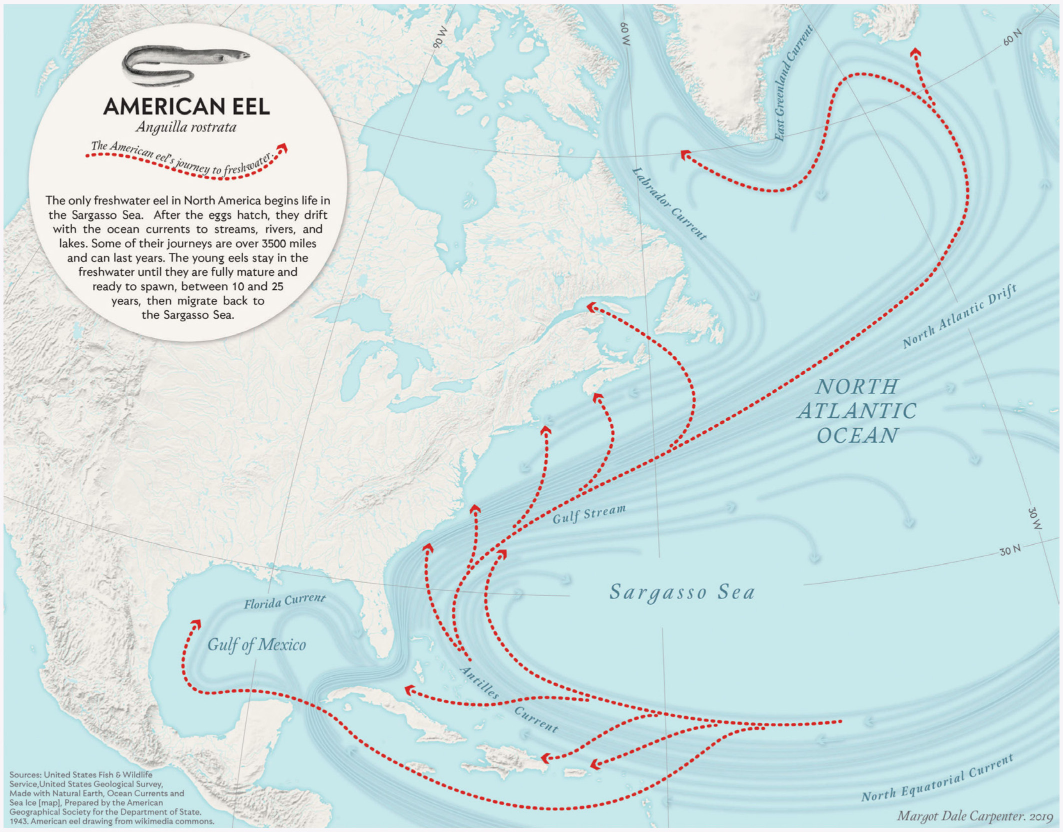
Migration Away From Flooded Land in Seattle.

From Panama City, Panama, Mir Rodriguez Lombardo joined the challenge and, working from some previous research, chose to map *Plant Migrations*. He read peer-reviewed articles to decide which plants to map and employed QGIS and Inkscape to create his art, with “frantic iterations near the end.” Unfortunately, a communication breakdown with GC staff (namely, me) resulted in only two of the four plant migration maps Lombardo made being published in the printed version. We regret this error and are pleased to publish his intended two-page spread here. A correction to the digital version is in the works and Lombardo’s complete maps will appear there.

Of the event, Lombardo said it was “great to listen in on the talks and to feel part of a bigger thing.” Guerrilla Cartography is pleased to have created a community of cartography and found that collaborations across the globe in real-time are not just possible, but fruitful.



Plant Migrations.

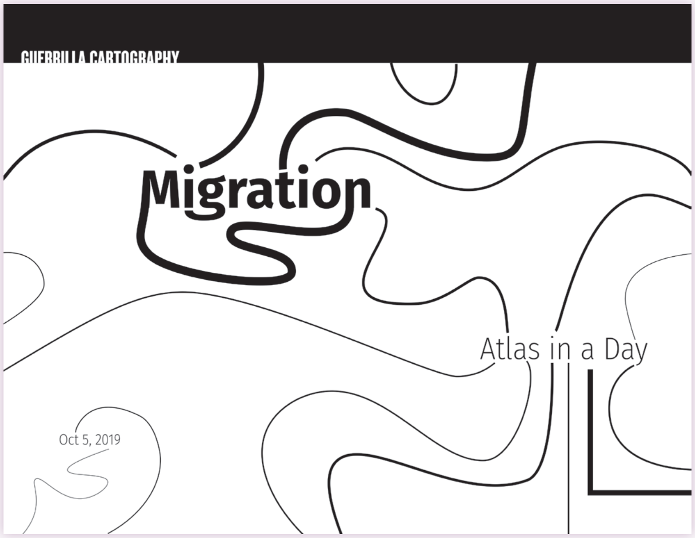


American Eel: The American Eel’s Journey to Freshwater.

Margot Dale Carpenter, a freelance cartographer in Belfast, Maine, joined the challenge because, “I really like the idea of an artistic splurge effort and it seemed like a great way to push my abilities (and) limits. Instead of over-thinking a project, this demanded a run and dive -in. I liked that.” Her map, *American Eel: The American Eel’s Journey to Freshwater* is based on a well-established migratory pattern that passes by her town; she has seen the American Eel in the Atlantic Ocean off the dock in downtown Belfast. While she loves hand-drawing maps, she decided on a digital medium because it’s easier to deliver a higher quality image (no scanning required) and the challenge time limit made it more efficient to work digitally.

THE ATLAS

After the challenge day, GC took a little time to reflect on the maps that were created and then ordered them into a sort of narrative, both graphic and philosophical, by choosing just one of the myriad possible arrangements. A final document was published online within a week of the challenge; click here to download.



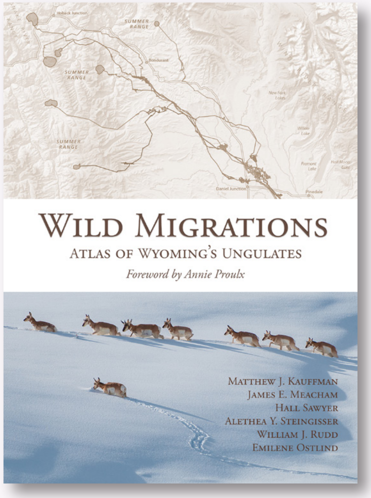
The atlas cover.

The maps in this atlas interpret the theme of migration in diverse ways, considering the movements of people, animals, climates, physical materials, and cultural artifacts over time and space. Some of them represent the culmination of years of research on a critical topic; others are quick sketches inspired by current events and concerns. Collectively, they add substance and content to one of the most critical issues our planet faces today.

ABOUT GUERRILLA CARTOGRAPHY

The brainchild of Darin Jensen, Guerrilla Cartography (GC) has its antecedents in the Geography Department at UC Berkeley. Then the staff cartographer and cartography instructor at Berkeley, Jensen organized interested students to create ***Mission Possible***, an atlas of the Mission District of San Francisco, in 2011. Considering the class as the crowd, it was Jensen's first foray into crowdsourcing cartographic content for a thematic atlas.

GC was founded in 2012 on the idea that a new paradigm for cooperative and collaborative knowledge-caching and -sharing could have a transformative effect on the awareness and dissemination of spatial information. With the able assistance of Molly Roy and other UC Berkeley scholars and cartography students, the initiative sought to globally crowdsource maps on a theme, compile them into an atlas, and produce a printed volume in under a year. With contributions from over 120 collaborators in thirteen countries, ***Food: An Atlas***, was published and printed seven months after the initial call for maps. GC became a 501(c)(3) registered nonprofit corporation in 2014 and published its second atlas, ***Water: An Atlas***, in 2017. In February 2020, GC announced the theme for their next atlas, "Shelter"; see their call for maps. To read more about our efforts, check out "Guerrilla Cartography: Promoting Diverse Perspectives and the Expansion of the Cartographic Arts," by Alicia Cowart and Susan Powell, in *Cartographic Perspectives* 92.



WILD MIGRATIONS: ATLAS OF WYOMING'S UNGULATES

By Matthew J. Kauffman, James E. Meacham, Hall Sawyer, Alethea Y. Steingisser, Willima J. Rudd, and Emilene Ostlind

Oregon State University Press, 2018

208 pages, $9\frac{5}{8} \times 13\frac{1}{4}$ inches

Hardcover: $50.00, ISBN 978-0-87071-943-1

Review by: Michelle Church, Michigan State University

Wild Migrations: *Atlas of Wyoming's Ungulates* is beautifully written and illustrated, and describes the historical and contemporary migrations of Wyoming's ungulates (hoofed mammals). The atlas is divided into seven chapters, the first five of which are thematically focused, followed by two of reference material. The thematic chapters each begin with short one-page essays by Emilene Ostlind, introducing the concepts covered. Most of the essays narrate a journey undertaken by one or more representatives of the species discussed in that chapter. The narrations are both informative and entertaining, and effectively pull the reader deep into the story.

Ostlind opens the introductory chapter with an essay entitled "A Migratory Landscape." In it, we follow a female mule deer as she leaves her winter range and heads north, wearing a GPS collar that allows researchers to trace her migration route. The story of this deer's journey helps us to understand the importance of ungulate migration to the ecosystems of the American West. Early on, we learn that an ungulate is a mammal that walks on hooves, that there are eight ungulate species in Wyoming, and why it is that they migrate. A two-page spread features drawings of the animals—male, female, and young—along with detail illustrations of their antlers, horns, and hooves. The visuals here, and throughout this entire atlas, are beautiful. They are bright and clear, and best of all, self-explanatory—the important facts are highlighted, but the maps are easy to read and understand, and not overloaded with text. Through them, we see ungulate migration patterns within Wyoming, as well as how they fit into the patterns of ungulate migration around the world.

The rest of the chapter explains not only *what* animal migration is and *why* it is important, but how the *when* and *where* is as important as the *what* and *why*. The atlas tells us, through text and pictures, that the habitats of the Wyoming ungulates are dominated by sagebrush steppe, but that the animals also seasonally range into areas of alpine meadows, coniferous forest, deciduous woodland, grassland, and cropland. Elevations range from a low of 3,099 feet along the Belle Fourche River in the northeast to 13,804 feet at the summit of Gannett Peak in the Wind River Range. Temperatures range from -40° to 100° Fahrenheit, and while some areas in the state receive less than 10 inches of precipitation a year, the surrounding mountains get over 60 inches. Another important fact to note is that Wyoming has a low human population density—and it is this, along with topography and weather, that makes it possible for the ungulates to migrate. The next section of this chapter contains detailed looks at each of the eight ungulate species—mule deer, pronghorn, elk, moose, bighorn sheep, bison, white-tailed deer, and mountain goat. Two-page spreads feature graphics and field notes showing the current range, distribution, estimated population, and harvest statistics for each species, along with migration routes and seasonal habitat, including their summer and winter ranges.

The second chapter concerns the long history of ungulate/human relations in what is now Wyoming. In it we learn about the first hunters, the American Indians, and about the newcomers: the trappers and explorers. The chapter tells the story of ungulate population decline due to exploitation and over-harvesting, but also the establishment of national parks, forests, and refuges, and how the restoration of feeding grounds has led to a recovery of the populations. The opening essay, "Ancient Rituals" (wherein we follow another collared mule deer, this time during hunting season), explores the age-old practices and rituals that have surrounded the hunting of ungulates from ancient to modern times. We learn about how these animals were hunted, and what the practice meant to the first hunters, as well as what it means to the hunters of today—after the repopulation of stocks that had been hunted out. In the essay, our deer and her fawns get safely away, while the hunter, "participating in the ancient rituals that [have] sustained humans since they first arrived on this western landscape," continues to wait (35).

Chapter Three takes us behind the science of migration. In her "Studying Migration" essay, Ostlind narrates the story of a deer that has been captured, examined, and collared by researchers. We learn how scientists are working to understand ungulate migration, where it has been and where it is going. This deer was captured at the end of one winter, with the intention of recapturing it early in the next to analyze the data on her collar and to measure the fat she had put on over the summer.

The chapter continues to outline the history and ever evolving methods of migration research, from collared neckbands to radio telemetry to GPS collar studies. The discussion of research methods is divided into two parts: collection and analysis. Data collection covers topics such as satellite-upload versus store-on-board GPS collars, animal capture and collaring, and raw GPS data points. The discussion of analysis deals with how these findings are mapped and analyzed, and, in particular, about the way migration patterns and timing are revealed in the data. There is a graph and timeline of the pattern and timing of each species' migration and stop overs.

A section entitled "Surfing the green wave, the quality of forage" delves into topics of nutrition and other events that trigger migration. In this section we follow a mule deer on its journey, with particular attention focused on the energy she expends lactating (to feed her fawn) and trudging through snow. This leads into a discussion of the effects of snowpack on four of the migrating ungulate species—pronghorn, mule deer, elk, and moose—illustrated with precipitation graphs for 2013, a drought year, and for 2015, a wet one. These species exhibit *fidelity*, which is what researchers call the tendency among animals to return to the same habitats year after year. For example, over one hundred moose winter along the Buffalo Fork River, just east of Grand Teton National Park, returning year after year to the same place throughout their up-to-twenty-year lives. The atlas illustrates this fidelity with photos and maps of their migration routes and seasonal ranges.

Not all ungulates in Wyoming migrate: some reside in a fixed range, and others just wander like nomads. Still others, like the bison, had migrated in the past, but ceased to do so as their populations dwindled (by 1902 only 25 bison remained in the Yellowstone National Park refuge), although as their numbers have rebounded, migrations have begun again.

Wolves and grizzly bears also inhabit the Wyoming ranges, and their activities have significant impacts on the state's migrating ungulate populations. The atlas covers these relations with maps, graphs, and charts. The fourth chapter is about these threats, along with others, dramatized in the opening essay: "Barriers to Migration." This time we are with eight mule deer on the migration trail at night. They have already passed through several towns, crossed hundreds of lawns, and jumped miles of fence, and only one barrier remains before reaching the open range of the Red Desert: State Highway 28. As it is starts to snow, seven of the eight successfully leap over the fence and onto the road, but one, a fawn, cannot. Truly, "a changing landscape makes it ever more difficult for migratory animals to complete their seasonal journeys" (89). This particular fence was just one in a long series of impediments and barriers along the migration route—and just one example of the multiplying threats and challenges discussed in this chapter.

Population growth and energy development bring fences, roads, and rural development. Widespread, industrial-scale exploitation of gas, oil, and wind power, especially along the Interstate 80 corridor, has resulted in winter range habitat loss and constriction of migration corridors, forcing changes in migration routes, travel speeds, distances traveled, and available stopping places. In addition to these artificial migration bottlenecks, there are natural restrictions as well, such as Trappers Point, an open sage-brush-covdered ridge about a mile wide that as many as 50,000 deer, pronghorn, elk, and moose traverse.

Other challenges to the ungulate population covered in this chapter include hunting, diseases (including brucellosis and chronic wasting disease), climate trends, the changing landscape (lost forest cover, wildfires, bark beetle infestation), and food web disruption.

Conservation efforts are discussed in Chapter Five, in particular the efforts being made by ranchers like Maggie Miller. Miller's ranch in western Wyoming spans the roughly twenty-five miles between the Wyoming Range mountains and the Green River. Unlike many other ranches in the area that have been broken up and parceled out, the Miller ranch preserves the open ranges needed by various migrating species, including ungulates. Emilene Ostlind's final essay, "Sustaining Migration," recounts the experience of observing curlew migration with the ranch owner as she tells about her wildlife conservation efforts. Many areas in Wyoming have experienced land closures (primarily fencing) related to human pressures, but research findings have led to greater awareness, especially in Western Wyoming, of the critical ecological role played by wildlife migration. Conservation efforts there are in full swing, but land closures and industrial sprawl continue to creep closer and closer.

The atlas provides numerous maps and other graphics that clearly portray and contextualize the efforts by rangers like Miller, as well as the significant challenges those efforts have faced. Legal disputes swirl around the discovery, assessment, conservation, and protection of migration corridors—which often stretch hundreds of miles, crossing, merging, and dividing, and which are commonly used by multiple herds and species—that lie on land seen by humans as owned resources to which they have exploitation rights. The Red Rim Fence Dispute is one notorious example. In the mid-1970s, a rancher—who wanted to mine coal—enclosed "his" land with a twenty-eight-mile fence. That land, however, also happened to be critical wintering habitat for a large herd of pronghorn. Blocked from their winter range, an estimated seven hundred of them perished the first year. The dispute dragged on for close to twenty years before the State of Wyoming purchased the land and established Red Rim-Daley Wildlife Habitat Management area.

The atlas concludes with seven pages of reference maps covering the state's physical geography, counties and cities, and land ownership, and a list of data sources and atlas sponsors. I have nothing negative to say about *Wild Migrations*: *Atlas of Wyoming's Ungulates*. It is everything a good thematic atlas should be, and all its parts work together seamlessly as a coherent whole. Emilene Ostlind's opening essays are outstanding. She gently pulls you into each story, and makes you feel like you *are* the deer, the hunter, or the researcher, and an integral part of the unfolding story. The other writing is also excellent—packed with information, yet delivered in a clear and readable manner, and supported by maps and graphics that could almost tell their stories all by themselves, but that work together with the text to make each issue or situation crystal clear. The maps and graphics throughout the *Atlas* are are colorful and easy to read and understand; they are enjoyable and informative at the same time. Each is well laid out, with text that enhances but does not overwhelm—in each instance there is just enough text to let us know what is going on. The pictures throughout the *Atlas* are breathtaking. They are so real and vibrant, there were times I felt like I could reach out and touch the animal. I could look at this atlas, at the pictures, the graphics, and the maps, all day.

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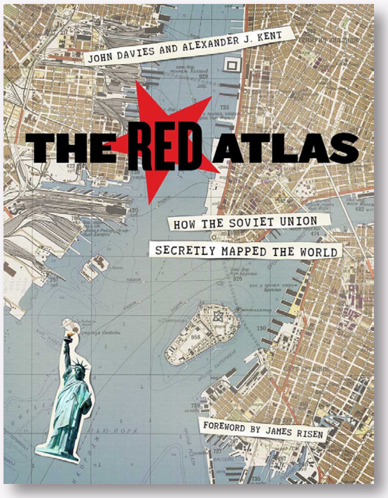


THE RED ATLAS: HOW THE SOVIET UNION SECRETLY MAPPED THE WORLD

By John Davies and Alexander J. Kent

University of Chicago Press, 2017

234 pages

Hardcover: $35.00, ISBN 978-0-226-38957-8

eBook: $35.00, ISBN 978-0-226-38960-8

Review by: Allan Mustard

In the 1980s, when I was a first-tour diplomat newly assigned to the US Embassy in Moscow, among the items issued to me upon arrival was a street atlas of Moscow prepared by the Central Intelligence Agency (CIA). It was highly detailed, and included all the streets and many of the public buildings in the city, unlike Soviet maps available in bookstores and newspaper kiosks, which were sparser and also harbored distortions and deliberate errors—errors included by the Soviets to deceive and confuse foreigners. We did not know, at the time, that maps of a quality similar to, and even better than, our CIA products existed in the USSR. They were, however, classified "secret," and we had no access to them. These were the now-famous products of Josif Stalin's ambitious project to map the entire world.

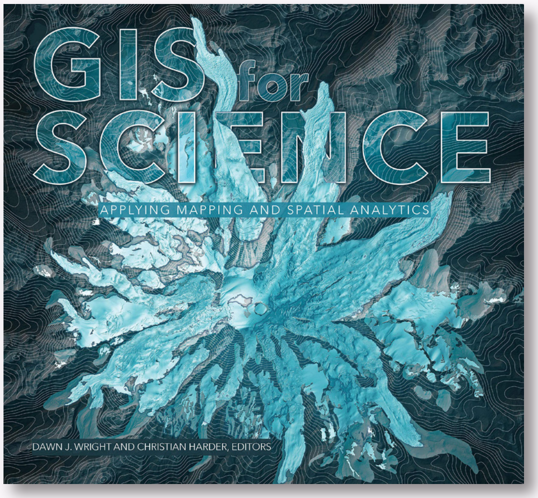
The Red Atlas: *How the Soviet Union Secretly Mapped the World* begins by recounting how some of these maps, to this day still classified in Russia, were discovered in the Baltic states after independence and sold to Western collectors (including to me; I have a complete set of 1:500,000 maps of Turkmenistan). The narrative then shifts to detective work: how did the cartographers collect the detailed information included on the maps? Data on the USSR itself was largely derived from Soviet aerial photography, coupled with on-the-ground data collection, but where did they learn so much about other lands—many of them openly unfriendly? The *Red Atlas* authors conclude that much of the information was clearly derived from maps published in the targeted countries—in particular United States Geological Survey maps of the United States and Ordnance Survey maps of the United Kingdom. In fact, because the provenance of the cartographic data was so obvious, soon after the maps came to light, Her Majesty's government threatened anyone using the Soviet military maps with lawsuits for copyright infringement. Not all of the maps mined for information came from the target countries' own mapping agencies, however. Davies and Kent, authors of the *Red Atlas*, point out that several cartographic errors appearing on maps prepared by the German military for their intended invasion of the British Isles are reproduced in the Soviet maps, a happenstance that leads them to conclude that there was a clear inheritance. Similarly, not all information on foreign countries came from maps—some came from ground truth: Soviet diplomats, military attachés, and spies, with eyeballs and camera lenses on site. Information on the number of lanes in a roadway, or the load-bearing capacity of a bridge, for example, or the products manufactured by a factory, could only be collected by someone on the ground—sometimes by simply chatting with local residents (as occurred in at least one documented case). Today, of course, some of this data collection is much easier; for much of the world, one needs only to visit the Mapillary (**mapillary.com**) or Google Streetview (**google.com/streetview**) websites to count a road's lanes or read the sign on a factory.

If nothing else, the authors' study of the maps demonstrates the importance of ground truth and local knowledge. An entire chapter is devoted to cartographic errors, many of which betray misunderstandings about the territory being mapped (including the misidentification of streams and creeks as roads, or inclusion of others that simply didn't actually exist), or in some cases, the local culture (for instance, misidentification of a "Mechanics Institute"—essentially a social institution for the acculturation of working-class Britons—as an institution of higher education). In some cases, streets bear the wrong names and buildings torn down decades earlier persist on paper. Davies and Kent estimate that the total number of maps generated by the Soviet mapping program exceeded one million, although the vast bulk of them remain under lock and key in Russian military installations and copies of only a fraction of this number have come to light in the West. Thus, considering both the geographic scope of the project and the challenge of cribbing information from maps annotated in scores of languages, it is understandable that some errors should have crept in, and one can forgive the Soviet cartographers their occasional mistake.

Not surprisingly for a book about maps, about half its space is taken up with map reproductions, including several side-by-side detail comparisons of Soviet and the Western maps from which the cartographers seem to have purloined information. The *Red Atlas* authors express their apologies for the uneven quality of images—limited, as they are, by the quality of the original maps themselves—but I found them generally quite legible, thanks in part to the high quality of the paper and obvious care taken in reproduction. Given the emphasis on graphic information in this volume, I advise buyers to select the hardbound volume over the e-book.

The book includes a selection of the symbols used on Soviet maps with explanations of their meaning. It is probably too much to ask that the entirety of the "symbology" be presented, but it would have been nice, since I possess a substantial collection of the maps, and the meaning of some symbols is less than obvious.

The Red Atlas: *How the Soviet Union Secretly Mapped the World* does not shy from the most obvious question: *why*? Why did Stalin think the Soviet Union needed maps of the entire world? Did he plan to invade each and every country, one by one? The authors speculate that a more likely intention for these maps was to facilitate civil administration after the proletariat overthrew the then-existing regimes and came, one by one, voluntarily, into the Soviet fold. On the other hand, the authors might have inadvertently supplied a different answer to that question with the opening line of Chapter Two: "Maps are instruments of power . . . ." Perhaps Stalin's reasoning was as simple as that.



GIS FOR SCIENCE: APPLYING MAPPING AND SPATIAL ANALYTICS

Edited by Dawn J. Wright and Christian Harder

Esri Press, 2019

237 pages, with maps, satellite imagery, and photography

Softcover: $39.99, ISBN 978-1-58948-530-3

Review by: Daniel G. Cole, Smithsonian Institution

The objective of *GIS for Science: Applying Mapping and Spatial Analytics*, according to editors Dawn J. Wright and Christian Harder, was to assemble some "relevant and interesting stories about the state of the planet in 2019," (ix) about the integration of GIS into science, and about a few of the scientists using these tools to help solve a number of real-world problems. The result is a beautiful, multi-authored book with many maps, images, spatial data, and background stories that is presented to both a general audience and to scientists who may be starting to incorporate GIS in their scientific research. This review will focus primarily on how the book draws attention to a number of interesting and worthwhile projects, and, by lifting them out of the fray, provides hope for the future of GIS in scientific research. It will also identify some minor issues with the book's editing, layout, and writing. *GIS for Science*, like many multi-authored books, is a bit uneven in quality from chapter to chapter.

The contents are organized in six thematic groups—an Introduction and five Parts—and all, save the last, contain chapters that are generally between ten and twenty pages. Chapters in the first four thematic parts are case studies, while the fifth part, called "Technology Showcase," has eleven two-page articles. Each of the Parts also has its own two-page introduction and each chapter has a section called "Endnotes" (that is utilized in various ways by different authors). There is a companion website as well, containing online resources that complement the case studies and articles (gisforscience.com).

The three sections of the Introduction offer context for the use of GIS in science, suggestions for using the book, and describe the importance of science to the planet, and these are penned, respectively, by Jack Dangermond (president of Esri) and Dawn Wright (Esri's chief scientist), the book's editors Dawn Wright and Christian Harder (an Esri technology writer and information designer), and Kathryn Sullivan (geologist and former NASA astronaut).

Part 1, entitled "How Earth Works," contains four chapters. The first is "Global Ecosystem Mapping" by Roger Sayre (United States Geological Survey) and it describes the development of a standardized, high-resolution map of the world's ecosystems by a team of public- and private-sector scientists. He begins by emphasizing the importance of understanding both the spatial and ecological perspectives on global ecosystems, and stresses the value of the National Geography Standards—eighteen points of basic geographic skills, knowledge, and ways of thinking, first published in 1994 and intended to guide geographic education in the United States—in conjunction with the United Nations' Sustainable Development Goals for terrestrial, coastal / marine, and freshwater ecosystems. He outlines the work behind the already completed project map sets: Ecological Land Units and Ecological Marine Units. The Land Unit maps identify almost four thousand unique combinations of bioclimate, landforms, lithology, and land cover in two dimensions at a resolution of 250 meters, while the Marine Unit maps resolve around 52 million data points archived over 57 years into 37 distinct, three-dimensional volumetric regions at a horizontal resolution of 27 kilometers. Sayre notes that work on the Ecological Coastal Units is currently underway, and they will be followed by the Ecological Freshwater Units.

This chapter is illustrated with two world maps that each spread across two pages. The first is a map of Ecological Land Units (4–5), that uses the Goode homolosine equal-area projection. Unfortunately, the map overflows its page space so that New Zealand, Oceania, and eastern Australia are absent. The other two-page map, on pages 18 and 19, illustrates the global Ecological Marine Units using the plate carrée projection. This time, a small portion of northeastern New Zealand and a slice of the central Pacific Ocean are missing. A scale bar—in any event, usually considered inappropriate on this projection—is also cropped. Sayre provides seventeen endnotes tied to the text, and extensive online resources that include peer-reviewed articles, technical reports and web map apps.

Chapter 2, "What Lies Beneath," by Daniel Coe of the Washington (State) Geological Survey, presents seven case studies on the Columbia Gorge landslide inventory, focusing on the use of lidar data for mapping "geology, landslides, and faults; to study volcanoes, glaciers, and rivers; and model tsunami inundation" (25). He uses the chapter's endnotes section to list references, and the online site has links to a story map, a poster, a data portal, and web map apps, plus websites from the Washington Department of Natural Resources and the Washington Geological Survey.

Melanie Brandmeier (Esri Deutschland [Germany]) deals with different types of volcanic eruption as well as the various sizes of eruptions experienced by ten large volcanoes around the world in Chapter 3, "The Anatomy of Super Volcanoes." The scope of her interest is world-wide, but she spends most of the chapter discussing the Andes—a mountain chain with over 185 active volcanoes—ultimately focusing on the Cerro Galán caldera of northwestern Argentina and others on the altiplano of Peru. Brandmeier goes on to discuss the Andes Ignimbrite Database she compiled as part of her Ph.D. thesis, and the workflow in ArcGIS and R-Studio she employed in the space-time mapping and analysis of volcanic flare-ups that have occurred over the past 26 million years.

There is some confusion in this chapter about the date of the nineteenth-century eruption of Mt. Tambora in Indonesia—apparently the largest in recorded human history—with the text putting it in 1885, although a figure caption gives the more generally accepted year of 1815 (44). It would also have been helpful if the map on page 46 (on an unnamed projection that might possibly be Natural Earth) showed the locations of the caldera and ignimbrite study area under discussion. This chapter list its photo credits and literature references in its endnotes, and there are peer-reviewed articles, a story map, a database, a slide deck, and a poster online.

The fourth chapter, "Predicting Global Seagrass Habitats" by Orhun Aydin and Kevin A. Butler—both members of Esri's Spatial Statistics Team—starts with an outline of the ecological value of seagrass and a report on the overall status of seagrass ecosystems. The authors then describe the GIS models they used to help understand where it is that seagrass will grow, paying particular attention to their employment of machine learning tools. Tables depict temperature and salinity graphs with layouts of the data plotted against model outputs using random sample consensus, support vector machine, multi-layer perceptron, and random forest modeling methods for six different regions of the world. They finish with world maps of seagrass density and an emerging hotspots analysis using hexagonal binning, along with a perspective view of an area in Australia that illustrates a space-time hotspot analysis for prediction of future seagrass habitat. Unfortunately, the world maps are both in the Mercator projection and each includes an inappropriate scale bar. The authors have their endnotes tied to the text along with three photo credits. Online resources consist of a story map and a slide deck, plus a couple of blogs and Esri reports.

Olga Wilhelmi and Jennifer Boehnert, both with the National Center for Atmospheric Research, or NCAR, contributed "Extreme Heat Events in a Changing Climate"—the book's fifth chapter, and the first of four in Part Two. They begin by discussing the relationship between extreme heat and human health, and move on to how heat is measured, and to issues related to warning the populace about heat stress. A map of Houston showing the urban heat island effect—overlaid with yellow circles locating cooling centers and eight different icons to indicate other places to get cool—illustrates the section on responding to extreme heat. This is followed by a discussion of extreme heat in a changing global climate, illustrated by world maps of temperature and heat index anomalies comparing the 1986–2005 period with forecasts for

2046–2065 and 2081–2100. The chapter finishes with another map depicting nighttime summer average temperatures in the Houston area, along with graphs visualizing the temporal changes in extreme heat events, and the GIS workflow used to prepare the data. In this chapter, the endnotes are really references, while websites, blogs, lesson plans, and the NCAR data portal can be found online.

"Finding a Way Home" by Lauren Griffin and Este Geraghty (both with Esri) deals with applications of GIS for the study of homelessness in the United States, and begins with a graph of the number of homeless in each state per 100,000 residents and a graduated circle map of the total numbers of homeless per state. For the rest of the chapter, though, the focus is on Los Angeles County, with a dozen county-wide maps and a few closeups around the city of Los Angeles. GIS workflows were established to analyze, predict, and map factors triggering or contributing to homelessness risk, as well as cataloging mitigating factors and evaluating mitigation progress. The maps in this chapter are, for the most part, very nicely designed, but for some reason the map on the right-hand side of page 99 is duplicated on page 101. At the end of the chapter, the authors have forty-five endnotes and the online resource page has five story maps, two case studies, and three blogs.

The seventh chapter, "Restoring Coastal Marine Habitats" by Zach Ferdaña, Laura Flessner, Matt Silveira, and Morgan Chow (all of The Nature Conservancy), Tom Brouwer (from FloodTags), and Omar Abou-Samra (with the American Red Cross), addresses the use of nature-based solutions to achieve coastal resilience, and includes two case studies. The first deals with the island of Grenada and the issues of storms and rising seas. Interestingly, in a book about GIS, the authors include a photo of the 3D cardboard model of the Grenville Bay area they constructed for interacting with the local populace, but do not show the digital 3D model that they created for the same area. The second case study concerns mangrove restoration in the Semarang area of Indonesia. The ArcGIS Pro models incorporating the locations of existing mangroves and flood zones that were used to identify areas with potential for restoration efforts are discussed, and two of the output maps are included. Once again, references populate the endnotes section, and online there are links to several websites, web apps, lesson plans, and a story map.

"Modeling Bird Responses to Climate Change" is the title of chapter eight, and it comes from Molly Bennet of the National Audubon Society, with contributions from her colleagues Brooke Bateman, David Curson, Gary Langham, Curtis Smalling, Lotem Taylor, Chad Wilsey, and Joanna Wu. It begins by noting the Audubon Society's history of work to protect birds, before looking at some examples of current work. There are maps of how the summer and winter ranges of some birds may shift northwards due to climate change, and a migration map for five classes of western hemisphere birds. There is also an inventory and comparative evaluation of Important Bird Areas, Priority Forest Blocks, and Climate Strongholds—all important to bird conservation—in North Carolina. Other case studies have maps depicting Important Bird Areas in Mexico and in western Colombia, and some of the wetlands in Maryland that are important for sea birds, identifying more than two hundred sites that will become suitable for refuges as the sea level rises. They finish with a discussion of Climate Watch (**climatewatchdata.org**). Of especial note in this chapter is the elegantly, simple generalized western hemisphere map on page 128 of migration routes and important bird areas throughout the two continents. With this chapter, the endnotes should be labeled as "Photo Credits," and the online resources has links to three story maps, three web maps, and the Audubon Mapping Clearinghouse portal.

Part 3, "How We Look at Earth," is divided into two chapters. Chapter 9, "Mapping Ancient Landscapes," by Jason Ur and Jeffrey Blossom (both of Harvard University) discusses efforts to map the ancient Assyrian empire, and focuses specifically on the work of the Erbil Plain Archaeological Survey (**scholar.harvard.edu/jasonur/pages/erbil**) in what is currently the Autonomous Kurdistan region of Iraq. A good deal of discussion is included on the Survey team's use of drone imagery and digital surface models in conjunction with magnetometry surveys, historical satellite imagery, and fieldwork. This GIS work helped local and Western archaeologists discover the lost kingdom at Kurd Qaburstan (2000–1500 BCE), examine major Assyrian canal excavations, and disentangle evidence of ancient forced migrations from that of others as recent as the 1980s. There are twenty-eight endnotes at the end of the chapter, while one story map, two web mapping apps, a video, and the Harvard Center for Geographic Analysis website are all available online.

The tenth chapter tells of a partnership between the Chesapeake Conservancy and Microsoft to assess the condition of riparian areas in four Pennsylvania counties—using high resolution imagery and lidar—and to suggest where riparian buffer restoration projects should occur. Unfortunately, there are no endnotes or references for this chapter, but the online resources provide five videos, three web maps, a PDF atlas, and a data portal from the Conservancy, plus three additional articles.

There are two chapters in the fourth part, "Training Future Generations of Scientists," and in the first, "A Glacier in Retreat," Jacki Klancher, Todd Guenther and Darren Wells (all from Central Wyoming College) address the changes in depth and extent of the Dinwoody Glacier at Gannett Peak in west-central Wyoming. The authors have been engaged in an ongoing study of the glacier for over six years—leveraging the participation of students as part of an interdisciplinary climate change expedition—documenting the glacier's thickness using ground penetrating radar and its extent using a GoPro camera hanging from a kite. The authors have also conducted anthropological studies of the Wind River Range using GIS to predict buffalo jump locations that prehistoric indigenous Americans could have used. References, and map and photo credits, populate the endnotes section of this chapter, and the online resources contain three videos, three story maps, a blog, and a connection to the Living Atlas of the World.

The University of Redlands team of Dan Klooster, David Smith, and Nathan Strout contributed "Panamapping: GIS for Conservation Science," the twelfth chapter of *GIS for Science*. In it, they discuss the use of GIS for conservation in the Mamoní Valley Preserve of central Panama—more specifically in two micro-watersheds of tributaries to the Rio Mamoní—in a project undertaken in cooperation with Experience Mamoní / Fundación Geoversity, a non-profit ecological / educational organization in Panama (**experiencemamoni.com**, **geoversity.org/en**). They worked with the indigenous Guna people of the area to conduct GPS mapping of trails, streams, and the micro-watershed boundaries, and they also conducted high-resolution 3D mapping surveys from UAVs, all while struggling with challenges involving the vegetation canopy and weather.

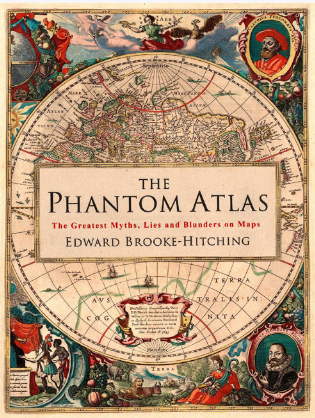
Both this and the previous chapter are good examples of practical field work for students learning about conservation biology using GIS. While acknowledgements are given at the end of the chapter, there are, unfortunately, no endnotes, citations, or credits. There are, however, three videos, a story map, a blog, a 3D fly-through, two websites, a slideshow, and an article online.

Part 5 is the Technology Showcase, and consists of eleven two-page exhibits, all authored by Esri staff:

- *Emergence of the Spatial Cloud*
- *Equal Earth Projection*
- *Science of the Hex*
- *Modeling the Footprint of Human Settlement*
- *Modeling Green Infrastructure*
- *Jupyter Notebook Analysis*
- *3D Empirical Bayesian Kriging*
- *National Water Model*
- *A High-Resolution Martian Database*
- *Sentinel-2 Imagery Viewer*
- *The Power of Storytelling for Science*

The online resources for the Showcase include seven blogs, two slide decks, four story maps, three articles, two lessons, the NOAA data portal, eight websites/apps/maps, three videos, two links to the Living Atlas, and a book. Oddly, neither the articles nor any of the online links refer to the image from the *Arctic DEM Explorer* (**livingatlas2.arcgis.com/arcticdemexplorer**) shown at the start of this section, which is identified only by the figure caption.

Overall, *GIS for Science*: *Applying Mapping and Spatial Analytics* holds lots of promise, and the online links provide plenty of additional information and data for readers to consume. As was noted, the book is a bit uneven, and has some shortcomings—these include the misuse of the subtitle Endnotes, the occasional misuse of map scale bars, and one duplicated map. Certainly, too, all the authors should have been instructed to provide references. Nonetheless, these problems will not prevent readers from enjoying, and profiting by, this text.



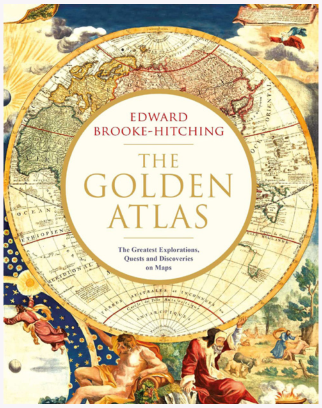
THE PHANTOM ATLAS: THE GREATEST MYTHS, LIES AND BLUNDERS ON MAPS

By Edward Brooke-Hitching

Chronicle Books, 2018

256 pages, color maps and illustrations, bibliography, index

Hardcover: $25.95, ISBN 978-1-4521-6840-1



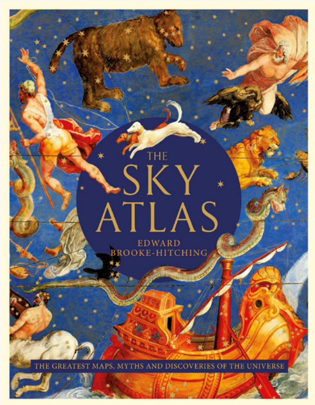
THE GOLDEN ATLAS: THE GREATEST EXPLORATIONS, QUESTS AND DISCOVERIES ON MAPS

By Edward Brooke-Hitching

Simon & Schuster UK, 2018

256 pages, color maps and illustrations, bibliography, index

Hardcover: $25.95, ISBN 978-1-4711-6682-2



THE SKY ATLAS: THE GREATEST MAPS, MYTHS AND DISCOVERIES OF THE UNIVERSE

By Edward Brooke-Hitching

Chronicle Books, 2020

256 pages, color maps and illustrations, bibliography, index

Hardcover: $29.95, ISBN 978-1-79720-118-4

Reviews by: Jenny Marie Johnson, University of Illinois at Urbana-Champaign

Edward Brooke-Hitching has penned a trio of extensively illustrated titles exploring facets of notable maps and of the histories of cartography and exploration. *The Phantom Atlas*, *The Golden Atlas*, and *The Sky Atlas* each provide an easy entry for map enthusiasts, armchair historians, and beginning scholars through approachable and understandable text, clean and clear illustrations, and, occasionally, some astonishing examples of geographic apocrypha that have persisted into the late twentieth, and even the early twenty-first, centuries.

The first title, *The Phantom Atlas*, examines fifty-eight instances where non-existent features or species have appeared on maps—in some cases being propagated from map to map for centuries. Some of these features are well known—such as the Island of California, the Great

River and the Sea of the West, and Terra Australis—while others are perhaps unfamiliar to North American readers, like Australia's Inland Sea and the representation of Korea as an island. These non-existent locations appeared on maps for a variety of reasons; while some were mythical—for example: Earthly Paradise, El Dorado, St. Brendan's Island, and Thule—most were simply errors. In an era when fact-checking information about distant places was difficult or impossible, it was easy for individuals to invent interesting locales in which to set their self-aggrandizing tales. Map compilers, who had to rely heavily on the (hoped for) veracity of traveler's tales, picked up these stories and their settings, and included them on their maps—places such as Frederick Cook's Bradley Land, Robert Peary's Crocker Land, or many of the lands appearing on the 1588 Zeno Map. Some of these locations, including Sandy Island (New Caledonia), Sannikov Island, Maria Theresa Reef, and Dougherty Island, continued to be included on maps and in atlases in the 20th century despite repeated failures to locate them. The author treats each of the fifty-eight apocryphal locations or species in alphabetical order, in sections of between two and ten pages, all of which are illustrated with reproductions of appropriate maps. Often an enlarged portion of a map will be included, tied by a line to its location on the full map. Because each of the sections stand largely alone, with only occasional references to the others, readers can chose to read only those sections of greatest interest. In addition to covering non-existent geographical features, Brooke-Hitching shows and discusses two maps, the *Carta Marina* (1539) and the *Nuremberg Chronicle* map (1493), that depict mythical plant and animal species, and the book also has a section on the numerous appearances of Patagonian Giants on maps from the sixteenth through eighteenth centuries.

The Golden Atlas focuses not only on the stories found on maps, but also stories *about* maps, setting maps in the social and intellectual contexts of their production by highlighting the exploits and tales of great discoverers and discoveries. The volume could almost be considered a history of exploration illustrated with maps. It is organized chronologically, and a timeline marches across the top of each double spread of pages with the era(s) being discussed highlighted. In thirty-nine fairly brief chapters, Brooke-Hitching sweeps through more than four thousand years of human history: from Sixth Dynasty Egyptian explorations (circa 2345-2181 BCE) through Shackleton's 1914–1917 expedition to the Antarctic, the adventure with which, the author argues, the heroic age of exploration came to a close. "Cartography too by this point had long shed its artistic plumage to take up residency in its modern division of scientific tool, and it feels right that a curation of its most splendid examples should end here also" (*Golden Atlas* 246).

The bulk of the chapters revolve around the exploits and discoveries of specific individuals. There is one chapter on the Dutch East India Company and the European discovery of Australia and another on the beginning of what the author calls the "age of female travelers," which he places at about 1846. All of the other chapters center on those personalities who might be considered "the usual suspects" of European exploration, discovery, and eventual exploitation. The *Golden Atlas* is not so much a history of cartography as a history supported by cartographic illustrations. The maps are rarely at the center of the conversation, and only occasionally does the text even briefly explain the importance of the particular map being used as an illustration. For example, the chapter "Willem Barentsz, Henry Hudson and the quest for an Arctic passage, 1594–1611" contains four maps, which include a map by Barentsz (posthumously published in 1598) and another from the journal of a participant in Barentsz's final voyage. The text does not discuss any of these maps, although the captions do give readers some idea of why the maps were included. Someone interested in a broadly sweeping history of exploration will be happy with *The Golden Atlas*; a reader looking for information about maps produced by or for exploration activities will not.

In *The Sky Atlas*, Brooke-Hitching turns his attention from Earth to the heavens. In his opinion, celestial maps are "the most overlooked genre of mapmaking," perhaps in part because "maps of the world above reflect little of the world below" (*Sky Atlas* 12), but also because of the differences in how Earth and sky are experienced, and because the sheer vastness of the celestial realm requires some imagination to find place markers and patterns. This work is divided into four sizable sections—"The Ancient Sky," "The Medieval Sky," "The Scientific Sky," and "The Modern Sky"—each with eight to twelve brief, targeted chapters of ten or fewer pages. Chapters have a variety of kinds of focus: the celestial and astronomical map output of entire civilizations or societies, technologies, the work of specific astronomers, or the search for and discovery of specific celestial bodies. Like *The Golden Atlas*, *The Sky Atlas* often is more a cartographically illustrated history of celestial discovery and philosophies than a history of the graphics that depict the heavens. The text does not focus on discussion of specific maps, but instead presents descriptions of the circumstances or contexts in which maps were produced or used. For example, the chapter on Halley's Comet is illustrated with nine maps and other graphics, not one of which is specifically referred to in the text. Fortunately, in this chapter, and throughout the book, the illustration captions are often extensive and do a good job explaining the connection of image to topic. Most of the text and accompanying illustrations center on European astronomy. There are, however, also chapters on ancient China, the Jain universe, Islamic astronomy (including the development of the astrolabe and its impact on European astronomy), and Mesoamerica. Should *The Sky Atlas* whet the reader's appetite for more, the "Select Bibliography" at the end of the volume could fill that need. It includes a number of core works on the history of astronomy and some works on the history of astronomical mapping.

The three titles were clearly intended to be independent publications, and while a few maps appear in more than one book, they are viewed through slightly different lenses in each. For example, Hondius's *Nieuwe caerte van het Wonderbaer ende Goudrjcke Landt Guiana* (1598) appears in the "El Dorado" chapter of *The Phantom Atlas*—because it includes the mythical Lake Parime on which El Dorado was supposedly located—and it also appears in *The Golden Atlas*'s chapter on Sir Walter Raleigh's search for El Dorado.

In all three of these titles, the text is easy to read, engaging, and informative. They are intended for the interested lay reader, rather than an academic audience that usually needs footnotes and endnotes. There are no such citations, and, although the map captions usually include the name of the cartographer and the date of publication, the reader must examine the illustration to discover the map title. In this way they serve as partial or casual citations, but unfortunately it is not always clear if a map was a separate publication or part of an atlas or other volume. There are some places where Brooke-Hitching refers to the work of specific scholars, but, again, does not provide enough information to unambiguously identify his sources. In *The Phantom Atlas* section on California as an island, for example, Brooke-Hitching writes: "In fact 249 maps showing California Island (not including world maps) were identified by historians Glen McLaughlin and Nancy H. Mayo in 1995" (*Phantom Atlas* 66). Similarly, in discussing the Mountains of Kong, he writes that "after the publication of Rennell's map the mountains rose up on a series of other works—forty, in fact, have been found by the American academics Thomas Bassett and Philip Porter to bear the Kong falsity" (*Phantom Atlas* 149).

There is, however, nothing in his bibliography that appears to be a citation to either of these mentioned works—potentially leaving a novice researcher or entry-level enthusiast at a dead end.

The "selected" bibliographies appear to be *highly* selective, as they are quite short—only one page long. Although there are a sprinkling of works that, in the context of Brooke-Hitching's texts, could be considered primary sources—such as Hakluyt's 1589 *The Principall Navigations* or Flinders' 1814 *A Voyage to Terra Australis*—most of the titles are secondary works, some similar to Brooke-Hitching's titles, that were published during the last fifty years. No rationale is given as to why any particular title appears.

Edward Brooke-Hitching's *Phantom Atlas*, *Golden Atlas*, and *Sky Atlas* are a trio of works that are engaging and easy to read. All three are slightly less than 10 inches tall, so they definitely are not glossy coffee table books. Readers looking for larger illustrations will need to look to other titles or online resources. They are, however, lavishly illustrated with maps and other graphics, often with extensive captions. The captions usually allow for the reader to identify what the illustrations are but they are not citations. Because the chapters in all three are more or less self-contained, readers do not need to read the entire book but can elect to read sections of specific interest and still understand the content. These works could be used to guide a student to possible paper topics or to supply images of maps with specific styles or depictions. They might be useful as "starter" texts for someone who comes to the library and simply asks "Do you have anything on…" Certainly, Brooke-Hitching's three works on maps and the history of cartography and exploration are ideal for the casual reader and beginning armchair scholar.

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PEER-REVIEWED ARTICLES

TITLE: The title serves as the author's invitation to a diverse audience. It should be chosen wisely. The title section should include the full names of the authors, their email addresses, and their academic or professional affiliations.

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.

REFERENCES: References should be cited parenthetically in the text, following the author-date system found in *The Chicago Manual of Style,* 17th ed. (**chicagomanualofstyle.org**). When making a direct quote, include the page number. Example: (Doe 2001, 38).

Books: Invert the first author's name (last name, first name, and middle initial). Middle initials should be given wherever known. For books with multiple authors,

authors' names are listed in the order in which they appear on the title page, with the last author's name preceded by a comma and *and*. Note: With more than ten authors, invert first author's name and follow it with a comma and the words et al. without italics in the reference list.

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. http://doi.org/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.

Websites: Websites may be generally referenced in running text ("On its website, the Evanston Public Library Board of Trustees states…") rather than with a URL listing. If a more formal citation is necessary, use: Name of author(s). Year. "Title of Document." *Title of Complete Work (if relevant)*. Access date. URL.

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.

Maps: Maps should be treated similarly to books, to the extent possible. Specific treatment may vary, however, and it is often preferable to list the map title first. Provide sufficient information to clearly identify the document.

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.

E-mail correspondence: E-mail messages may be cited in running text ("In an e-mail message to the author on October 31, 2005, John Doe revealed…") instead of in a note or an in-text citation, and they are rarely listed in a bibliography or reference list.

Additional examples: For additional examples, please consult *The Chicago Manual of Style*, 17th ed. (chicagomanualofstyle.org).

DOI NUMBERS: DOI numbers for references must be included whenever available. You can look up DOIs at www.crossref.org/SimpleTextQuery.

REFERENCES LIST: The list of references should begin in a separate section, immediately after the text. Entitle the section "References" and list all references alphabetically by the author's last name, then chronologically. Provide full, unabbreviated titles of books and periodicals.

FOOTNOTES: Footnotes should be used sparingly: i.e., only when substantive enough to amplify arguments in the text. They should be addressed to a single point in the manuscript. Footnotes should be numbered sequentially in the text and will appear at the bottom of the page.

UNITS OF MEASURE: *Cartographic Perspectives* uses the International System of Units (metric). Other units should be noted in parentheses.

EQUATIONS: Equations should be numbered sequentially and parenthetically on the right-hand edge of the text. If special type styles are required, instructions should be provided in the margin adjoining the first case of usage. Authors should carefully distinguish between capital and lower-case letters, Latin and Greek characters, and letters and numerals.

TABLES: Tables should be discussed in the text and denoted by call-outs therein, but the meaning of a table should be clear without reading the text. Each table should have a descriptive title as well as informational column headings. Titles should accent the relationships or patterns presented in the table.

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