Cartographic Perspectives

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ABOUT THE COVER: The Philippines, by Hannah Dormido, hand-drawn in her unique *Dormi-dots* style. To see more of Hannah's work, visit hannahdormido.com.

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LETTER FROM THE EDITOR

In the months since my last letter, time has gone both very quickly and very slowly. I'm still sitting in my home office, staring at the same screen, in a kind of Groundhog Day in December. The year has been full of challenges of one sort or another for everyone, no matter where you live and no matter where you work or study. As I reflect on how I've handled my own challenges, one thing my mind keeps coming back to is how important community has been to me in getting through the year. Professionally, the NACIS membership makes up a big part of my community and networks, and I am very thankful and grateful to have had that community to turn to for support and commiseration. I'll draw your attention to a few ways that community has made a difference for me in the last few months.

Like me, some of you attended Virtual NACIS a few months ago in October. The Society's early experimentation with live streaming presentations, which began several years ago and was initiated for other reasons, turned out to be a prescient decision. It meant that both the meeting organizers and attendees had some experience with these technologies, and I think that this allowed them to move beyond the basics and create the best online meeting I've attended all year. Perhaps some of you feel the same way. Although, like many of you, I would have preferred to be able to attend the meeting in person, the virtual meeting really felt like a NACIS conference to me. The interactions I observed and participated in, both on Slack and at the social events, were the same great conversations I would have been having in person, with the added bonus of actually being able to hear the whole conversation at NACIS Night Out and not waking up with a hoarse voice from straining to make myself heard in a noisy room of cartographers! It was a few days of (almost) normality that I needed sorely, having at that point spent 110 days in lockdown where I live in Melbourne, Australia. I felt very grateful for the significant effort that the conference organizers, Mamata Akella and Pat Kennelly—with the support of the rest of the NACIS Board—put into making this a NACIS meeting like any other, even if in some ways it was unlike any other.

I am likewise grateful for all of the hard work that went into the crafting of the *Atlas of Design*. If you've ordered the most recent *Atlas of Design*, Volume 5, you will also have received a volume full of inspiration and delight by now, as I have. It is the latest instalment in a series edited by NACIS members, and many NACIS members are numbered among the contributors or members of the jury that selected the maps for the volume. I hope that for those of you who are in the thick of terrible COVID-19 outbreaks in the northern hemisphere winter are able to turn to that volume for distraction, pleasure, and dreaming of a return to a more normal existence.

Finally, I would be remiss if I did not thank all of the people whose support makes it possible to produce *CP*. Firstly, there is the editorial team: Daniel Huffman (Assistant Editor); Jake Coolidge, Sarah Bell, Fritz Kessler, and Mark Denil (the section editors); and Sarah Battersby, Cynthia Brewer, Matt Dooley, Matthew Edney, Sara Fabrikant, Bernhard Jenny, Patrick Kennelly, Mark Monmonier, Ian Muehlenhaus, Michael Peterson, Anthony Robinson, Amy Rock, and Robert Roth (the Editorial Board). In particular, I would like to thank Sarah Bell for her two years of service as the Practical Cartographer's Corner Section Editor, as she will be stepping down from the role in 2021.

Secondly, there are the reviewers. In a time when there has been more work and fewer resources in many universities because of the shift to remote teaching and learning, it has become more challenging to find reviewers, so for these contributions, I am very grateful. The following people provided reviews of papers in the peer reviewed papers section:

Matt Beaty
Arzu Çöltekin
Jeremy Crampton
Craig Dalton
Tiffany Earley-Spodoni
Alison Feeney
Carolyn Fish
Sarah Goodwin
Jeff Howarth
Laurent Jégou
Bernie Jenny
Fritz Kessler
Scott Lieske
Sebastian Meier
Mark Monmonier
Ian Muehlenhaus
Michael Peterson
Anthony Robinson
Amy Rock
Robert Roth
Erik Steiner
daan Strebe
Denis White
Travis White
Cathy Yinghui

In *CP 96*, you will find two PEER-REVIEWED ARTICLES. In the first, Jonathan Nelson and Alan MacEachren present a design study that captures and documents the design process that was used to develop a cartographic interface that can be used to interact with a very large bicycling dataset. Their study provides a window into their development and evaluation process, which spanned both industry and academic settings. In the second article, Ate Poorthuis and colleagues introduce Florence, a new JavaScript-based, open-source framework for teaching web-based cartography and data visualization. This framework allows a heightened focus on cartographic theory, rather than requiring students to acquire some knowledge of software engineering in order to be able to use one of the dozens of different web mapping platforms used in industry.

Charles Preppernau introduces us to his technique for making a normal map in the PRACTICAL CARTOGRAPHER'S CORNER. Maybe this is not the kind of normality we are all yearning for, but it's a kind of normality we can at least access in this moment. I encourage you to check out his article.

In VISUAL FIELDS, Jen Mapes and Sara Koopman provide us with some insights into how they developed an interactive map, entitled *Mapping May 4th*, as well as a wall-sized print map, which hangs in the Kent Historical Society. Both maps tell the story of a Vietnam War protest that was held at Kent State University, and resulted in the deaths of four of the protestors.

Garrett Dash Nelson introduces the Leventhal Map & Education Center's digital exhibition, *Bending Lines: Maps and Data From Distortion to Deception* in CARTOGRAPHIC COLLECTIONS. This exhibition, originally planned to be held in the library's exhibition spaces, had to be pivoted to an online-first exhibition once the library closed to the public because of COVID-19. The exhibition explores the mapmaking process and attempts to help the public develop an appreciation for how cartographic decisions shape the resulting maps. This is done through an examination of both historical persuasive maps and a series of contemporary maps specifically commissioned for the exhibition with the aim of showing how the same dataset can result in maps telling different stories in the hands of different cartographers.

CP96 includes two REVIEWS of atlases produced by the Guerrilla Cartography group. Abe Parrish reviews *Water: An Atlas*, while Nat Case reviews *Food: An Atlas*. To find out more about the Guerrilla Cartography group, if you missed it, see the **Visual Fields contribution in *CP 94***, written by founder Darin Jensen. Providing an interesting counterpoint to reviews of two atlases, Alison Olivierre and Charla Burnett team up to discuss the merits of *This Is Not an Atlas: A Global Collection of Counter-Cartographies*.

Several volumes have recently been published about W. E. B DuBois's Paris Exhibition at the 1900 World's Fair, including **one that was reviewed in** *CP 93*. Krystle Harrell reviews an edited volume, *Black Lives 1900: W. E. B. Du Bois at the Paris Exposition*, whose chapters examine the historical context of the exhibition. In his review, Glenn Humphries argues that we need more monographs that celebrate individual maps in the way Hongping Annie Nie's monograph, *The Selden Map of China: A New Understanding of the Ming Dynasty* does. Rounding out the reviews section, Vincenza Ferrara provides an opinion on *Focus on Geodatabases in ArcGIS Pro*, which may be of interest to those of you who are making or are contemplating making the switch to Esri's latest platform.

Let's hope 2021 brings an end to the COVID-19 pandemic. An unexpected benefit of Virtual NACIS 2020 was that it enabled participation from international locations and brought new members to the Society. I hope we can use what we've learned in these challenging times to build a stronger, more connected cartographic community worldwide.

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

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User-centered Design and Evaluation of a Geovisualization Application Leveraging Aggregated Quantified-Self Data

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Individual movement traces recorded by users of activity tracking applications such as Strava provide opportunities that extend beyond delivering personal value or insight to the individual who engages in these "quantified-self" (QS) activities. The large volumes of data generated by these individuals, when aggregated and anonymized, can be used by city planners, Departments of Transportation, advocacy groups, and researchers to help make cities safer and more efficient. This opportunity, however, is constrained by the technical skills and resources available to those tasked with assessing bicycling behavior in urban centers. This paper aims to address the question of how to design cartographic interfaces to serve as mediated platforms for making large amounts of individual bicycling data more accessible, usable, and actionable. Principles of cartographic representation, geovisual analytics techniques, and best practices in user interface/experience design are employed to arrive at an effective visualization tool for a broad urban planning audience. We use scenario-based design methods to encapsulate knowledge of map use practice gleaned from the development process, and conduct a post-implementation, two-part user study with seven domain experts to further assess the usability and utility of the interactive mapping tool.

KEYWORDS: cartographic design study; user-centered design; movement data; quantified-self (QS); urban planning

INTRODUCTION

Advancements in global navigation satellite and positioning systems, together with the subsequent increase in use of geo-enabled tracking devices, have resulted in unprecedented amounts of individual movement data (Swan 2012; Laube 2015). These data are increasingly being generated using personal devices, such as smartphones and other wearables (e.g., augmented eyewear, pedometers, smartwatches, textiles, wristbands, etc.). At the most ambitious end of the self-tracking spectrum is the Quantified Self (QS) community, which is composed of individuals who believe in "self-knowledge through numbers" and who use these devices to track biological, physical, behavioral, environmental, and/or other information about themselves (Swan 2013).

The movement data generated by quantified-selfers can offer more than just direct personal insight to the individual who engages in QS activities. The large volumes of data generated by these individuals, when aggregated and anonymized, can also be used to inform city safety (Zeile et al. 2015), preferential route choices (Baker et al. 2017), and air pollution exposure (Sun and Mobasheri 2017). Ubiquitous computing and Internet of Things (IoT) technologies create further potential for integrating individual movement data into smart city initiatives, such as traffic congestion monitoring (Zanella et al. 2014). This can result in a more humanized, bottom-up approach to city planning (Smyth et al. 2013). The opportunity, however, is constrained by the technical skills and resources available to those tasked with assessing bicyclist or pedestrian behavior in urban centers. This paper aims to address the question of *how to design interactive mapping tools that can help urban and transportation planners leverage personal fitness data to better inform infrastructure decisions that aid in the safe and efficient movement of bicyclists?*

More specifically, in this problem-driven research, we examine the design of a commercial interactive cartographic application intended to support urban and regional planning. The interactive mapping tools considered in this design study are focused on utilizing large volumes of individual movement data contributed voluntarily by users of an activity tracking application, Strava. *Metro* is a small division of Strava (the company, which shares a name with its application) that aggregates and anonymizes data on bicycling activities recorded on the platform, and licenses these data to a variety of organizations that are taking data-driven approaches to city planning. Based on a needs assessment and work domain analysis carried out by the first author while employed by Strava, the following insights emerged:

- There existed a disconnect between what Strava Metro assumed data users were capable of (in terms of big data management, analysis, and visualization), and the reality of their time, resources, and abilities.

- Data users faced significant challenges with data size/complexity, resulting in frustration, confusion, and limited ability to extract value from the data.

- Most data users aimed to accomplish some variant of the following tasks: quantify/qualify ridership; distinguish between commute and recreational bicycling corridors; and identify candidate areas for modifying or creating new bicycle facilities.

Thus, we set out to develop a partnership with data users to alleviate their frustration and help address their needs. More specifically, we initiated a multi-year, user-centered design study to develop a geovisualization tool to make Metro data more accessible to stakeholders in the city planning process. These stakeholders may possess limited, or even no experience with geographic information systems (GIS) or spatial analysis. However, the tool should also support more advanced analysts, and offer immediate insights into the fundamental tasks outlined above. A major contribution of our work is the methodological framework we present for evaluating the extent to which the proposed design solution addresses the needs outlined above.

In the following sections, we first ground our design framework in relevant literature on cartographic approaches to mapping movement, geovisual analytics techniques for interacting with complex representations of movement, and urban interfaces (or city dashboards). Next, we introduce *Metro DataView*, an interactive network flow map designed to make data on bicycle activity more accessible, usable, and useful to decision makers, stakeholders, and researchers in the urban planning domain. A simplified approach to visualizing individual movement traces is then considered, followed by a presentation of a three-stage user-centered design and evaluation model employed to both formatively and summatively assess the cartographic tools presented in this work. That model combines a hypothetical use case scenario and claims analysis with a post-implementation user study to (1) characterize the domain problem, (2) synthesize knowledge of map use practice gleaned from the development process, (3) assess the extent to which the geovisualization tools support insight discovery, and (4) evaluate interface usability and utility. The paper concludes with a discussion of tool adoption and impact, major contributions, design limitations, and opportunities for future research and development.

BACKGROUND

This section provides background on cartographic approaches relevant to mapping individual activity traces; highlights ongoing research in the geovisual analytics community focused on exploring and making sense of complex movement data with an emphasis on transportation applications; and concludes with an overview on urban interfaces and their relevance to the visual communication of movement for an urban planning audience.

CARTOGRAPHIC APPROACHES TO FLOW MAPPING

Individual movement data are commonly structured as series (or trajectories) of point records, each composed of a latitude/longitude coordinate pair and a timestamp. Mapping these points directly is the simplest approach to visualizing and attempting to make sense of data in this form (Andrienko et al. 2008). Mapped depictions of raw GPS point data, however, become less feasible if the number of trajectories is large, if they reveal personally identifiable information, or if the analytical goal is to detect group—rather than individual—movement behavior. One, if not all, of these conditions will likely be met when engaging with individual movement data. In these cases, data aggregation becomes a viable strategy for preserving individual privacy while also making analytical tasks computationally tractable and mapped results visually meaningful (Rinzivillo et al. 2008).

Approaches to representing the spatial flow of objects in aggregate form have existed since at least 1845 (Robinson 1967). Effective flow maps are difficult to create, and have traditionally been drawn carefully by hand. Tobler (1987) introduced the challenges of migration flow mapping by computer, and, despite decades of advancement in GIS technology, creating effective digital flow maps remains difficult today (Rae 2011; Zhu and Guo 2014; Zhou et al. 2019). Connecting straight lines between locations on a map is inadequate, because the map quickly becomes cluttered and illegible. More sophisticated approaches to creating flow maps involve algorithm-driven line bundling and aggregation (e.g., Phan et al. 2005; Buchin, Speckmann, and Verbeek 2011; Debiasi et al. 2014). Such approaches have the advantage of reducing visual clutter through the offsetting or merging of lines. However, they become increasingly ineffective as data size and dimensionality increase, as well as when locations for origins and destinations and the arbitrary lines between them disguise the underlying patterns of the spatial phenomenon under study (Guo 2009).

GEOVISUAL ANALYTICS APPROACHES TO MAKING SENSE OF FLOWS

Interactive geovisual analytics approaches allow us to move beyond messy cartographic representations of movement into an environment that lets users filter, analyze, and more effectively make sense of large, complex flow data. These approaches oftentimes leverage computational data summarization, pattern extraction techniques, and linked views (Andrienko et al. 2008). For example, Boyandin et al. (2011) proposed linking two separated origin and destination maps with a non-spatial temporal heatmap to represent change in movement flows over time more effectively. Other notable works include those of Wood, Dykes, and Slingsby (2010), and Wood, Slingsby, and Dykes (2011). These authors explored the benefits and shortcomings of representing flows with curved symbols in comparison to other, more novel, approaches such as gridded views and origin-destination (OD) maps (i.e., an origin-destination matrix overlaid on geography). With respect to computational pattern extraction, Guo (2009) introduced a methodological framework that combined hierarchical and multivariate clustering, together with interactive flow maps, and demonstrated the value of that framework in the context of migration mapping. This work was later extended to more effectively support multi-resolution flow clustering on large datasets (Zhu and Guo 2014), and to develop a multi-scale flow density estimation and selection methodology for visualizing patterns in complex OD pairs (Zhu et al. 2019).

Transportation, in particular, is an active research area in the geovisual analytics community, because professionals in this domain rely on interactive, visual tools to support their analyses of vehicular and pedestrian movement (Andrienko et al. 2017). Many data types, derivatives, and visual representations have been developed to inform the spatial, temporal, and contextual properties of aircraft, automobiles, pedestrians, ships, trains, and other moving entities. We refer readers to Chen, Guo, and Wang (2015), and Andrienko et al. (2017) for comprehensive surveys of data visualization frameworks and techniques relevant to traffic and transportation data, but we will highlight two particular works that emphasize the diversity of research being conducted in this application area. Zeng et al. (2013), for example, considered both data aggregation and pattern extraction techniques in their exploratory analysis of passenger re-distribution patterns at intersections in traffic networks. The authors further adapted a variant of the circos figure (i.e., a circular plot for exploring relationships among objects and positions; see Krzywinski et al. 2009) to visualize the flow of travelers through interchanges. More recently, Zhou et al. (2019) proposed a visual abstraction approach that leverages a Natural Language Processing word embedding framework, together with adaptive sampling, to make sense of large amounts of OD data. The authors demonstrated how their visualization system reduced visual clutter and highlighted human mobility patterns using bicycle share and mobile phone location datasets.

The work we present in this paper contributes to the growing body of research on the representation and analysis of movement data by introducing and evaluating an integrated network and OD flow map constructed from the aggregation of individual bicycling traces. Network flow maps have received less attention than their radial and distributive counterparts due to limited access to trajectory data, particularly individual trajectory data, as well as challenges surrounding data size and complexity. Through processes of data abstraction and novel techniques for rendering large geospatial data in a web browser, this paper offers an effective framework for making large amounts of individual movement data more usable, useful, and accessible, while also preserving the privacy of the data creators.

URBAN INTERFACES

Beyond the research on mapping and analysis of flow data outlined above, the system presented here also draws upon research on urban data interfaces, often termed *dashboards* (Few 2004). These dashboards provide analysts, decision makers, and the public with access to data about the city, and are increasingly being used for urban planning and real-time city monitoring. For example, Maynooth University, in partnership with Dublin City Council recently undertook an extensive Building City Dashboards (BCD) project. The BCD project focuses on expanding the Dublin Dashboard, one of the most comprehensive urban interfaces to date (Kitchin, Maalsen, and McArdle 2016).

On one hand, urban interfaces provide citizens and planners alike with a multifaceted, data-driven perspective on their city. On the other, this perspective is biased as a result of data cleansing, data that are (un)consciously not included, a lack of information on how the data were sourced and/or derived, and the varying abilities that users have to make sense of the data. Mattern (2014) cautions against the "instrumented" rationalization of the city mediated through an inevitably incomplete interface that lacks in affect and civic collaboration. Mattern provides guidelines for urban interfaces and asks designers to consider composition and framing of screen elements and how they interact over time and space, scale of context (entire city vs. street corner), intended audience, and the types of information about the city that cannot (or should not) be represented by data visualizations. As big social media data are increasingly leveraged to feed urban dashboards and geovisualization tools more broadly, the proper design and use of those tools must reflect the (semi-)volunteered nature of data collection; respect the privacy of the data creators in the collection, storage, analysis and visualization of the data; and consider the uneven density and representativeness of social media data across space and time (Martin and Schuurman 2020).

As humans, our experiences in and understanding of cities are bound in place, space, and time. Urban interfaces undoubtedly benefit from, if not require, a cartographic component. In many cases, the map may be the central element of the interface, thus conceptualizing and creating effective urban interfaces benefits from expertise not only in user interface (UI) and user experience (UX) design, but also map design (Roth 2017). Further, the design process gains from balancing interaction design frameworks relevant to data visualization and cartography (e.g., Shneiderman's [1996] Information Seeking Mantra or Roth's [2013] taxonomy of cartographic interaction primitives) with an iterative, user-centered approach to defining (or refining) interaction flows in response to feedback provided by those who will use the interface. In the following section, we introduce a map-centric urban interface designed to provide city planning professionals, local advocacy groups, and researchers with insights into how bicyclists move across urban networks.

METRO DATAVIEW

Metro DataView is an interactive flow map that depicts volumes of unique bike trips, commute-designated trips, and bicyclists across an urban network. In addition, the cartographic tool provides an option to view a rasterized heatmap of the GPS points that define the activity traces used in the creation of the other views.

DataView differs from many urban bike maps due to its ability to relay objective information on how bicyclists are moving across a street network. Oftentimes, bike map design in urban planning contexts is based on subjective input provided by the "average" bicyclist. Wessel and Widener (2015) surveyed dozens of urban bike maps and found that Departments of Transportation and planning agencies in cities across the United States were publishing maps that assigned bike routes to ill-defined classifications, such as "preferred," "use with caution," or "not recommended." In some cases, subjective context was also used to represent gradient (e.g., "steep hill" vs. "very steep hill") and safety (e.g., "difficult intersection"). This subjective design approach can be attributed to a lack of data on infrastructure and ridership, as well as to the Federal Highway Administration's "bicycle level of service" initiative that aims to evaluate the suitability of roadways for bicycle activity based on "comfortability" ratings provided by a subset of bicyclists for a sample of road segments (Harkey, Reinfurt, and Sorton 1998). Ratings can be correlated with road characteristics (e.g., pavement condition, shoulder width, speed limit, etc.) to extrapolate level-of-comfort designations across the entire network (Landis, Vattikuti, and Brannick 1997).

However, defining the "average" bicyclist is problematic, and as a result, many urban bike maps leave much to be desired with respect to objectively informing a diverse audience of bicyclists on how to successfully navigate the city. There are, though, some noteworthy exceptions to this subjective design approach. Wessel and Widener (2015) designed a printed bike map of Cincinnati, Ohio that intentionally did not include any unquantifiable information on roadway or terrain characteristics, with the intent that bicyclists of all types could make more objective wayfinding decisions. Similarly, but more narrowly focused, Brügger, Fabrikant, and Çöltekin (2017) conducted an empirical study to comparatively evaluate three linear elevation change symbolization methods (variation in color hue, color-coded arrows, and elevation profiles) to gain insight into how to design static maps to better facilitate bicycle route planning. Most similar to the design solution presented in our work is the Madrid Cycle Track initiative, in which Romanillos and Austwick (2016) developed network flow and heat maps from volunteer bicyclists to reveal mobility patterns across Madrid, Spain based on journey purpose (casual vs. messenger) and sociodemographic characteristics (age and gender). Bike maps, such as these examples and *DataView*, which quantify and effectively communicate ridership across the network, as well as other characteristics of the urban environment, can help bicyclists to choose safe and personally appropriate routes and assist city planning professionals in making strategic infrastructure decisions that promote bicycling as a recognized mode of active transportation (Su et al. 2010).

In the following subsections, we formally introduce Strava, the activity tracking platform by which bicycling trips were collected, aggregated, and made available for *Metro DataView*. Next, we provide a high-level summary on how the bicycling trip data are processed to support effective and efficient visualization and interaction. Lastly, system design decisions are described in detail.

CASE STUDY DATA PLATFORM

Strava is a social network for athletes that provides a platform for application users to record, analyze, and share their fitness-related activities. Tens of millions of activities are uploaded to the platform daily from users all over the world, and over two billion activities had been recorded in total between the company's inception in 2009 and December 2019 (Strava 2019).

Activities recorded by platform users provide opportunities that extend beyond just delivering personal value or insight to the individual who engages in quantified-self activities (Lee and Sener 2020). The large volumes of data generated voluntarily by users of these types of applications, when aggregated and anonymized, can be used by city planners, Departments of Transportation, advocacy groups, and researchers to help make cities safer and more efficient for bike and pedestrian activity (DiGioia et al. 2017). This requires transforming large numbers of activity traces into actionable insights for a variety of stakeholders in the urban planning space.

Metro is a small division of Strava that licenses aggregated and anonymized activity data to Departments of Transportation and other city planning organizations. Researchers are leveraging Metro data to better understand spatial patterns in bicycling and pedestrian behavior across many different application (and geographic) areas. For example, Griffin and Jiao (2015) evaluated the relationship between place-based/road network variables and the geography of bicycling-for-fitness in Travis County, Texas. Metro data have been used to facilitate smarter mobility planning in Johannesburg, South Africa (Selala and Musakwa 2016), and to model the relationship between bicycling trip purpose and air pollution exposure in Glasgow, UK (Sun and Mobasheri 2017).

A consideration when using Metro data is that the Strava user group reflects only a subset of the bicyclist population. Many of the users engage primarily in sports and training activities, not necessarily in everyday commuting trips. Recognizing this, prior studies have aimed to evaluate the representativeness of Metro data. For example, the Centers for Disease Control and Prevention reported a strong association ($\rho = 0.60$) between the number of Strava-tracked commuters and the number of active commuters sampled by the US Census Bureau's American Community Survey (ACS) in four major cities (Whitfield 2016). However, *intracity* correlation may vary as result of population density, social (dis)advantage, and overall ridership in the area (Conrow et al. 2018). At the very least, crowdsourced fitness data can complement and extend traditional active transportation surveillance and analysis despite sample and other biases inherent in user-generated data sources (Jestico, Nelson, and Winters 2016; Ferster et al. 2017; Lee and Sener 2020). Moreover, these data exhibit unprecedented spatial and temporal resolution, allowing for new approaches to measuring changes in bicycling behavior across an urban network as a result of infrastructure change and implementation (Boss et al. 2018).

However, the success of such approaches hinges on data accessibility and utility. In the following subsection, we explain the data abstraction process by which streams of individual movement traces recorded on Strava are transformed into summarized data views that a relevant audience can visualize and interact with using *Metro DataView*.

DATA PROCESSING & ABSTRACTION

Bicycling activities (i.e., streams of GPS points) recorded on Strava that are made publicly available by platform users are first queried from a PostGIS database based on a geographic area of interest and specified timeframe. Next, a map-matching process (White, Bernstein, and Kornhauser 2000) is performed to identify street network geometry traversed by bicyclists. More specifically, GPS points are aggregated against a vector street network (e.g., OpenStreetMap extract, TIGER network, etc.), intersection nodes (derived based on where the street network breaks), and arbitrarily defined hexagons with a 350-meter diameter. For street and intersection aggregations, the first and last 500 meters of each activity trace are cropped to preserve user privacy. Activity start and endpoints are only used in the hexagonal aggregation process, because these are created for the purpose of exploring origin-destination patterns in bicycling behavior and the size of the areal unit preserves user privacy. The aggregation processes output counts of unique individuals, activities, and commute-designated trips appended to all three types of spatial geometry. If a trip begins and ends at different locations, it is designated as a commute. Median interchange crossing times are also derived at the intersection level. This results in trajectory-oriented views of movement from both origin-destination and route-based perspectives (Andrienko and Andrienko 2010). The combined approach of map matching and aggregation has been identified as an effective strategy for outputting a useful dataset for transportation planning while also maximizing geoprivacy (Sila-Nowicka and Thakuriah 2016).

The three spatial datasets are output in GeoJSON format and converted into vector map tiles. Rendering GeoJSON directly on the client is not computationally practical because it requires downloading the entire data file on every map load. Vector tiles reduce the amount of data transferred to the client by returning vector representations only of features visible within the current map bounds and zoom level (Eriksson and Rydkvist 2015). In comparison to raster tiles, feature attribution persists through the GeoJSON-to-vector-tile transformation. As a result, features can be dynamically styled, manipulated, and interacted with on the client in real-time.

FEATURES & FUNCTIONALITY

As noted above, *Metro DataView* is an interactive mapping tool that depicts aggregate patterns of bicycling behavior across a road network. The intent of the tool is to provide city planning professionals and stakeholders, particularly those who possess limited or no GIS expertise, with a simple interface for: easily distinguishing commute from recreation bicycle corridors; identifying candidate areas for fixing or creating new bicycle facilities; and quantifying ridership pre- and/or post infrastructure change. Visual representations of counts of unique bike trips are displayed by default. An interactive tutorial is initiated when the application is loaded, to introduce and familiarize users with the interface and functionality. Learnability is one of the fundamental components of system usability, because a user's initial experience with an interface involves making sense of how it works and what it depicts (Nielsen 1993). Interactive tutorials are effective strategies for conveying short, chunked sequences of syntactic knowledge to novice map users (Roth, MacEachren, and McCabe 2009; Mead 2014).

System features can be accessed in the control panel, which is in the upper left corner of the map interface. Area-of-interest, timeframe, and global statistics on the total number of activities and bicyclists being represented in the interface are specified at the top of the control panel. Below this information are buttons that allow users to switch between the following unique data views: *Rides*, *Commutes*, *Cyclists*, or *Heat*. Only one of these views can be selected at a time. Figure 1 provides an overview of the layout of *Metro DataView's* various features. Intersections, origin-destination polygons, and destination-origin polygons can be toggled on or off. When on, these layers are overlaid on top of the street network and correspond to whichever aggregate data view is enabled. For example, if the "Commutes" view is selected, the intersection layer will depict counts of commutes at interchanges across the network (see Figure 2). Similarly, if the "Cyclists" view is selected, the origin-destination layers will depict the number of bike riders starting or ending at each of the

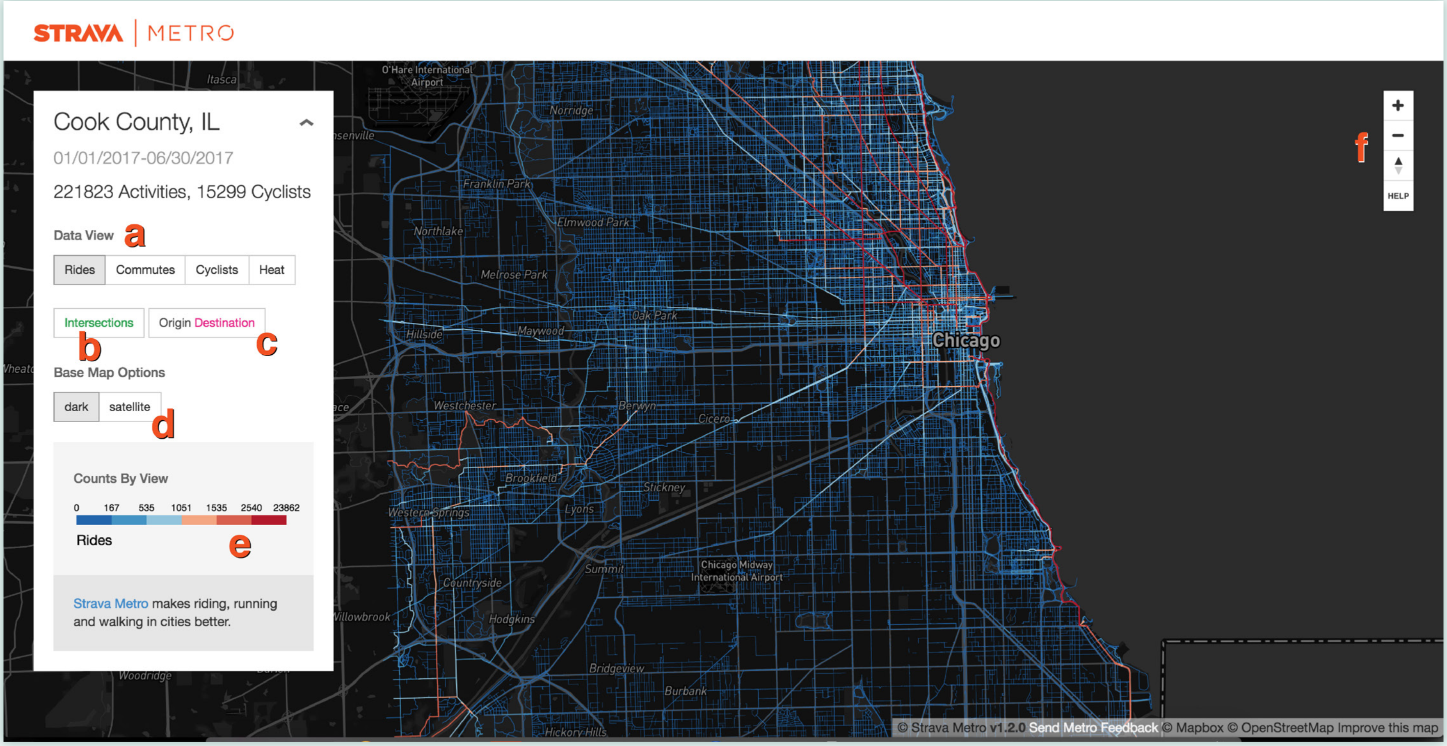


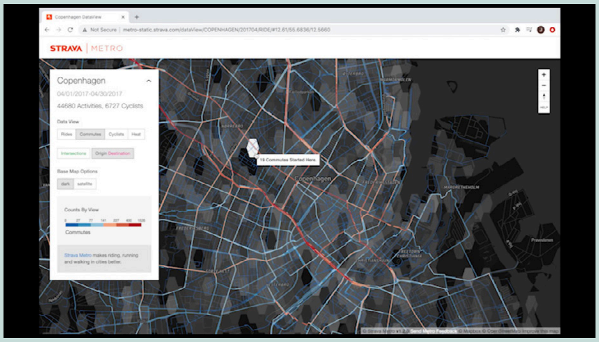
Figure 1. *Metro DataView: (a) network view options; (b) intersection toggle; (c) origin/destination toggle; (d) basemap selection; (e) network legend; (f) navigation and help.*

arbitrarily-defined hexagonal areas across the network (see Figure 3). Additionally, users can view a non-aggregated, rasterized heatmap of GPS points from the activities used to create the other views (see Figure 4). Satellite imagery is also available as an alternative to the default dark base map.

The network flow map is the primary layer within the tool and is symbolized using both variations in line width and a diverging blue-red color scheme to represent the volume of counts across road segments. Counts on streets are binned into six classes based on a variant of the Jenks (1967) natural breaks method, and colors were selected using *ColorBrewer*, an online resource for selecting logical color schemes for thematic data (Harrower and Brewer 2003). Wider lines and darker shades of red signify road segments with higher counts. Narrower lines and darker shades of blue (with dark blue having the lowest visual contrast with the black map background) denote road segments with lower counts. The intent of this symbolization is to show the volume of bicycling behavior, highlight key corridors of activity, as well as identify prominent areas of inactivity.

A complimentary intersection layer can be toggled on and off atop the network flow map to provide additional perspective on whichever network view is selected (Figure 2). The size of intersection point symbols is scaled based on the number of unique bike trips, commute-designated trips, or bicyclists aggregated to the points. Higher counts are represented by larger points. The opacity of intersection point symbols is varied based on median crossing times through the intersections. More opaque point symbols depict longer intersection crossing times, helping to draw attention to potentially problematic interchanges atop a dark base map.

Additionally, a view of origin-destination polygons can also be toggled. These are based on the previously



Click to watch a short video demonstrating DataView mentioned layer of contiguous 350-meter hexagonal bins. *Metro DataView* can support both origin- and destination-first views (i.e., users can select an origin and see all destinations associated with that origin or users can select a destination and find all origins associated with the destination). Polygon color value is varied to reflect the number of unique bike trips, commute-designated trips, or bicyclists that started or ended within the area. Darker shades of grey denote lower counts; lighter shades signify higher counts. Clicking on a polygon returns all destination (or origin) polygons associated with that polygon. The map automatically zooms to the bounds of the associated polygons and highlights them in shades of pink. Figure 3 depicts commute destinations across Fredrikstad, Norway and the associated origins of one selected destination.

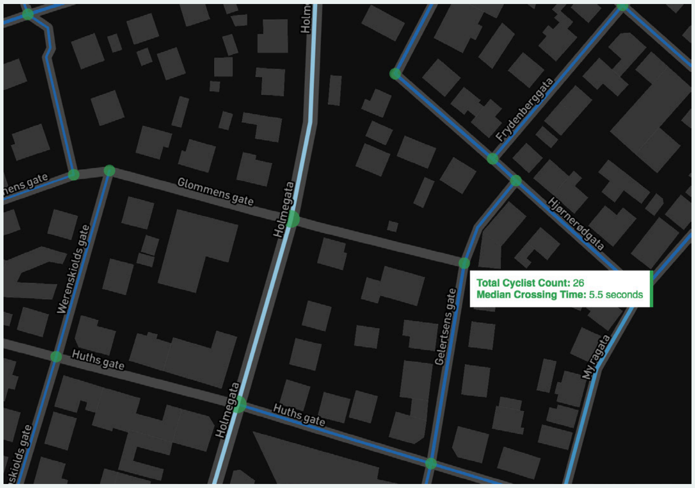


Figure 2. *Intersection points representing the aggregate number of bicyclists crossing an interchange; count and median crossing time statistics shown on hover.*

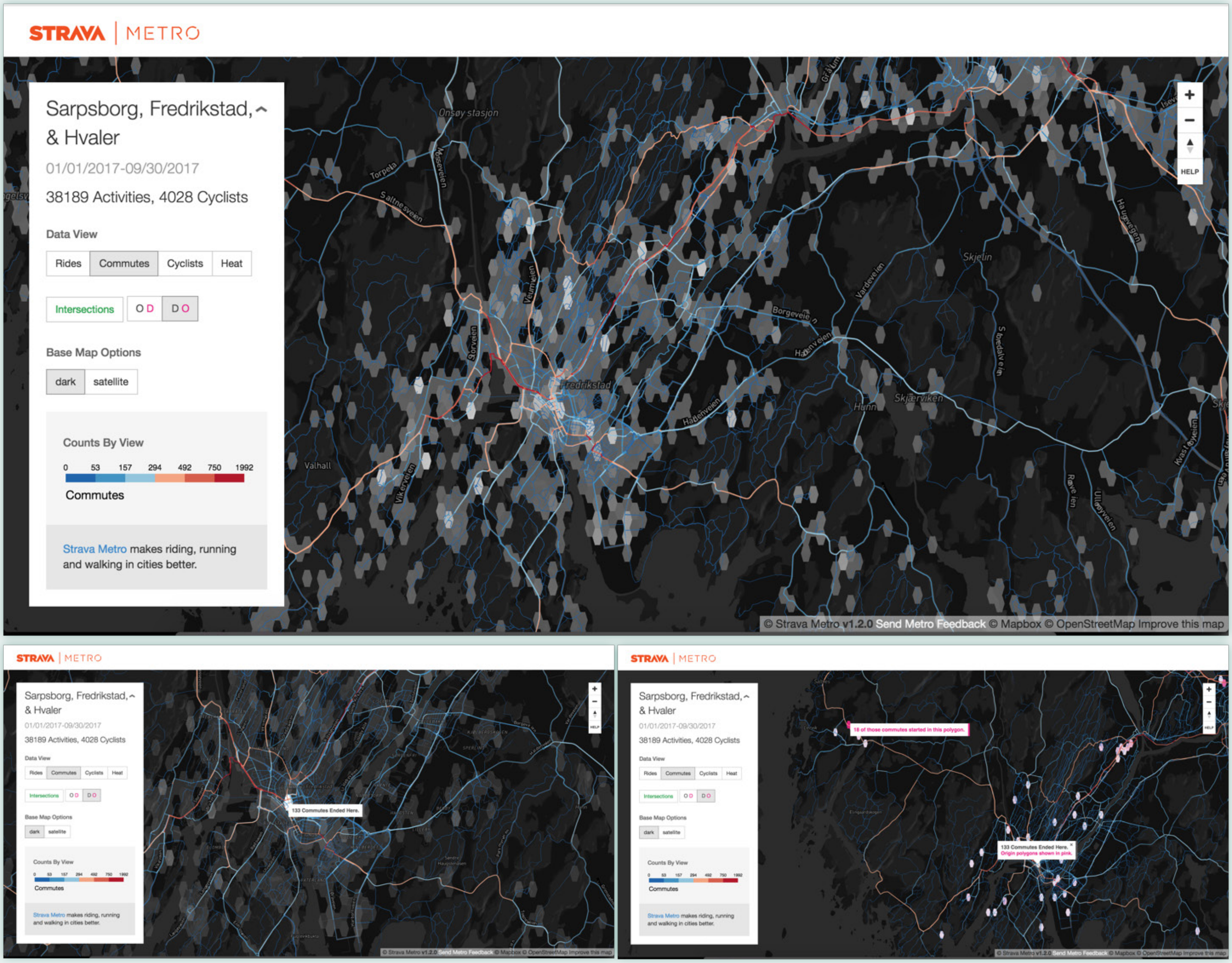


Figure 3. *Overall patterns in commute-designated bike trip destinations across Fredrikstad, Norway (top); hover on a destination polygon to obtain a count of commute trips ending in the area (bottom left); click on a destination polygon to reveal all associated origin polygons (bottom right).*

Lastly, users can select the *Heat* view, which depicts a rasterized heatmap of the movement traces that were aggregated to create the views described above (Figure 4). Counts are not available in this view. Activity density can only be inferred relatively. This view supports users in discovering missing or inaccurate geometry in the street network that was used for aggregation. The validity of the aggregated counts is contingent on the locational accuracy of the underlying street network. Thus, the heatmap not only depicts a rasterized representation of raw movement traces, but also serves as a guide for correcting or adding to an existing vector road network (i.e., if hotspots are seen that do not follow existing roads or paths, this may suggest that a segment of geometry needs to be created or updated in the base map).

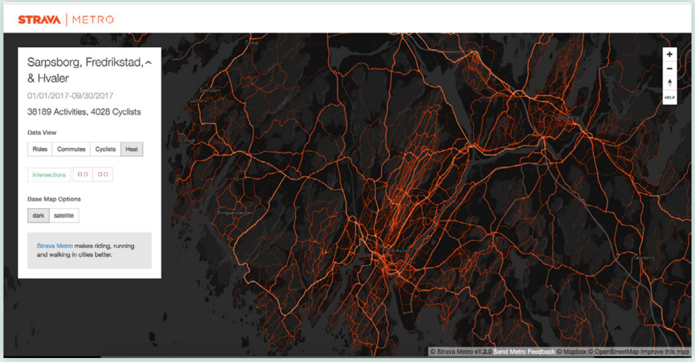


Figure 4. *Rasterized heatmap view of GPS bicycling traces across Fredrikstad, Norway.*

In summary, *Metro DataView* is designed to visualize an aggregated bicycling dataset in ways applicable to an urban planning audience. In the next section, we consider a simplified approach to visualizing individual activity traces that extends the rasterized point heatmap view already incorporated into *DataView*.

SIMPLIFIED APPROACH TO VISUALIZING ACTIVITY TRACES

To explore directions for future visualization development and further inform the design of *Metro DataView*, we implemented an alternate approach to visualizing patterns in bicycling behavior. The approach consolidated and extended the raster-only heatmap view seen in Figure 4, and did not require a computationally expensive aggregation process. Instead, a hierarchical visualization and interaction design approach was taken to seamlessly transition raster to vector representations of GPS bicycling trace data as a function of map zoom level. As the user zooms in on the interactive web map, static raster tiles representing GPS points transition to vector paths, revealing more subtle intricacies of movement patterns through city centers and along recreational trails. This visual abstraction approach builds upon the foundational work of Peuquet (1981) on translating and integrating raster-vector data representations, as well as the respective works of Brewer and Buttenfield (2007), and Stolte, Tang, and Hanrahan (2003) on multiscale symbol representation for USGS DLG reference map data and multiscale visualization using data cubes. The raster and vector representations are designed to look visually consistent; hence, users should not notice or be distracted by transitions in data representation when interacting with the map. Figure 5 shows small- and large-scale depictions of bicycling traces.

There were two main objectives for exploring this alternate approach to visualizing bicycling traces. The first objective was to assess if the approach had the potential to further

Figure 5. *Small to large (left to right) map scale depictions of raster to vector representations of bicycling traces.*

broaden and diversify the *Metro DataView* user group. This raster-vector map integration could be implemented quickly and at a low cost because it did not require data aggregation. The tradeoff, however, was that the visualization of behavior patterns remained relative; functionality to obtain counts on a single street was not provided and was computationally impractical to implement. The second objective for exploring this approach was to further understand the merits of the more comprehensive *Metro DataView* service, and to better outline what a minimally viable product was from the perspective of a non-technical stakeholder in urban planning (i.e., someone unfamiliar with and potentially uninterested in undertaking analysis with Metro data, but who might find value in a simple visualization of bicycling behavior).

In the following section, we discuss the user-centered design and evaluation model used to assess the extent to which features and functionality of both the heatmap and *DataView* support city planning professionals in making informed decisions on bicycle infrastructure implementation.

USER CENTERED DESIGN & EVALUATION

The cartographic interfaces described in this work resulted from a multi-dimensional, in-depth long-term case study patterned after Shneiderman and Plaisant (2006), and consisted of three major stages of user-centered evaluation:

1. Scenario Based Design
2. Insight Discovery
3. Usability & Utility Evaluation

In stage one of the study, we employed scenario-based design techniques (Rosson and Carroll 2002) to formatively assess client (and potential client) feedback that was solicited in various ways (through structured surveys, focus groups, phone calls, in-person discussion, and email correspondence) over a two-year product development cycle.[1] Insights generated through this collaborative effort were integrated into a hypothetical use case scenario and supporting claims analysis to characterize the domain problem, exemplify the design challenges, and synthesize knowledge of map use practice gleaned from the development process.

Stages two and three of the study focused on summative assessment. We recruited seven non-client domain and visualization experts to evaluate the extent to which *DataView*, specifically, supported insight discovery (stage two) and was deemed useable/useful (stage three). Insight discovery was informed through a semi-constrained task and usability/utility were evaluated via survey. We report on the methodology and results for each stage in the following subsections, which are organized at the highest level by assessment type.

FORMATIVE ASSESSMENT

Scenario-Based Design

Scenario-based design (SBD) principles were employed to present a "sketch of use" for both the standalone heatmap and *DataView*. SBD focuses on how people will use a system as opposed to describing a system's features and functionality (Rosson and Carroll 2002). Scenarios of envisioned use are typically defined at early stages of system development to guide the design process (e.g., MacEachren et al. 2011), but can also be effective at informing other stages of system evolution (Rosson and Carroll 2002). In this instance, we are presenting a hypothetical use case scenario and complementing claims analysis to abstract the domain problem into essential tasks (scenario) and the necessary data representations and interactions to support those tasks (claims analysis). This scenario synthesizes insights gleaned from a two-year human-centered business practice carried out by the first author while employed by Strava, working with a range of clients, and is prototypical of one that would be common in a large Department of Transportation organization.

Scenario

Susan is a bike and pedestrian facilities project manager working for a hypothetical State Transportation Agency. Susan is responsible for overseeing all phases of the project lifecycle, from

1. Client feedback collected over the two-year development cycle was part of Strava business activities, thus not considered to be "research" at the time and as a result, is not directly reportable here.

scoping and right-of-way to preliminary engineering and construction. As part of a smart city initiative, the State has appropriated 45 million dollars over a 5-year period to research, design, and implement bicycle infrastructure and recreational facilities in the State's largest urban center.

The initiative is currently in research and scoping phases with some projects already identified and others yet to be defined. Various locations within the urban center have been identified as "hubs" for bicycle activity, and three Eco Counters have been purchased and installed to generate data on how many bicyclists are moving through these specific areas. The challenge, however, is that these counters are relatively far apart in a large urban center and cannot begin to inform key corridors throughout the heart of the network. Installing more counters is not fiscally practical, so Susan searches for cheaper, alternative data sources to complement the counter data. She discovers the report published by the Centers for Disease Control and Prevention (Whitfield 2016) that showed strong correlation between counter data and crowdsourced bicycling data maintained by Strava Metro. Susan reaches out to Metro to inquire more about its data and visualization services. Susan acknowledges that she is not trained in GIS and data analytics, and that she has very limited internal resources to leverage for data mapping and analysis. As a result, she decides to license DataView, and agrees to test out a beta heatmap service that Metro is actively developing.

Susan was informed that the beta heatmap is simpler to use than DataView, so she visits that link first. The webpage renders, and Susan is intrigued by the bright blue and white lines that represent GPS traces from bicycle activities. There's so many of them that on top of the dark basemap, they almost seem to illuminate the entire road network. She zooms in on the map to the locations of each of the three Eco Counters. The heatmap seems to confirm an influx of bicycling activity at those locations. She then zooms in to other areas that have been designated as key recreation and commute corridors, and again finds dense, saturated blue lines on the heatmap. Susan pans outward in various directions. She follows the lines around intersections, into parks, and through the residential and financial districts, attempting to identify popular routes and noteworthy destinations along those routes. Susan tries clicking on the map and the lines, hoping to find activity counts or functionality to toggle between commute and recreational-designated trips, but nothing happens. After fifteen minutes of exploration, Susan realizes that while she has detected known trends, she lacks quantifiable evidence needed to more effectively inform where to construct or modify essential infrastructure. Moreover, Susan isn't a bicyclist herself, which makes parsing the relative distinction between "less" or "more" rides on a given street very difficult.

Next, Susan inputs the URL link to DataView. She steps through the onboarding experience and is optimistic that the functionality will better serve her needs. Upon completing the short tutorial, she first switches between the various data views (rides, commutes, cyclists) in the control panel. Colors and patterns in the network map change, and the street legend updates based on the view. Susan quickly realizes that this map looks much different than the heatmap she had previously viewed; there appears to be fewer lines and less noise. She leaves the "commute" view selected and zooms in to one of the Eco Counter locations on Main Street. Rather than finding many overlaid lines, she discovers that the actual road segments have been colored and widened based on the number of commutes that crossed each one. She hovers on the segment nearest to the Eco Counter, and a dialogue box pops up and relays that 3,577 commute-designated bike trips happened along that segment over the last three months. She then switches between the other two views: "rides" and "cyclists." The color and width of the lines update Agency, and she learns that a total of 5,674 bike trips crossed the segment, accounting for 2,884 unique bicyclists.

Because the street segments are symbolized based on counts, Susan no longer needs to pan around attempting to follow patterns. Rather, she zooms out and quickly detects vibrant shades of red illuminating key corridors throughout the network. Susan has now identified a corridor of interest intersecting the Eco Counter location on Main Street. She toggles between the "origin-destination" and "destination-origin" views. Susan finds many popular origin polygons in the northern suburbs that all relate to a small and spatially-focused number of destination polygons in the southern, financial district. The street network map reveals a handful of popular arteries that all seem to flow into the Main Street corridor. Looking more closely, Susan notices that ten blocks south of the Eco Counter location, the primary commute route abruptly diverges into a residential area for about 13 blocks before returning to Main Street. She zooms back in to the newly discovered area of interest and toggles "intersections" on. The small, brightly colored nodes quickly convey that median crossing times for bike trips through the more direct, yet less traversed part of Main Street are significantly longer than those through the residential area detour. Susan isn't overly familiar with the area, but finds this pattern somewhat surprising because she knows that an unprotected bike lane already exists along the entire stretch of Main Street. She switches the basemap from "dark" to "satellite," and finds *that the number of car lanes on Main Street abruptly changes from two with no roadside parking to one with roadside parking. The bike lane appears to be quite close to the parking spaces, and in some cases, it almost looks like cars are parked partway in the bike lane. Given this insight, Susan initiates a new protected bike lane project in the State's internal prioritization and selection system. She also forwards the DataView link to various local bicycle advocacy groups. Community input and buy-in are essential, and Susan is hoping that these groups can provide additional qualitative insights on the impact of the potential project to bicycle safety and efficiency along that corridor.*

Claims Analysis

SBD claims analysis aims to provide a balanced view on challenges and opportunities surrounding system features that have important consequences for users (Carroll and Rosson 1992). Positive and negative claims are made about features to evaluate system design decisions and help identify focused opportunities for subsequent user testing (MacEachren et al. 2011). Table 1 presents a claims analysis on key features in the standalone heatmap and *DataView*, and was used to guide the design of a post-implementation user study, which we report on in the following subsection.

SUMMATIVE ASSESSMENT

Methodology & Participants

A post-implementation, two-part user study, consisting of task and survey components, was conducted to evaluate the design and utility of *Metro DataView* from the perspectives of non-client domain experts. The standalone raster-to-vector heat map did not move forward to this stage of evaluation because it did not relay activity or bicyclist counts, which was functionality that had been deemed essential by users in stage one. Study design was informed by a synthesis of best practices for evaluation of geovisual analytics systems, which emphasizes *instruction*, *analytical work*, and *feedback collection* as the primary components of an effective study design (Savelyev and MacEachren, 2020). The first part of the study focused on a semi-constrained insight discovery task, in which participants were provided with a web link to the interactive mapping tool for the entire US state of Utah and instructions on how to use it. Participants were asked to explore the interface at their convenience over a period of a week and write a short essay (up to 500 words) based on a self-selected role (e.g., city planner, local advocate, transportation analyst, etc.).

Visualization	Feature, Followed by Claims
heatmap	*Interactive raster to vector representations of GPS bicycling traces*
	+ allows users to explore intricacies in individual movement traces + does not require computationally expensive aggregation process + seamlessly transitions between data representations across map scale + is simple to use and very responsive - does not provide activity counts - does not enable filtering by trip type - is visually noisy
DataView	*Interactive network flow map*
	+ provides aggregated counts mapped to a linear street network + allows users to identify key corridors throughout the network quickly + is visually concise - requires an accurate linear street network basemap for aggregation process - cannot relay individual movement traces
	Option to switch between aggregate data views (rides, commutes, cyclists)
	+ allows users to assess patterns in total vs. commute-designated trips + allows users to relate the number of unique bicyclists to number of trips taken - does not distinguish recreation-designated trips
	Option to overlay intersection data
	+ allows users to identify high (and low) volume movement across intersections + allows users to assess median crossing time - is visually noisy as a result of many overlapping intersection nodes in dense urban areas
	Option to overlay origin-destination and destination-origin polygon data
	+ allows users to identify and quantify prominent patterns in commute behavior + helps users identify candidate locations for new bike facilities - routes between pairs can only be inferred using the network flow map - does not support selecting more than one origin (or destination) at a time

Table 1. *SBD Claims Analysis for Heatmap and DataView.*

The task prompted participants to clearly articulate (1) their selected role, (2) insights gleaned through interacting with the tool, (3) goals or approaches taken when interacting, (4) what visualizations/functionality were employed in arriving at various insights, and (5) to what extent the tool supported insight discovery. The intent of this exploration activity was to provide evidence about *DataView's* ability to support a broad range of insights on the part of participants, while also providing a consistent framework for synthesizing results.

The second part of the study entailed an online follow-up survey, consisting of a mix of multiple choice questions, five-point Likert scale ratings, and open-ended response questions, designed to evaluate the usability and utility of *Metro DataView*. Usability metrics were based on the system usability scale (Brooke 1996). Utility metrics followed a format similar to those designed by Pezanowski et al. (2018) and Robinson et al. (2020) but were adapted to explicitly evaluate the extent to which *DataView* facilitates better understanding of bicycling behavior at various spatial resolutions and could help city planners or Departments of Transportation make informed decisions on bicycle infrastructure design and implementation.

Seven participants engaged in the study; six completed both parts, while one submitted an incomplete and unusable essay alongside a complete survey. Participants were recruited using email lists that targeted experts in the use of interactive maps as an input to decision-making (e.g., geography, urban planning, or place-related policy making domains) and experts in the design of interactive, web-based interfaces to explore data (e.g., data visualization, cartography, or human-computer interaction domains). Figure 6 depicts a visual summary of participants' demographic and professional backgrounds.

Task Activity Results

The task component of the study resulted in six essays, ranging in length from 121–516 words, with a mean word count of 273. Table 2 summarizes essay content, and is organized based on the selected roles, goals, specified interactions, noteworthy insights, and recommendations for tool enhancement provided by the participants.

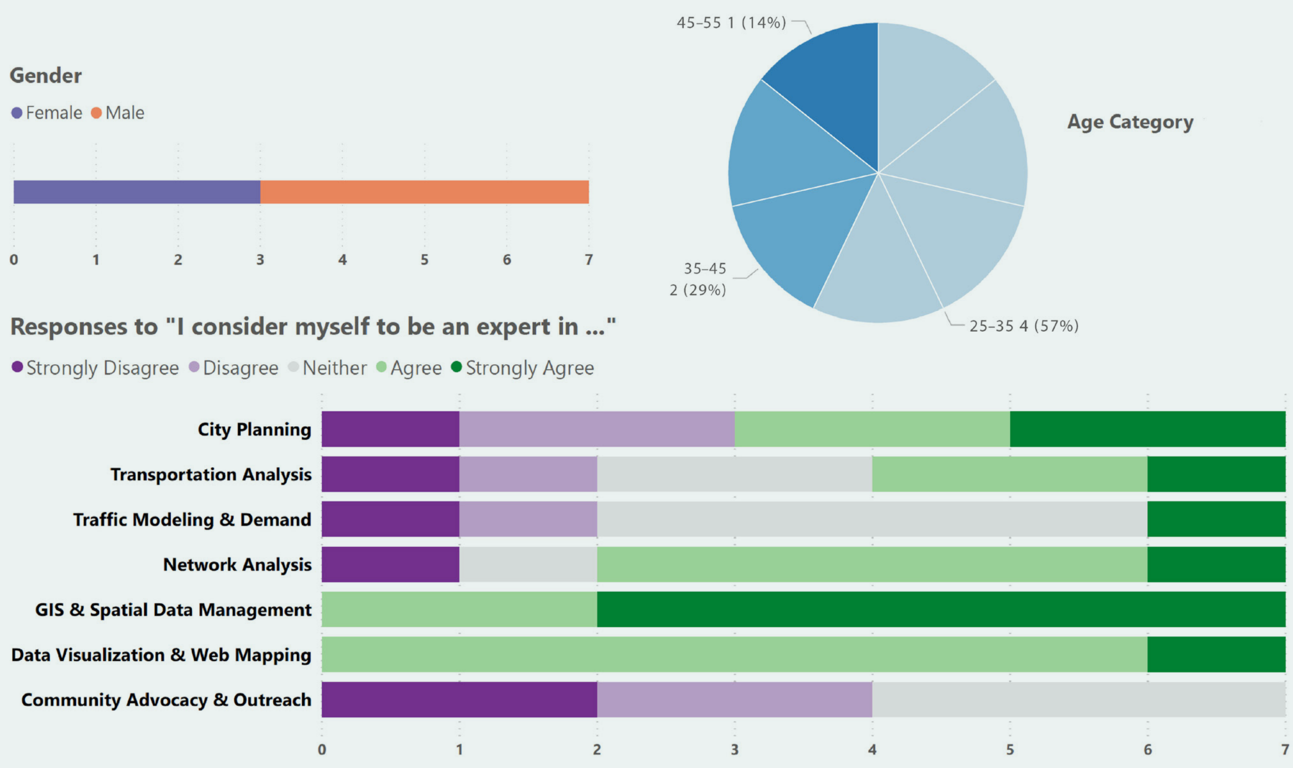


Figure 6. *Visual summary of participants' demographic and professional backgrounds.*

Role		
GIS Mobility Analyst	*Goal/Task*	*Interactions*
	explore patterns in commute behavior (e.g., how long are commutes, do they seem dangerous, do they link the suburbs to the downtown, and how do they differ from recreation rides?); anticipate dangerous intersections	• switched between "ride," "commute," and "cyclist" network views • overlaid intersection points
	Exemplary Insights	*Recommendations for Improvement*
	• people are taking long commutes and using windy roads • most popular intersections were in central Salt Lake City • Heber City looks like it would be conducive to biking but there are not many rides there • commute patterns don't always align with overall patterns	• create ratio between number of unique bicyclists and commute vs. recreation trips • allow users to filter by season
City Planner	*Goal/Task*	*Interactions*
	identify roads that can be converted into bicycle highways (especially for commuters during rush hours)	• switched between "ride," "commute," and "cyclist" network views • overlaid intersection points • overlaid origin-destination polygons
	Exemplary Insights	*Recommendations for Improvement*
	• discovered high-volume routes which were used primarily by commuters	• allow users to select network classification schemes other than Jenks • enhance intersection symbology to more effectively convey wait time
Not Specified	*Goal/Task*	*Interactions*
	exploration	• overlaid origin-destination polygons
	Exemplary Insights	*Recommendations for Improvement*
	• Origin-Destination polygon interaction is most useful for understanding network demand of bicyclists	• disable click to zoom if origin-destination polygons are active to facilitate more effective data retrieval • limit auto zoom to nearest destination polygons when origin is selected
Planner	*Goal/Task*	*Interactions*
	exploration	• switched between "ride," "commute," and "cyclist" network views • overlaid intersection points • overlaid origin-destination polygons
	Exemplary Insights	*Recommendations for Improvement*
	• Constitution Blvd and 3200 West seem to have a lot more waits in daily commute than the distribution of rides, which means the roads are used more often by the local bicyclists than the tourists • Bike trips in Park City are mostly centered in Park City because the OD nodes are in the same area, while only a few trips come from Salt Lake City • Downtown, Park City areas, and the intersection of the highway are popular destinations of bike trips	• Not Specified

Table 2. *Participants' approaches to insight discovery.* *Continued on next page.*

Role		
Local Advocate	*Goal/Task*	*Interactions*
	increase bike commuting and safety in the Provo/ Orem metro area; identify most popular routes and outliers; determine which routes were on roads and which were on trails	• switched between “ride,” “commute,” and “cyclist” network views • switched between basemap options • overlaid intersection points • overlaid origin-destination polygons
	Exemplary Insights	*Recommendations for Improvement*
	• mountain biking is popular at the north entrance to Provo Canyon; people also commute around this area, with the other major commuter destinations being downtown Provo and Brigham Young University • routes on the periphery of town near Utah Lake are popular for leisure riding, not commuting • to get between Provo and Orem, routes along the Murdock Canal Trail and University Ave or Canyon Rd are more popular than the more direct, but busier, State St • there is not a real popular way for bikers to go along University Parkway, a major transportation and commercial thoroughfare in these cities • Kuhni Road is very popular with bicyclists, and I wonder if that is a new arterial	• enhance color scheme for linear network when satellite basemap option is selected • enhance intersection symbology to more effectively convey volume vs. wait time
Park / Forest Service Analyst	*Goal/Task*	*Interactions*
	explore overcrowding of outdoor recreation spaces; find park areas that were heavily used and determine what routes were most common	• switched between “ride,” “commute,” and “cyclist” network views • overlaid intersection points • overlaid origin-destination polygons
	Exemplary Insights	*Recommendations for Improvement*
	• there wasn’t as high of a density of rides, commutes or bicyclists in Zion National Park, Arches, and Canyonlands NP as compared to other parts of the state	• ability to filter by user-specified geographic area and season

Table 2. *Participants’ approaches to insight discovery. Continued from previous page.*

In summary, the six participants explored the tool from different perspectives with some overlap or similarity in assumed roles. Self-directed tasks or goals ranged from well-defined to broad exploration. Most participants interacted with and commented on insights obtained from using *DataView’s* various features; however, one participant chose to focus their assessment solely on the utility of the origin-destination polygons. Four of the six participants provided very specific insights about findings at particular locations, whereas two participants provided shorter, more general insights. Five participants provided recommendations for how to improve the interface. Overall, the types of insights and recommendations for system improvement provided by participants aligned with the claims made about *DataView* based on a synthesis of client collaboration carried out by the first author, Jonathan Nelson, while working for Strava Metro (see Table 1). For example, participants demonstrated success in using the three different network views to identify prominent bike corridors. However, they also expressed the need to distinguish recreation-only from commute corridors. Similarly, participants overlaid intersection and

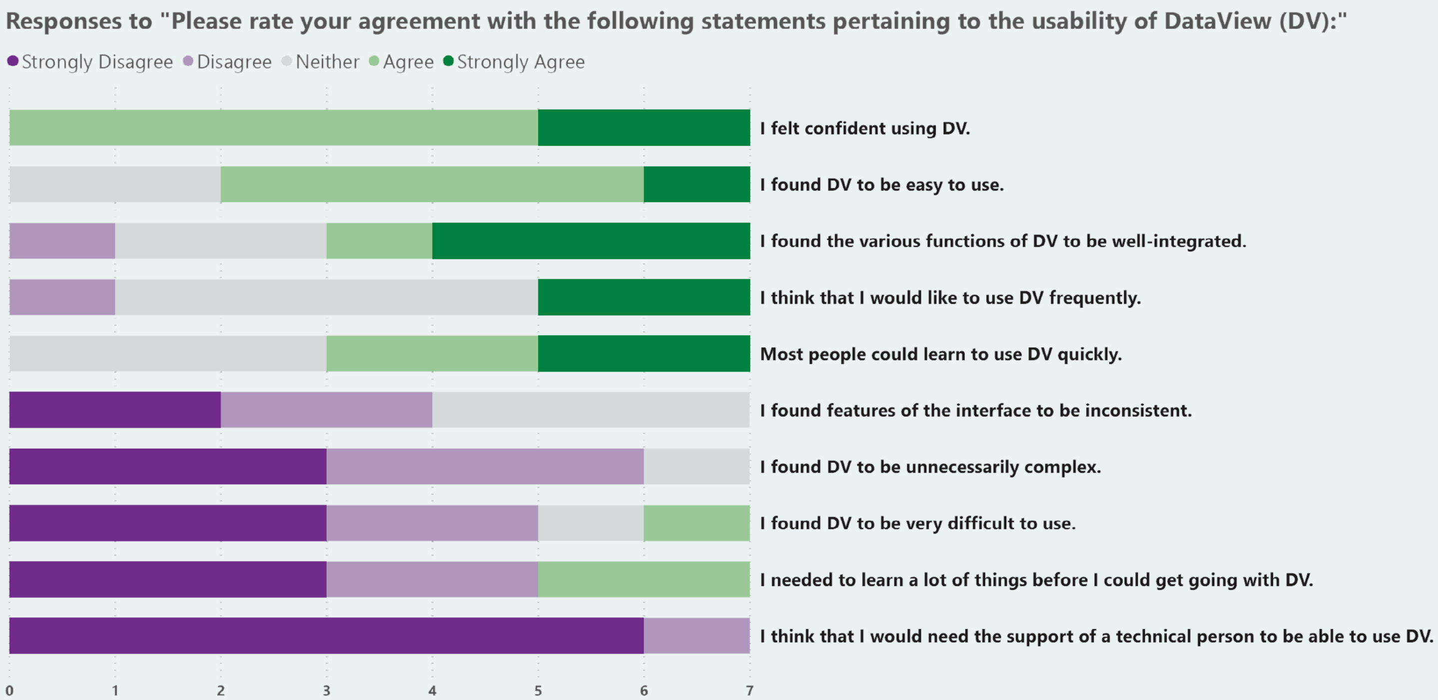


Figure 7. *Visual summary of participants' usability ratings.*

OD polygon data successfully to make inferences about movement volumes, wait times, and prominent origin/destination locations. However, they highlighted additional challenges interpreting symbology. In some instances, participants provided input for system improvement that extended beyond the negative claims identified in the claims analysis. We explore these recommendations in more detail in the following section on usability and utility evaluation.

Usability/Utility Results

Results from the online follow-up survey included seven participants' responses to a mix of Likert scale, multiple choice, and short answer questions designed to collect feedback on the usability and utility of *Metro DataView*. The first four questions focused primarily on time spent using the interface and initial impressions of its design and effectiveness. One participant reported having spent 30–45 minutes using *DataView*, three participants spent 15–30 minutes, and three spent less than 15 minutes. All participants reported stepping through the entire onboarding experience. The majority of respondents characterized their initial experience using *DataView* to be straightforward and found the overall design of the interface to be effective. Figures 7 and 8 provide visual summaries of the strengths and weaknesses of *DataView* in terms of usability and utility.

Overall, the majority of participants found the tool easy to use and its functionality well integrated. Moreover, most participants also agreed that *DataView* facilitated a better understanding of bicycling behavior at various spatial resolutions and that the tool could help city planners or transportation departments make informed decisions on infrastructure design and implementation. However, participants' agreement was more divided on whether or not the tool could prompt new hypotheses about the decisions that bicyclists make when navigating through a city or whether it could be helpful when generating an analytical report to prompt further action.

In addition to rating their agreement with the statements shown in Figures 7 and 8, participants were also asked to provide short answer recommendations for improvements that could be made to enhance *DataView's* usability and utility. Six participants provided input. Some of the feedback echoed what had been distilled in the claims analysis and in participants' essay responses, such as the desire for temporal filtering and spatial selection. Additionally, participants recommended incorporating information on where bicycle infrastructure already exists, to more effectively communicate to decision makers where improvements need to be made, and to better inform bicyclists about more preferred or safe routes. Participants also suggested incorporating other modes of travel and predictive

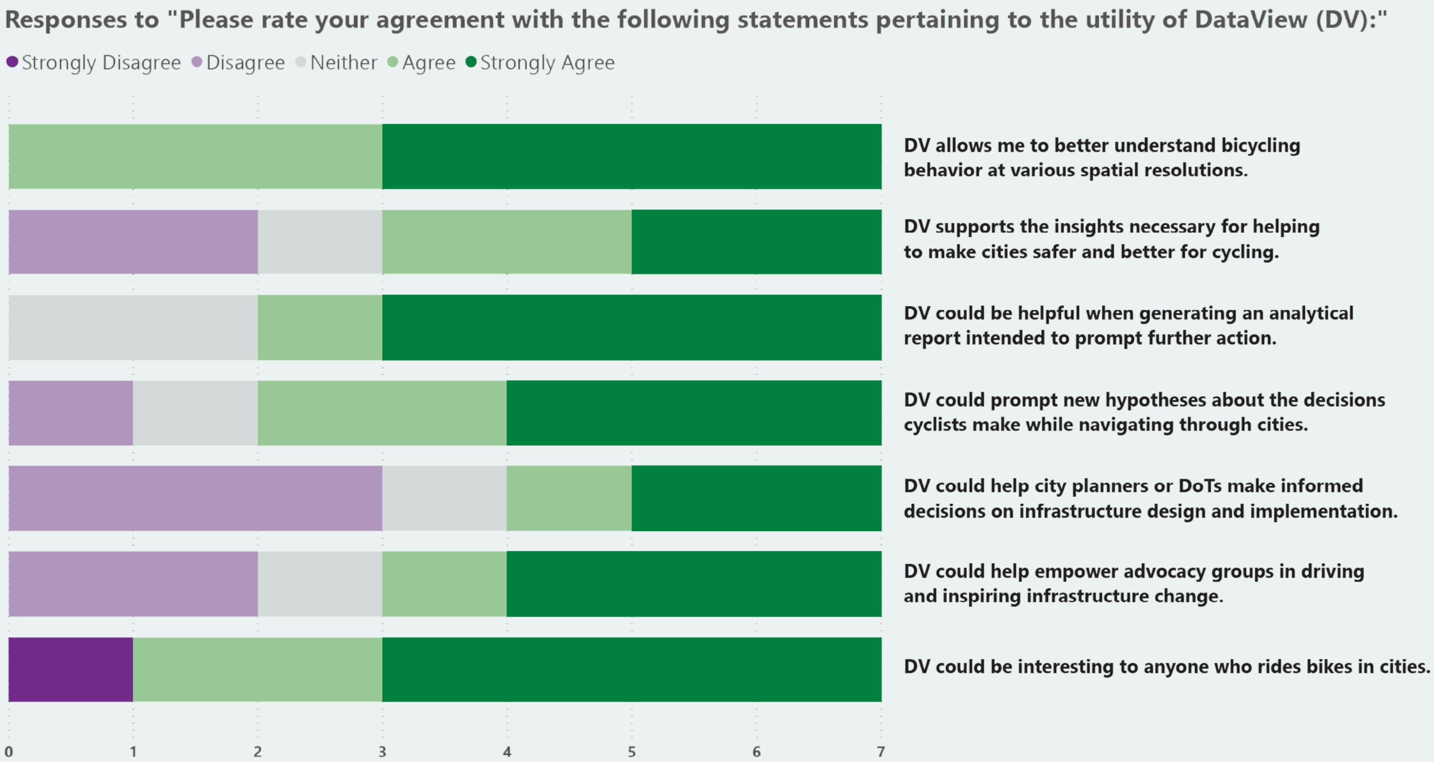


Figure 8. *Visual summary of participants' utility ratings.*

modeling to provide a more complete representation of movement across the network and identify hotspots for accidents. Results from this post-implementation user study will be shared with Strava to help inform ongoing development of Metro's visualization tools and services. In the following section, we highlight the impact of *DataView* in the context of client adoption and propose opportunities for future research and development based on the input from non-client domain experts.

DISCUSSION

Metro DataView has been delivered to city, state, and regional Departments of Transportation, local advocacy groups, and researchers across the globe. From smaller towns (e.g., Conway, Arkansas and Grey County, Ontario) to large government agencies (e.g., Colorado State Department of Transportation and Transport for London), *Metro DataView* is being used to inform the city planning process. For example, Transport for London leverages the interactive mapping tool and the underlying data that support it to generate network demand models and assess the potential for growth in bicycle transport throughout the Capital. In Queensland, Australia, the Department of Transport and Main Roads uses *DataView* to quantify the impact of bicycling infrastructure investment. The Florida Department of Transportation prioritizes street sweeping efforts based on insights extracted from the tool. In October 2017, Texas Public Radio published a piece on how the Texas Department of Transportation and local planning organizations were using the tool to better understand how bicyclists were moving across the state's network to prioritize where to implement new facilities and bicycle infrastructure (Flahive 2017).

This work describes a unique circumstance: a novel and impactful cartographic product was conceptualized and created in an industry setting, while also being grounded in academic methodology and scholarship. On one hand, this situation created an opportunity that enabled the widespread adoption of an effective decision-making tool as summarized above. On the other hand, conducting this research in a commercial environment resulted in not being able to report on specific methods or findings from client-centered design studies that were carried out over a two-year product development cycle. To address this shortcoming, we employed a scenario-based design strategy to distill our collaborative efforts with clients into a hypothetical use case scenario and supporting claims analysis. While some transferable knowledge to other design studies is inevitably lost in the translation, this approach forced us to synthesize both the wealth and diversity of client feedback into a cohesive and guiding design narrative. This narrative served to abstract and characterize a real-world domain problem and helped to focus our follow-up evaluation methods toward assessing system features and functionality that were deemed essential by the target audience. Combining scenario-based design techniques with task assessment, usability, and utility evaluation enabled rich, multi-dimensional insights into how geovisualization tools can be designed to support city planning professionals in making cities safer and more efficient for bicyclists. While this multistage design study required significant time and effort, the depth of insight into the domain problem and effectiveness of the proposed design solution would not have been achievable if only a single method had been employed.

The impact and "success" of this work is a direct result of the multistage user-centered design model that guided its evolution. The value of engaging with intended users and stakeholders of a system during the development process cannot be overstated, echoing recent scholarship in interactive cartography (e.g., Slocum et al. 2003; Robinson et al. 2005; Roth et al. 2010; Delikostidis, van Elzakker, and Kraak 2016). Moreover, this work aligns with at least three opportunities proposed by Roth et al. (2017) for adapting user-centered design methodology to interactive cartographic studies: namely contextualizing and emphasizing the process (not just the result), conducting purposeful rather than convenient study participant sampling, and promoting and illustrating the value in being comprehensive and thorough. While user-centered design aims to ensure system success, defining and evaluating success is challenging. The question of "to what extent does the system meet or exceed the expectations and desires of its users?" can be subjective and inappropriate to quantify. Unlike controlled experiments that are replicable and generalizable, user-centered design studies tend to inform a more specific situation, making its findings transferable and insights contextual only to similar use cases (Sedlmair, Meyer, and Munzner 2012).

For Strava Metro, there was a clear need to develop interactive, visual ways of making activity data more accessible, usable, and useful. Feedback from organizations using the data indicated users' frustration, confusion, and limited ability to generate valuable insight into the spatiotemporal patterns of bicycling behavior. Having identified this need, we conducted a multi-dimensional, in-depth long-term case study consisting of three major stages of evaluation: (1) scenario-based design, (2) insight discovery, and (3) usability and utility assessment. Stage one translated over two years of collaborative efforts—working with Departments of Transportation, local advocacy groups, and other city planning professionals—into a transferable abstraction of a real-world problem, while also illustrating design challenges and identifying focused opportunities for further user testing. Stages two and three of the study explored these focused opportunities through an insight discovery task and usability and utility assessment completed by seven non-client domain experts. This design framework was selected because the goal was to obtain both formative and summative insights, but with a focus on qualitative rather than quantitative results. Moreover, the intent was neither to assess nor quantify how the final system compared to other tools capable of delivering similar insights, but to design and implement a specific system to meet stakeholder and client needs.

Two key findings resulted from stage one of the study. The first is that the visualization solution produced needed to relay counts of bike trips across the road network and distinguish commute from recreation trip types. Second, inferences on relative activity density provided by the raster-to-vector heatmap were deemed insufficient for making informed planning decisions. Results from stages two and three of the study reinforced stage one claims made about *DataView* based on the synthesis of findings from working with clients over the product development cycle. For example, seven non-client domain and visualization experts demonstrated success in using the three different network views to identify prominent bike corridors, and successfully overlaid intersection and OD polygon data to make inferences about movement volumes, wait times, and popular origin/destination locations. These results also revealed important system shortcomings and opportunities for future work. For example, *DataView's* current inability to relay information on the presence and condition of bicycling infrastructure limits users' inferences on the connectedness of the network. Information on volume alone is insufficient for understanding how many people aren't biking but could be if infrastructure was improved. Additionally, functionality to support enhanced spatial and temporal filtering would advance users' abilities to make sense of the more nuanced patterns of commute and recreational behavior.

More broadly, there exist opportunities to extend the technical framework to support the aggregation, tiling, and mapping of multiple data sources to relay a more complete and representative depiction of how individuals and entities move and interact across a network. As noted above, crowdsourced fitness data represent only a subset of the active population, and should serve to complement and extend more traditional approaches to active transportation surveillance and analysis (Jestico, Nelson, and Winters 2016; Ferster et al. 2017; Lee and Sener 2020). User-generated fitness data, for example, can be combined with survey and counter data to more effectively model the flow of bicyclists across a network (Whitfield 2016). Additionally, supplemental data on crash incidents, roadway characteristics, and environmental factors can be integrated with crowdsourced activity data to help prioritize safety initiatives and inform why some routes are more popular than others (Quartuccio et al. 2014; Quercia, Schifanella, and Aiello 2014; Sun and Mobasheri 2017). Multiple data sources, together with civic collaboration and input, foster a more complete and honest urban interface (Mattern 2014).

CONCLUSION

In this work we presented a design strategy to address a problem-driven research question: *how to make large amounts of aggregated and anonymized individual movement data more accessible and actionable to stakeholders in the city planning process*? We employed cartographic principles of representation, geovisual analytics techniques, and best practices in UI/UX design to arrive at an interactive mapping tool that can communicate the complex flow of bicycling traces across urban street networks to experts trained in transportation analytics and modeling, as well as a broader, public audience. A major contribution of this work is our approach to combining scenario-based design methods with a post-implementation user study to characterize the domain problem; map essential user tasks to data representations and interactions; articulate the design rationale; and validate the design solution.

Beyond presenting an adaptable and flexible design approach, we proposed an innovative technical framework for rendering, and enabling interaction with, large geospatial datasets in the browser. Additionally, we explored a hierarchical visualization design approach that seamlessly transitions raster to vector data representations across map scale. The intent of this approach was to leverage scale-specific advantages of each data representation type in the context of web mapping. Rendering activity traces as raster pixels at small map scales and as vector paths at large map scales is an effective strategy for achieving reasonable client performance while enabling more flexibility in map interaction. While the raster-to-vector heatmap did not meet the needs of this study's target audience, there exist opportunities to extend this visualization paradigm through design and evaluation of interaction strategies across scale (i.e., addressing the disconnect between visual consistency and interaction inconsistency across scale). Future research is also needed to address design limitations identified by study participants. While incorporating more advanced spatial and temporal filtering functionality into the interface is a relatively clear need, inclusion of predictive modeling, bicycling infrastructure information, and data on other modes of transportation will require additional user input to capture the context of the need and the breadth of its applicability to the target audience group.

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Florence: a Web-based Grammar of Graphics for Making Maps and Learning Cartography

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Online, web-based cartography workflows use a dizzying variety of software suites, libraries, and programming languages. This proliferation of mapmaking technologies, often developed from a software engineering rather than a cartographic foundation, creates a series of challenges for cartography education, research, and practice.

To address these challenges, we introduce a JavaScript-based open-source framework for web-based cartography and data visualization. It is built on top of existing open web standards that are already in intensive use for online mapmaking today, but provides a framework that is firmly based on cartographic and visualization theory rather than software engineering concepts. Specifically, we adopt concepts from Bertin's Semiology of Graphics *and Wilkinson's* Grammar of Graphics *to create a language with a limited number of core concepts and verbs that are combined in a declarative style of "writing" visualizations. In this paper, we posit a series of design guidelines that have informed our approach, and discuss how we translate these tenets into a software implementation and framework with specific use cases and examples. We frame the development of the software and the discussion specifically in the context of the use of such tools in cartography education.*

With this framework, we hope to provide an example of a software for web-based data visualization that is in sync with cartographic theories and objectives. Such approaches allow for potentially greater cartographic flexibility and creativity, as well as easier adoption in cartography courses.

KEYWORDS: cartography; geovisualization; web mapping: grammar of graphics; software; education

INTRODUCTION

Cartography has always relied on technology in the pursuit of making maps. The start of the twenty-first century is no different in that sense. But today's technology has enabled radical changes, and a proliferation in not only how we make, but also how we consume maps. A host of technologies that came along with Web 2.0 over the last twenty years has now changed significantly how we share and read (online) maps, even jumpstarting the concept of "viral" cartography (Muehlenhaus 2014; Robinson 2019; Shannon and Walker 2020). New media, such as web-based and other online maps, have also opened up new opportunities for readers to interact with the map (Roth and MacEachren 2016), and have quickly become one of the research frontiers in cartography and geovisualization (Griffin, Robinson, and Roth 2017).

Along with these changes in consumption, the actual practice of creating maps—the *how* of mapmaking—has also shifted. Computer-based cartography in the late twentieth century was conducted primarily using a small number of desktop user interfaces—including mainstays such as ESRI's *ArcMap* GIS software and Adobe's vector editing software, *Illustrator*—that were employed to create static maps. In contrast, "new" workflows that are focused on creating web-based maps use a dizzying variety of software suites, libraries, and programming languages. As just one example, Roth et al. (2014) include 35 different technologies in their 2014 assessment of web mapping technologies. The six years since their tally have not seen a convergence of these technologies—far from it.

This proliferation of map consumption and production has brought many new people—not necessarily trained in cartography—to the practice of making maps, and has created a unique opportunity or even a renaissance for the academic field of cartography (MacEachren 2013). Certainly, (new) online mapping programs and certificates such as the University of Kentucky's New Maps Plus and Penn State's online geospatial education are an indication of a healthy interest from both academia and industry in all these new changes and possibilities. As a side-effect of this process, new cartographic software now draws from a wide range of software development paradigms, reflecting the variety of backgrounds of its developers. While this has created a welcome diversity in the cartographic software landscape, the drawback is that new technologies may speak less directly to a consistent set of cartographic principles.

This current software landscape creates a series of challenges for cartography education, research, and practice. First, the computer science paradigms on which many new technologies are based can be challenging for students without prior training in computer science or programming experience. This creates barriers to entry and can distract from teaching cartographic core principles and theory (Sack and Roth 2017; Sack 2018; Ricker and Thatcher 2017). Second, many new tools are less grounded in traditional cartographic theory, in ways that can limit their flexibility—the much-maligned use of the default Web Mercator projection in many mapping tools being a case-in-point (Battersby et al. 2014; Šavrič, Jenny, and Jenny 2016). Third, the absence of a single, canonical technology suite or paradigm limits the transferability of skills between all these different types of software and libraries.

In this paper, we speak to these challenges by introducing a JavaScript-based framework for web-based cartography and data visualization. It is built on top of existing open web standards that are already in intensive use for online mapmaking today, but provides a framework—or Application Programming Interface (API) in technical terms—that is based firmly on cartographic and visualization theory rather than software engineering concepts. Specifically, we adopt concepts from Bertin's *Semiology of Graphics* (2010) and Wilkinson's *Grammar of Graphics* (2013) to create a "language" with a limited number of core concepts and verbs that are combined with a declarative style of "writing" visualizations. With this framework, we hope to provide an example of software for web-based data visualization that is in sync with cartographic theories and objectives, and thus allows greater cartographic flexibility, lets users be more creative, and is potentially easier to adopt in cartography courses.

In the next section, we will first unpack in greater detail the aforementioned challenges surrounding web-based cartography. In doing so, we provide a survey of the current practice of online, interactive cartography. Subsequently, we outline the core tenets of our approach and describe the core elements of the framework. Finally, we will provide specific use cases and examples of how these core elements can be combined flexibly to create cartographic visualizations. We will end the paper by discussing our approach and looking ahead to potential future work.

CURRENT SOFTWARE AND PRACTICES FOR CREATING AND TEACHING WEB-BASED CARTOGRAPHY

THE LINK BETWEEN CARTOGRAPHIC THEORY AND MAPPING SOFTWARE

Cartography has a long-standing tradition of building theory around maps. What are maps? How do they represent and produce the world (Crampton 2010)? And how can we think systematically about their construction (MacEachren 2004; Kraak and Ormeling 2011)? At the heart of this systematic approach to cartography, we find

Bertin's idea of visual variables (Bertin 2010). Coined in his 1967 *Semiology of Graphics*, it is still influencing cartographic thought today (cf. the recent special issue on Bertin's legacy in *Cartography and Geographic Information Science*; Harvey 2019).

If we look beyond cartography to the related field of information visualization, Bertin's original ideas around visual variables have been further formalized into a system that Wilkinson dubbed the "grammar of graphics" (2013). Although there are different versions and interpretations of this system (cf. Munzner 2014 for a comprehensive treatment), it generally relies on a process of translating[1] data values (be they quantitative or categorical) into the visual variables[2] (e.g., position, size, or colour) of a graphical mark[3] (e.g., a point or a line). While Wilkinson's original publication was accompanied by a software implementation of the system, the grammar of graphics didn't significantly catch on in practice until Hadley Wickham implemented a version of it for the R programming language (Wickham 2010). Wickham's implementation—*ggplot2*—has helped transform R into one of the key languages for data visualization (including maps) used today. It has also inspired the adoption of its grammar-of-graphics API into a range of other programming languages.

This translation of theory into software brings us to the nexus of cartographic theory and its practice. The connection between the two is at the core of cartography (cf. Tobler 1959). After all, academic cartographers themselves often combine thinking and theorizing about maps with the act of making maps. A common approach to computer-based mapmaking uses desktop software with graphical user interfaces, often combining a GIS software (e.g. Esri's ArcMap) with a vector-editing graphics program (e.g., Adobe's Illustrator) in a single workflow. If not directly built on top of, these softwares are at least very much compatible with cartographic theory. For example, they provide straightforward workflows to build multiple layers in a map, assign data variables to visual variables, or change a map's projection. We see this reflected in the discipline's textbooks as well: many of the oft-used cartography textbooks cover the theory and practice of mapmaking *without* going into specific software-based how-to instructions (e.g., Kraak and Ormeling 2011; Slocum et al. 2009; Dent 2009). The "translation" to software is left to an instructor's own lab materials or a compendium book. This split of concerns seems to work reasonably well partly because the software and the theory are in sync.

THE ECOSYSTEM OF WEB MAPPING AND INTERACTIVE DATA VISUALIZATION

Building on top of cartography, the field of geovisualization, with its genesis in the 1980–1990s personal computer era, has capitalized significantly on the affordances of new (web) technologies to build interactive mapping interfaces. We see examples of this in early work focused on exploratory data analysis (Anselin, Kim, and Syabri 2004) to more recent examples focused on understanding output of specific algorithms (Fabrikant, Gabathuler, and Skupin 2015) or specific data sets (Pezanowski et al. 2018). Geovisualization systems have become powerful mapping and analytical tools for the end user. Despite their power, and often due to their bespoke design, they can be remarkably easy and convenient to use (e.g., Nost et al. 2017; Roth, Ross, and MacEachren 2015). In contrast, *creating* such geovisualization tools remains a complicated endeavour, often performed by experts. Although there is promising work focused on making geovisualizations easier to create, for example through no- or low-code software (e.g., Gahegan et al. 2002; Hardisty and Robinson 2011), geovisualizations seem to rely on the use of a wide variety of programming languages and software libraries, without a single, or even a small, set of canonical approaches emerging.

This proliferation of different approaches is not due to a lack of promising work in (academic) cartography. For example, Nagel et al. (2013) developed a library, *Unfolding*, for writing interactive maps in Processing and Java, while Ledermann and Gartner (2015) provide a "cartographic" API for making maps with JavaScript (JS). More recently, Degbelo, Sarfraz, and Kray (2020) created *AdaptiveMaps*, a no-code semi-automatic approach to making thematic web maps that is based on Bertin's visual variables. This no-code or low-code approach also shares similarities with the full-stack (i.e., covering both spatial analysis and cartographic functionality) approaches to web cartography that commercial providers are now offering—CARTO,

1. Or encoding, or mapping (depending on the author)

2. Or channels, or aesthetics, or dimensions

3. Or geometries

Mapbox, and Esri are primary examples of companies in this space.

Nonetheless, many online web maps are still made by utilizing one or more smaller JavaScript libraries. For maps specifically, *Leaflet* (**leafletjs.com**) and *OpenLayers*(**openlayers.org**) are the go-to technologies for creating "slippy" maps. They use a basemap that can be panned and zoomed, similar to the map solutions by Apple, Google, and Microsoft that have become commonplace. These base maps can subsequently be overlaid with additional (thematic) map layers. Similarly, for larger datasets, WebGL approaches (which utilize a computer's Graphical Processing Unit for greater performance) such as *Deck.gl* (**visgl.github.io/deck.gl**) and *Mapbox GL* (**docs.mapbox.com/mapbox-gl-js/api**) exist. For cartographic work that goes beyond the "basemap + thematic overlay" paradigm, the collection of JavaScript modules collectively referred to as *D3* (Bostock, Ogievetsky, and Heer 2011; **d3js.org**) has become a commonly used tool.

The reference to D3 also brings us to the connection of cartography with the larger field of information visualization. D3, although used extensively for mapmaking, did not emerge from or for cartography specifically. Instead, its key contributors, Heer and Bostock, laboured to devise a system that makes it possible to design interactive data visualizations in a much more broader sense of the word (Bostock and Heer 2009; Heer and Bostock 2010). D3 is a relatively low-level implementation of their approach in JavaScript. More recently, Heer and colleagues have created the *Vega* system that operates at a higher abstraction level and is more squarely based on the grammar of graphics (**vega.github.io**). It is relatively language-agnostic, as it stores and describes visualizations with the interoperable JSON standard (Satyanarayan et al. 2017). Along similar lines, *Data Illustrator* merges the grammar of graphics with vector editing into a single system (Liu et al. 2018) through the automatic binding of data variables to visual components that designers can easily work with. Although many information visualization libraries also support the creation of maps, support for key cartographic principles (e.g., the selection of an appropriate projection) is often not a primary concern.

CHALLENGES FOR EDUCATORS

As we stated before, this splintered state of affairs in web mapping brings with it a few specific consequences. With so many different (programming) technologies available, it has become a formidable challenge to teach online web mapping—especially in the context of curricula that are not focused heavily on software engineering. As Sack (2018, 39) recently pointed out while taking the pulse of web mapping education in the United States: "*The two greatest challenges in teaching web mapping were, unsurprisingly, teaching students how to code and keeping up with rapid technology changes in the industry.*"

There are different responses possible to the challenge of teaching students how to code, which also depend strongly on the specific degree programme in which a web mapping course or module is offered. One such approach, partly supported by newer tools such as Esri's online suite, is to use low-code solutions. However, as creative or bespoke online cartography still requires manual coding, relying only on such solutions might be detrimental to the field at large—especially since programming skills are becoming increasingly useful in other parts of our discipline. Another approach is to treat courses that rely on programming as more advanced or upper-level and to set up specific prerequisites to enrolment. This has several potential downsides (cf. Ricker and Thatcher 2017)—one of which is an increase in the barriers to entry, which is especially poignant for domain experts for whom programming is often a means to an end.

Instead, we would like to argue for a continued emphasis on teaching programming to cartography and GIS students. The base technologies of the modern web (HTML, CSS, and JavaScript) have reached a level of maturity and consistency that makes learning them more straightforward now, compared to the state of affairs at the start of the millennium. We posit that it is mainly the "jungle" of web mapping software, built on top of those base technologies, that proves difficult to teach. There are several reasons for this. Different web mapping software and libraries do not operate from a consistent foundation and implement similar things in different ways. Furthermore, many technologies do not "sync" well with cartographic theory. This leads to situations where instructors need to reserve a significant amount of class time to teach the idiosyncrasies of a library rather than core cartographic principles. If we add to that the fact that many new tools seem to be using significantly different approaches, it is no wonder educators are hesitant in taking on this task.

This challenge is exacerbated by the fact that many of the current web mapping libraries are either developed outside of the discipline or have (design) goals that are not necessarily in line with cartographic principles. A simple illustration: the production of a thematic choropleth map that uses a classification scheme to translate a quantitative variable to a limited set of colours on the map is a mainstay in any cartography class. However, it is a surprisingly complicated undertaking in most of the popular mapping libraries. For the Leaflet mapping library, it requires the developer to write a custom function to implement a classification scheme, and another custom mapping function that contains logic to translate data values to colours. And then we haven't even tried to use a non-Mercator projection! While this approach might be sensible or even preferred from a software engineering perspective, it becomes a pedagogical distraction in a cartography class—akin to asking a student in an introductory statistics class to write and implement their own fitting function for a linear regression.

CONSISTENT SOFTWARE DEVELOPMENT BY AND FOR CARTOGRAPHERS

Drawing parallels with the discussion around geocomputation and GIS (Harris et al. 2017; Gahegan 2018; Poorthuis and Zook 2020), we argue that the academic field of cartography can address the challenges around web mapping by playing a more prominent role in developing software for this purpose, and, in doing so, build stronger connections between visualization practice and cartographic and visualization theory.

Here we also draw inspiration from Wickham's development of the ggplot2 library for the R programming language (Wickham 2010), which adopts the grammar of graphics as its theoretical foundation. Somewhat in parallel with ggplot2, the R community has developed a constellation of libraries collectively referred to as the *tidyverse* (Wickham et al. 2019) that provides a consistent approach and design to common data science tasks, from data manipulation, to modelling, to visualization. It is predominantly developed by and for a community of domain experts and users, including efforts such as rOpenSci (Boettiger et al. 2015) that organize peer review of software. New libraries are continuously being developed and adhere to the same tidyverse design principles. This consistency is key: the adoption of additional libraries becomes much faster and easier for users as they don't need to grasp a new set of design principles or idiosyncrasies for every additional library. In an education context, this means that only a limited set of software design concepts needs to be taught and focus can otherwise remain on domain concepts.

Tidyverse-compatible libraries for mapping exist as well: *ggmap* (Kahle and Wickham 2013) and *tmap* (Tennekes 2018). In fact, the tidyverse ecosystem can be used very effectively by the modern cartographer, but is limited in its facility for interactive maps. Most interactive maps are created for the web, and creating content for the web is not (yet) one of R's core strengths—although possibilities do exist (Chang et al. 2019). We highlight the success of the tidyverse approach as an inspirational example and ask how we can translate these lessons to the field of web mapping.

A WEB-BASED GRAMMAR OF GRAPHICS FOR MAPMAKING

In this paper, we introduce Florence: a web-based mapping and visualization library that is aimed at addressing the challenges outlined in the previous section. To do this, we have used a specific set of core tenets as design guidelines (DG) in developing the library.

- **DG1:** A web mapping library should be built *on top of* modern web standards. Using and teaching Florence means teaching these technologies (CSS/HTML/JS), instead of replacing or hiding them. Florence is a relatively small convenience layer around those technologies, with its main purpose being to re-anchor web mapping on cartographic theory.
- **DG2:** A web mapping library should take note of and leverage the current generation of JavaScript frameworks. Such frameworks make web development faster and more convenient. Adopting them also allows for visualizations to integrate more seamlessly in larger web development projects. In addition, skills gained through using the library for the purpose of mapmaking will transfer to other domains (e.g., UI/UX design; Roth 2017).
- **DG3:** A web mapping library should be modular rather than one-size-fits-all. This means a reliance on small(er) building blocks that can be mixed together

creatively. Similarly, it should allow the user to extend and build their own modules for oft-used functionality or specific visualizations.

- **DG4:** A web mapping library should perform as little magic or "black box" behaviour as possible. While such "one-click" solutions might entice new users, they generally inhibit an immediate understanding of how and why things work. In addition, black boxes can ultimately make creative, custom use more difficult. This is an explicit deviation from the low/no-code approach. We do not advocate for using less code but instead endeavour to make code easier to understand and reason about.

- **DG5:** A web mapping library should allow for the declarative authoring of visualizations, rather than the more common imperative approach. Imperative programming—giving step-by-step instructions that state *how* you build up to a final goal—for visualizations can often be difficult to reason about, as the reader/author needs to build up a mental picture of the visualization by running through all the imperative steps in the code. Declarative programming—stating *what* the final goal should look like—is a better fit for cartography and follows a larger trend in information visualization (Heer and Bostock 2010; Satyanarayan et al. 2016). Many recent JavaScript frameworks (cf. DG2) allow for the adoption of this approach.

- **DG6:** A web mapping library should be anchored explicitly on a theoretical foundation. Florence is based on the grammar of graphics (adapted for mapmaking purposes). This makes it easier to switch between spatial and non-spatial visualizations and build (linked) geovisualizations with graphs and maps using the same toolset.

- **DG7:** A web mapping library should provide easy ways to "escape" the software abstraction provided. If a user wants to get creative and go more low-level and use native SVG, or add on another visualization library, they should be able to do so. Similarly, if they prefer to work with a higher-level of abstraction, ready-made modules for commonly used visualizations should be provided or possible to create.

CORE ELEMENTS

With this set of design guidelines, we built Florence on top of Svelte: a reactive JavaScript framework that is notable for its simplicity and easy learning curve (**svelte.dev**). Svelte is structured around declarative "single file components" that combine the three core web technologies into a single file: HTML and SVG markup for layout; JavaScript for interaction and computation; and CSS for styling (DG1). Svelte files look very similar to regular HTML files, because they are effectively standard HTML files with a little bit of extra logic sprinkled in through a well-designed template syntax. Importantly, this syntax allows users to create connections between HTML (layout) and JavaScript (interaction and computation) to build declarative and reactive components and pages—which is exactly what is needed to build visualizations and web maps.

There are a number of additional, more technical advantages that Svelte provides over other JavaScript frameworks, but its main reason for adoption here is the ease with which Svelte can be learned and adopted (DG2). This is especially the case compared to other frameworks, such as React, that rely on powerful but complex software engineering concepts that are relatively difficult to learn for non-software engineers.

The central piece of Svelte's template syntax is the use of curly braces (`{}`) in HTML mark-up. Any JavaScript (or references to JS variables) inside such braces will be automatically evaluated. Importantly, updates to variables will automatically be reflected in the rendered page. As such, Svelte's "*Hello World*" is straightforward to understand, even for somebody who has not come into contact with the framework before.

```
<script>
      let name = 'world'
</script>
<h1>Hello {name}!</h1>
```

Built on this technical foundation, Florence provides a series of components that can be imported and combined to build visualizations (DG3, DG5), similar to how HTML elements are combined to build a web page. Figure 1 shows how these components relate directly to the various concepts of the grammar of graphics (DG6). In the next sections, we will discuss the core set of components. A deeper treatment, including documentation and more elaborate examples, can be found at the documentation website (**florence.spatialnetworkslab.org**). Florence can be installed into any JavaScript project through the Node Package Manager (npm) or by forking or extending any of the live code examples on the website. The source code for the software can be found on Gitlab (**gitlab.com/spatialnetworkslab/florence**).

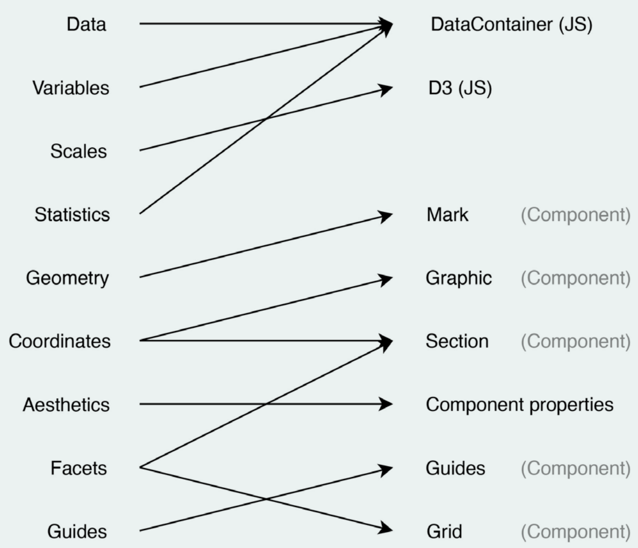
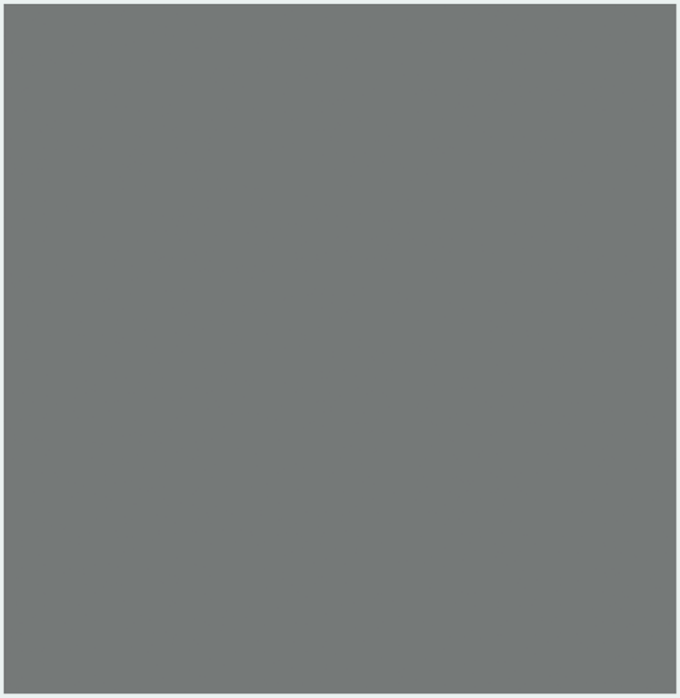


***Figure 1.** Relation between Wilkinson's original grammar of graphics concepts and their implementation in Florence, after Wickham's (2010) comparison between Wilkinson and the ggplot2 approach.*

GRAPHIC & SECTION

Every Florence visualization starts with a `Graphic`.[4] A user can think of this as a blank canvas that becomes available as a drawing space. Each `Graphic` has a specific width and height (measured in pixels in these examples, but it can also be made relative to the web page dimensions). The `Graphic` is like a supercharged SVG element—in fact, under the hood, drawing a `Graphic` will indeed draw an SVG element to the page.

In order to create an empty `Graphic` of 500 by 500 pixels, we can import the component from Florence and draw it to the page (Figure 2). Properties of components are specified in a syntax that is similar to HTML attributes. In this instance, we give the width and height properties of the `Graphic` a value of 500.



```
<script>
  import { Graphic } from '@snlab/florence'
</script>

<Graphic width={500} height={500} backgroundColor={'gray'}>

</Graphic>
```

***Figure 2.** `Graphic` component. Here, and in Figures 3–7, the code is displayed on the bottom with the rendered visualization displayed on the top. Interactive version available at florence.spatialnetworkslab.org/examples/cp-figure2.*

The `Graphic` has a sister component called a `Section`. As many visualizations consist of multiple panels, facets, and insets, `Sections` can be used to subdivide the `Graphic` for this purpose. Each `Section` has its own dimensions and position and—as we will see later—its own coordinate system. For example, we can draw non-overlapping left and right panels (Figure 3).

The same logic can be used to draw overlapping `Section`s, such as when multiple map layers need to be drawn on top of each other.

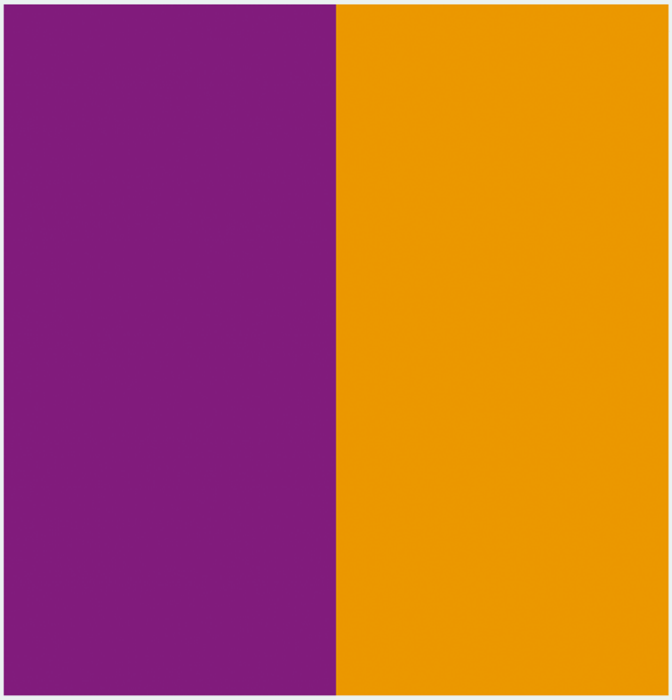
MARKS

To actually draw content, we rely on the grammar-of-graphics concept of the *mark*. A mark specifies a

4. Florence components are capitalized to distinguish them from HTML elements. We set them in monospaced type to make it clear when a reference to a component is made.

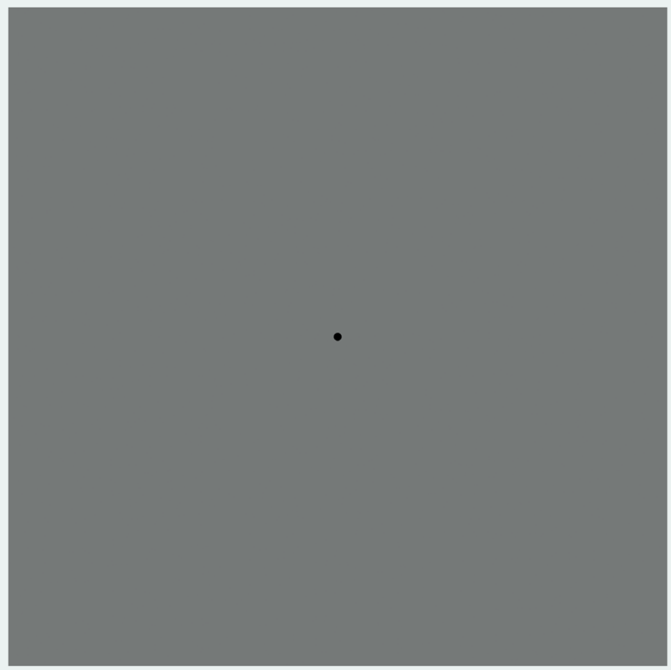
geometric object whose visual properties can encode data attributes. In this sense, marks are similar to the points, lines, and polygons central to vector cartography. Florence makes the following basic marks available: `Point`, `Symbol`, `Line`, `Rectangle`, `Area`, `Label`, and `Polygon`. Each mark supports a set of encoding channels through the properties of its components. These are categorized by position, shape, size, colour, textual attributes, transitional attributes, and interactivity. With these primitive marks, almost any visualization can be expressed. Figure 4 shows a `Point` mark drawn in the centre of our `Graphic` by setting the x and y positional properties of the component.

Of course, most visualizations need to draw not just a single mark but a larger set of them. Florence provides a `Layer` version of each mark for this purpose. Instead of providing a single value each to the x and y properties, we can simply provide an array of values, one for each mark.



```
<script>
  import { Graphic, Section } from '@snlab/florence'
</script>

<Graphic width={500} height={500}>

    <Section
      x1={0}
      x2={250}
      y1={0}
      y2={500}
      backgroundColor={'purple'}
    >
    </Section>

    <Section
      x1={250}
      x2={500}
      y1={0}
      y2={500}
      backgroundColor={'orange'}
    >
    </Section>

</Graphic>
```

Figure 3. *`Graphic` component with two non-overlapping `Section` components. Interactive version available at florence.spatialnetworkslab.org/examples/cp-figure3.*



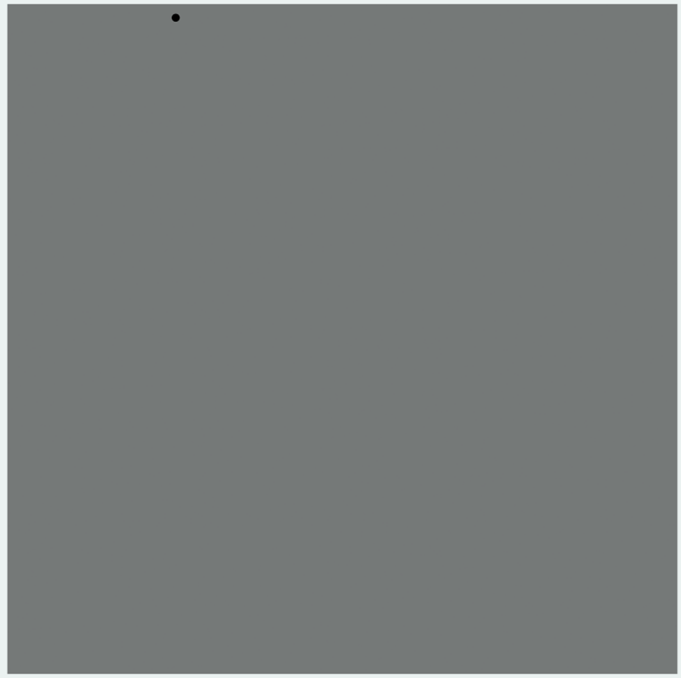
```
<script>
  import { Graphic, Point } from '@snlab/florence'
</script>

<Graphic width={500} height={500} backgroundColor={'gray'}>
  <Point
    x={250}
    y={250}
  />
</Graphic>
```

Figure 4. *A simple `Point` mark, with an x and a y property, in the centre of a `Graphic`. Interactive version available at florence.spatialnetworkslab.org/examples/cp-figure4.*

The `Layer` will draw as many marks as there are values in the supplied array. For example, to draw three points:

```
<PointLayer
   x={[0, 250, 500]}
   y={[250, 250, 250]}
/>
```

Apart from positioning a `Point` (or any other mark) with individual x and y coordinates, Florence also understands GeoJSON natively. Since GeoJSON is the de-facto standard for storing and sharing spatial data on the web, this is an important advantage for web mapping. Any mark can be given coordinates in GeoJSON format through the `geometry` property. For example, in Figure 5 we have a simple GeoJSON object with a single point representing the Dinagat Islands. Its geometry is directly "given" to the `Point` mark without any need for additional translation.



```
<script>
  import { Graphic, Point } from '@snlab/florence'

  const myGeoJSON = {
    type: 'Feature',
    geometry: {
      type: 'Point',
      coordinates: [125.6, 10.1]
    },
    properties: {
      name: 'Dinagat Islands'
    }
  }
</script>

<Graphic width={500} height={500} backgroundColor={'gray'}>
  <Point
    geometry={myGeoJSON.geometry}
  />
</Graphic>
```

Figure 5. *A* `Point` *mark positioned with GeoJSON geometry. Interactive version available at florence.spatialnetworkslab.org/examples/cp-figure5.*

SCALES

If not specified, the coordinate system used inside the `Graphic` or `Section` will be based on the pixel dimensions. However, for most visualizations and maps we don't want to "think" in pixel coordinates. We might not even know the pixel coordinates in advance, as the visualization needs to grow or shrink dynamically depending on the available screen size. To enable this, we need a process to translate data values to positional values. In the context of the grammar of graphics, this process is most often referred to as *scaling*. In essence, a scaling function takes a data value as input, and outputs the appropriate location on the screen (i.e., a pixel coordinate) – mapping from "data space" to "pixel space."

In many software programs, this scaling is performed hidden from the user. In Florence, we take the opposite approach and make scaling explicit and transparent through user-supplied scaling functions (DG4). Florence is agnostic about the actual scaling functions used. A user can create their own functions, but they can also rely on the D3 scaling functions that have become close to an industry standard for data visualizations. Florence follows the D3 conventions for scaling functions for this reason.

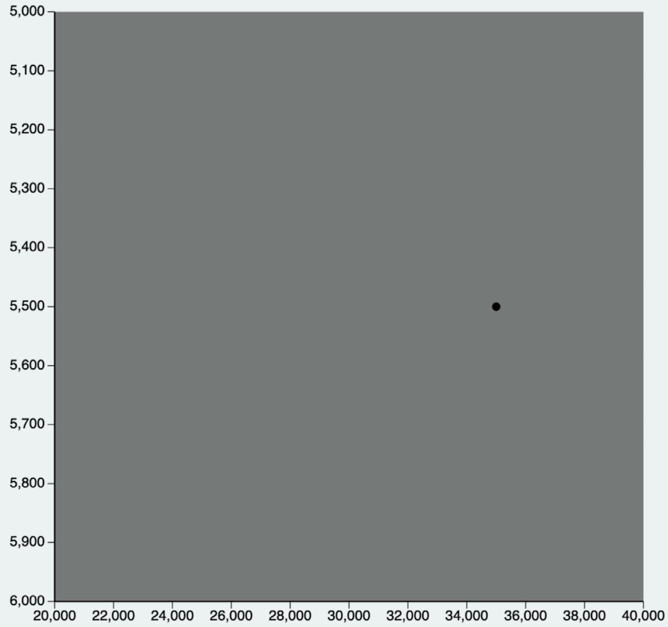
Scaling functions can be passed to the `Graphic` or `Section`, where they will be used to create a "local coordinate" system by using information about the pixel dimensions of the component. Once such a local coordinate system is created, marks can be positioned in this local coordinate system or "data space," rather than with absolute pixels. This makes it much easier to reason about placing marks and annotations within the visualization, and it allows for the dynamic resizing of any visualization.

For example, in Figure 6 we create a `Graphic` with an x-axis is based on a continuous variable that ranges from 20,000 to 40,000, and a y-axis with quantitative values ranging from 5000 to 6000. We then place a single point inside the `Graphic` at coordinates [35000, 5500] using the local coordinate system. Note that `{scaleX}` is just a shorthand for `scaleX={scaleX}` in the Svelte framework.

As scaling of geographic coordinates is a special case (i.e., the x and y dimensions generally need to be scaled together to maintain the aspect ratio), Florence provides built-in scaling functions for geographic data. Figure 7 demonstrates how to scale two triangular polygons using their bounding box. The `createGeoScales` function returns an object with a `scaleX` and `scaleY`. The spread syntax (`{...geoScales}`) is a Svelte shorthand for `scaleX={geoScales.scaleX} scaleY={geoScales.scaleY}`.

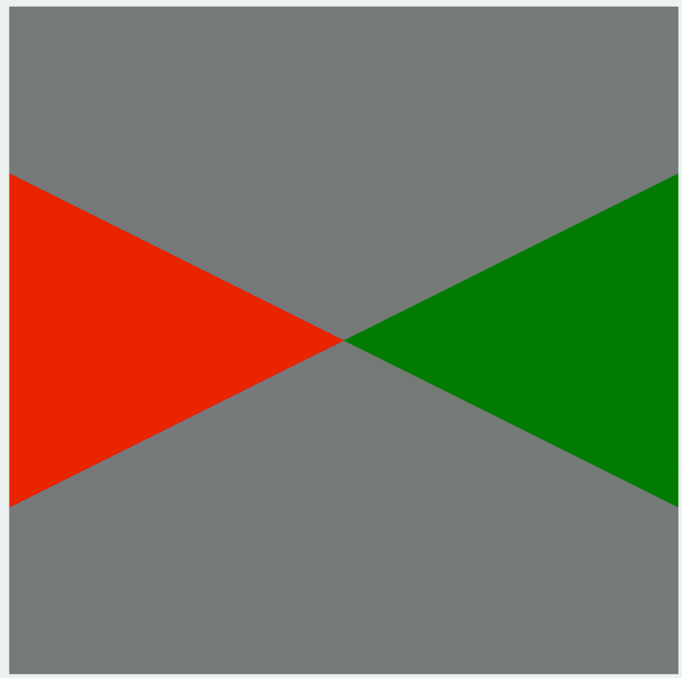
DEALING WITH DATA

Maps, like any visualization, often rely heavily on the transformation, aggregation and filtering of data. Conventional GIS programs offer a wide range of functions for this purpose. While most data transformations can be readily performed in JavaScript, this often requires a high level of JS software engineering knowledge. Moreover, since JS isn't designed as a data science language per se, the mental model for these transformations is much lower-level than ideal for cartography.




```
<script>
  import { Graphic, Point, XAxis, YAxis } from '@snlab/florence'
  import { scaleLinear } from 'd3-scale'

  const scaleX = scaleLinear().domain([20000, 40000])
  const scaleY = scaleLinear().domain([5000, 6000])
</script>

<Graphic
  width={500} height={500}
  padding={40}
  backgroundColor={'gray'}
  {scaleX} {scaleY}
>
  <Point
    x={35000}
    y={5500}
  />

  <XAxis />
  <YAxis />
</Graphic>
```

Figure 6. *A `Point` mark positioned in "data space." Interactive version available at florence.spatialnetworkslab.org/examples/cp-figure6.*



```
<script>
  import { Graphic, PolygonLayer, createGeoScales } from '@snlab/florence'

  const triangles = [
    { type: 'Polygon', coordinates: [[[0, 0], [5, 2.5], [0, 5], [0, 0]]] },
    { type: 'Polygon', coordinates: [[[10, 0], [5, 2.5], [10, 5], [10, 0]]] }
  ]

  const bbox = {
    x: [0, 10],
    y: [0, 5]
  }

  const geoScales = createGeoScales(bbox)
</script>

<Graphic
  width={500} height={500}
  backgroundColor={'grey'}
  {...geoScales}
>
  <PolygonLayer geometry={triangles} fill={['red', 'green']} />
</Graphic>
```

Figure 7. *Scaling polygons while maintaining the aspect ratio. Interactive version available at florence.spatialnetworkslab.org/examples/cp-figure7.*

To aid in this, we provide a sidecar data handling library that is designed to mirror the logic and concepts in tidyverse's *dplyr* "grammar of data manipulation" (Wickham et al. 2015) (DG6). In this way, any user familiar with the *tidyverse* approach will be able to adopt its logic quickly. The source code for the library, including documentation on all its functions, can be found on Gitlab at: **gitlab.com/spatialnetworkslab/florence-datacontainer**.

The library allows for loading row and column–oriented datasets, as well as GeoJSON data, into a consistent data structure referred to as a `DataContainer`. This `DataContainer` then offers familiar transformations such as:

- **Select:** for selecting a subset of columns
- **Filter:** for filtering a subset of rows
- **Mutate:** for creating new columns (based on some calculation)
- **Group by:** for aggregating data based on a specific column
- **Summarise:** for summarizing data about each aforementioned group

Many geovisualizations allow the end-user to interactively filter, subset, and aggregate data, so we consider these data transformations as essential ingredients in any web mapping toolset. A `DataContainer` also provides some shortcuts for accessing oft-used information in map design, such as the domain of a variable or its data type.

In addition, it has built-in support for binning with different classification schemes, functionality that is useful for both non-spatial histograms as well as the classification common in choropleth maps. It also allows for the reprojection of spatial geometry data. By building on top of the open source *proj4js* library (**github.com/proj4js/proj4js**), any projection supported by the proj4 ecosystem can be used to create visualizations. An example of this can be seen in Figure 8, which reads in an external GeoJSON file projected in a country-specific coordinate system. This custom projection works out-of-the-box with Florence and the map is automatically sized to fit the dimensions of the `Graphic`. Additional styling is provided through the use of the `fill`, `stroke`, and `strokewidth` component properties (aesthetics). In the second panel, the `fill` aesthetic is mapped to a categorical colour scheme (through the use of a scale provided by D3) based on the province name.

Commonly used elements such legends, graticules, and—for non-map visualizations—axes, can be created with built-in components or the user can create their own custom

```
<script>
  import { Graphic, Section, PolygonLayer, createGeoScales } from '@snlab/florence'
  import DataContainer from '@snlab/florence-datacontainer'
  import { provincesGeoJSON } from './provinces.js'

  const provinces = new DataContainer(provincesGeoJSON)
  const geoScales = createGeoScales(provinces.bbox())
</script>

<Graphic width={500} height={500} {...geoScales} flipY>
  <PolygonLayer
    geometry={provinces.column('$geometry')}
    fill={'rgb(230,230,230)'}
    stroke={'white'}
    strokeWidth={1}
  />
</Graphic>
```



```
<script>
  import { Graphic, Section, PolygonLayer, createGeoScales } from '@snlab/florence'
  import DataContainer from '@snlab/florence-datacontainer'
  import { scaleOrdinal } from 'd3-scale'
  import { schemeCategory10 } from 'd3-scale-chromatic'
  import { provincesGeoJSON } from './provinces.js'

  const provinces = new DataContainer(provincesGeoJSON)
  const geoScales = createGeoScales(provinces.bbox())

  const colorScale = scaleOrdinal()
    .domain(provinces.domain('statcode'))
    .range(schemeCategory10)
</script>

<Graphic width={500} height={500} {...geoScales} flipY>
  <PolygonLayer
    geometry={provinces.column('$geometry')}
    fill={provinces.map('statcode', colorScale)}
    stroke={'white'}
    strokeWidth={1}
  />
</Graphic>
```

Figure 8. *A map of Dutch provinces. Dutch spatial data is often provided in a country-specific projection and coordinate system ("Rijksdriehoeksstelsel"), which isn't compatible with most JavaScript mapping libraries that rely solely on WGS84. The bottom panel shows a categorical colour scheme applied to the province name. Interactive version available at florence.spatialnetworkslab.org/examples/cp-figure8a and florence.spatialnetworkslab.org/examples/cp-figure8b.*

implementation using the grammar of graphics (i.e., combine `Sections` with different marks).

INTERACTION

Although higher levels (a "grammar," if you will) of abstraction for web mapping interactions exist (Roth 2013; Roth et al. 2014), we have chosen to rely on a slightly lower-level abstraction that is consistent with native browser event listeners for both desktop (mouse) and mobile (touch) events (DG1, DG4). We use this approach so that knowledge gained with HTML/JavaScript will transfer easily to Florence and vice versa. We consider this a useful trade-off for geovisualizations because they often need to include interactions with both visual elements (e.g., click on a map element) in addition to more "conventional" page elements (e.g., clicking on a button). The same event-listener approach can be used for both types of elements.

Florence uses an R-tree based spatial index (**github.com/mourner/rbush**) for detecting "hits" in an efficient manner that scales up to large datasets. Listeners for different user events can be set on both `Graphics` and `Sections` as well as on individual marks. With these basic building blocks, any of the common geovisualization interactions (e.g., pan, zoom, highlight, brush, select, linked views, etc.) can be achieved. Importantly, Florence provides useful information about the mark being interacted with, including its identifier and its location in both "data space" and "pixel space" (see Figure 9 for an example).

SPECIFIC USE CASES AND EXAMPLES

Florence eases the execution of many common tasks in cartography through its flexible combination of `Sections` and marks. For example, map insets—often used to show an overview or different parts of non-contiguous countries, can be created by simply creating a separate `Section` for each inset and giving that section its own scale/bounding box (and thus its own coordinate system). This is difficult to achieve with web mapping libraries like Leaflet, and requires the use of a composite, custom projection in D3[5]. A common scenario is to display the contiguous United States, with Alaska and Hawaii as separate insets. Each would have their own, appropriate projections and bounding boxes. To achieve this with Florence, GeoJSON data for all states can be filtered into three separate `DataContainers` (one for the contiguous United States, one for Alaska, and one for Hawaii) and

5. e.g., **github.com/d3/d3-geo/blob/master/README.md#geoAlbersUsa**

```
<script>
  import { Graphic, Section, PolygonLayer, createGeoScales } from '@snlab/florence'
  import DataContainer from '@snlab/florence-datacontainer'
  import { provincesGeoJSON } from './provinces.js'

  const provinces = new DataContainer(provincesGeoJSON)
  const geoScales = createGeoScales(provinces.bbox())

  let selectedIndex = null
</script>

<Graphic width={500} height={500} {...geoScales} flipY>
  <PolygonLayer
    geometry={provinces.column('$geometry')}
    fill={({ index }) => index === selectedIndex ? 'yellow' : 'rgb(230,230,230)'}
    stroke={'white'}
    strokeWidth={1}
    onMouseover={e => { selectedIndex = e.index }}
    onMouseout={e => { selectedIndex = null }}
  />
</Graphic>

<h1>
  {selectedIndex ? provinces.row({ index: selectedIndex }).statnaam : 'No province selected'}
</h1>
```

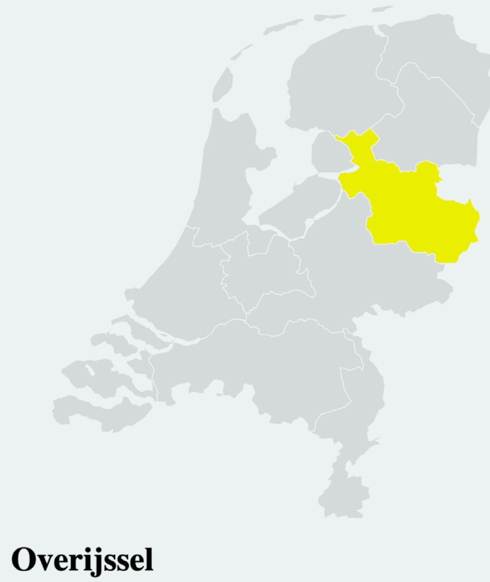


Figure 9. An example of a hover-based interaction. When the user hovers over a province, the province lights up in yellow, and its name is displayed beneath the map. Interactive version available at florence.spatialnetworkslab.org/examples/cp-figure9.

each DataContainer is then used to set up a Section with its own projection and scaling.

Similarly, small multiples—a grid of smaller maps, each showing a different variable (e.g., one for each year in a dataset)—can be achieved in an automated fashion by using Svelte's {#each} syntax to repeat a separate Section for each variable. In the code example below, years is an array of numbers that represent the years in a dataset. Through Svelte's slot property syntax (let:cells), the Grid component makes an object called cells available to all components inside of it. This object contains the x and y coordinates for each "cell" or Section so they can be automatically arranged into a grid formation.

```
<Grid names={years} let:cells>
    {#each years as year}
        <Section {...cells[year]} {...geoScales}>
            <PolygonLayer
                geometry={data.column('$geometry')}
                fill={data.map(year, someScale)}
            />
        </Section>
    {/each}
</Grid>
```

Similar logic can also be applied to create, for example, atlas-like functionality, in which a map is created for each province in a dataset.

One approach somewhat unique to cartography is the visualization of multi-dimensional spatial datasets through small pie charts or other such "micro diagrams" (Gröbe and Burghardt 2020) that are displayed at specific locations on a map to visualize some additional information about that specific location. Depending on the complexity

Figure 10. *"Map sparklines" as an example of micro diagrams. Used here to show the evolution of COVID-19 cases in different Dutch provinces in an animated manner. Code and interactive version available at florence.spatialnetworkslab.org/examples/cp-figure10.*

of the type of diagram, these can be challenging to implement with web mapping software. However, with the grammar-of-graphics approach, we can think of each micro diagram as an individual Section (with its own coordinate system) that we can simply position at the right geographic coordinates. An example of this, replicating Mathieu Rajerison's approach (Rajerison 2020) for "map sparklines" can be seen in Figure 10.

TEACHING WITH FLORENCE

In the spring of 2020, we used the framework as a core library to teach an introductory course in interactive data visualization at the Singapore University of Technology and Design. The course had no specific prerequisites and attracted students from a wide variety of backgrounds. Most students had no significant programming experience and only three students had worked with HTML before. None had prior training in cartography. We include a short discussion of our experience teaching with Florence here as an initial pilot study of the potential effectiveness of our approach, pending a more formal and systematic assessment (see Discussion & Future Work).

The first half of the course built a foundational understanding of HTML/JS/CSS and the Svelte reactive framework, by recreating charts produced by Du Bois and his colleagues for the 1900 Paris Exhibition (Battle-Baptiste and Rusert 2018) using each of those technologies. The second half of the course introduced the grammar of graphics and its implementation with the Florence framework. Students then created a series of visualization dashboards and interactive maps during class exercises, while simultaneously working on an independent project.

The main challenge for students in the course was to learn the foundational computing concepts within HTML/JS/CSS, as well as the Svelte framework. After that, picking up the grammar of graphics, and by extension the Florence library, seemed natural to students. From a pedagogical point of view, it is interesting to note that many students did not fully realize that they were actually using an external software library. Rather, they were just writing JavaScript based on the core concepts from the grammar of graphics, such as marks and scales.

As highlighted before, Florence serves as a convenience layer on top of core web technologies. This enabled students to branch out creatively in their final projects, combining and linking different visual ways to analyse and present their data, using everything from maps and graphs to regular UI elements such as form elements and text (DG5, DG6). In some cases, students built relatively bespoke and complex web applications, in which the use of Florence was observed to be helpful in easing the path to linking to "low-level" approaches, which can otherwise be challenging to achieve with libraries that provide more out-of-the-box, "one-click" solutions (DG3, DG4).

Importantly, Florence's easy interoperability with other libraries (DG7) allowed student projects to merge the grammar-of-graphics foundation taught in the class with libraries such as *d3-force* to display network data and *mapbox-gl* to display a pannable basemap under a Florence visualization. This was also useful for students who came to the course with the expectation of learning D3 or some other existing library and were initially disappointed to learn Florence instead. The foundation of the grammar of graphics allowed them to quickly adopt other libraries and approaches in their final projects. While the library in its current state is not without its limitations, we are encouraged by this initial use case, which shows clear promise as a teaching tool for web-based cartography and data visualization.

DISCUSSION & FUTURE WORK

With a flexible combination of the core components discussed here, many (spatial) visualizations can be created. Importantly, once the grammar-of-graphics approach is adopted, a user can employ the concepts to "think through" a visualization, breaking it down in its constituent marks and scales even before starting the actual coding process. In our experience teaching with Florence, the easy transition from HTML to the use of Svelte and Florence—as well as the declarative approach to writing visualizations—works well for students that do not come from a software engineering background. By design, Florence does not have much embedded "magic" and, in some cases, requires relatively verbose code (DG4). We argue that this should not be seen as a downside as it leads to greater understanding and easier customization and adaptation in student projects.

The modular, component-based approach aids in this flexibility as well. Although the framework only provides a limited set of primitive marks, they can be easily expanded (DG3, DG7). For example, a box plot is an example of a visual element that is not a single mark but rather a collection of different marks that indicate the different quartiles and outliers. This collection of marks can be turned into its own higher-level "boxplot" component and can subsequently be re-used across a project and shared with other users or projects. In this way, higher-order layers can be created—to the point of entire pre-defined maps that can serve as templates. As an example, the sparklines seen in Figure 10 can be saved as a component as well—allowing the user to create one for any country by passing a reference, via the component properties, to a GeoJSON file for the spatial polygons as well as a table of x/y data for the actual sparklines.

Although our initial use of the library in teaching showed promise, a more thorough evaluation in an educational context is warranted. Such an evaluation could take two specific approaches. First, the extent to which the design goals are achieved, and the library's impact on a student's learning of web-based cartography skills and concepts can be formally assessed in subsequent iterations of the course. Roth and Sack's (2017) methodology provides a clear and structured evaluation approach for this purpose through employing instructor observation logs, student feedback compositions, and exit surveys. However, by its very nature, such an approach evaluates the library only in the context of the course in which it is used.

To provide a more direct comparison to other commonly used libraries in web mapping (e.g., D3, Leaflet), a survey with an experimental design could be conducted with cartography practitioners that have a working understanding of web technology but might use varying tools in their day-to-day practice. A few common mapping scenarios could be implemented, supplemented with small lessons, across different technologies to measure the effectiveness of those technologies in relation to the aforementioned design goals. Since both the research population and likely sample size will be small, such a survey could be combined with qualitative exit interviews as well.

There are some obvious limitations in the implementation of the first version of the library as well. For example, currently Florence only supports rendering in SVG. However, its rendering backend is written to allow for different rendering approaches. For larger datasets, SVG has certain limitations. In future work, we would like to explore expansion to both HTML canvas and WebGL rendering. The latter is an especially promising technology for creating geovisualizations of very large datasets. Although some more general WebGL visualization libraries exist (Ren, Lee, and Höllerer 2017), to the best of our knowledge no convenient approach currently exists for creative cartography with WebGL.

Similarly, it would be fruitful to build on our current implementation of interactions to provide a higher-level "grammar" of interactions (cf. Roth 2013). In relation to this, Florence currently does allow for a basic set of transitions and animations, including tweening. Animation has been a long standing interest in cartography (Karl 1992; Lobben 2003), but recent work has called for caution around the use of animation to facilitate change detection in choropleth maps (Fish, Goldsberry, and Battersby 2011). We believe extending the grammar to interactions and animations (cf. the R library *gganimate*; gganimate.com), and thus easing its use, will enable a wider variety of use cases for animation in web mapping, beyond the common case of mapping temporal change to frames in an animation.

In evaluating its approach and current capabilities, we put Florence forward as an example of software designed for web-based data visualization that is speaking directly to the discipline of cartography, and cartography education in particular. We are optimistic that such approaches and a concerted effort around developing software for cartography have the potential to not only open up new ways of creative mapmaking but also help address the significant challenges in teaching web-based mapping in our cartography curricula.

DATA & CODE AVAILABILITY

The source code repository for the software can be found on Gitlab: **gitlab.com/spatialnetworkslab/florence**. A deeper treatment, including documentation and more elaborate examples, can be found at the documentation website: **florence.spatialnetworkslab.org**.

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Bending Lines: Maps and Data from Distortion to Deception

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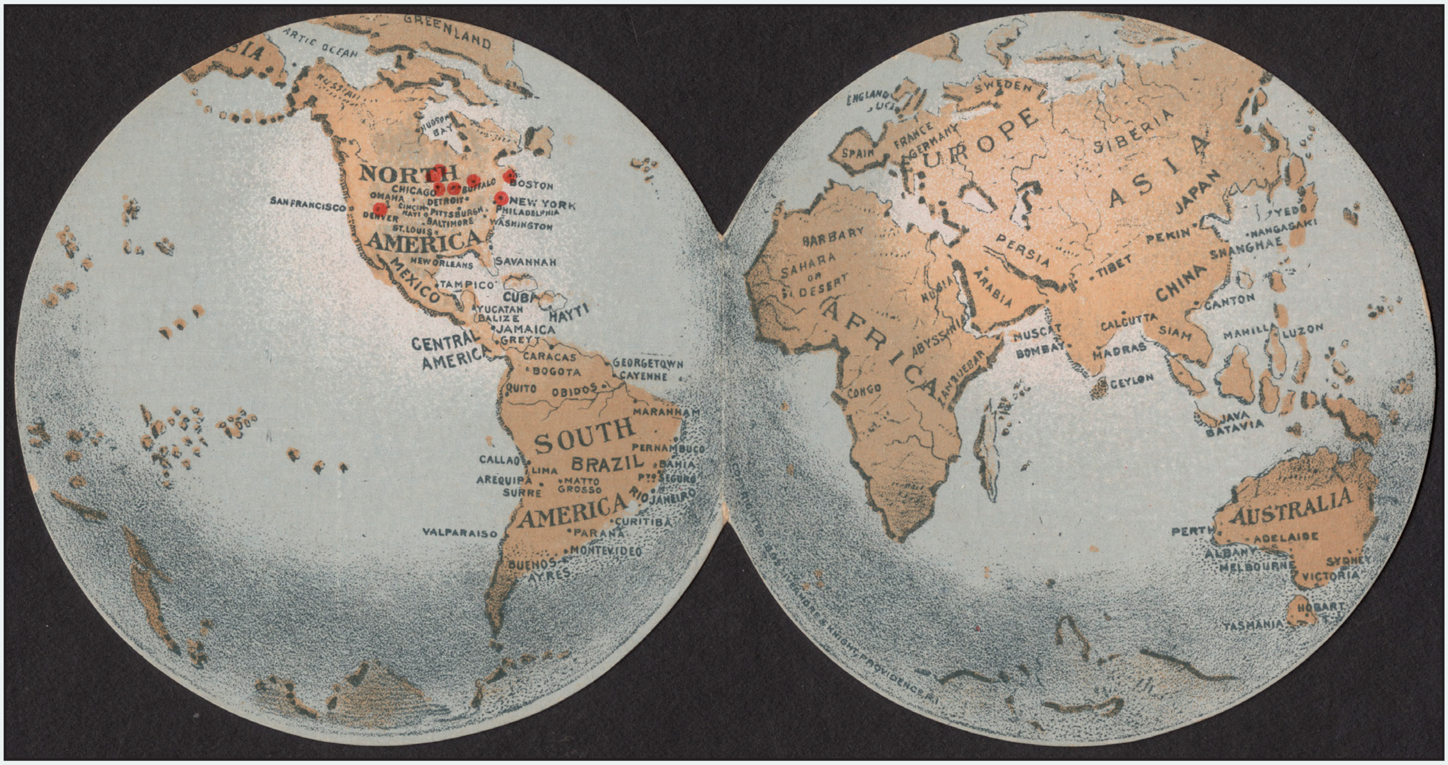
For those who work with maps as a profession, the fraught relationship between cartographic representation and truth is a familiar problem. But for the vast majority of casual readers and users of maps, the epistemological status of maps is typically much more straightforward: maps seem to show the world as it really is. In the popular imagination, "maps don't lie," to borrow the maxim that appeared in the headline of a 2019 *New York Times* column written by Charles Blow.

Blow's headline, written in reaction to Donald Trump's mischievous distortion of a National Weather Service map forecasting the path of Hurricane Dorian, became the subject of much head-shaking amongst scholars steeped in the critical tradition of geographers such as J. B. Harley, Judith Tyner, and Mark Monmonier, all of whom have pointed to the ways in which maps can indeed be used to lie, deceive, cheat, and dominate (e.g., Harley 1989; Tyner 1982; Tyner 2015; Monmonier 2018). But most people are not equipped with this automatic skepticism towards maps—getting directions to the local grocery store, after all, hardly feels like the terrain on which the forces of social and political contestation are brought to bear. Maps, at least the way they appear in most people's everyday lives, carry the stamp of trustworthiness. And it is precisely this veneer of good faith which can make maps so dangerously persuasive.

The Leventhal Map & Education Center at the Boston Public Library (LMEC) launched an exhibition and initiative in May 2020 with the goal of examining how truth and belief are constructed through cartography and the visual display of information. The show, ***Bending Lines: Maps and Data from Distortion to Deception***, was moved to an online-first format due to the COVID-19 pandemic. Beginning with the familiar categories of propaganda maps and persuasive cartography, and expanding to include themes around information literacy, data justice, and the social construction of belief, *Bending Lines* is a wide-ranging attempt to highlight the many ways in which cartography bends the truth—both for nefarious, oppressive reasons as well as, at times, in service of counter-hegemonic movements. Indeed, *Bending Lines* expands the categorical limits of "persuasive" cartography outward to include all forms of mapmaking, noting that reduction, simplification, and symbolization ("lies," of a sort) are not incidental but inherent in the act of representation. Rather than simply trying to replace the public's faith in maps with a reactionary distrust, however, *Bending Lines* instead argues in favor of a critically informed trust, showing how maps must always be evaluated in terms of their position within systems of authority and power.

DEVELOPMENT AND BACKGROUND OF THE EXHIBITION

The original inspiration for an exhibition on truth and lies in cartography came in 2018 from Belle Lipton, LMEC's Geospatial & Cartographic Information Librarian, and Dory Klein, the Center's Map Librarian at the time. The P. J. Mode Collection at Cornell University served as a model for curating a set of objects around the category of "persuasive cartography," the term first coined in 1974 by Judith Tyner in her doctoral thesis (1974). Lipton additionally brought the theme of data literacy to bear on the exhibition's agenda. Working with Ronald Grim, the Curator at the time, the Center applied for grant funding from the Institute of Museum and Library



Services (IMLS) to support the exhibition; we were successful in the application, and *Bending Lines* was made possible by IMLS grant MA-10-19-0400-19.

Front (top image) and back (bottom image) of a trade card of the American Radiator Company (1892).

I joined the Map Center as the new Curator of Maps & Director of Geographic Scholarship in August 2019 and took on the overall responsibility for planning and writing *Bending Lines*, working closely with Lauren Kennedy, the Center's Design & Communications Lead. Additional development of the exhibition was undertaken by the entire LMEC staff, including Michelle LeBlanc, Lynn Brown, Lauren Chen, Connie Chin, Rachel Sharer, and interns Madison Bastress and Cory Seremetis.

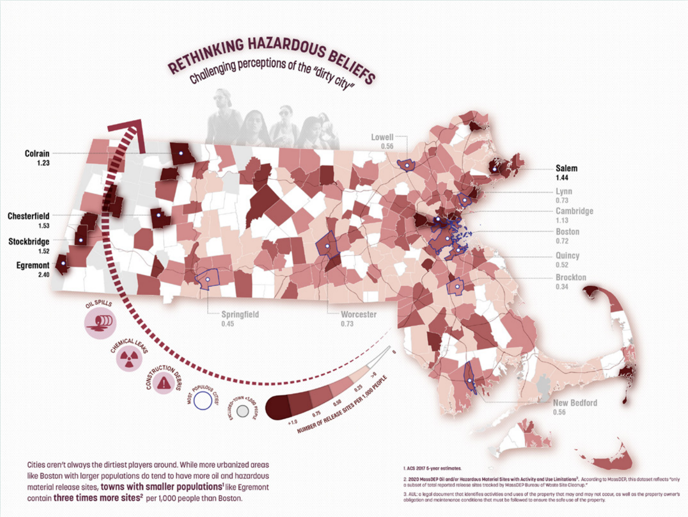
Through the course of our planning, the remit for *Bending Lines* changed from "persuasive cartography" as a taxonomic category in the study of cartography to a broader question about how maps construct the truth. We sought to emphasize truth as a *construction*, rather than a simple binary state, foregrounding how cartographic veracity is configured by political and social relationships, as well as by registers of meaning and symbolism that acquire significance and viability in the same manner as a written language. Consequently, we drew not only from the scholarly literature on persuasion and propaganda, but also from the social studies of science that have influenced fields such as critical cartography and data feminism. Whether in the form of a sixteenth-century cartographer struggling to incorporate evidence from trans-Atlantic voyages into

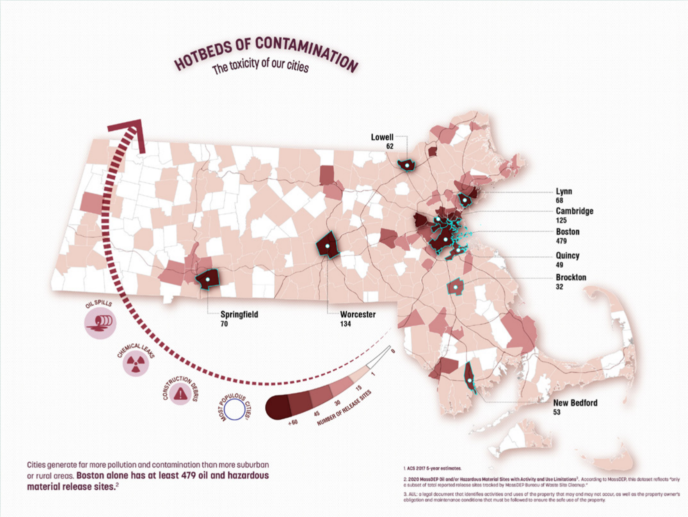
Ptolemaic geography or a modern day big data analyst grappling with a Census variable that poorly captures the heterogeneity of a social phenomenon, we aimed to show that the underlying struggle remains the same: the human process through which the overwhelming complexity of the real world is reduced and simplified into geographic knowledge. This simplification, of course, can easily become the tool of nefarious intentions in the hands of those who deliberately try to cheat and deceive. But it is not simplification *itself* which accomplishes the lie, for even the best, most sincere cartographers are still practitioners of this reductive representation.

STRUCTURE OF THE EXHIBITION

Rather than taking the typical taxonomic approach of categorizing maps by their purpose, *Bending Lines* is divided instead into three broad sections. In the first, "Why Persuade?", we examine the motivations that would lead someone to purposefully use maps for persuasive goals. This question flips the locus of explanation from the object itself to the social process that produced the object, and answers to the framing question include "to sell land," "to incite a war," and "to promote a political campaign," amongst others. The second section, "How the Lines Get Bent," looks at the techniques and methods of cartography, explaining how choices ranging from projection to classification result in skewed versions of the truth, even in cases where the mapmaker or data designer has gone out of their way to present reality as faithfully as possible. Here we show that a choice, such as a coordinate system, may not be made with the intent to deceive, but may nonetheless have the consequence of promoting one viewpoint to the neglect of alternative, equally feasible, perspectives. The final section, "The Power to Make Belief," ties the exhibition's guiding questions together by showing that what someone is able to know about the world from looking at a map is a function not simply of what is displayed in the map itself, but instead a social process that depends on trust in institutions, displays of identity, and the machinations of political power.

A special feature of the exhibition is a series of newly commissioned maps for a section called "Same Data, Different Stories." In this section, we composed a set of data objects about Massachusetts, and gave this data set to six cartographers. We asked these cartographers to select from the data available and create two maps that offered competing arguments. Here, we sought to show that data *by itself* cannot lead to any single conclusion or proof, but, instead, that the choices and conceptual frames that a cartographer brings to a project of data design will inevitably shape what sorts of proofs the data seems to offer. Margaret Owens, Andy Woodruff, Lauren Tierney, Julia Wolfe, and (acting as a team) Madison Draper and Alison D. Ollivierre each created pairs of maps that challenge readers to rethink their assumptions that geospatial data offers an unvarnished, perfectly objective truth free of human interpretation.



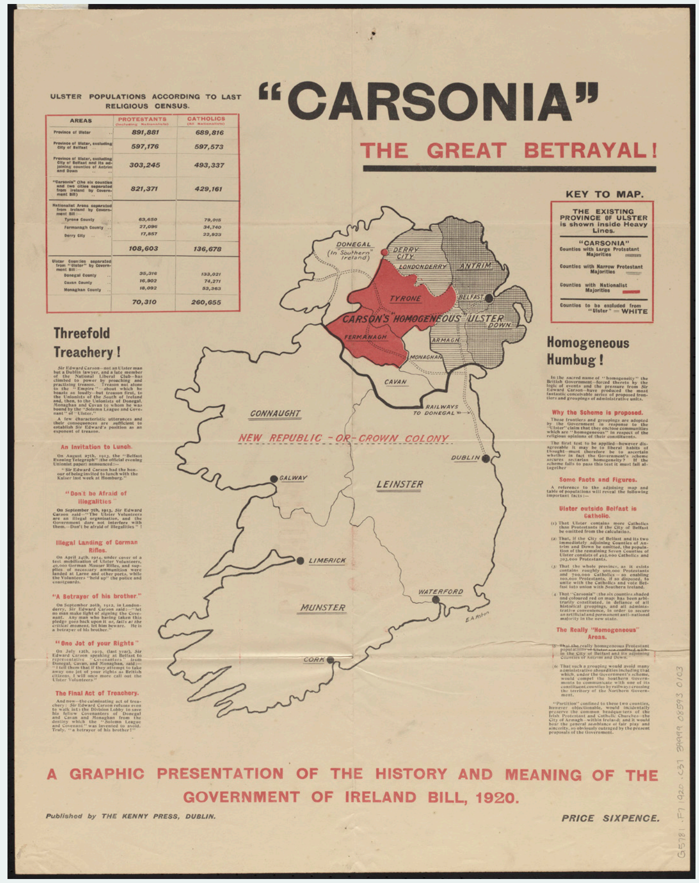


Two maps by Maggie Owens in the "Same Data, Different Stories" section show how data can be manipulated to draw different conclusions.

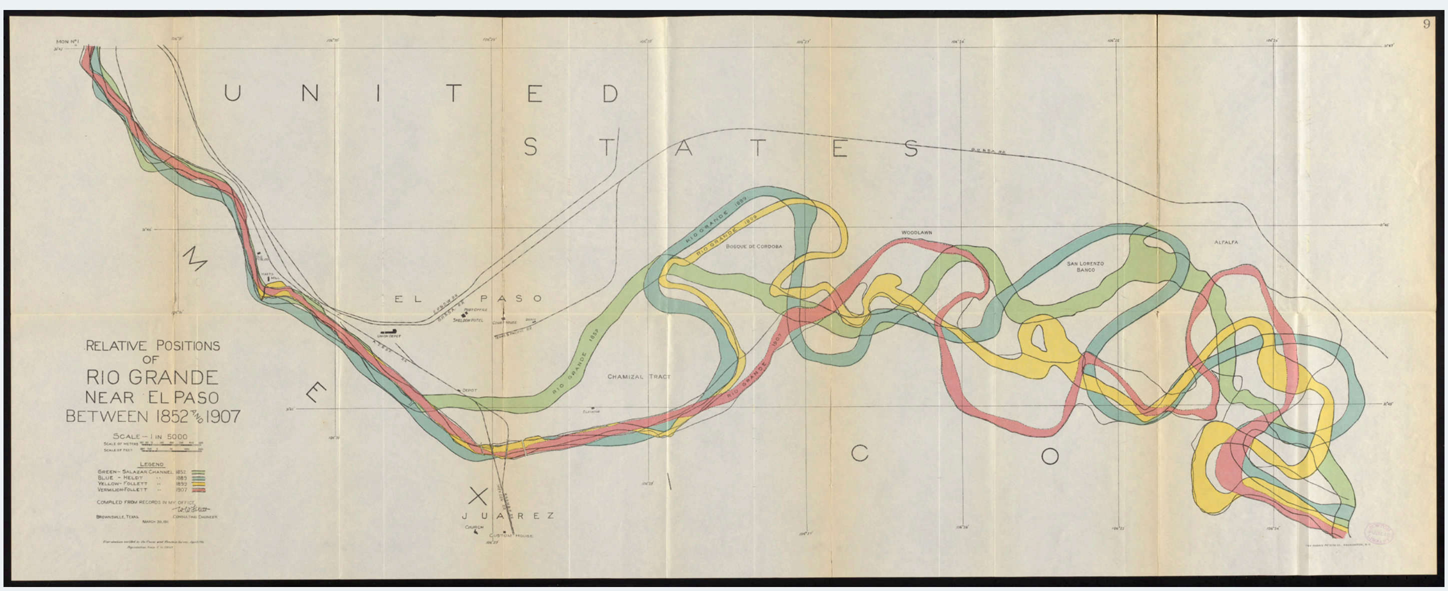
NOTABLE OBJECTS

The permanent collections of the LMEC include many of the most famous examples of persuasive cartography, such as Frederick W. Rose's *Serio-comic War Map for the Year 1877* (1877), with its octopus presentation of the Russian Empire; the U.S. Army Morale Service Division's periodical *Newsmap*, produced during World War II to narrate the official version of the war effort; and William Bunge's *Nuclear War Atlas* (1988), a series of anti-proliferation maps republished from a 1982 poster. We also discovered many objects in the collection which had not previously been interpreted in this light, such as a 1920 Irish nationalist broadside entitled *"Carsonia" The Great Betrayal!*; an enormous 1918 map published by the National Highways Association, urging investment in road infrastructure; and an 1839 map of the northern border of Maine, used in the negotiations that led to the Webster-Ashburton Treaty. We also found suitable material in the BPL's research collections, including original maps of the Chamizal boundary dispute between Mexico and the United States—a cartographic skirmish described in Chapter 3 of Monmonier (2010).

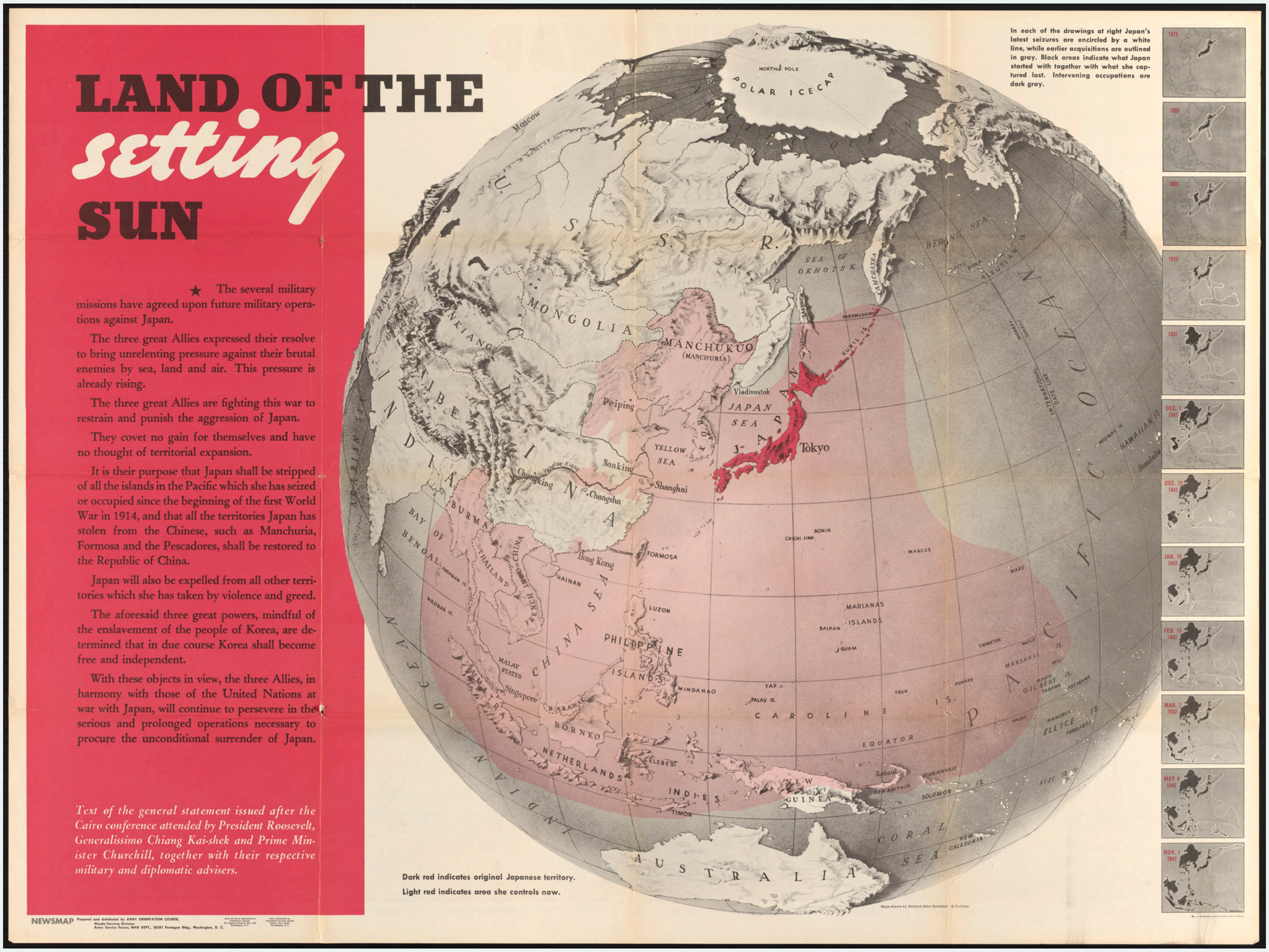
Acquisitions also brought new material into our collections for display in *Bending Lines*. The exhibition gave



E. A. Aston, "Carsonia" The Great Betrayal! *(Kenny Press, 1920).*



W. W. Follett, Relative Positions of Rio Grande Near El Paso Between 1852 and 1907 *(International Boundary Commission, 1911).*

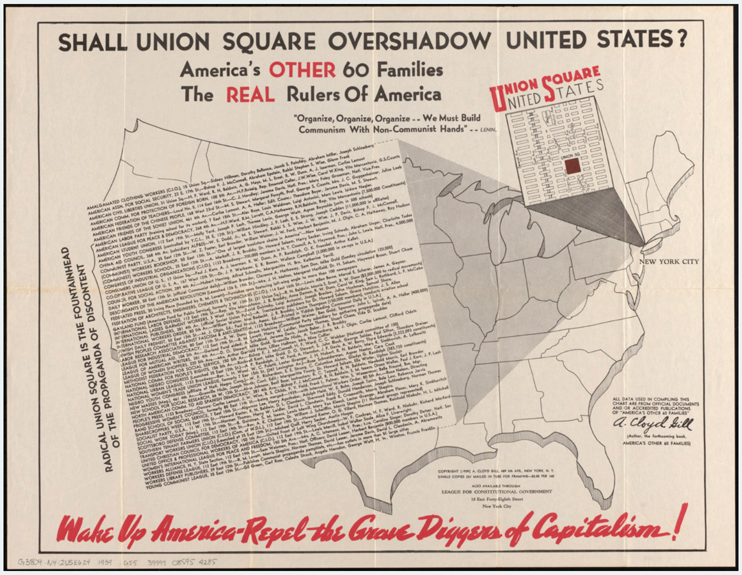


Richard Edes Harrison and US Morale Services Division of the Army Service Forces, "Land of the Setting Sun," Newsmap *(December 27, 1943).*

us a reason to acquire our first object by Charles Joseph Minard, an 1862 map of cotton imports to Europe which pioneered the use of flow lines. A 1980 piece of pop cartography, S. Orozco's tourist map of Acapulco, offers an extreme example of the use of mapmaking in support of commercial advertising and corporate branding. A pair of maps of Manhattan show how related cartographic techniques can be deployed for opposite ideological goals: the first, an 1895 map by the reformer Walter Vrooman, argues for municipal socialism, while the second, a 1939 map by the right-wing activist A. Cloyd Gill, warns of a Communist takeover of the United States. A 1978 tourist map of South Africa, published by the apartheid government, shows the use of selective generalization to obscure the relative importance of Black towns in comparison to the cities built and populated by European colonizers, an example of subtle cartographic racism described by Kelso (1999).

Regrettably, some of the newly acquired objects were not able to be included in the digital show, due to the closure of the library's digitization lab at just the time when these objects were scheduled to be photographed. These objects include the 1938 *Atlas of To-day and To-Morrow*, created by the left-wing, anti-imperialist cartographer Sandór (Alexander) Radó; a Nazi-produced *Deutscher Schulatlas* from 1943, showing the white supremacist geography of *Lebensraum*; and Herbert Bayer's 1953 *World Geo-Graphic Atlas*, a masterpiece of information visualization in the High Modernist register.

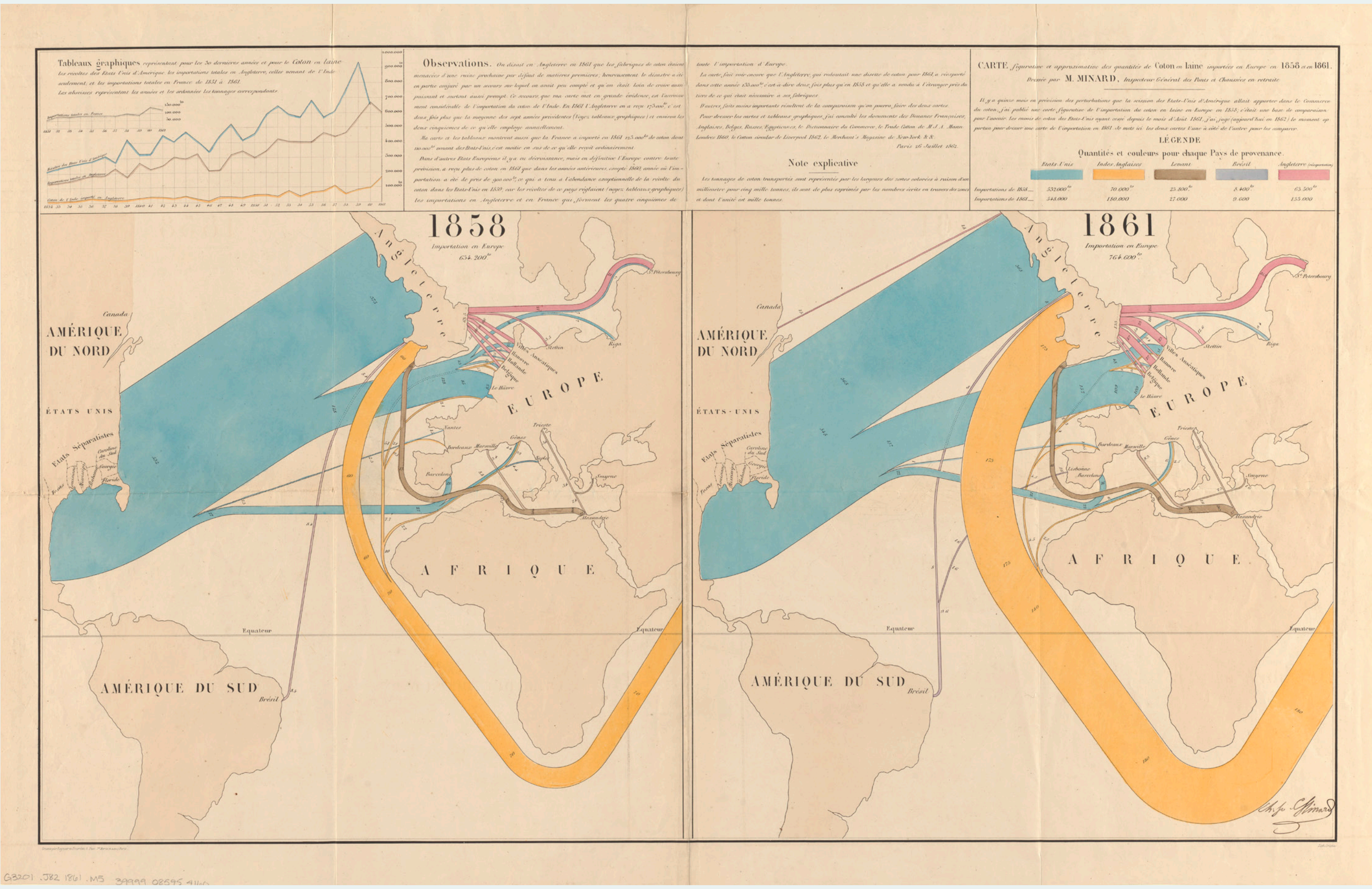
In addition to the newly commissioned maps for the "Same Data, Different Stories" feature, *Bending Lines* also includes several other contemporary maps that are meant to showcase cartography used for social movements that countervail hegemonic power structures. For instance, Margaret Pearce's 2017 *Coming Home to Place Names in*



A. Cloyd Gill, *America's Other 60 Families: The Real Rulers of America* (League for Constitutional Government, 1939).

Raúl the Third and Elaine Bay, *Boston Kids Count* (Leventhal Map & Education Center, 2020).

Walter Vrooman, "Map of New York City showing concrete socialism in red, and private enterprises in white, 1895," in *Government Ownership in Production and Distribution* (Patriotic Literature Publishing Co., 1895).

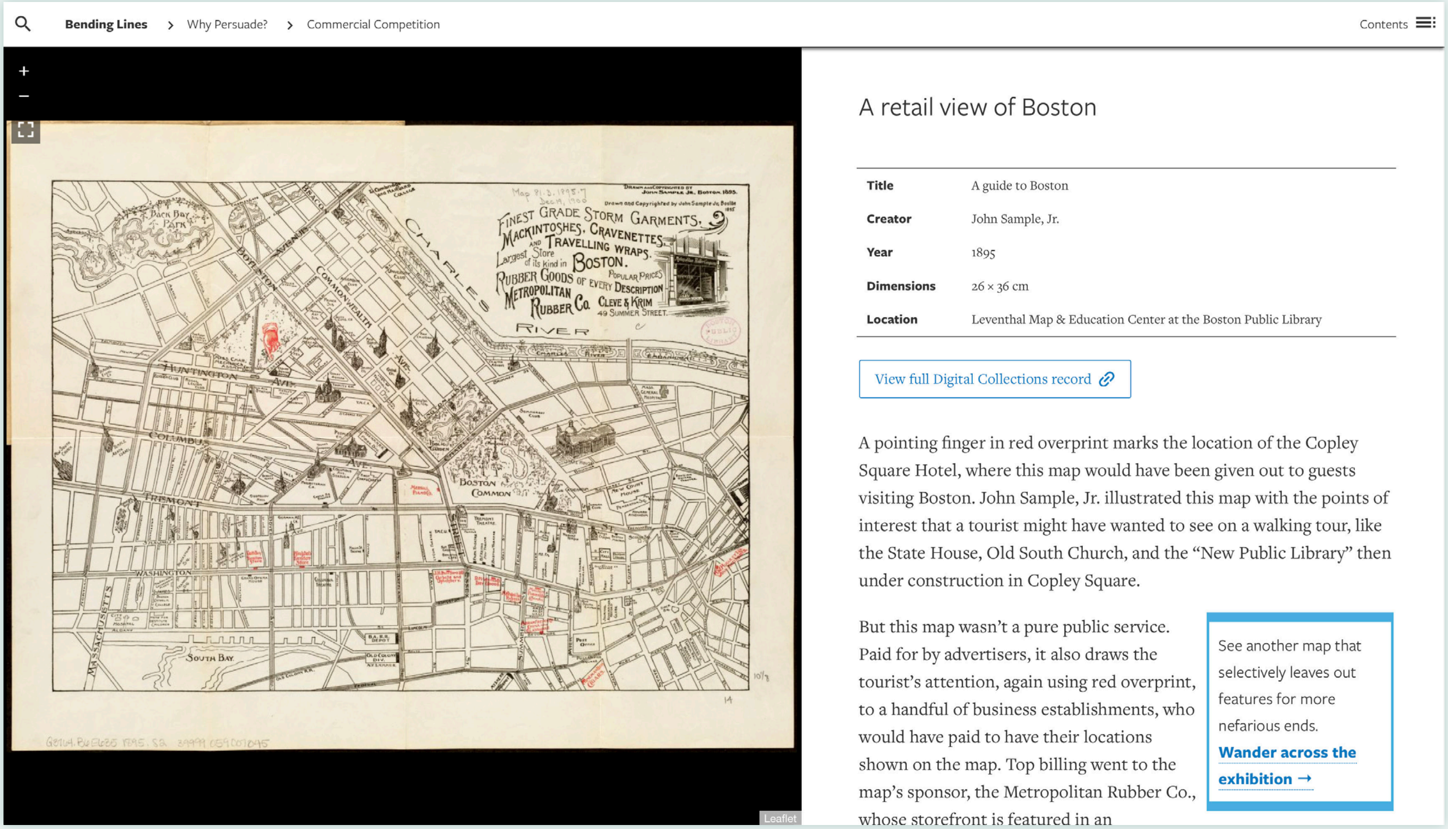


Charles Joseph Minard, Carte figurative et approximative des quantités de coton en laine importées en Europe en 1858 et en 1861 *(1862).*

Canada and the 2008 *People's Republic of Cambridge* map produced by Institute for Infinitely Small Things both show how alternative presentations of toponymy can be used to challenge the dominance of European and male names in the North American landscape (see also Pearce 2014; kanarinka 2011). And, as part of the LMEC's focus on K–12 education, a special section for educators and students features an original cartoon map by the Boston-based artists Raúl the Third and Elaine Bay, based on a choropleth map of American Community Survey data showing the relative concentration of Boston's youth population. Like the rest of the exhibition, this map, titled *Boston Kids Count*, challenges the reader to think about what forms of visual, textual, and argumentative evidence we look to in order to secure our belief that a map is accurate, reliable, and, most importantly of all, the inspiration for taking action.

AN ONLINE EXHIBITION

We were already framing objects and finishing our reproductions in early March 2020 when the Boston Public Library announced its closure to the public to combat the spread of the COVID-19 pandemic. It became clear within the first several weeks of the lockdown that we would not be able to mount the show in a traditional gallery format, and consequently we shifted all of our efforts into redesigning *Bending Lines* for an online-first experience. This effort was greatly aided by the fact that I had already begun working with a beta software environment called Quire, developed by Getty Publications for the creation of digital exhibition catalogues. Based on the Hugo static site generator, with additional layers of customization from the Getty team, Quire is designed by default to create a paginated, linearly traversed site that is analogous to a printed catalogue. We spent considerable effort customizing the Quire templates to produce a digital exhibition that was less linear, and more multi-faceted.



The digital exhibition of Bending Lines.

The online exhibition retained the overall structure of the physical show, and we were able to use most of the objects planned for display, with the exception of those that were not digitized or for which we could not secure rights to distribute digital images. But the digital format also enabled us to add many features which would not have been possible in a static exhibition—for instance, Andy Woodruff's interactive version of Charles Deetz's famous map head projection, and Mike Bostock's interactive presentation of Tissot's indicatrix, both of which were created using the D3.js visualization package for JavaScript. An embedded version of Districtr, the draw-your-own electoral district map created by the Metric Geometry and Gerrymandering Group at Tufts, was added to the section on electoral mapping. And an original interactive, "Do You Trust This Map," allows visitors to look at modern-day maps from television, print, and social media, and evaluate them on a range scale of trustworthiness, in a similar vein to scholarly studies on "viral" mapping by Muehlenhaus (2014) and Griffin (2020).

The digital exhibition—which includes, in addition to the exhibition material, bibliographic metadata for the objects, a scholarly references section, and links to each object's authoritative copy on the LMEC or partner libraries' digital repositories—is available at **leventhalmap.org/digital-exhibitions/bending-lines**.

CONCLUSION: QUESTIONING BELIEF WITHOUT DESTROYING TRUST

Bending Lines is a show that was curated deliberately in an active dialogue with the issues around media, science, knowledge, and communication that have destabilized the politics of the present day. The Boston Public Library, the first large free municipal public library in the country, was founded in the middle of the nineteenth century on the principle that education and citizenship went hand in hand. In this spirit, *Bending Lines* makes the case that the ability to critically examine forms of data representation is a crucial skill for making sense of the complicated, conflictual issues which run through every level of our lives, from community planning decisions to global environmental governance.

Equipping the public with a more careful skepticism of cartographic authority, setting visitors up to critically examine their own beliefs about maps, is one of the foremost goals of this exhibition. At the same time, our planning was done in the context of a society that was challenged by too little trust. Complaints about "fake news" and conspiratorial narratives about the work of scientific institutions are now widespread in the political dialogue of the United States and many other countries. How, then, can we present an argument that "all maps distort the truth" without leading visitors to the paranoid conclusion that "no maps can be trusted"?

The framing, which we repeat throughout *Bending Lines*, emphasizes the fact that omission, simplification, and distortion are not, *in and of themselves*, the playthings of liars and frauds. Instead, we draw attention to the fact that the world is simply too big and too complicated to understand without shorthand devices such as maps and figures. The direction of our critical inquiry, then, should not run along the lines of "does this map perfectly correspond with the world?"—since no such map exists, and indeed

John Speed, A New and Accurat Map of the World *(1626).*

no such form of any human communication exists—but instead along the lines of "*why* did the creator of this object choose the particular perspective on the world that is shown here?" Examining the word "accurate"—a term that appears on many early modern maps, including the 1626 John Speed double hemisphere map shown in *Bending Lines*—offers one hint to support this thesis: accuracy derives etymologically not from a sense of objective matching with a world prior to interpretation, but, instead, from the term *care*, referring to the mapmaker's intentions and practices in creating the map. In this sense, we have tried to show that an "accurate" map is one where the mapmaker has taken a caring, judicious approach to representing the world as fairly and as sensitively as possible, and has considered the power dynamics that underly their use of visual language.

Perhaps most importantly of all, *Bending Lines* forms just the first part of a series of initiatives at the LMEC to equip citizens with the skills, resources, and institutional support to act not only as consumers of cartographic knowledge, but as producers of it, as well. Following the famous maxim "map or be mapped" (Stone 1998), the exhibition argues that ordinary people cannot simply rely on the good intentions of professional cartographers to tell an unproblematically objective truth, but must instead engage in forms of cartographic communication that run in both directions. By connecting *Bending Lines* with our education programs in both K–12 classrooms and with adult learners, we believe that if there is to be something like a substantive truth in maps and data, it will come not in a single, perfect map, but rather in the back-and-forth of an ongoing dialogue amongst many kinds of producers of geographic knowledge.

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Normalizing the Normal Map

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INTRODUCTION

Before becoming a cartographer, I made 3D graphics and animations. My favorite projects were those where I had to achieve my goals by using the tools available to me in ways that were very different from their intended purpose. As a cartographer, I've continued borrowing and "misusing" tools from computer graphics, especially the *normal map*. The more I use normal maps in cartography, the more I feel that they *should* be considered a common tool in both cartographic representation and GIS analyses. Unfortunately, up until recently there has been little mention of them in cartographic communities or scientific literature. I'd like to help popularize their misuse.

Readers may already be familiar with the aspect-slope map (Figure 1), which represents surface orientation using two angular measurements. A normal map is the linear coordinate version of an aspect-slope map; it represents surface orientation using a type of 3D vector called a surface normal.

This article will go into the specifics of what a normal map is, how to make one, and some ways to use them in cartography.

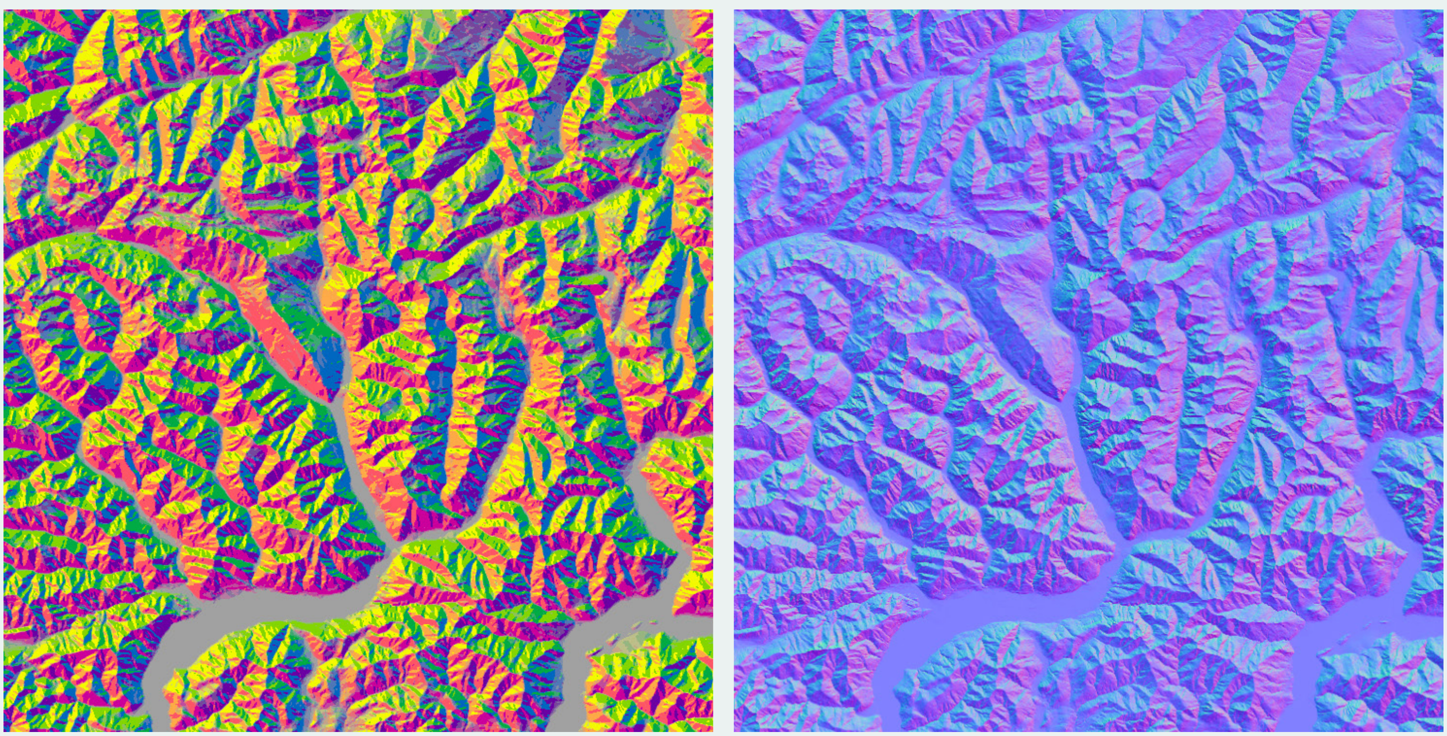

Figure 1. *Two methods for displaying surface orientation.* ***Left:*** *an aspect-slope map.* ***Right:*** *a normal map.*

WHAT IS A NORMAL MAP?

PICK A POINT on a surface. Imagine a line originating from this point that is one unit long and perpendicular—or normal—to the surface. This line is a vector called a surface normal. A normal map is a raster where the cells represent the normals of a surface.

Vectors have two main properties that will be important for the remainder of this discussion:

- They have a length (also called magnitude) and a direction. In the case of surface normals, the direction is also the direction that the surface faces.
- They have a component for each of their dimensions. A 3D vector like a surface normal has three components: x, y, and z. These components are the distances traversed by the vector along each axis of the coordinate system it is drawn in (Figure 2).

The components of a vector are related to its length by:

$$\sqrt{x^2 + y^2 + z^2} = length \quad \text{(Equation 1)}$$

A normal has a length of one, making it a unit vector. Values for unit vector components have a range of (-1.0, 1.0), and if one component is close to 1.0 or -1.0, the other components will be close to 0. This known range of values makes it easy to remap the components to the range (0, 255) used for RGB color channels:

$$colorValue = 255\left(\frac{componentValue + 1}{2}\right) \quad \text{(Equation 2)}$$

Usually, x is assigned to red, y to green, and z to blue. So, for a level surface, the normal vector would be (0, 0, 1.0) and the corresponding color is RGB(128, 128, 255) or #8080FF. This is the blue color predominant in many normal maps.

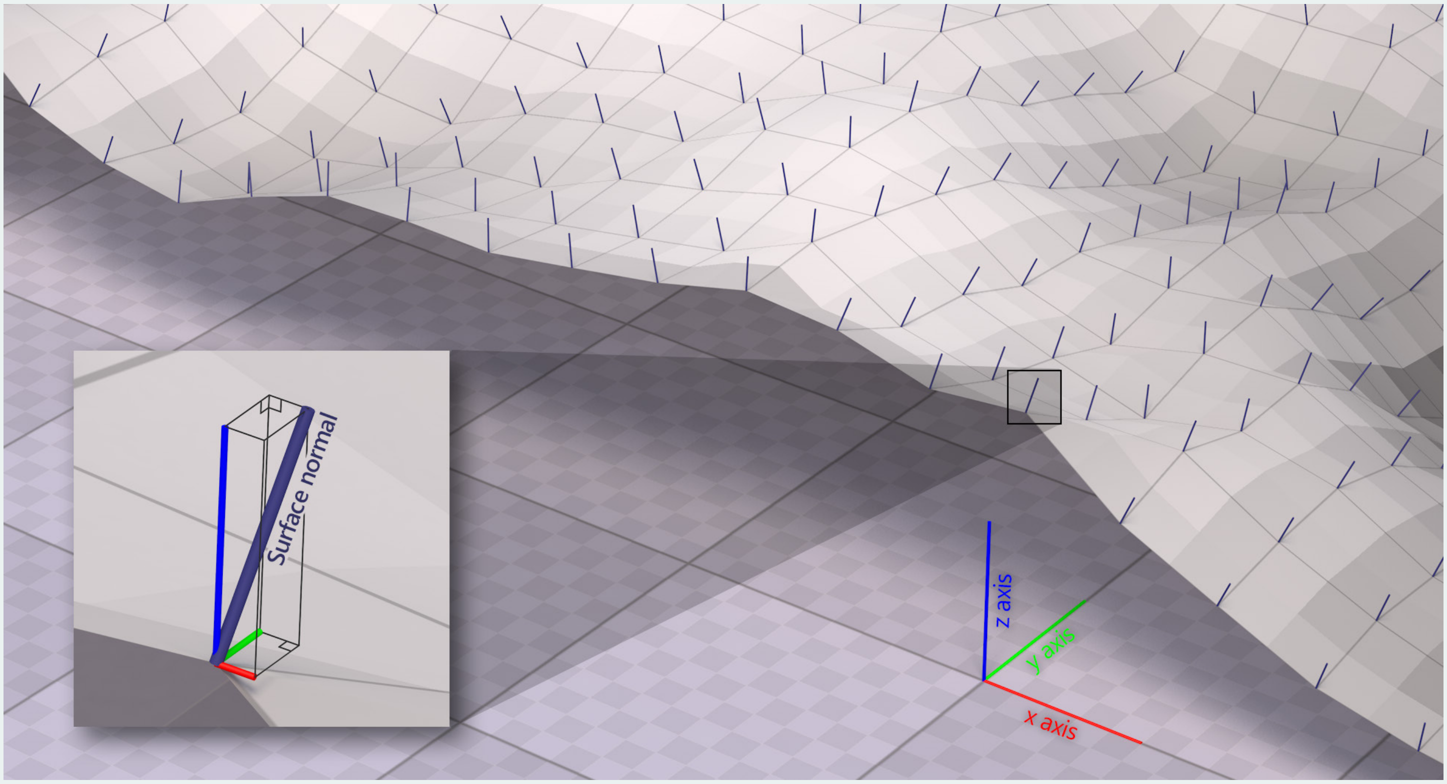

Figure 2. *A 3D surface generated from an elevation raster. Each vertex represents the center of a raster cell, and the normals are drawn from these vertices, perpendicular to the average surface around them.* ***Inset:*** *the distances traveled along each axis by the normal are its components. This one travels a little bit to the east (positive x), a bit more to the north (positive y), and mostly upward (positive z).*

CREATING A NORMAL MAP

Normal maps and the tools used to make them are ubiquitous in graphics apps, but for best results, I recommend creating and working with them in a GIS or with a scripting language like Python. Most of this article assumes that you are using a GIS or coding environment to work with normal maps.

USING GRAPHICS SOFTWARE

Most graphics apps have a function for generating normal maps from grayscale height maps. Those that don't will usually have normal map plugins available. Graphics apps often disagree on whether y or z is the vertical axis, and on which direction is positive along each axis. Assuming your map is oriented with north at the top of the page, the convention I will use for this article is: +x = east, +y = north, and +z = up. If your app does not follow this convention, or you prefer another, you can reorder or invert the color bands (or channels) until they meet your needs.

Some apps have options for generating normal maps in world, object, and tangent space, but these should all be the same for a geospatial elevation map. If not, tangent or world space should be the safest options. If the normal map looks bluish in flat areas, reddish on east slopes, and greenish on north slopes (as in Figure 1), it is similar to those described in this article.

USING A GIS OR PYTHON

Many of the uses for normal maps that I'll discuss later require the ability to perform mathematical operations on rasters. I recommend using a GIS or a programming language like Python to produce and work with normal maps because they make these operations much easier and faster. My two preferred methods for creating a normal map are discussed below.

Option 1: Compute the Components Using Aspect and Slope

Conceptually, the simplest way to make a normal map in a GIS without a specific tool is to first make a slope raster and an aspect raster from your elevation map. Since a normal map is the vector form of the aspect-slope map, it can be obtained by the conversion of these angles to a vector:

$$x = \sin(aspect) \times \sin(slope) \qquad \text{(Equation 3)}$$

$$y = \cos(aspect) \times \sin(slope) \qquad \text{(Equation 4)}$$

$$z = \cos(slope) \qquad \text{(Equation 5)}$$

Once the components are calculated, compositing these raster bands will yield the normal map:

$$\boldsymbol{n} = (x, y, z) \qquad \text{(Equation 6)}$$

Option 2: Compute the Components Using Elevation Gradients

This method is the same one used in Pyramid Shader (terraincartography.com/PyramidShader). It is more direct and probably generates smaller errors than Option 1:

1. **To get the x component, subtract the value of the cell's right neighbor from the value of its left neighbor. Do the same for the top and bottom neighbors to get the y component.** These are elevation gradients (change in elevation, or "rise") along the x and y axes.

2. **The z component for every cell is initially the raster's cell width plus its cell height.** It might seem counterintuitive to use a constant obtained from horizontal distances as the vertical component, but it may be helpful to think of this as the "run" and x and y as the "rise." With both normals and linear functions, zero rise and a nonzero run indicate a level surface or line, while a high rise with the same run indicates a steep surface or line.

   With all three components, the vectors have the correct direction, but the magnitude will vary from cell to cell. It needs to be 1.0 for all cells.

3. **Get the magnitudes of the vectors.** Use Equation 1: $\sqrt{x^2 + y^2 + z^2}$

4. **Divide each component by the magnitudes** to make the vector a unit vector. Note that the value of z will now be small if the value of x or y was large. Or, if it was the only nonzero component, i.e., the surface was level, z will now be 1.0, and the vector will be (0, 0, 1.0).

5. **Write x, y, and z to the red, green, and blue bands of a raster, respectively.**

While this workflow should be doable using the raster tools in most GIS packages, it is best suited for Python or any other programming language. An implementation with NumPy and ArcPy might look like Example 1.

The syntax `H[a:b, c:d]` is a way to get a copy of the array as if the array was shifted one cell in a given direction. This allows you to make four additional arrays containing the original array's left, right, top, and bottom neighbors for each cell, and then subtract those arrays from each other.

PROPERTIES OF A NORMAL MAP

If the normal map is split into its component bands (Figure 3), the bands appear similar to three perpendicular hillshades lit from the positive direction of their respective axes; east, north, and directly above. This is a useful point that I'll come back to when I talk about soft hillshading.

```
import numpy as np
import arcpy

def NormalMap(H, cX, cY):

    # Pad the raster by 1 cell to help deal with raster edges; will be undone in next steps.
    H = np.pad(H, 1, 'edge')

    # x component = left neighbor - right neighbor (also trims width by 1 cell)
    X = (H[1:-1, 0:-2] - H[1:-1, 2:])

    # y component = bottom neighbor - top neighbor (also trims height by 1 cell)
    Y = (H[2:, 1:-1] - H[0:-2, 1:-1])

    # z component = cell width + cell height
    Z = np.ones(X.shape, dtype='float32')
    Z *= cX + cY

    # Get the magnitudes of the 3D vectors
    M = np.sqrt((X ** 2) + (Y ** 2) + (Z ** 2))

    # Divide each component by the magnitude, then stack them into a 3D array
    N = np.stack((X / M, Y / M, Z / M), 2)

    # Make the band the first axis; output axes will be (band, row, column)
    N = np.moveaxis(N, 2, 0)

    return N

def NumpyToRGB(array, corner, cX, cY, srs, destination):

    compX = arcpy.NumPyArrayToRaster(array[0], corner, cX, cY)
    arcpy.DefineProjection_management(compX, srs)

    compY = arcpy.NumPyArrayToRaster(array [1], corner, cX, cY)
    arcpy.DefineProjection_management(compY, srs)

    compZ = arcpy.NumPyArrayToRaster(array [2], corner, cX, cY)
    arcpy.DefineProjection_management(compZ, srs)

    finalComp = arcpy.CompositeBands_management([compX, compY, compZ], destination)
    arcpy.DefineProjection_management(finalComp, srs)

elevationRaster = arcpy.Raster(inputPath)

cX = elevationRaster.meanCellWidth
cY = elevationRaster.meanCellHeight
srs = elevationRaster.spatialReference
corner = arcpy.Point(elevationRaster.extent.XMin, elevationRaster.extent.YMin)

ElevationArray = arcpy.RasterToNumPyArray(elevationRaster)
NormalArray = NormalMap(ElevationArray, cX, cY)
NumpyToRGB(NormalArray, corner, cX, cY, srs, outputPath)
```

Example 1.

The blue color of the most common variant of normal maps is due to the behavior of the z, or blue band. The z-band is usually close to or equal to 1.0 because nearly level ground is more common than slopes, and it is always greater than 0 because these rasters cannot show vertical cliffs or overhanging surfaces. Meanwhile, the x and y bands can be positive or negative, are usually close to 0, and their absolute values are always less than 1.0. Each color on the normal map represents a different orientation. Unlike an aspect raster, it is always the case that the closer the colors (or components) of two normals are to each other, the more similar are their orientations.

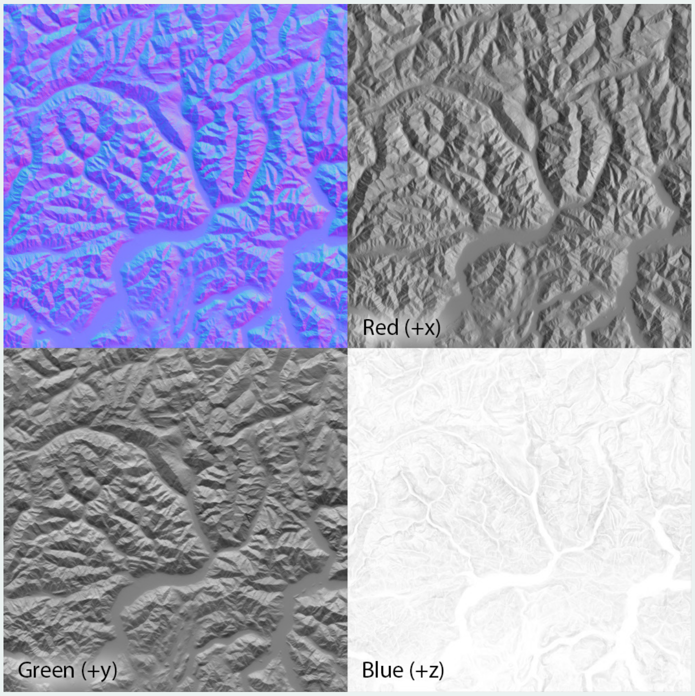

Figure 3. A normal map and its three component bands. For each band, white is equal to 1.0, medium gray to 0, and black to -1.0.

APPLICATIONS FOR NORMAL MAPS

Normal maps are seen most commonly in interactive 3D graphics, where rendering times are of high importance. Typically, a high-resolution mesh is used to create a normal map, which is draped or wrapped onto a simplified version of the mesh in a manner similar to a texture. The renderer reads the values of the normal map instead of the actual surface normals of the mesh when performing lighting calculations (Figure 4). Having a low-density mesh that responds to light like a high-density mesh greatly improves rendering time with minimal impact on quality.

This works because the two most important factors for modeling the interaction of light with a surface are: the orientation of incoming light rays, and the orientation (or normal) of the reflecting surface.

This is also true for cartographic relief representation; in many cases elevation rasters are an abstraction of the information we use for terrain shading. Now I'll discuss some benefits of working directly with normal maps in cartography, starting with basic hillshading.

SOFT HILLSHADING

A common hillshading technique is based on a model of light diffusion described by Lambert (1760), and is called Lambert shading. It uses the following procedure:

1. Compute the surface normal at each cell of an elevation raster.

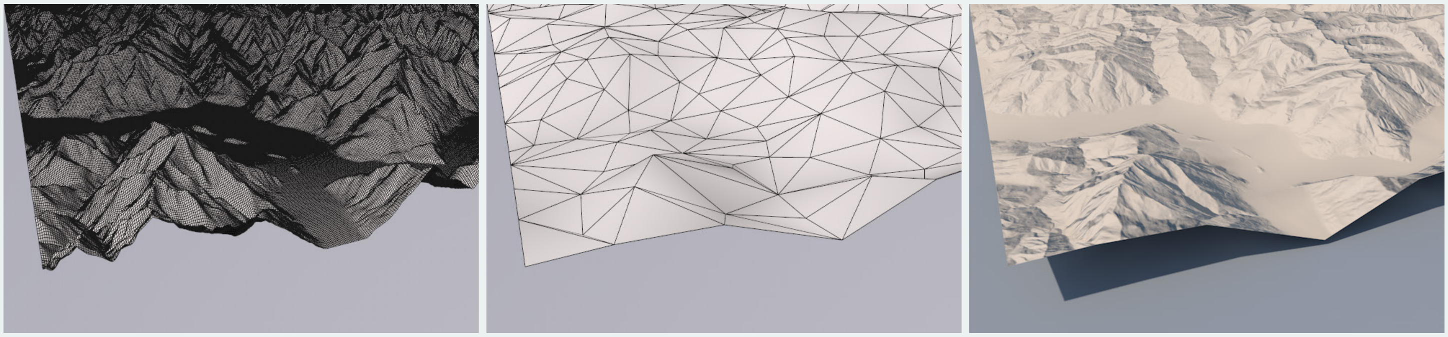

*Figure 4. A dense mesh (**left**) may not draw fast enough for an interactive display, while a simplified version (**center**) may draw quickly but lack the desired detail. A normal map generated from the full-resolution mesh can be used to override the simplified geometry's normals during shading (**right**), giving the benefits of both.*

2. Take the dot product between that normal and the direction of the light source. This produces a raster with values between -1.0 and 1.0.

3. Set all negative values to zero and multiply all values by the output format's value for white (in the case of an 8-bit raster, this is usually 255).

Previously I mentioned that the individual bands of a normal map are similar to hillshades lit from their respective axes. This seems a bit of a stretch if we compare the two (Figure 5), but it turns out that if the Lambert method stopped before step 3, they would be identical. That final step essentially took everything equal to or darker than medium gray in the right image and clipped it to black, adjusting the contrast accordingly. This included the level surfaces, which were perpendicular to the light vector.

Even with standard lighting, it is common for a cartographer to reduce contrast or add transparency to a Lambert hillshade. Since this work essentially undoes the last step of the Lambert method, and since the low clip on negative values isn't reversible, it makes more sense to perform the shading yourself and skip step 3. If it turns out that the contrast or clip are necessary, you can apply them yourself.

Step 1 is complete upon the creation of a normal map. For step 2, you'll calculate the dot product between the normal map and a constant unit vector representing the lighting direction. Not all apps have a dot product function out of the box, but you can compute it by multiplying the respective components of the two vectors together, then summing the results:

$$\boldsymbol{n} \cdot \boldsymbol{l} = \boldsymbol{n}_x \boldsymbol{l}_x + \boldsymbol{n}_y \boldsymbol{l}_y + \boldsymbol{n}_z \boldsymbol{l}_z \qquad \text{(Equation 7)}$$

Using a single cell of a terrain surface with a westward slope of 36.87° as an example, the normal for that cell would be (-0.6, 0, 0.8). Typical hillshade lighting, from a 315° azimuth and elevated by 45°, corresponds to the vector (-0.5, 0.5, 0.71).

$\boldsymbol{n}$ = (-0.6, 0, 0.8)
$\boldsymbol{l}$ = (-0.5, 0.5, 0.71)
$\boldsymbol{n} \cdot \boldsymbol{l}$ = (-0.6 × -0.5) + (0 × 0.5) + (0.8 × 0.71)
= 0.87 (light gray on a scale from -1.0 to 1.0)

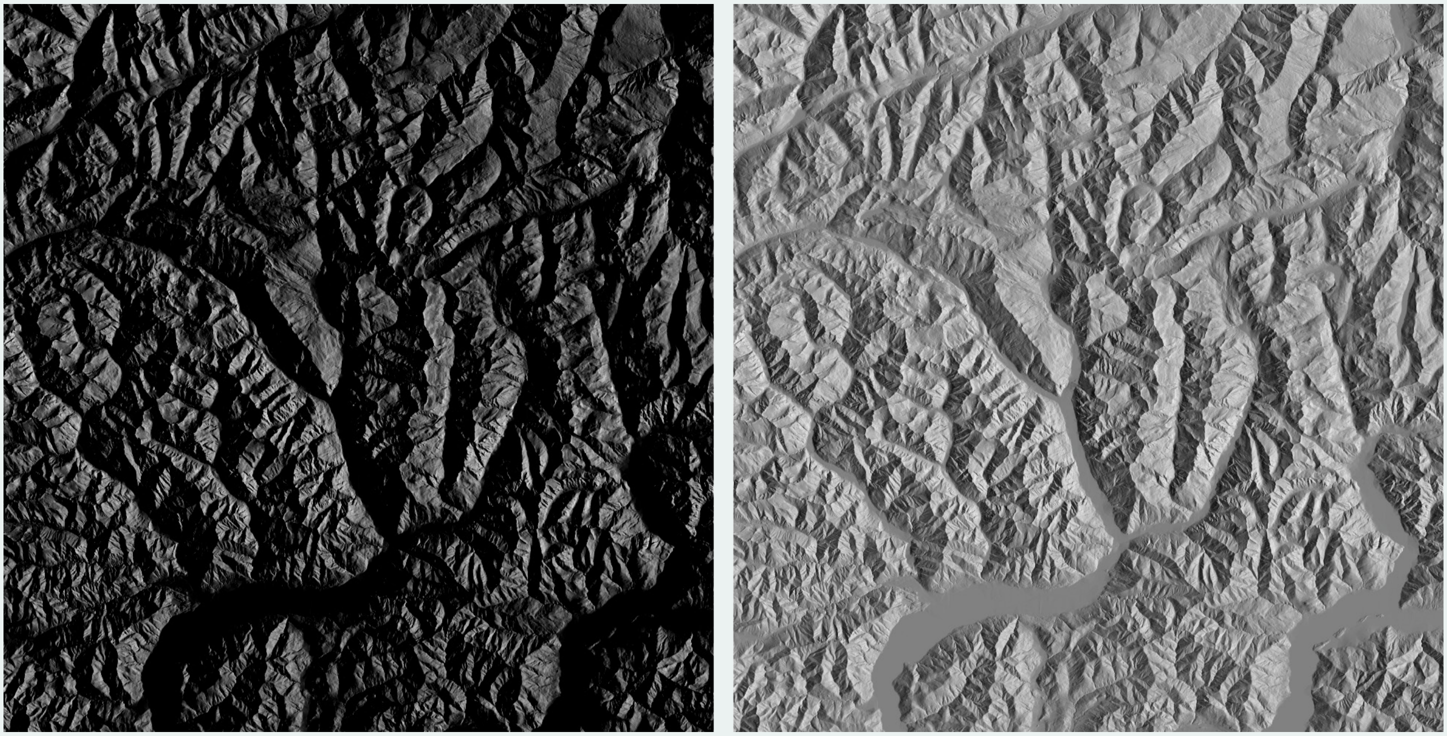

Figure 5. Left: *A Lambert hillshade lit from the eastern horizon.* ***Right:*** *The normal map's x-band, or the same Lambert hillshade before the final step of the algorithm was performed.*

Figure 6 shows an example of this method, which I refer to as soft hillshading, and illustrates the relationship between surface orientation, lighting angle, and shading. The illustration makes it clear that this is not a realistic model of direct lighting. However, shading a terrain exclusively with direct lighting is itself unrealistic, since indirect light is cast on the terrain by the sky and from surrounding illuminated surfaces. In any case, as cartographers, we often favor clarity over realism.

APPROXIMATING MANUAL RELIEF WITH NORMAL MAPS

Manual shaded reliefs have characteristics that make them both very useful for terrain visualization and very difficult for automation (Marston and Jenny 2015; Hurni 2008). I focus on three of these characteristics here:

- Major landforms have greater visual weight than small landforms, reducing visual clutter and noise.
- Lighting and shading are adjusted locally to show features of equal prominence at roughly equal contrast, regardless of the map's lighting direction.
- Greater contrast is given to the crests of peaks and ridges, and less is given to valley floors, regardless of their absolute elevation.

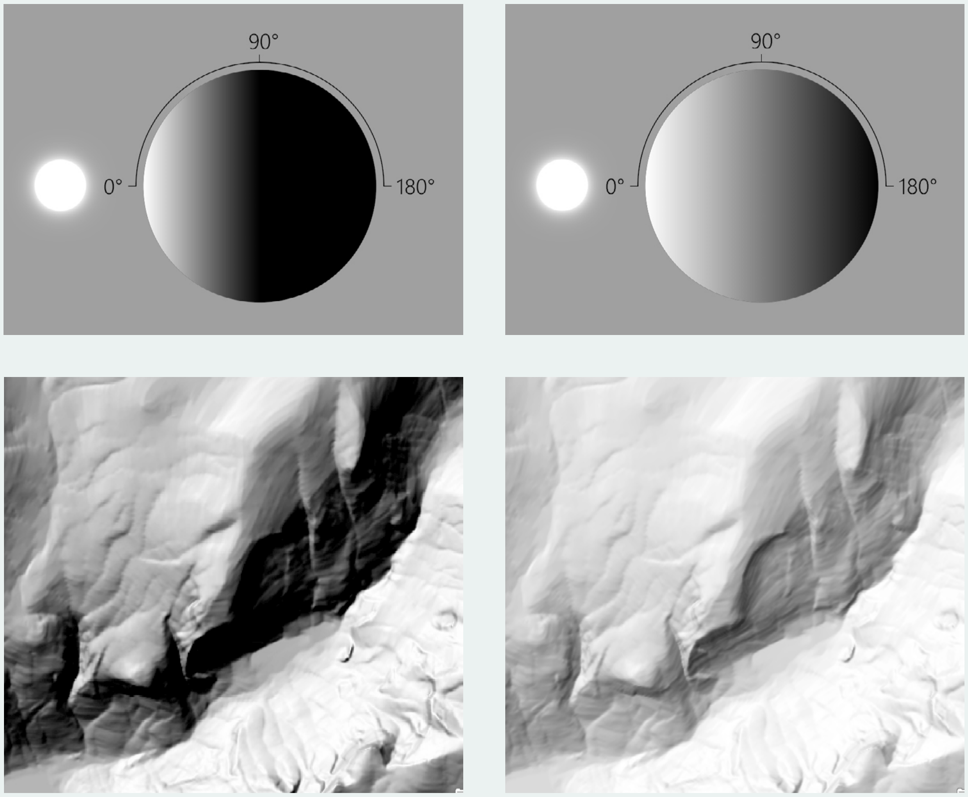

Figure 6. Left: *Lambert shading will only illuminate surfaces that face toward the light source at least partially.* ***Right:*** *With the same lighting angle, soft hillshading preserves all the information in the surface, has a contrast profile that is less harsh, and requires less correction by the cartographer.*

Figure 7. *A standard analytical shaded relief (**left**) compared with a manual shaded relief by Imhof and Leuzinger (1963;* shadedreliefarchive.com/Graubuenden_SW.html*; **right**). Despite deviating from what more physically accurate lighting would portray (or because it deviates from it), this style is better able to communicate a mental map of the relative significance of topographic features.*

These characteristics are beyond the capabilities of standard hillshading (Figure 7), and many researchers, myself included, continue to explore methods for automated relief shading that more closely approximate manual reliefs. My own explorations have mostly involved the use of normal maps, and I have found that normal maps can be applied to each of the characteristics listed above.

Terrain Generalization in Orientation Space

In Lambert hillshading, all slopes of a certain orientation are given the same shade, whether that slope occurs over a contiguous area of one square meter, or thousands of square meters. Thus, in Lambert shading, it is common for small, insignificant topographic features to visually

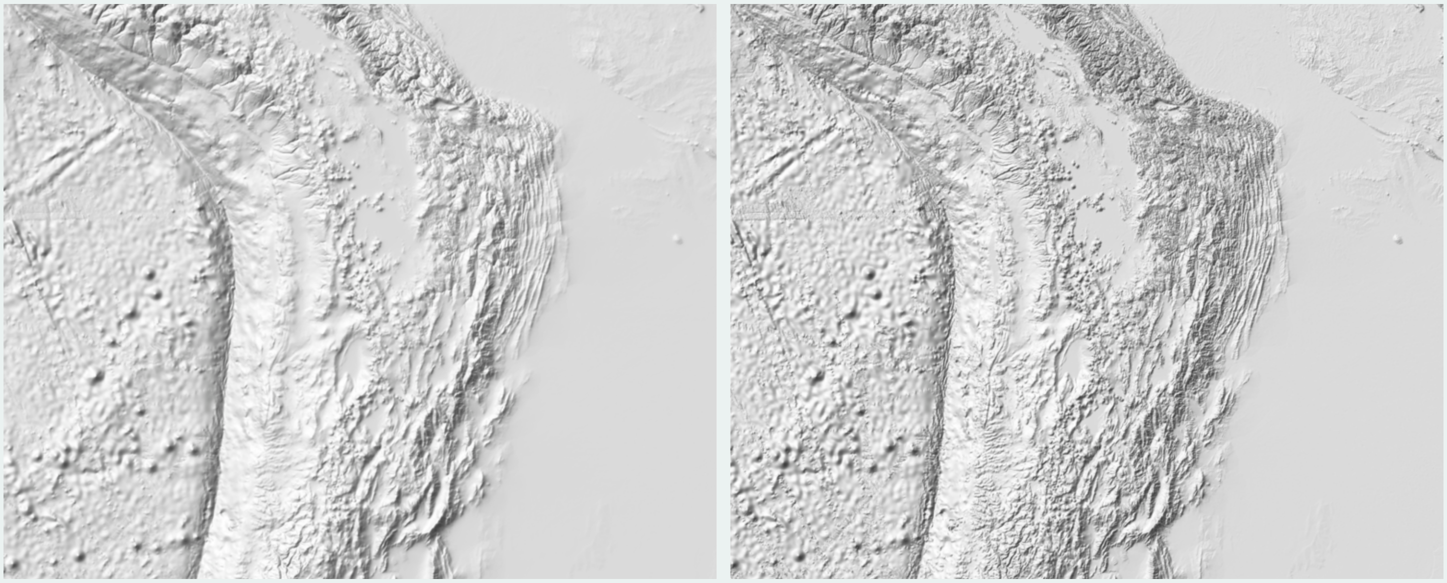

Figure 8. *A comparison of an Andes hillshade based off generalized (**left**) and ungeneralized (**right**) elevation data. The area northeast of center is an especially good demonstration of how Lambert shading with an ungeneralized elevation raster can obscure large features.*

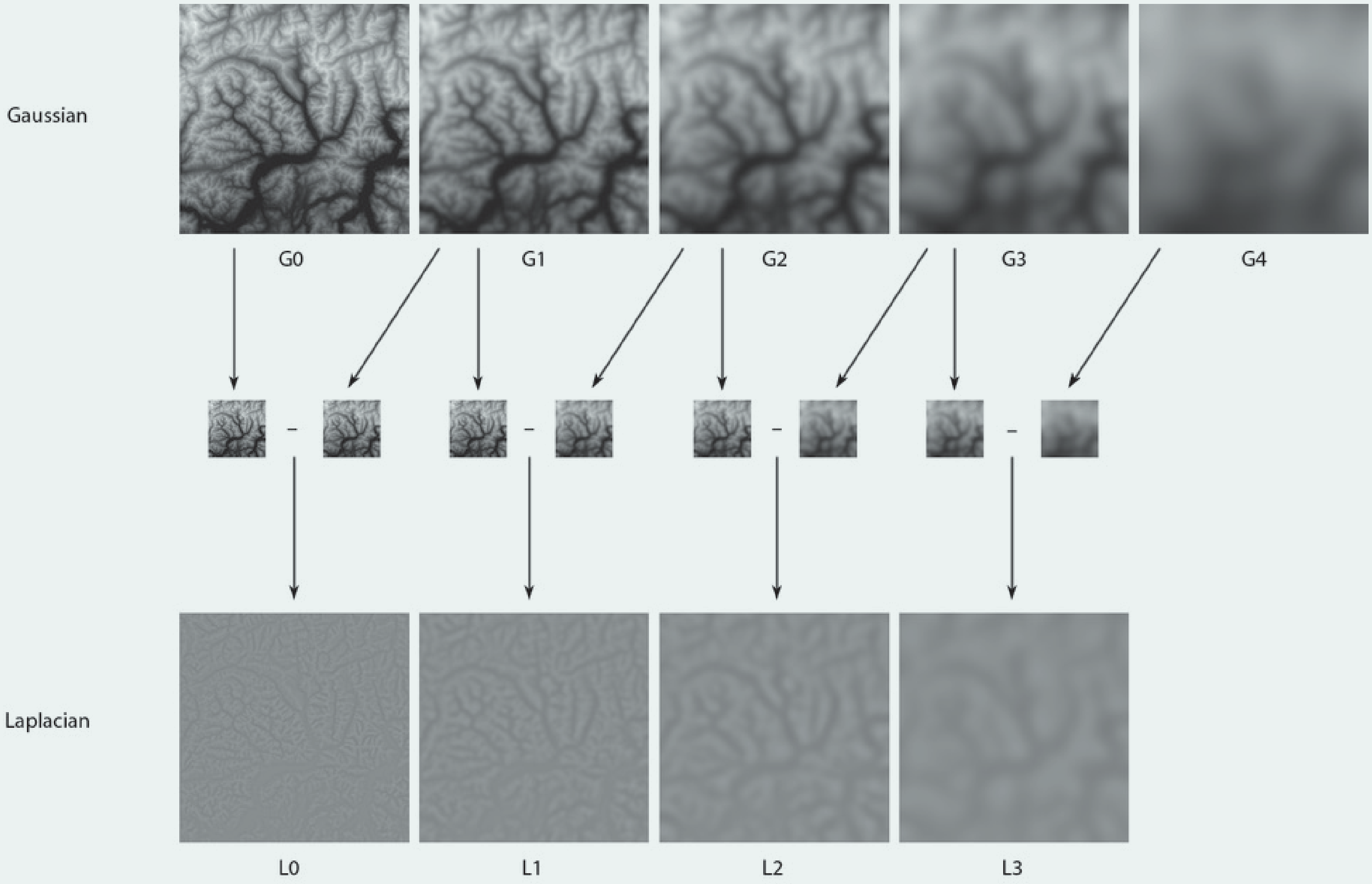

Figure 9. *Construction of a Laplacian pyramid. Starting with an elevation raster (represented by G0), run a series of Gaussian filters, each with twice the radius of the previous. The resulting set of blurred elevation rasters is a Gaussian pyramid (top row). To produce the levels of the Laplacian pyramid (bottom row), subtract each level of the Gaussian pyramid from the previous level. The sum of all Laplacian levels plus the largest Gaussian level is the original elevation raster, so the elevation raster can be generalized by assigning different weights to these levels.*

overwhelm the large features that they are a part of. This is especially true on small-scale maps (Figure 8).

Some readers may be familiar with Pyramid Shader, a project I worked on as a member of the Oregon State University Cartography and Visualization Group (**terraincartography.com/PyramidShader**). This Java application uses Laplacian pyramids to isolate different frequencies, or scales, of detail in an elevation raster (Figure 9). Higher (smaller) frequencies are given a lesser weight than lower (larger) frequencies, so the shading influence of small features is more proportional to their size. The isolated levels of detail are then recombined to produce a generalized elevation raster for hillshading. I describe Pyramid Shader's method in greater detail on my blog: **geolographer.xyz/blog/2017/2/27/an-introduction-to-pyramid-shader**.

Since working on Pyramid Shader, I've explored using normal maps instead of elevation rasters, and median filters instead of Gaussian filters (Figure 10). Like the Gaussian filter, the median filter tends to smooth out regions of similar color. Unlike the Gaussian filter, median filters preserve edges where colors abruptly change. On an elevation raster, edges correspond to sudden changes in elevation, which usually represent cliffs. On a normal map, edges correspond to abrupt changes in orientation, which include cliffs, ridgelines, stream channels, edges of floodplains, and other major topographical features that a cartographer will likely want to retain. In other words, median filters on a normal map remove the details we don't want and preserve the details we do want.

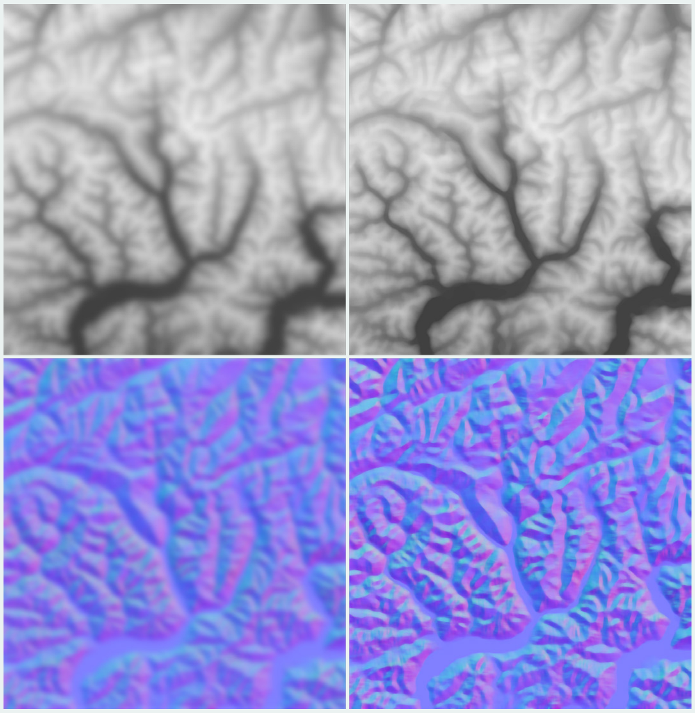

Figure 10. *Comparison of Gaussian (**left**) and median (**right**) filters on an elevation raster (**top**) and a normal map (**bottom**). The normal median (lower right) has the best results in terms of eliminating noise while preserving scale-specific features of cartographic interest, and thus is used in the modified pyramid generalization algorithm.*

Substituting normal maps for elevation rasters, and median filters for gaussian filters, it is possible to build a pseudo-Laplacian pyramid in a similar manner to Pyramid Shader (Figure 11). The median filters can take much longer to compute than the Gaussian filters, but they are worth the wait.

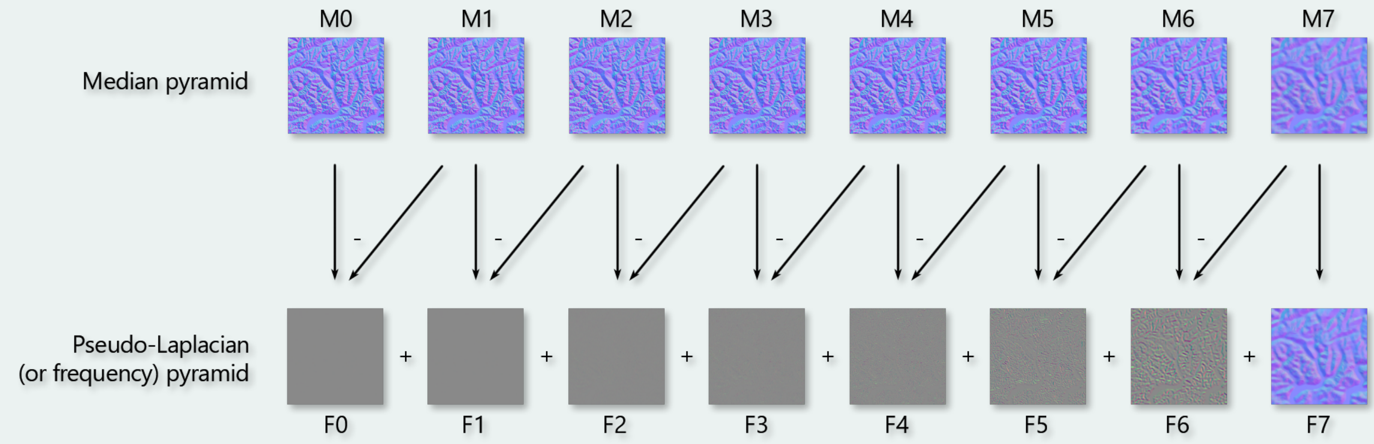

Figure 11. *A modification of Pyramid Shader's approach. Build a median pyramid from a normal map, and then use the differences between those medians to build a pseudo-Laplacian pyramid.*

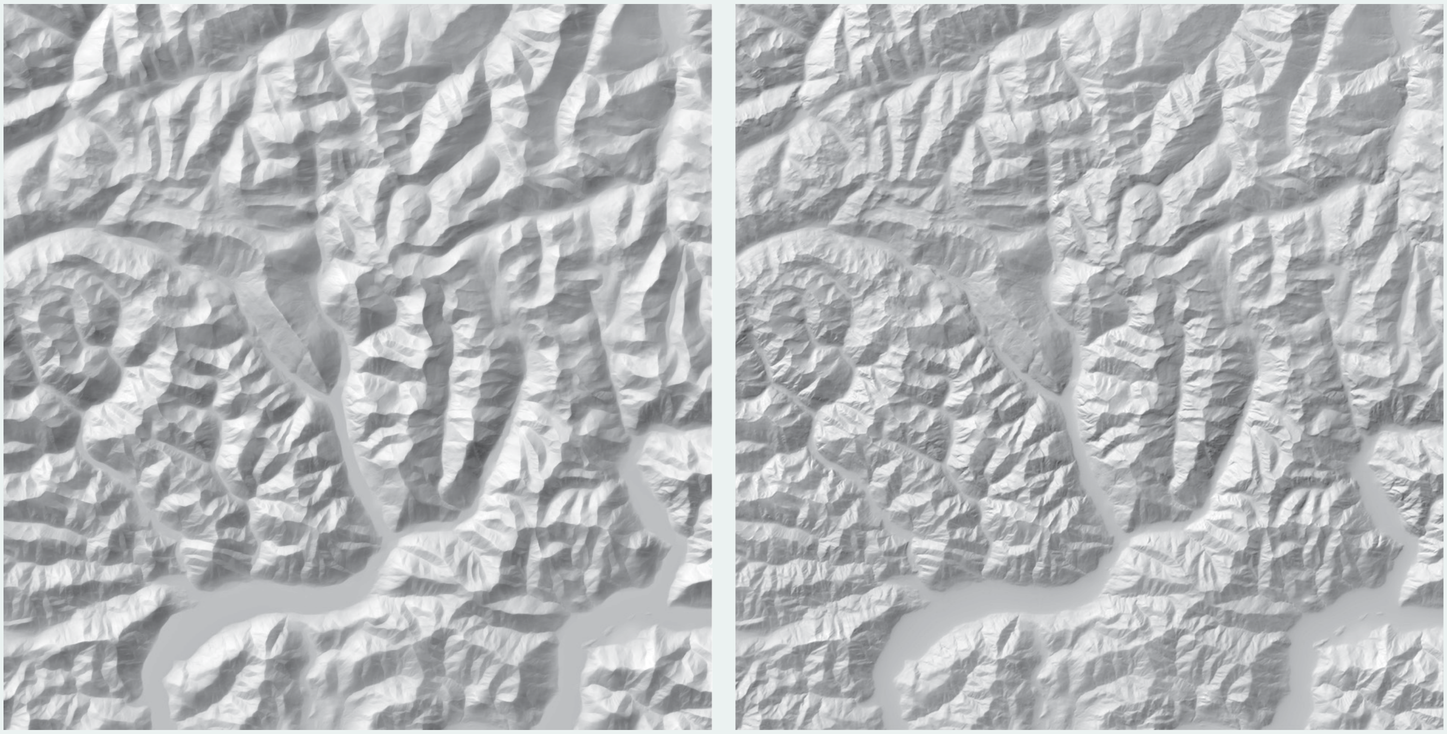

*Figure 12. Normal median generalization (**left**) with exponential weights allows for very strong generalization of small features without blurring large features. In Pyramid Shader (**right**) the same terrain, with the same number of pyramid levels, cannot have its weights reduced further than what is shown here without visibly blurring the ridgelines and valley edges of large-scale features.*

Once the frequency pyramid is generated, weights can be assigned to each level of the pyramid, and then they and the largest median level are summed together to form the pyramid-generalized normal map.

Pyramid Shader currently uses a linear system to assign weights, but my preferred method is to use an exponential function so that the coarsest frequency level has a weight of one, and each finer frequency level's weight is $1/b$ of the weight of the previous level. If, for example, you set $b = 2$, every finer level of detail has half the weight of the one before it:

$$w = 1 / b^{(n-1)-l} \qquad \text{(Equation 8)}$$

Where w is the weight applied to a level, b is a user-selected base for the exponent, n is the number of levels, and l is the number of the current level. Here, level numbers start at 0, not 1.

Exponential weighting causes fine levels to be more sensitive to generalization than coarse levels, which allows the relative generalization of larger features to be kept to a minimum. The use of normals, medians, and exponential weights allows the cartographer to generalize small features further and preserve the sharpness of large features more easily than with Pyramid Shader's linear Laplacian method (Figure 12).

Variable Lighting Direction

As discussed in the soft hillshading section, the dot product takes two vectors as inputs. One of these inputs was variable, and the other was constant. However, there is no reason why they can't both be variable. By using a variable light vector for hillshading, a cartographer can emulate the local lighting adjustments in manual hillshading. What would this light vector raster look like?

First, since it will represent a unit vector, this raster will have the same value limits as the normal map, and it will satisfy Equation 1. Unlike with the normal map, the z-band can be negative, which would mean the light is coming from below the ground (probably an uncommon case, but I encourage you to experiment with it). So, the light vector raster can be any color you'd see in a normal map, plus the colors with negative z values.

Second, a dot product between two unit vectors is 1 when the vectors are equal and -1 when they are opposite. So, the most brightly lit areas will be where the normal map and light map are equal, and the darkest areas will be where they are opposite.

Recall that the standard cartographic light vector is (-0.5, 0.5, 0.70711), or #3FBFD9. This is a dull cyan. The areas where lighting is not modified will be this color on the light vector raster. Areas where lighting should be adjusted will be a different color. Good lighting direction choices would be from the west (-0.70711, 0, 0.70711), which is the color #257FD9, or from the southwest (-0.5, -0.5, 0.70711), which is the color #3F3FD9. You can obtain the color for these or any other light vector by using Equation 2 through Equation 5.

To approximate manual hillshading, the lighting should change only for major topographical features according to their generalized aspect, which can be obtained from a smoothed normal map. In the previous section, I covered using median filters to smooth normal maps at different scales. For the following example, I'll use the highest of those median levels. Again, I recommend using median normals rather than Gaussian normals.

1. **Multiply the z-band of the largest median level by 0.1.** Large values for the z-band can reduce the quality of the final result, but z must be non-zero for proper handling of level surfaces, so it is simply reduced here.

2. **Divide the result of step 1 by its magnitudes.** Use Equation 1 ($\sqrt{x^2 + y^2 + z^2}$). With the z-band reduced, this new unit vector raster is essentially an aspect map using vector values, which will be called the xy raster.

3. **Compute the dot product between the xy raster and a horizontal vector perpendicular to the azimuth of your main light.** There will be two vectors that fit this description, but either choice will lead to the same result in the next step. In this example, my main light is from the northwest, and I chose the vector pointing to the southwest horizon (-0.70711, -0.70711, 0).

4. **Take the absolute value of the result of step 3.** Surfaces facing directly toward or directly away from the horizontal vector in step 3 should have their lighting adjusted in the same way, and conveniently have the same absolute value. The result of this step is a mask representing the ratio with which to apply the adjusted light vector vs. the main light vector. If you want to narrow the range of aspects where lighting is adjusted, multiply this mask by itself before moving on.

5. **Create the initial light vector raster with the expression (adjustedVector × maskLayer) + (mainVector × (1 - maskLayer)).** This is a weighted sum of your chosen light vectors, using the mask's value (or its complement) as the weight.

6. **Divide the light vector by its magnitudes as in step 2.** You now have a variable light vector raster, where the light source rotates smoothly between your main and adjusted lighting angles depending on color.

7. **Compute the dot product of your regular or generalized normal map and the light vector raster.** I strongly recommend using a generalized normal map from the previous section for this step.

The output of this process is a soft hillshade (Figure 13) where, as large features face more to the southwest or northeast, the light direction rotates toward your chosen adjusted vector.

Another, simpler option might now be apparent from Figure 13; you could paint your light vectors using your

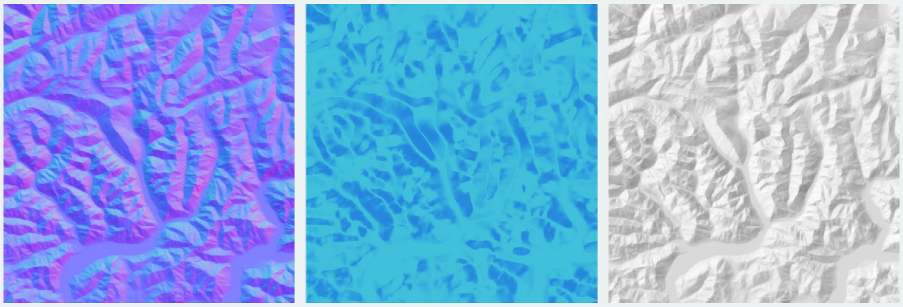

Figure 13. *The dot product between a generalized normal map (**left**) and a light vector raster derived from one of the pyramid levels used to make that normal map (**middle**) is a soft hillshade with a variable light source (**right**). Note that the brightest parts of the hillshade are where the normal map and light vector colors are most similar. In the light vector raster, cyan corresponds to standard lighting from the northwest and blue corresponds to lighting from the southwest, both elevated 45°.*

app of choice. All you need are the colors corresponding to the unit vectors, which you can get using a spreadsheet and Equation 2 through Equation 5, or by constructing a reference image such as Figure 14. Due to the potential for color reproduction issues, I recommend building your own or first verifying that the colors are correct using the equations. While painting may produce colors that are not quite unit vectors, they should usually be close enough to get decent results.

Figure 14. *A reference for unit vector colors on, left to right, a sphere, a faceted cone with a slope of 45°, and a beveled cube.*

Variable lighting vectors can be useful for applications other than manual hillshading; they could be used to make the lighting change by latitude on a worldwide hillshade, to simulate changing sun position in an animated or interactive map, or to highlight regions on a map as if they're lit from multiple light sources if your platform doesn't otherwise support them. I'm sure there are many other uses that you could come up with.

Feature Contrast

The last feature of manual hillshading I'll cover here is the sharpening of contrast on ridgelines. This procedure is best done as part of the pseudo-Laplacian pyramid generalization discussed previously. It is labor-intensive if not done with a script, so if you are not using Python, I recommend only performing this operation for the largest pyramid levels. The steps are:

1. **Run a high-pass filter on the pyramid level with a radius matching the radius of the median that was used on it.**

2. **Multiply the high-pass filtered raster by a mask.** The creation of the mask is described below. Optionally, you can also apply an additional multiplier here if you want even more sharpening.

3. **Add the result to the median pyramid level.**

4. **Divide the result by its magnitudes and proceed with the generalization as above.** Use Equation 1 to obtain the magnitudes. This step may not be necessary, but in some cases not performing it may cause the weighted sum in the generalization process to create unexpected results.

The creation of the mask is the most complicated part of this process, but it is necessary because the high-pass filter will sharpen flat areas near slopes. I recommend starting with either a local hypsometric (LH) raster as described by Huffman and Patterson (2013), or the difference raster from the same paper if the LH raster contains NoData cells. In either case, use the same radius as the median filter for your pyramid level. Once that is done:

1. **Divide the LH raster by its maximum value, then take the maximum between the result and 0.** This clips all negative values and ensures the highest value is 1.

2. **Take the square root of the raster.** Since all values are between 0 and 1.0, this will increase the middle values in the raster without any change to the minimum or maximum, similar to a curve operation in Photoshop where the center of the curve is moved upward.

This should yield a raster where convex areas are close to 1 and concave areas are 0, on a scale roughly matching that of your median normal map and the high-pass filter you ran on it.

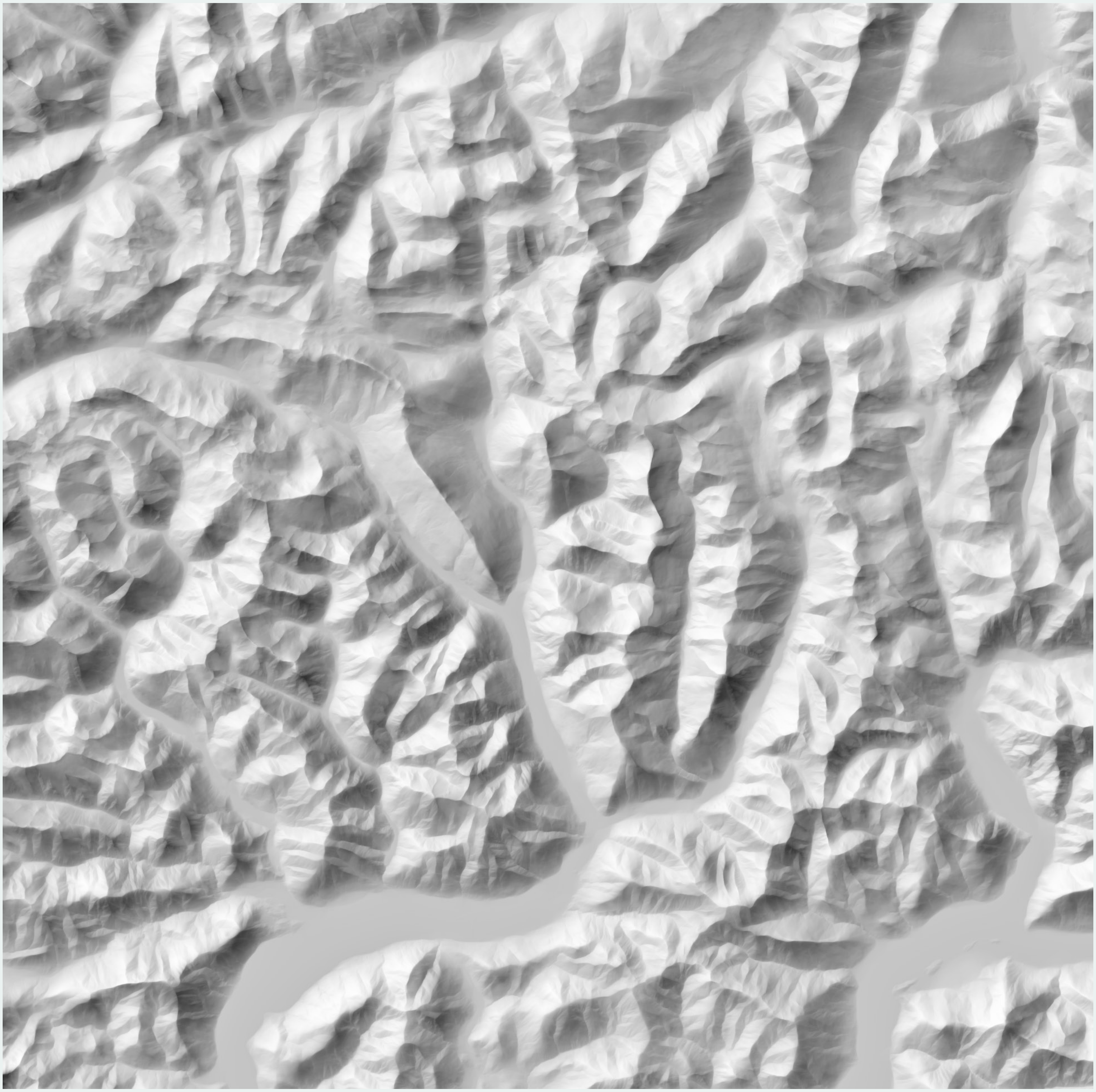

Figure 15. *A hillshade incorporating all the applications for normal maps discussed in this article. In addition, the mask for ridge sharpening was also used to lower contrast in the valleys.*

CONCLUSION

Many of the applications I discussed here can be very labor-intensive and are more practical as scripted tools. Pyramid Shader has a tool for creating normal maps and soft hillshades, and I am working to finish an ArcGIS Python toolbox called Relief Toolbox that contains those, in addition to the rest of the applications described in this article. It will be available at **links.esri.com/ReliefToolbox**.

There are more cartographic applications for normal maps that I haven't covered here. Even though I've used some of them professionally, I'm still exploring how to make them work consistently and practically before discussing them in a practical cartography context. In summary, further research is recommended.

Still, I hope this at least serves as an introduction and encourages cartographers and toolmakers to explore the uses of normal maps in cartography. Again, if you've ever made a hillshade before, you've essentially used normal maps; possibly without being aware of it. I think normal maps should be at least as commonly seen and talked about in cartography and GIS as they are in computer graphics.

ACKNOWLEDGEMENTS

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The Graubünden/Ticino elevation data used for most of the terrain examples in this article was compiled by Jonathan de Ferranti and is available at **viewfinderpanoramas.org**. The elevation data for Figure 6 was obtained from the US Geological Survey at **nationalmap.gov/elevation.html**. The data for Figure 8 was taken from the GEBCO_2014 Grid, version 20150318, available at **www.gebco.net**.

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Sharing Stories of Tragedy: Mapping Narratives of the Kent State Shooting

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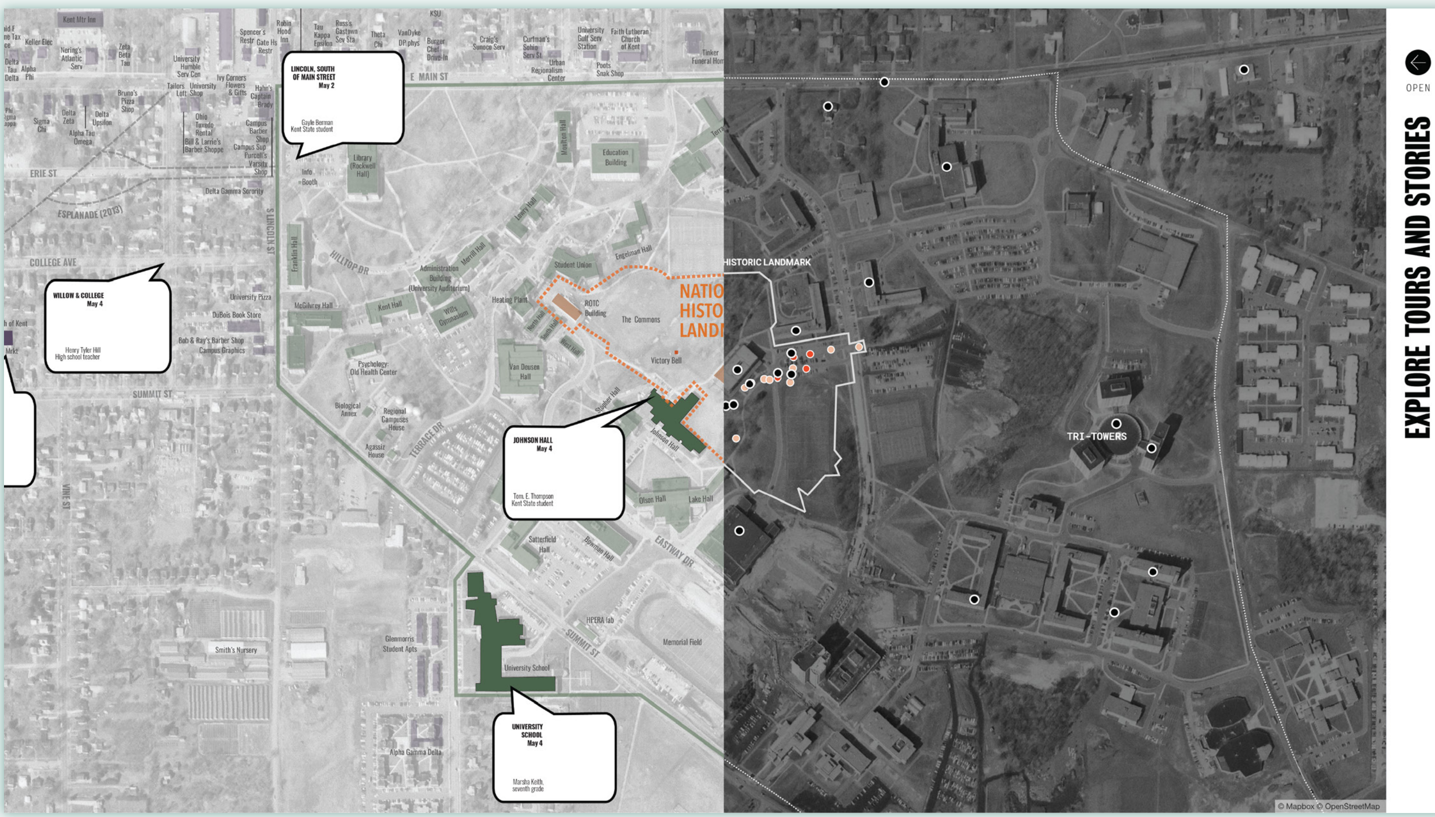
On May 4th, 1970, in Kent, Ohio, the Ohio National Guard shot student protesters at Kent State University, killing four and wounding nine. It was a turning point in the history of the Vietnam War and underscored the importance of freedom of speech and the right to protest. Even 50 years later, debates continue regarding exactly what happened and who was to blame, as a divide remains between those who feel the shooting was unwarranted and others who think the protesters brought the violence onto themselves. Particularly in northeast Ohio, encouraging engagement with varied viewpoints is essential to promoting reconciliation.

Our goal is to do this by mapping stories told by those who experienced these events first hand: students, faculty, business owners, and other local residents, in an effort to create a dialogue among map users from a wide variety of backgrounds. These stories are drawn from oral histories collected by the Kent State Library and the Kent Historical Society. To share them with the broadest audience possible, we designed two maps. One is interactive, available at **MappingMay4.Kent.edu**, and allows users to add their own stories and reflections to the map. The other is a wall-sized print on display at the Kent Historical Society.

As both Kent State faculty and a city resident, I (Mapes) was motivated to create a mapping project that showed perspectives from the broader community. As I learned about the events of May 4, I realized that, while multiple



memorials were tied to the site of the shooting (a National Historic Landmark), little research and commemoration had focused on the events preceding the shooting in the broader campus/downtown area. Hundreds of photos and oral histories of May 1970 indicate the importance of understanding this broader site: student protesters frequently marched into downtown; the National Guard were called out due to unrest downtown during the weekend before May 4; an off-campus Students for a Democratic Society (SDS) house rattled the nerves of local residents; and after the shooting, the military occupation of campus and downtown increased tensions between the city, campus, and law enforcement. I saw the oral histories, tied to a map, as a way to document the fear and paralysis felt during these days both in the city and on campus.

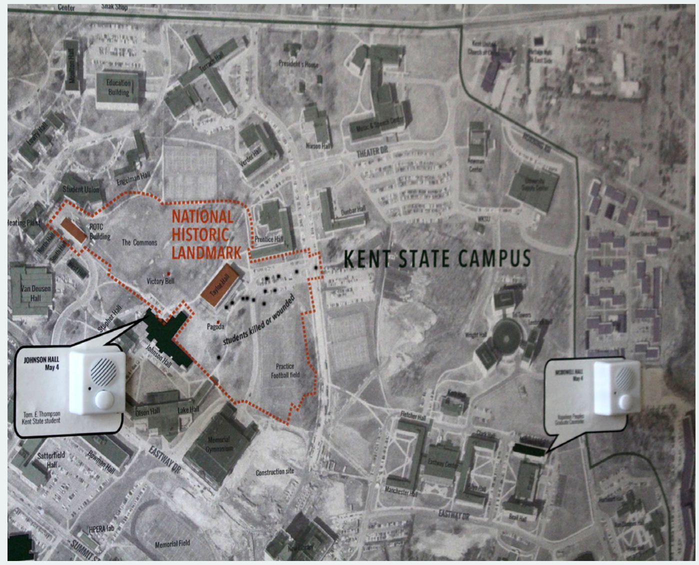
Over dinner with a new colleague, Sara Koopman, a geographer working in our university's School of Peace & Conflict Studies (established in 1971 as a "living memorial" to those killed in the shooting), we found a common interest in using maps to promote understanding and reconciliation in communities that have experienced trauma. We began to work together to build a website that could share stories of May 4th with a broader audience. Since the spring of 2019, we have analyzed more than 130 oral histories in the university archives, along with more than 100 collected separately by the Kent Historical Society, to identify specific places described by interviewees. From the interviews, we collected stories about these places—"geo-narratives" that share individuals' experiences in a specific time and space. So far, we've found more than 300 stories in the oral histories that are connected to 100 specific locations. We then mapped each location—some were easy to find, but others involved research to figure out where places were located in 1970. We also combed through university and community archives to find historical photos of these places, finding images that matched about 75 of the locations. One of the best sources turned out to be the university's yearbook, which was digitized a few years ago. But we also found newspaper clippings at the Historical Society and old postcards. We also added a basemap—a US Geological Survey aerial photograph taken on April 9, 1970—and identified all downtown businesses in 1970 using a reverse directory (which allows looking up the name of a business located at a particular address).

From a cartographic perspective, our goal was to simplify a large amount of spatial data and make it accessible to a diverse audience. There is no lack of information on the Kent State shooting, and our library's special collections, paired with those of the Historical Society, were filled with photos, newspaper clippings, maps, and written and spoken histories. But as they are housed and configured, many of these data are not easy to access. For example, though digitized, the oral histories are often at least an hour long and are very particular to an individual's experiences. One of our key audiences, those who were young adults in the 1970s, is also sometimes not digitally savvy. Our goal was to take these stories and reshape them to be more easily heard and shared by people of all ages.

Access to both an aerial photograph from 1970 and reverse directory data served as an impetus for a static map. When I mentioned this idea to the May 4 collection librarian, she suggested that a map like this would also be a great way to help those being interviewed remember and share their story. But the map's size posed challenges. Originally provided to interviewees as a 24 × 36 inch poster, those giving oral histories (often in their 70s) found this unwieldy, so I reformatted it to multiple, tiled, 8 × 11 maps of the city and campus.

The next step for this map was to create a large version that could promote broader public engagement. We originally envisioned a "talking wall" where an interactive map was projected onto a wall in downtown Kent. This was pared down to two exhibits, one at the Historical Society, and another at the campus's May 4 Visitor Center, a **wallpaper-like map** (9 × 7 ft) with buttons on specific locations that play short audio clips of stories.

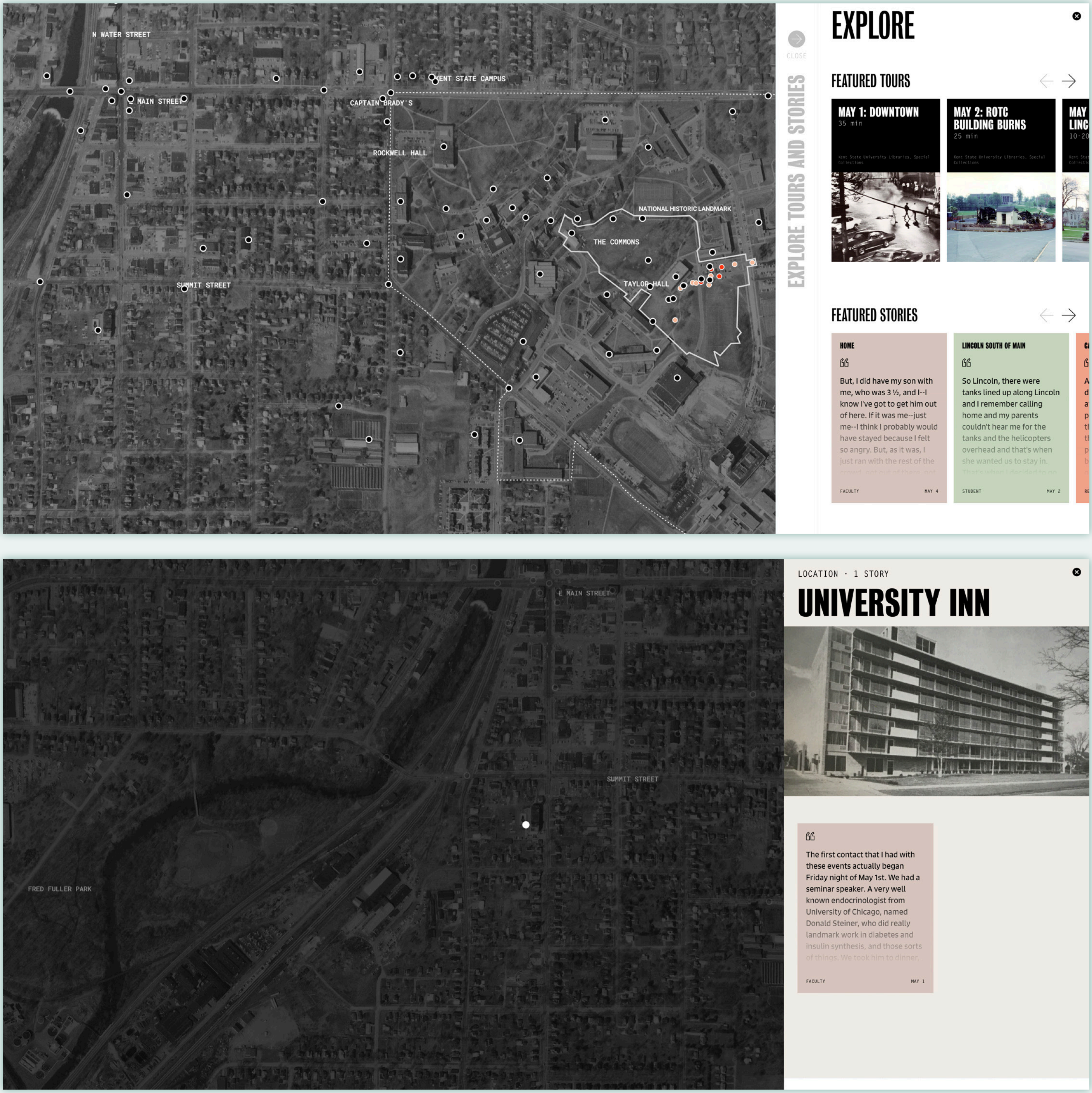
The big map had some restrictions: labels, even for the clustered downtown businesses, needed to be large enough


NATIONAL HISTORIC LANDMARK
KENT STATE CAMPUS
JOHNSON HALL
May 4
The Commons
Victory Bell
Practice Football field
EASTWAY DR
THEATER DR

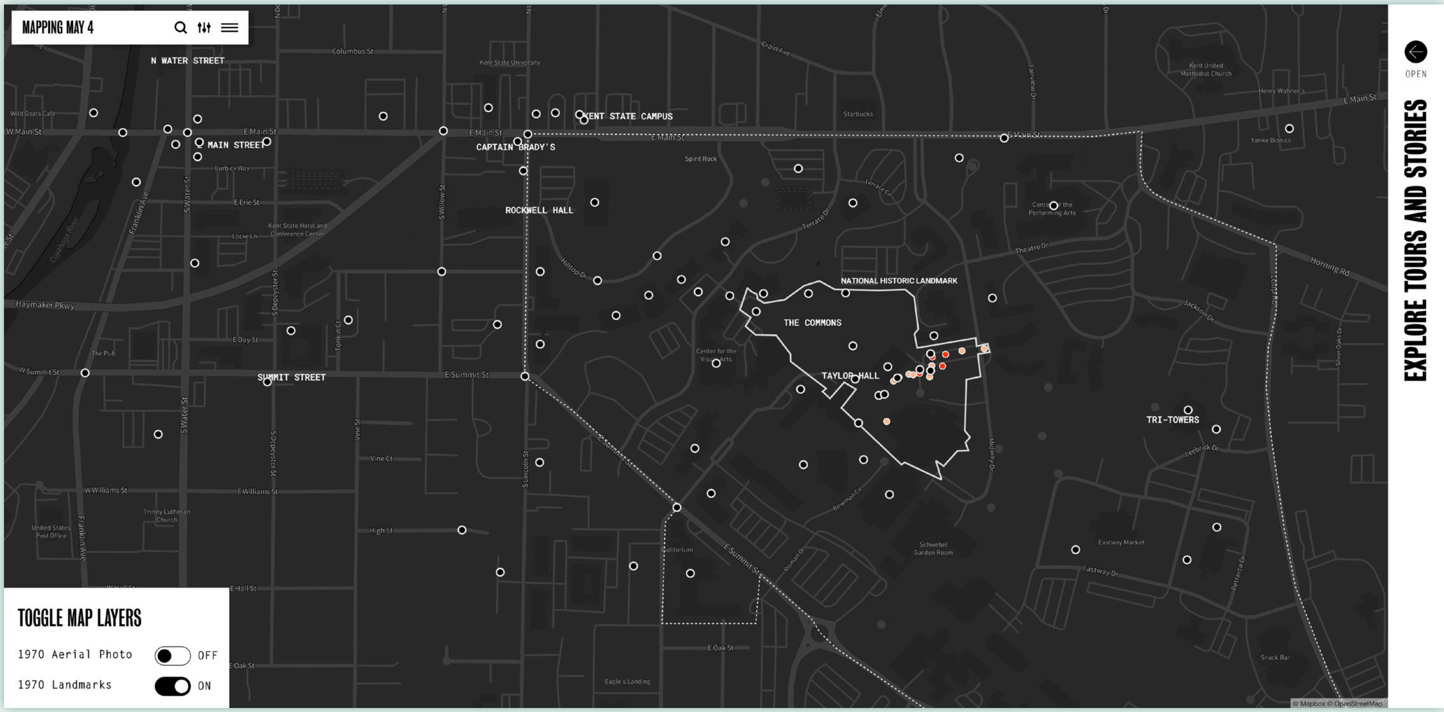

BIG DADDY'S PIZZA
May 1
Diane Gallagher
Kent State student
PORTAGE NATIONAL BANK
May 2
Roger DiPaolo
Junior high school student
THOMPSON'S DRUGSTORE
May 2
Jim Myers
VP and manager
LINCOLN, SOUTH OF MAIN STREET
May 2
Gayle Berman
Kent State student
WILLOW & COLLEGE
May 4
Henry Tyler Hill
High school teacher
SPARKLE MARKET
May 2
Peter Jedick
Kent State student
West Side Fire Station
Triangle Serv Sta
Joe & Ann's Laundromat
Wright Htg & Air Condg
N WATER ST
Lauren Mfg Co
Sellman P G Tire & Appl Co
St. Patrick's School
N DEPEYSTER ST
DePeyster Elementary School
KSU Art Dept
Kent Equip Sls
Community House
St. Patrick's Church
St. Patrick's Convent
N WILLOW ST
N LINCOLN ST
UNIVERSITY DRIVE
Seaver's Cafe
Pirates Alley
Airflow Antiques & Junque
Krahling Mart
Big Daddy's Pisanello's Pizza Shop
Kent Cove
JB's
Ron-De-Vou Lounge
Unitarian Universalist Church
GOUGLER AVE
Central School
Yellow Unicorn
SDS House
Jeanne Hammers
Bty Shop
All Pro Golden Cue
Stahl's Bakery
Chuck's Barber Shop
Campus Clnrs
Snelling & Snelling
Shirts & Skirts
Rogen's Ltd
Ohio Bell Tel Co plnt
Daisy's Bty Shoppe
Lincoln Research Bldg
United Christian Fellowship
Lane & Assoc
Martin R W & Son Equip Co
Masonic Temple
Kent Mtr Inn
Kincaid F Income Tax Service
Keller Elec
Nering's Atlantic Serv
Zeta Beta Tau
University Humble Serv Cen
Spencer's Restr
Robin Hood Inn
Gate Hs Restr
Tau Kappa Epsilon
Russ's Gastown Sev Sta
Theta Chi
VanDyke DP phys
Ward's Union Oil 76
Delta Tau Delta
Alpha Phi
Kent Theatre
MAIN ST BRIDGE
Kent Free Library
American Legion
RIVER ST
Bruno's Pizza Shop
Tailors Left
University Shop
Ivy Corners Flowers & Gifts
Hahn's Captain Brady
Sigma Chi
Delta Zeta
Delta Upsilon
Alpha Tau Omega
Phi Sigma Kappa
Ohio Tuxedo Rental
Bill & Larrie's Barber Shoppe
Campus Barber Shop
Campus Sup
Purcell's Varsity Shop
Info Booth
Library (Rockwell Hall)
ERIE ST
Jerry's Diner
B&T Cab
Frink's Barber Shop
Kent Car Wash
A&P Food Store
Kent Dvlpmt
The Record Courier
Delta Gamma Sorority
ESPLANADE (2013)
Kent Ofc Sup
VFW
US Post Ofc
Eddie's Stag Bar Restr
The Dome
Hall Ins Agcy
Legendary Leather
Jacobs GM Wallpaper & Paint
Stallard's S Ohio Service
State Liquor Store
Party Fare
City Cab
FRANKLIN AVE
Riverview Apts
Portage Paper Bx Co
COLLEGE AVE
S LINCOLN ST
Franklin Hall
HILLTOP DR
US Post Office annex
Kent Canadian Club
Second Store
Graven BL RI Est
Barker RA & Co
Ferry B A Grocery
City Fire Dept
University Pizza
McGilvrey Hall
Kent Hall
DuBois Book Store
HAYMAKER PARKWAY (1975)
IPM Corp
City Bldg
Church of Kent
Sparkle Super Mrkt
Bob & Ray's Barber Shop
Campus Graphics
STOW ST BRIDGE
Will-Mark Ptg & Duplicating Co
Al's Bar
Kent Typewriter Co
City Fin Dir/Tax Dept
Portage Constn Co
B&G Atlantic Serv Sta
Dr. Adamle
Psychology: Old Health Center
Rice's Sunoco Serv
SUMMIT ST
Mandi's Cafe
Biological Annex
Regional Campuses House
Flynn's Marathon Serv
University Inn
Agassiz House
S WATER
Kent Area

The wall map.

to be legible from a distance. It needed to show landmarks familiar to long-term residents, but not so many that it was cluttered. In the end, I (Mapes) decided to add building footprints only to businesses for which we had 1970 names, and the aerial photograph was lightened so as not to distract from more important elements. Highlighted story locations and overall scale were chosen strategically, so that they didn't require users to reach too high or low; while the map was nine feet high, most of the key features needed to be at eye level, within three to six feet from the floor. I also worked around some temporal issues by setting most of the map in 1970, but adding four key post-1970 Kent landmarks: two highway bypasses (Haymaker Parkway and SR 261), a new bridge, and an outline of the National Historic Landmark. We also chose to add the locations where students were wounded and killed in the shooting to provide context for those new to the story and geography.



The interactive website.



To produce the interactive website, we worked with a local design firm, Each + Every, who helped us decide on the look and feel of the map and developed the code behind it. The first version of the website used the Google Maps API, but when we received additional funding (from Kent State University and Ohio Humanities), I recommended we switch to Mapbox to allow for improved tiling of the aerial photo and the creation of a more stylized basemap. Overall, we decided on a design that was mostly greyscale, to let the images and stories speak louder than the map itself.

As with the static map, there were basemap challenges with the dynamic map. Users ranged from those who only knew the Kent of 1970, to those who only know today's Kent, to people who had never visited but wanted to learn

Outdoor exhibits.

more about the shooting. We ended up not including a lot of detail but adding a search function that would let those with memories tied to specific places search for these locations. A few landmarks were labeled (streets, the campus boundary), but we relied heavily upon a hover feature to add context for those browsing the map, without creating clutter.

Our initial hope was to create an app that would "ping" the user when they walked by a site with a story. This proved difficult to program, but we created a location-aware site that shows the sites closest to users on smartphones, and offers walking tours based on each day of the events leading up to and including the shooting. We also let users add their own stories and reflections to existing or new places on the map with text, audio, photo, or video. This interactive feature of the map is essential to creating a dialogue between users and across history, and was particularly important when our in-person tours were postponed due to the pandemic.

The second version of the website was released in April 2020, timed to coincide with the 50th anniversary of the shooting. Over the May 1–4 weekend, we had 1,631 users, and nearly 3,000 overall between April and August 2020. While users came from 44 different countries, nearly half were from Northeast Ohio. The main cartographic parts of this project are complete, but we continue to add stories as more oral histories are recorded and archived, and to reach out to a broader audience by developing lesson plans for high school and college students.

WATER: AN ATLAS

Edited by Darin Jensen, Alicia Cowart, Susan Powell, Molly Roy, Chandler Sterling, and Maia Wachtel

Guerrilla Cartography, 2017

208 pages, 74 maps, 19 illustrations

Softcover: $40.00, ISBN 978-0-9884272-2-8

Hardcover: $80.00, ISBN 978-0-9884272-2-8

Review by: Abraham Kaleo Parrish, University of Miami

Water: *An Atlas* is a crowdsourced thematic publication focused on water issues around the world. Unlike a traditional thematic atlas—one that covers a particular subject over a specific geography and seeks to construct a focused narrative from its material—this work is more like a curated anthology of maps about water. Its 74 maps were contributed by 134 authors—enthusiasts, activists, academics, resource regulators, resource managers, and scientists—working either individually or collaboratively, in groups of up to seven. Each map presents its own particular issue framed from its own particular viewpoint, and approached in its own, often unique, way. The atlas distilled from this material does not attempt to force any grand narrative upon its contents, but rather allows its diversity to show how complex and varied the issue of water really is.

Most of the mapmakers represented in the atlas are American, and this may explain the fact that 31 of the 74 maps depict North America. There are also, however, substantial contributions from creators from all over the world, and that diversity is reflected in the overall geographic scope. Maps of the world are the second most numerous (17), followed by Asia (10), Africa (6), Europe and Oceania (4 each), and lastly South America, with only two maps. The various maps in the collection range in scale from small world maps at 1:130,000,000 up to some local area maps at about 1:5,000.

The contents are organized into eight chapters, each more or less representing a loosely watery topic—"Imagination," "Place," "Habitat," "Control," "(Over)Use," "Politics," "Pollution," and "Climate"—with between eight and fourteen maps each, followed by a chapter entitled "Exploration" with activities for kids. Each chapter opens with a short introductory paragraph or two provided by the editors, but these serve more as a description of the chapter's theme than as an analysis of its contents—very much in keeping with the overall editorial approach that prevails throughout the atlas, of letting the map creators express their viewpoints and tell their own stories.

In one of the three introductory essays, editor Darin Jensen describes Guerrilla Cartography (**guerrillacartography.org**) as "an atlas publisher with a mission to widely promote the cartographic arts and facilitate the expansion of the art, methods, and thematic scope of cartography, through collaborative projects" (xv). This atlas certainly delivers on that mission, but with varying degrees of success. While I found the majority of maps to be very engaging, drawing me in for a significant amount of time, there were a number that were significantly less so, eliciting just a few moments of interest before I moved on to the next.

Some of the aspects of the cartographic arts Jensen sees himself and his fellow editors promoting include aesthetic concerns, technical accuracy, thematic clarity, qualitative descriptive text, and supplemental graphics—including pictorial illustrations, conceptual diagrams and quantitative statistical visualizations. The editors view them all as contributing to the expression of the overall point the creator is trying to communicate to the reader through the map.

The editors see data projection and scale as key components of mapmaking's technical accuracy aspect, and several projects incorporating interesting and pertinent projections can be found throughout the atlas. Sarah Dorrance's "*Synergy*: a Buckminster Fuller World Map Projection" (34) in the "Imagination" chapter utilized (as advertised) a Fuller projection. The map, a mosaic assembly of ceramic tiles, is abstract in appearance—yet it carries real information about mean low oceanic water temperatures while simultaneously functioning as a decorative art piece. Benjamin D. Henning's *Where the Algae Grow* (56) makes use of a gridded cartogram to reveal long-term ocean and large lake chlorophyll concentration estimates in an effective way.

Henning's cartogram is interesting, but Atlanta architect Chuck Clark takes geographic geometry to an extreme by using his own non-Euclidean world projection to create two of the most interesting, beautiful, and technical maps I have ever seen. Clark's composition, entitled *Two Complementary World Maps With Constant-Scale Natural Boundaries Composed to Show Watersheds and Currents with Uninterrupted*(*!*) *Oceans* (40) utilizes his Constant-Scale Natural Boundary projection, which he describes as a foldable projection geometry requiring "hand plotting with Renaissance-era tools and skills" (41). Each map depicts the worldwide movement pattern of water as it drains from mountains to circulate in the "closed lake" (40) we usually think of as the oceans, and then, in the complementary map, shows it again—inside out! This is a pair of maps that must be seen to be appreciated. The volume and usability of the detail on this map—the indication of inter-basin waterways, the selection of landmarks along edges/divides, and the way the Panama and Suez Canals are depicted as looping around through the non-space of the projection interruptions—provide just the right amount of locational information to allow and facilitate a good read of the geography on this unusual and (at first) seemingly disorienting projection without over-cluttering the space. This, along with his balanced composition, excellent use of color—especially the comprehensive elevation symbolization spanning both land and water—not only places this map among the best this atlas has to offer, but produces a uniquely comprehensive and comprehendable map of planetary hydrology that stands with the best in any atlas.

There were some other examples of maps in the atlas, however, with projections that I think were less than ideally suited for the information and message they were attempting to convey. *Water Depletion in Global Watersheds* (96) by Kate A. Brauman, Perrine Laroche, and Natalee Desotell in the "Over(Use)" chapter presents us with an equirectangular projection when something equal area would have been better suited to a map trying to show the percentage area of world water depletion. Compounding the problem, the legend for the map mixes quantitative percentage depletion categories (e.g., 5–25%) with two qualitative categories: "Dry-Year" and "Seasonal." Furthermore, the text explains that the percentage depletion is based on water availability between 1971 and 2000, but the water use data is just for 2005. Thus, not only is water depletion—either as a volume or as a proportion—hard to gauge, but the ranges and categories of data values are vague. An accompanying logarithmic graph, with consumption by sector, does not make anything any clearer, leaving me uninterested in the map.

The use of color, composition, and style are tools for the cartographer aiming to produce beautiful, attractive maps, and are key elements in the cartographic arts that Jensen tells us were central to the atlas curators. Aesthetic signals are an important part of communicating a message—they draw the reader's attention, and keep that attention focused long enough for the reader to discover the map's message or to appreciate its artisanship.

Some of the map creators focused their efforts mostly on aesthetics. Louis Paul White's *Whales of Alaska* (66) could have been an uninteresting map, but for the highly stylized watercolor-like appearance of Alaska and surrounding oceans, the mystical looking north arrow, the migration routes indicated with a curved string of whale species names, and the amazingly detailed line drawings of whale types sorted by size in the legend. White utilizes a variety of elegant fonts for labels and is very creative in arranging them. For example, while his mountain ranges are labeled rather conventionally with curved text, he labels selected mountain peak labels with a text triangle—the mountain name forming the peak top and the elevation (in feet) serving as the slightly rockered bottom. This gives a nicely stylized and distinguished label for these features that contrasts well with the impressionistic coloring of the base map, which by itself gives only vague indication of the presence of mountains. White's composition is spot-on, with a textured seascape (that is just as interesting as the landscape), sprinkled with lens flare effects, one of which focuses your attention on the shield-shaped cartouche and another on a nicely illustrated sperm whale in the Gulf of Alaska that appears to be vomiting up pink ambergris. Along with the use of color and style, the composition provides a nice balance to this map, and, like the extremely valuable end product of ambergris, White has produced a valuable aesthetic work of cartography. Most importantly, I believe, he has captured the essence of whales in his cartographic style by evoking feelings of magic, majesty, and elegance.

By contrast, some of the other maps in *Water* succeeded in communicating pertinent data, but left me aesthetically disappointed. One such map is *How Much Water do we use to Raise Catfish?* (Amanda Buczynski et al., 106), unnecessarily cluttered by a thicket of call-out arrows. There were also maps that were visually appealing, but could have done a better job of communicating. Greg Fiske's *Yukon River Delta* (178) displays a beautiful Landsat false-color composite image of the Yukon River delta, and points out how the "spectral band combination" he chose to use "reveals the vast complexity of the water-dominated landscape." The text mentions how fires and melting permafrost contribute to carbon loss to the atmosphere, but it remains unclear what this map was intended to show. The reader is told the colors represent some sort of "complexity," but without any indication as to what the complex of colors might mean. Furthermore, a regional inset map showing recent and historical burn areas shows clearly that the main image includes only a tiny (although, no doubt significant on the ground) burn zone—one that seems, frankly, indistinguishable on the main map.

Supplemental illustrations and data graphics can add a lot of weight to a message conveyed through cartography. This atlas has no shortage of these elements, and some of the best are demonstrated in Martino Correggiari's *Fog Collection*: *Alternative Technology for Local Water Projects* (76). It features a detailed illustration of advection fog collection equipment and set-up, and another of a system installed in the Chilean Atacama coastal mountain range, alongside a world map showing locations of current and potential fog collection projects by type. There is also a small but cleverly designed high-data-density chart showing the surprising amount of water that can be collected with this technology, accompanied by succinct, descriptive text. Altogether, through clarity and context at multiple scales, Correggiari communicates his message promoting this alternative technology very effectively.

In contrast, I felt Bartlett, Gibbs, and Sweely's map of *Aquaponics in California*: *Potential Agricultural Water Savings* (108) fell short of its potential for communicating this equally interesting alternative technology. There is a schematic diagram of the aquaponics cycle, and some text stating that it has potential to save what may or may not be be significant volumes of water, but it is all presented without significant context. It would have been more informative to, for example, provide statistics on current water-use volumes, allowing a comparison to the size of the claimed savings. An illustration of the mechanics of the technology would also have been useful. I, myself, was at first imagining farmers harvesting fish waste and sprinkling it as fertilizer on plants, but, upon further research, I discovered the method is actually a symbiotic combination of aquaculture with hydroponics—growing plants with their roots dipping into water (instead of soil) in tanks used for raising aquatic animals, such as fish. None of this was revealed clearly in the map.

In the atlas' opening essay, *Maps as Story*, Douglas Gayeton tells of situations where maps communicate by presenting coherent stories (a language) to impart understandability to the geography. That the opposite also happens is evidenced by Susan Powell's map, *Counties in Mongolia Containing Color-named Lakes* (46). In this situation it is that which is found in the world—the geography—that formatively influences the language used to discuss it and thus the way it is understood. Some years ago, Susan Powell and I were librarians for the same map collection, and I remember discussing with her how the Hawaiian words for north and south were the same as the words for left and right, indicating that the cultural direction of the Hawaiians was eastward facing. Susan, who had spent a substantial amount of time in Mongolia and was fluent in the language, shared that the Mongolian words for east and west were the same as the words for right and left—making south the Mongolian cultural direction. Our theory was that this influence on language was due to geography, particularly in relation to the sun. In this case, Hawaii is practically on the Tropic of Cancer, where the sun always rises close to due East, while Mongolia is much further north, where the sun is mostly in the southern sky and yurt doors always face south. I was impressed to see Susan's map illustrating the influence geography asserts on language, applied to the realm of lake names in Mongolia.

Although *Water*: *An Atlas* was never meant to be comprehensive, consistent, or cohesive, I would have liked to have seen the editors work into their chapter descriptions a bit more analysis of what they saw as the significance of the maps they chose to include. Without their guidance, I was forced to find my own way of approaching the contents. I found it useful to explore the atlas in different sequences—looking, for example, at the seven maps of California that are scattered among the chapters, or viewing various maps of overlapping geographic areas as temporal comparisons. A section about the backgrounds, influences, experiences, and philosophies of some of the map creators as cartographers and storytellers would also have been interesting. Much as the life of an artist in an art history book reveals certain things about their artwork, it would be interesting to learn what it was that led these mapmakers to the variety of perspectives expressed in the atlas.

Overall, this atlas has a substantial number of high quality maps communicating a variety of interesting perspectives on the topic of water. The collection meets the goal set out by the editors to use this crowdsourced, collaborative project to widely promote and expand the cartographic arts, its methods, and its thematic scope. I rate *Water*: *An Atlas* as a good value in terms of the quality and quantity of maps, and appreciate the generously wide, 30 centimeter, page size. This atlas is a great resource for cartographers or map enthusiasts looking for a wide variety of examples of contemporary cartographic techniques.

Water: *An Atlas* takes its place beside Guerrilla's earlier publication, *Food*: *An Atlas,* and, after reviewing this one, I know I am looking forward to whatever comes next from the Guerrilla Cartography community.

[*note from the CP Reviews editor*: That would be *Atlas in a Day*: *Migration,* featured in ***Cartographic Perspectives 94***.]

FOOD: AN ATLAS

Edited by Darin Jensen and Molly Roy

Guerrilla Cartography, 2013

172 pages

Softcover: $40.00, ISBN 978-0-9884272-0-4

Review by: Nat Case, INCase, LLC

Food: *An Atlas* is a collection of more than 75 contributions—most of them combining map, text, and illustration—from well over 100 individual contributors, all on the subject of food and all sharing a broadly similar point of view. The focus is on under-served, over-looked, and oppressed communities, and on efforts to reform the food-stream, including the locavore movement, as well as organic, sustainable, and community-based agricultural practices. These priorities are in line with the activist ethos of Guerrilla Cartography, which describes itself as "a loose band of mapmakers, researchers, and designers intent on widely promoting the cartographic arts and facilitating an expansion of the art, methods, and thematic scope of cartography, through collaborative projects and disruptive publishing" (**guerrillacartography.org**). This 2013 book is the first in their "*An Atlas*" series, followed in 2017 by *Water*: *An Atlas,* and soon to be joined by the forthcoming *Shelter*: *An Atlas.* These works are high-profile products within cartographic activism communities, and probably should be part of a standard map library collection, if for no other reason than as artifacts of a distinctive and influential cartographic culture. This does not, however, mean they are "successful" in all the ways they want to be.

Calling themselves "Guerrilla," it seems, reflects the group's attitude toward organization more than their physical style: the contributors have clearly *not* been living rough for weeks while slogging through the jungle. Physically, *Food*: *An Atlas* provides a high-quality canvas for presenting its exhibits—perhaps suggesting more bohemian chic than insurgent. The atlases in this series present large spreads of informative graphics on smooth white opaque paper. Despite its general unity of ideology, the collection of maps in *Food* is diverse in terms of approach. The contents are grouped thematically into five sections: Production, Distribution, Security, Exploration, and Identities, and within each section they move from the global to the local in scale and focus, a pattern I honestly did not notice until I read the introduction. The reason this is not immediately clear is the huge diversity of content and style, and the fact that each contribution is a piece unto itself. Some of the exhibits are straightforward reference maps: Bill Rankin's *Harvesting the World* (13), for example—a time series showing the conversion of the Earth's surface to crop- or pasture-land since 1700—is outstanding. Others are explicitly centered on advocacy for a change in food culture or preservation of local values: *Another Pampa Is Possible!!!* (96), created by the Buenos Aires-based iconoclasistas group and exposing the destructive conversion of the Argentine grasslands to mono-crop soy production, is a well-done example of this.

However, too many of the other maps are, frankly, weak tea. Pedestrian design is one problem; a lot of the exhibits look like conference posters. This also complicates my task: how does one write a review of an entire conference poster session? In too many cases, the map elements seem to be gratuitous—not contributing enough or not providing useful information to justify their prominence—and this is more and more true for the more locally focused maps. The map for *Food Labels, Branding Place of Origin* (67), for example, is just a collection of unlabeled points that represent the locations of farms participating in a regional marketing group—a nice enough map, but one that defines a region with a scattering of points, and tells you nothing about the group or its activities otherwise. *Rice, Beans & A Pot: Foods as an Expression of Afro-Antillean Identity in the Archipelago of Bocas del Toro, Panama* (153) tells the story of the distinctive foodways of a region of Panama inhabited largely by West Indians of African descent. However, the maps in the layout show only where two particular cities in Panama are, the countries in the Caribbean where Afro-Antilleans came from, and where Panama is. The maps aren't useless, but in terms of what they lend to the story, they are oversized.

With its huge pages (12 × 12 inches) and good ground for sharp images and text, the book offers an ideal format in which to lay out its contents. One would expect the resulting production to be lavish—and indeed some of the reproductions are really well presented, but others appear to have been poorly scanned from hard-copy prints or subjected to unnecessary image compression, resulting in halos around much of the text. The result, especially in a slickly presented volume, is underwhelming.

On the other hand, the maps in the atlas, even the ones full of grass-roots advocacy, are oddly comfortable with the luxe format. The explicit message is about revolutionary, bottom-up change, but the way the data is collected, presented, and framed—as a big coffee-table book with full-color images on high-quality paper with a glossy cover, implies an bourgeois audience full of coffee tables next to bookshelves. While the book represents and talks about indigenous foodways, exploited workers, and other under-represented (and chronically underpaid) people in our global food system, it does so from the comfortable point of view of over-represented, college-educated, basically comfortable people (like me). It fails to communicate a point of view or voice that speaks to the experience of oppression. Then again, what maps out there do that, really? Modern cartography as a form speaks from a point of view that generally presumes authority and governance, or the possibility of that point of view.

The introduction says that "Each map is intended to tell its own story, but together the maps imagine a collective narrative, one that the reader is invited to enter on any page" (7). It is interesting to compare the way this intention is worked out with some other anthology atlases of the last decade. Examples that come to mind for me include the *Infinite Cities* trilogy (2010–2016) by Rebecca Solnit, Rebecca Snedeker, and Joshua Jelly-Schapiro; the NACIS *Atlas of Design* series (2012–present); and the two atlases that have thus far resulted from Ashley Nepp's seminars at Macalester College—*Curious City: In, Out, Above, Beyond Saint Paul* (2019) and *Meandering Minneapolis: A Cultural Atlas* (2020). Solnit et al.'s city atlases have a strongly activist and leftist political point of view, similar to that of *Food*, and also enjoy a large number of contributors. But the *City* atlases are more focused on their text, and the maps are of a piece with the book design, giving each volume a consistent look and feel that maintains a distinct physical unity. The *Atlas of Design* volumes have neither a political stance nor a central topical theme, but are juried, curated, and assembled using criteria based on the graphic qualities of the maps themselves (in full disclosure, I'm on the editorial team for the fifth volume). Each of the Macalester College atlases (for one of which I served in an advisory role), like *Food*, contain a huge variety of thematic and graphic approaches, but, as each focuses on a particular Minnesota city, the body of each volume coheres around that physical, social, psychic, and political entity. To my mind, in each of these cases, the strong, clear focus makes for a strong and unified atlas. With *Food*: *An Atlas*, the subject matter focus is too broad, and the approaches too varied, local, and disconnected from one another, to make the "collective narrative" described in the introduction hold up.

Part of the problem is that *Food*: *An Atlas* sets up an expectation of coherence by explicitly having an ideological slant. What sense of commonality does exist is rooted in that point of view, but, still, the connections between maps in this anthology end up seeming vague. The specific actions, patterns, and systems described in each entry have a lot of relevance for that affected part of the world of food, but the wider world itself, the sense of interconnection between and amongst systems, is thwarted by the anthology format. Many non-map collections and anthologies make a point of including an editorial introduction to each contributed entry, in which the relationship of this particular part to the wider volume's unifying context is communicated. Such framing would be really helpful here—providing a single editorial voice that places each contribution in position within a perceived larger shape represented by the atlas.

I am struck, however, by that peculiar turn of phrase: "together the maps imagine a . . . narrative" (7) from the remark quoted earlier. My mind turns to the idea of maps themselves being imaginative, and not just the products of imaginations. The phrase begs the question of the broader role of imagination in the creation of maps. We generally expect factuality and ground accuracy our maps, regardless of whether their framing is part of the machine of the modern corporate state, or a "radical" counterpoint to that machine. When do we get to "make stuff up?" When do we let our fancy roam free? Well, *Food*: *An Atlas*, gives much of the "Food: An Exploration" (118–125) section over to a group called the Geography Collective, which—extracting from their children's book *Mission: Explore Food* (2012)—asks us to play a few workbook-style games. There is, as well, the final map in this section and in the book, *The Landscape We Eat* (161)—about a northeastern Spanish dish, "Mountain and Sea"—where one drawing combines an elevation profile, a collage of ingredient source locations, and another that shows all of the ingredients mixed together. The combination doesn't tell us a specific story, but the juxtaposed elements leave open the possibility that the viewer might do some of that constructing themselves. Finally, *The Muckleshoot Traditional Food Map,* (149) is very conscious of how the shape and form of the graphic constitutes its own cultural patterning. It is not a work of fantasy, but it nonetheless builds a non-cartesian view of the Muckleshoot tribal homeland on and near Puget Sound.

As I write this review, I'm thinking about the many anthologies I've read, and my memory of their coherence has a lot to do with my expectations about where, in the work, that coherence would lie. I don't, for example, expect an anthology of ghost stories or modern fairytales to cohere except in being high-quality examples of their genre. The same is true with the *Atlas of Design*. It is in the joy taken in the craft of each piece, and in the provocation that each piece makes to the viewer—surprise, fascination, wonder, close study, and so on—that ties together the curated whole however much the specific responses may vary in form and theme. The theme, in that case, lies outside the subject matter of the collected works—and it allows us to draw connections between the works despite their clear variety. However, with non-fiction, and especially scholarly anthologies, there is often an over-arching (and maybe over-ambitious) theme introduced by the organizer or curator that is then seen to be carried out piecemeal by the individual contributors, who each seem to stake out and defend walled cities of individual research. This is easier to take in a *festschrift*, where the focus is on memorializing a particular beloved member of the clan, but in general, anthology creators outside the arts have a hard problem—in part because what we usually think of as a "scholarly" focus is centered so much on content over style and form. *Food*: *An Atlas*, problematically, tries to do both (and claims that it does both in the introduction), but ultimately does not overcome the cultural divide between style-based focus on unity and content-based focus on specific factual content.

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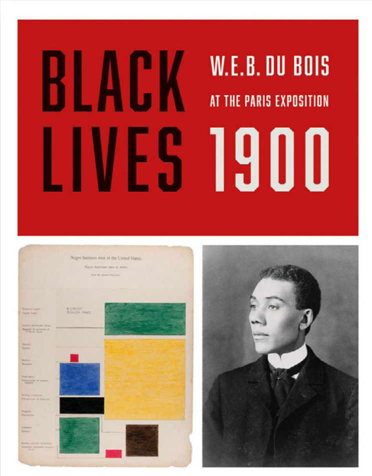

BLACK LIVES 1900: W. E. B. DU BOIS AT THE PARIS EXPOSITION

Edited by Julian Rothenstein

Redstone Press, 2019

144 pages

Hardcover: $35.00, ISBN 978-1-942884-53-8

Review by: Krystle Harrell

Black Lives 1900: *W. E. B. Du Bois at the Paris Exposition* beautifully weaves together Du Bois's groundbreaking graphic visualizations with photographs of Black Americans post-slavery, to tell the little-known story of *The American Negro Exhibit* at the 1900 World's Fair. This oversized (12 ¾" × 10") and colorful reproduction of artifacts from the exhibit effortlessly immerses the reader in a visual record of Black lives just 35 years after emancipation. The book is divided into three chapters, the first of which focuses on Du Bois and provides a historical context of the exhibit. The other two chapters present the main sections of the exhibit: one illustrating the conditions of Black persons in the entire United States, and the other a case study of Black persons in Georgia, the state with the largest Black population at the time.

In the introduction, the historians Jacqueline Francis and Stephen G. Hall frame the historical context and importance of Du Bois's exhibit. They highlight the fact that as the 1800s came to a close—fewer than 40 years since the ending of slavery—"the readily summoned image of the Black in the United States was that of an enslaved person…" (13). Herein lay Du Bois's motivation: to challenge this image. In just four short months following his commissioning by friend and attorney Thomas J. Calloway, Du Bois was able to create a triumphant display of "Black lives, in labor, worship, and leisure, at school, at work, and at home" (13). This achievement would not have been possible without his formidable, all-Black team including Booker T. Washington, librarian Daniel Murray, and numerous faculty members and students from Historically Black Colleges and Universities (HBCUs).

The authors explain that Du Bois's motivations and efforts to change the widespread image of Black people as inferior were not novel. Rather, he advanced the "program of displaying research in an aesthetic manner," which the abolitionists Fredrick Douglass and Sojourner Truth, and the educator Ida B. Wells initiated in the late 1800s (14). Just as Douglass and Truth tried to fight racist pseudoscience with studio portraits depicting "Black American achievement, agency," and subject matter, Du Bois continued the fight with his exhibit (14); going beyond photography, and introducing captivating infographics that were rooted in "demography, information science, and cartography" (14).

Francis and Hall go on to describe how Du Bois and his team used art as a way of telling the story of Black Americans, post-slavery. The works' vibrant color palette, basic geometric shapes, and hand-drawn graphics and maps stood out amongst the other exhibits portraying American life. This was important as they were situated in a back corner of the room, surrounded by "exhibits communicating the superiority of European nations" (16). To achieve their goals of countering the widespread stereotypes of Black Americans they had not only to draw in a wide audience, but they also had to keep that audience engaged with innovative data visualizations, ensure everyone could understand the exhibit by offering all the statistical charts in both French and English, and humanize Black

Americans by comparing their demographics to those of Europeans. Even though the message and success of the exhibit—which earned numerous accolades and medals at the exposition—were widely ignored by the White American press at the time, it is brought back to life between the covers of this book.

After Francis's and Hall's contextualization of the exhibit within the realms of art and history, there is a short note from the prominent American historian and Harvard Professor, Henry Louis Gates, Jr., regarding the photographs included in the exhibit. Gates explains that although Du Bois is best known for his literary contributions, this exhibit allowed him to explore his love of photography, and that in doing so, he launched the first Black American international media campaign. Du Bois waged a battle in the war of representation by interweaving the beautiful and elegant photographs of Black Americans with the engaging, modernist data visualizations of Black demographics. Thus, he actively countered the common "Sambo" and "Picaninny" images of Black Americans and conveyed their success, dignity, and joy in a way no statistical graph could.

The inclusion of a timeline in the first chapter further underscores the timeliness of the 1900 *American Negro Exhibit*. Ranging from 1847 to 1910, the timeline highlights key dates in history that impacted Black American lives, as well as events that likely underpinned Du Bois's activist motivations. These include his first experience with Jim Crow laws in 1885, becoming the first African American to earn a Ph.D. from Harvard in 1895, and publishing *The Philadelphia Negro*: *A Social Study* in 1899. *The Philadelphia Negro* was one of Du Bois's most significant early works in sociology and laid the groundwork for him to lead the 1900 exhibit showcasing Black American life on a global stage.

As America experiences a reckoning with the ever-relevant fact that its promises are not fulfilled equally, Du Bois's words, and his extraordinary efforts towards *The American Negro Exhibit* serve as a reminder of the power of visual and oral communication in the continued effort to realize social justice. In the first chapter, Julian Rothenstein, the book's editor, subtly highlights the applicability of Du Bois's work to the present day by thoughtfully interspersing the timeline and photographs with carefully selected excerpts of his literary works. In his version of *My Country 'Tis of Thee*, Du Bois uses this well-known song to address the deep flaws in the American nation and to give the Black American—who may struggle with honoring a country in which they "*do* love its ideals if not all of its realities"—a way out of feeling "boorish, or ungracious" (31). In this work, Du Bois evokes the pain of slavery's history as well as the hopefulness to be found in true freedom and equality, just as he subtly acknowledged American oppression while spotlighting Black achievement throughout the exhibit. Modern exhibits like those at the National Museum of African American History and Culture, and the National Memorial for Peace and Justice, provide poignant representations of Black American achievement and oppression. Such exhibits continue the efforts of Du Bois and his team to use empirical evidence and immersive visualization to rebuke long-held ideas of Black persons as inferior and to celebrate the contributions of Black persons to America.

In the remaining chapters, "A Nation Within A Nation" and "The Georgia Negro: A Social Study," readers are introduced to the stunning infographics and captivating photography of the exhibit. Here, Rothenstein allows the maps, charts, and photographs to tell their own story, save for small, identifying captions on the photographs. Each reproduction draws the reader in with its exciting colors, mesmerizing shapes and graphics, and striking portraits of Black Americans in their everyday lives.

The second chapter, "A Nation Within A Nation," introduces the first series of graphics from the 1900 exhibit, entitled, *A Series of Statistical Charts Illuminating the Condition of the Descendants of Former African Slaves Now in Residence in the United States of America*. In the first of two maps in the series, *Proportion of Negroes in the Total United States*, he compares the Black American population to the entire US population from 1800 to 1890, in 30-year increments. The second map similarly compares the Black American population to the total population of various European countries, using proportionally sized national outlines and population totals. In both maps, Du Bois uses color and size proportions to portray Black Americans as a "small nation of people" within the larger US nation, with a population size comparable to other nations (Du Bois 1900). Du Bois quietly undercuts the idea of Black persons as an insignificant or negligible component of either the United States or the world as a whole.

Also included in the chapter are twenty-two infographics that illustrate the demographics of this "Nation within a

Nation." In many of these data portraits Du Bois evoked new and interesting ways of visualizing demographic data, including a unique square-spiral used to show the disparity between Black Catholics and Black Protestants (14,517 vs. 2,659,460), the interesting use of proportional symbols to indicate the distribution of Black businessmen across the trades, and the color choices of black to brown to yellow in his illustration *The Amalgamation of the White and Black elements of the population in the United States*, depicting the striking increase in the number of biracial Americans from 1800 to 1890.

By breaking down such things as the change in the proportion of slaves to Black freemen, Black property valuation, Black landholders and businessmen, and the number of Black teachers and children in the public school system, Du Bois empirically characterizes the Black population as successful and determined. All of this success was achieved despite the numerous obstacles they faced following emancipation, including harsh Jim Crow laws and separate-but-equal provisions. In the final data portrait of the section, *The Rise of the Negroes from Slavery to Freedom in One Generation*, Du Bois explicitly highlights the progress of Black Americans in the face of oppression since 1860, stating, "In 1890 nearly one fifth of them owned their own homes and farms. This advance was accomplished entirely without state aid, and in the face of proscriptive laws" (84).

The second series in the exhibit, *The Georgia Negro: A Social Study,* is laid out in the final chapter, with an additional twenty-two data portraits and maps. The section opens with a map in which Du Bois illustrates the routes of the African slave trade, and makes his famous proclamation, "The problem of the twentieth century is the problem of the color-line" (86). Du Bois employs various cartographic techniques in the eight maps found in the series to illustrate the distribution of Black Americans in the United States, within Georgia, and their migration patterns to and from Georgia. Interspersed amongst the maps and photographs of the series are unique data portraits including the mesmerizing spiral graph depicting *Assessed Value of Household and Kitchen Furniture Owned by Georgia Negroes*, and the bullseye-spike combination used to illustrate *Assessed Valuation of All Taxable Property Owned by Georgia Negroes*.

The final data portrait, *Valuation of Town and City Property Owned by Georgia Negroes*, best frames Du Bois's narrative of Black Americans achieving success despite oppression. The simple line graph, depicting a general increase in Black property valuation from 1870 to 1900, is juxtaposed against the placement of text describing societal events including, "Political Unrest" in the late 1870s, or "Lynching" and "Disfranchisment and Proscriptive Laws" in the 1890s. These societal events underscore the oppression Black Americans faced following emancipation, while the solid black line soaring to the top of the graph illustrates their determination to be successful free Americans. The simplicity of this data portrait contributes to the clarity of Du Bois's narrative; the entirety of the exhibit can be summed up by this one visualization: Black success in the face of oppression.

By thoughtfully placing photographs near related infographics, Rothenstein achieved a balance between the empirical evidence and visual evidence in retelling Du Bois's story of the successful Black American. However, though the distribution of the photographs, data portraits, and maps were much appreciated, at times it seemed to make the second series appear disjointed. Specifically, the maps of *Negro Population of Georgia by Counties*: the years 1870 and 1880 appear on page 111, but the map of the 1890 population distribution is not displayed until page 134. Based on the handwritten numbers on the reproductions, it appears they are meant to be seen in sequence, and this separation in the book makes it difficult to compare the distribution changes across the period.

The book closes with Rothenstein quoting the modern author Ta-Nehisi Coates, who characterized the modern backlash toward Black success as holding that "the presentation of Black people as normal in their sort of bourgeois, everyday, easily integratable manner into America—actually was an attack on whiteness and white supremacy. . ." (137). In point of fact, Du Bois's presentation of Black achievement in 1900 was indeed an attack on white supremacy and could well be seen as constituting the first salvo in the war that wages on today—in social media and elsewhere. This book is a timely reminder of what Black Americans can achieve in the face of oppression, as well as a somber reminder that even though "the twentieth century" is over, "the problem of the color line" is not yet solved.

As we look to retell history and include more stories of Black American and minority success, this compilation of the artifacts from Du Bois's 1900 *American Negro Exhibit* provides a timely historical perspective of the post-slavery advancements of Black Americans. Though there have been recent compilations of the data portraits themselves (*editor's note: see CP 93 for* ***a review of one such book***), Rothenstein goes beyond the data, presenting the entirety of the story by including the historical events leading up to the exhibit, the novel data visualizations, and the immersive photography portraying the everyday lives of Black Americans. The efforts of Rothenstein—along with David Adjaye (Forward), Jacqueline Francis and Stephen G. Hall (Introduction), and contributor Henry Louis Gates, Jr.—combine to create a beautiful book of art and history. This collection is fit for display on any coffee table, and not just hidden on a bookshelf.

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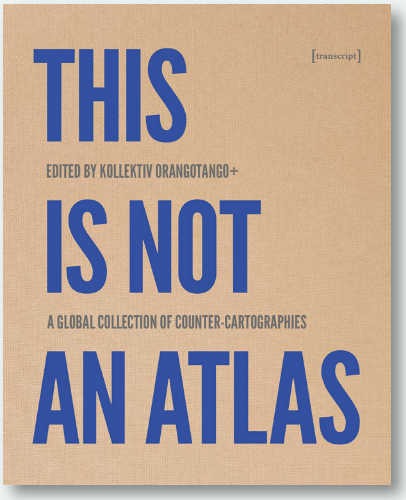

THIS IS NOT AN ATLAS: A GLOBAL COLLECTION OF COUNTER-CARTOGRAPHIES

Edited by Kollektiv Orangotango+

Transcript Verlag, 2018. Distributed by Columbia University Press

352 pages

Hardcover: $40.00, ISBN: 978-3-8376-4519-4

eBook: Free. notanatlas.org/book

Review by: Alison D. Ollivierre, Tombolo Maps and Design & the International Society for Participatory Mapping; and Charla M. Burnett, University of Massachusetts Boston & the International Society for Participatory Mapping

This Is Not an Atlas: *A Global Collection of Counter-Cartographies* is a curated collection of diverse counter-cartography projects and programs aimed to "to give an impression of how open and diverse the field [of counter-cartographies] has become, especially due to the practices of people without formal cartographic training" (18).

This book, in its hardcover format, commands your entire attention, if for no other reason than its slightly unwieldy size—over a foot tall and just under a foot wide. The hardcopy was published alongside a free, open access, eBook (PDF) version available for download at **notanatlas.org**—a site which also contains a growing, living library of counter-cartographies assembled by the authors. We have the utmost respect for the authors' decision to make the atlas freely accessible to a wide audience—and were especially pleased to have it in a format so easy to search and reference from a computer. It should be noted, however, that the large pages and spreads can be difficult to read on small eReader screens and that page numbers in the PDF differ slightly from those in the hardcopy version. The page numbers used in this review reflect the pagination of the PDF.

The thirty-eight projects and programs featured in the book were selected from nearly one hundred and fifty submitted in reply to a multilingual (English, German, and Spanish) call for maps in 2015. Each page of the Table of Contents features a world map with lines connecting a project's location to the chapter in which it is discussed. We compiled the three maps into one to provide a comprehensive view of all the project sites—where a project involved multiple locations, these points are also connected by lines (see figure on next page).

After the Introduction, the chapters are grouped into nine sections reflecting various dimensions of counter-cartography:

- Counter-Cartographies as a Tool for Action
- Counter-Cartographies Tie Networks
- Counter-Cartographies Build Political Pressure
- Counter-Cartography Is Education
- How to Become an Occasional Cartographer
- Counter-Cartographies Create Visibility
- Counter-Cartographies Show Spatial Subjectivity
- Counter-Cartographies as Self-Reflection
- Counter-Cartographies as Critique

Finally, the book ends with "This Is Not a Conclusion." These topic areas provide a broad and deliberately contemplative framework for the practice and study of counter-mapping, in a way that allows the readers of *This Is Not an Atlas* to gain a foundational understanding of both the reflexive nature of counter-mapping and the way it challenges the traditional power structures embedded in its framework.

The Introduction opens with a brief, but detailed, account of the origins of counter-mapping. It argues that, from its earliest use, the term *atlas* "come[s] with a promise: to show the world as it really is" (12) and that this promise of truth and knowledge has remained in effect over the centuries, despite all the changes that atlases have seen. By *not* claiming to "present an all-encompassing, true-to-scale, and objective view of the world with the collection of maps that are published in" *This Is Not an Atlas* (13), its editors see their "Not-an-Atlas" as "break[ing] with the conventions of traditional atlases [and] at the same time . . . building on other counter-atlases" (13). Thus, *This Is Not an Atlas* can be seen as both a body of evidence attesting to the current state of the civil resistance struggle, and as a manifestation of the people's struggle for self-determination.

Counter-geographies are spaces for civil disobedience and alternative modes of understanding. This collection highlights social movements that have empowered communities to share and analyze spatial data and take a stand against institutional policy and deeply embedded cultural norms in the name of progress. In the section entitled "Counter-Cartographies Tie Networks," Leah Temper discusses *The Global Atlas of Environmental Justice* (*EJ Atlas*) and how maps can be used to help resistance movements better organize and manage environmental conflicts (92). The *EJ Atlas* documents over 2,100 cases of ecological conflict around the world and uses point data to represent local mobilizations or protests as documented by the organizations or activists directly involved in resistance. In the section "Counter-Cartographies Build Political Pressure," Nora Flinkman provides an overview of the web and mobile *HarassMap* platform that helps document sexual harassment in Egypt—a region where such harassment is seriously underreported. The application, by facilitating safe and immediate reporting by victims and witnesses, helps the *HarassMap* Team develop metrics, author reports, and bring pressure to bear on local government and authorities to provide assistance to victims.

These social projects, and others included in this collection, make evident the usefulness of crowd-sourced methods for compiling and mapping events and phenomena that are not normally provided publicly (or even recorded) by those in power. As a result, a counter-cartography project often serves as a conduit for fostering alternative institution building and civil resistance, as well as environmental and social justice.

This Is Not An Atlas is notable for the powerful way it captures and juxtaposes the various techniques and methodological debates embedded in counter-cartography. In fact, by presenting projects that are distinctively counter-mapping alongside those that might be better defined as participatory mapping, volunteered geographic information (VGI) mapping, or even just mapping for oneself (using mental mapping, for example), *This Is Not an Atlas* presents an analytical space for discussion about what actually constitutes "counter" mapping. Sometimes, counter-mapping is seen as a derivative or sub-type of participatory, community, or collaborative mapping, and at other times the terms are used interchangeably. Thus, because there are no generally accepted definitions for any of these practices—what each would encompass or what its relation to the others would be—providing a framework space for that discussion could be seen as a valuable contribution. However, in presenting so many projects that define counter-mapping so variously, we, the reviewers, see *This Is Not an Atlas* as lacking a critical focus. In "Editorial – This Is Not an Atlas," which opens the Introduction, Severin Halder and Boris Michel note that they "understand counter-cartography as a political practice of mapping back" (13), a definition that, although incorporating one important aspect of the project of counter-mapping, fails to explicitly include specific characteristics vital to its overall nature. For many—including ourselves—counter-mapping means taking a stand against sources of power and symbols of injustice, and we see it as grounded in a will to fight dominant power structures and to struggle against the very real oppression facing communities in their attempts to redesign the world in a socially and politically progressive manner.

This Is Not an Atlas clearly states that it is not trying to be comprehensive in its selection of counter-cartography projects—nor, in practical terms, could it have hoped to be. However, while it is clear that the authors put a great deal of effort into presenting a geographically diverse collection of projects, the overall narrative still comes across as distinctly Eurocentric and does not address the practical methodological complaints that localized and indigenous communities have posed in critical debates. We were particularly disappointed by the absence or insufficiency of projects from the Caribbean, South Pacific, East Asia, and Africa. It is not clear whether this situation arose in the selection process, from a paucity of responses from those regions, or because the public calls for participation did not reach communities in those locales. It is worth noting that we, the reviewers, did not ourselves hear anything about the Kollektiv Orangotango+ call for maps, despite both actively working in the field of participatory mapping.

In the center of the book is a section titled: "How to Become an Occasional Cartographer: Insights into Various Mapping Guides as a Starting Point for your Practice." It differs from the other sections in that, rather than dealing with specific counter-mapping projects, it instead directly republishes mapmaking guides that could be useful to counter-mappers. The chapter is made up entirely by pages from: *Making Maps* (2011) by John Krygier and Denis Wood; *Manual of Collective Mapping* (2016) by Iconoclasistas (Pablo Ares and Julia Risler); and *A Guideline for Solidary Mapping* (2014) by Anna Hirschmann, Raphael Kiczka, and Florian Ledermann. The intention of including these excerpts is to allow the readers to have the guides readily "at hand" so they can "adapt the proposed techniques to [their] local contexts and to create new tools for [their] struggles" (164). However, this seemingly haphazard duplication of pages from other books and documents, suddenly inserted into the midst of the project material, feels jarring, and breaks the flow of *This Is Not an Atlas* as a whole. We believe that the intention behind this section would have been better served by an appendix containing a longer and more comprehensive list of resources that focused on how to make better maps and work more collaboratively.

This Is Not an Atlas was published in English, although most of the maps and graphics were not translated from their original languages. While we appreciated the variety of languages present in the book, we believe the lack of translations was a missed opportunity to make this English-language atlas accessible to all its readers. It would not have been necessary to translate entire maps, but including translations of titles, larger paragraphs of text, and essential captions or legends, etc. would have gone a long way for many readers. The translation of the poster on page 139 (*Workshop of Social Cartography in the Faculty of Philosophy and Language*) could have been taken as a model.

While some might find fault with the few spelling errors scattered throughout the book, we feel that, given the amount of text that was clearly written by non-native English speakers or translated from other languages, a few misspellings are a very minor issue. In regard to both of these language-related issues, we suggest a read of Ben Panko's article in the January 2017 issue of *Smithsonian Magazine*, entitled "English is the Language of Science" which provides some useful context on how bias towards English as the *lingua franca* can result in "preventable crises, duplicated efforts, and lost knowledge" (par. 12).

In conclusion, we were particularly impressed by the many interesting, unique, and lesser-known projects that this book was able to pull together, while still highlighting some inspiring, well-known projects. *This Is Not an Atlas*: *A Global Collection of Counter-Cartographies* demonstrates itself as a true asset to the genre of counter-mapping and is a great foundational read for any critical cartographer. We note that there are plans to use the **notanatlas.org** website to continue to share maps, struggles, and projects online—and that they have recently published a documentary and a video series (**notanatlas.org/videos**). We hope that others take inspiration from this compilation and that atlases, not-atlases, and anthologies like this continue to be published in our field.

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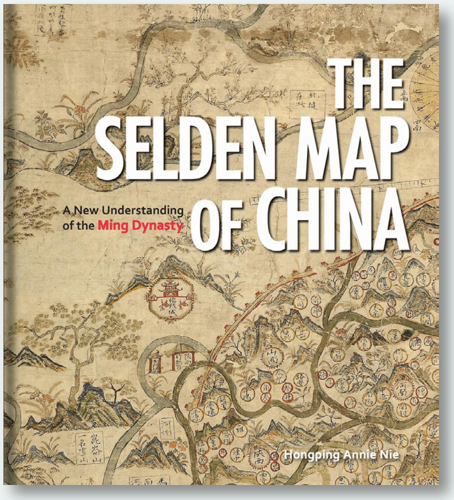
DOI: 10.14714/CP96.1649



THE SELDEN MAP OF CHINA: A NEW UNDERSTANDING OF THE MING DYNASTY

By Hongping Annie Nie

Bodleian Library, 2019

74 pages

Hardcover: $30.00, ISBN 978-1-85124-524-6

Review by: Glenn O. Humphress, Southeast Community College

In 1659, a map of East Asia was added to Oxford University's Bodleian Library as part of a donation from the estate of English lawyer John Selden (1584–1654). The map had no title and has come to be commonly called either the *Selden Map of China* or the *Nautical Chart of the Eastern and Western Seas* by Western scholars and Chinese scholars, respectively. Largely forgotten over the subsequent centuries, the "rediscovery" of the map in 2008 has resulted in several publications about it and what it indicates about Chinese relations with other parts of Asia during the Ming Dynasty.

One such publication is Hongping Annie Nie's *The Selden Map of China: A New Understanding of the Ming Dynasty* (2019). Unlike its predecessors—Timothy Brook's *Mr. Selden's Map of China* (2013) and Robert Batchelor's *London: The Selden Map and the Making of a Global City, 1549–1689* (2014)—the major focus of this brief but beautifully illustrated book is on the map itself as a library artifact and work of art, rather than on the time period in which the map was painted. The book is divided into five chapters, albeit without any kind of preface or introduction. The first, "A Discovery in the Library," begins with the now relatively well-known story of Robert Batchelor visiting the Bodleian Library to examine what was listed as a Chinese map from the Ming dynasty, and recognizing it as primarily a merchant nautical chart unlike any contemporary Chinese map he had seen before. Instead of a traditional, China-centered map that fit the impression of a solely inward-looking Ming China, the Selden map revealed seafaring routes used in trade with other parts of East and Southeast Asia, as well as descriptive text about how to reach as far west as the Persian Gulf and Red Sea. Batchelor's discovery had considerable impact on the reinterpretation of seventeenth-century Ming China's relationship with maritime travel and global trade. Nie does not end the story of the Selden map as a library document there, and this chapter also includes a brief discussion of the poor condition of the map when found by Batchelor, how it had been used and maintained by the library during its time there, and some details about the conservation program that was initiated after the recognition of its importance, along with pictures of conservation activities. I personally would have liked to have seen more on this important aspect of cartographic library work that is seldom mentioned when discussing maps in collections, but I appreciate that conservation received any coverage at all.

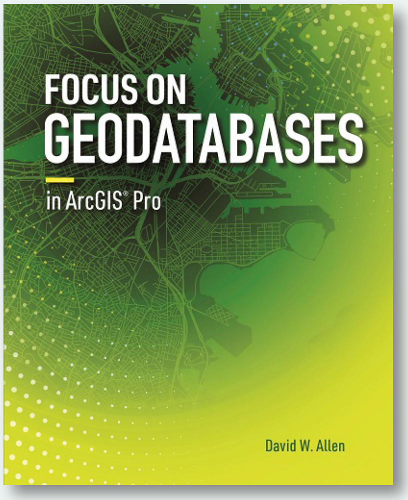
In the next chapter, "A Cartographic Work of Art," Nie generates a true appreciation of the cartographic, geographic, and artistic characteristics of the Selden map. The tone is set for the latter with the opening sentence, "The Selden map of China is a work of art, beautifully painted in multiple colours and black Chinese carbon ink" (9), while a few pages later Nie writes, "A nautical chart, the Selden map can also be appreciated as a beautiful landscape painting, a perfect combination of the two forms" (13). After stating its dimensions (158 by 96 cm), Nie speculates on why it was painted in the first place: "It is too big to have been conveniently employed as a chart.

Most likely it would have been used to decorate a wealthy merchant's house, hung on the wall as a display of its owner's maritime knowledge, connections and power" (9). It is that maritime knowledge that is so prominently on display in the map, and Nie details the differences between representations of geographic information about the interior mainland, and that about the coastal areas, seas, and islands. As someone with an interest in the historical geography of Okinawa (the largest of the Ryukyu Islands) and its connections to other parts of Asia, I found the discussion of the trade route between China and Ryukyu, as well as the representations of compass bearings along that route, particularly interesting. Ironically, by the time the Selden map was produced, Okinawa's centuries-old trade and diplomatic relations with China were experiencing a decline due to increased influence of Japan, culminating in the Japanese occupation of the Ryukyu islands in 1609. Nie also explores how the Selden map fits into both Chinese and Western cartographic traditions, comparing it to examples of fifteenth- through seventeenth-century maps from both traditions that cover roughly the same geographic area. While placing the Selden map firmly within Chinese cartographic tradition, Nie notes that the very fact that the contemporary European presence in Asia is recorded on the map allows for the possibility that the cartographer may have been able to consult Western maps or charts that may have influenced the design of the map produced. In depicting both historical features—such as the sea route to the Ryukyu Islands—and contemporary features—such as the early European presence in Asia—the Selden map reflects a transitional period in the human geography of the region.

The third chapter turns more fully to "The History of the Selden Map." Since nothing is known about the cartographer, or of the map's history in China, this part of the story is restricted to listing various ideas about when and where it was produced and from where the cartographer may have come. Equally unknown and speculated upon is how the map got to England. Any certainty in the map's history does not begin until it is in the possession of John Selden, a "London lawyer and Oriental scholar" with an interest in "maritime rights and trade" (29). After Selden's death in 1654 the map was given to the Bodleian per a request in Selden's will that it be donated to a public library. The remainder of this brief chapter describes certain documented uses of the map at the Bodleian, primarily in the late 1600s.

The remaining two chapters provide context for the Selden map. "Ming Dynasty Maritime Trade" provides a historical geography of Chinese maritime activities and trade from the mid-fourteenth century through the mid-eighteenth century, while "A New Understanding of the Ming Dynasty" describes the current understanding of the impacts of maritime trade on Ming China. These two chapters tread the more familiar territory covered by the Brook and Batchelor books, among others cited, and the Selden map gets almost no mention until the end of the last chapter. This reliance on other sources, most of which pre-date the rediscovery of the Selden map, creates a bit of a disconnect from Nie's final paragraph, which begins "The Selden map of China has changed forever the world's understanding of Ming China" (64). Without an integration of the material from the first three chapters with the material from the last two, the Selden map comes across as just one of many pieces of the puzzle, an important illustration providing a visualization of what other evidence already supports.

The common admonition that a reviewer should review a book on the basis of the author's intentions, rather than the book the reviewer wishes had been written, is complicated in this case by the lack of any introductory statement of what were the author's goals for the book. Thus, I find myself wishing for more of the three chapters about the map and better integration of that material with the two context chapters, while recognizing that neither of my wishes may have been a goal for the author. Ultimately, though, I think the strengths of this thin, richly illustrated book outweigh the organizational concerns of a cartophile writing a review for a cartographic journal. Nie's book celebrates the Selden map of China, and I wish we had more books like it celebrating more maps.



FOCUS ON GEODATABASES IN ARCGIS PRO

By David W. Allen

Esri Press, 2019

260 pages

Softcover: $59.99, ISBN 978-1-5894-8445-0

Review by: Vincenza Ferrara

The creation, modification, and storage of spatial data are issues of prime importance in geospatial work, as are concerns about data integrity and data sharing. Esri's geodatabase format is a powerful and sophisticated system for storing geographic information in relational databases—either in the form of an enterprise relational database management system (RDBMS) or an Esri file geodatabase—and accessing that data with Esri GIS software. *Focus on Geodatabases in ArcGIS Pro*, written by David W. Allen and published by Esri Press, is a technical workbook that leads the user through the conceptual and practical aspects of designing, building, and working with geodatabases in Esri's ArcGIS Pro 2.3 environment.

The book is divided into seven chapters plus a one-page "Introduction." In my view, the chapters fall into two groups, with the first four covering the topic of geodatabase creation—design, data population, and facilitation of access—and the remaining three focusing on various techniques available in ArcGIS Pro for working with and editing data. Each chapter has a similar structure, including the following elements:

- a brief theoretical explanation of the topic covered
- two hands-on tutorials with detailed learning objectives and step-by-step instructions
- two more suggested exercises, provided without instructions or tutorial data, but with a list of potential deliverables that could result from completing them
- a concluding summary of the topic covered, methodology applied, and results obtained in each tutorial
- a list of study and review questions
- a list of ArcGIS Pro Help documents suggested for further reading

Data and other materials associated with each tutorial exercise are available for download from the ArcGIS online website, and the downloads include a free 180-day trial for ArcGIS Pro software.

Chapter 1 deals with designing the logical model of the geodatabase, and outlines four important aspects that must be considered: what sort of data is the geodatabase meant to store? what is the hierarchical relationship between the elements? how will the data be edited? how will the data be maintained over time?

In the Chapter 1 tutorials, the geodatabase design process is carried out in spreadsheets, a methodology that keeps readers focused on the careful thought and pre-planning required. The aim, at this stage, is to lead the reader to consider how their design will support an accurateportrayal of the geographic features and their relationships. A well structured logical model for the geodatabase will significantly reduce the number of problems and mistakes that might arise when it is later populated with data. Furthermore, because some geodatabase elements, once created, cannot be changed but only deleted and re-created, modifying or fixing geodatabase design errors can be a very time-consuming task. If only for this reason, it is important to have a well thought-out logical model from the beginning.

It is in Chapter 2 that the user implements their design model by creating a geodatabase in the ArcGIS Pro environment. The explanations and tutorials guide the reader through the construction of each of the various hierarchical geodatabase data structure components—feature datasets, feature classes, tables, rasters, mosaics, and relationships—together with the establishment of data integrity rules through the specification of attribute domains and feature subtypes.

The loading of data into a new or existing geodatabase is covered in Chapter 3. The importance of understanding the data is emphasized—the structure of the data, how it will be represented, and how it will be manipulated—and an iterative procedure, centred on the Append geoprocessing tool, that can be adapted to account for and accommodate different feature types and feature subtypes, is proposed. Multiple import passes through the data may be required before every feature is "matched" (93) to its place in the database structure, but care at this stage pays dividends in data integrity.

Chapter 4 closes the first of the two parts that I have divided the book into (building the geodatabase), with methodologies for sharing geodatabase content online and for extending that content to three dimensions. ArcGIS Online (**www.arcgis.com**), with its range of tools for creating online applications such as story maps, is the author's recommended tool for data sharing, and the chapter´s first tutorial demonstrates rules for using such applications. The second tutorial explains in detail how 2D data can be transformed into 3D format using elevation attribute values.

The rest of *Focus on Geodatabases in ArcGIS Pro*—Chapters 5, 6, and 7—explores ways to edit and enhance geodatabase data.

Chapter 5 deals with line feature creation and editing, and focuses largely on the establishment of the snapping environment and use of the feature snapping tools. Snapping is fundamental to establishing line connectivity and maintaining feature accuracy.

Polygon feature creation is covered in Chapter 6, which delves into the role of group templates in building a framework of features with a minimum amount of user interaction. The seventh and final chapter is dedicated entirely to the application of feature topologies in simplifying the feature editing process, and for ensuring data completeness and integrity. A geodatabase topology is a set of rules governing the spatial relationships that are permitted between point, line, and polygon features. For example, a topology might specify that every line feature (representing, say, a pipe) can only join another line feature at a point (representing, in this case, a valve), and that a valve point can only exist at the junction of two or more (pipe) lines. GIS topologies, if properly planned and applied, are powerful tools, and, consequently, it is important to enforce such relationships during feature editing.

In ArcGIS Pro one can apply topologies on either the map or the geodatabase level, and this chapter deals with both types. A map topology is an on-the-fly way to set up temporary relationships among layers in an ArcGIS Pro project in order to ensure the validity of the relationships while the features are edited. A geodatabase topology, on the other hand, is a more robust set of rules, permanently stored in the geodatabase, that are available for use in other projects. One great advantage of a geodatabase topology is that it can be updated—new rules can be added or others removed—as requirements, or the situation being represented, evolve. The final tutorial is dedicated to building and validating a geodatabase topology rule-base.

Focus on Geodatabases in ArcGIS Pro is a do-it-yourself workbook dedicated to showing how to build a geodatabase from scratch. It starts at the beginning, with an outline of the conceptual rationale of the needs the geodatabase must serve, and the structure it will require to meet those needs. The first two chapters and their tutorials cover only the concept and logic of sound geodatabase design, and each subsequent chapter builds on the work covered in its predecessor. The workbook's focus moves progressively from how to structure a geodatabase, first on paper and then in ArcGIS Pro, through filling the empty framework with data, to activating the relational connections between records. This is an excellent training methodology that allows the reader to understand the relationship between a geodatabase and its geodata. However, because so may design decisions have to take into account specific aspects of the particular data involved, and its particular use and maintenance scenarios, a reader might well struggle at first with reconciling the connection between the book's somewhat abstract concepts and the realities of the task at hand. In the end, of course, that reconciliation can only come through experience, not from a book.

With the structuring and data-loading groundwork laid, the workbook moves on to demonstrating how new data is interactively created, manipulated, and maintained with ArcGIS Pro's editing tools. The range of tools covered is wide and their efficiency in ensuring data integrity is very high, but one of the most important takeaways is the way these tools can be used within the logical framework of a well designed geodatabase.

Great attention and the right amount of emphasis is placed on data integrity issues throughout this book. Good quality control practices are recommended, and the exercises focus particular attention on the specifics of implementation. In particular, the supplemental exercise following Tutorial 2-2, "Adding complex geodatabase components," and Tutorial 7-2, "Working with geodatabase topology," are outstanding. The latter, for example, provides a step-by-step approach to effective quality control: establishing topology rules; building a geodatabase topology; examining topology errors; and correcting the errors.

The book gives some specific advice and tips to instructors—deliverables to assign, study questions to ask, and readings to suggest—but recommendations are also given at a general level. The helpful advice is not restricted to a particular chapter's topic, either. For example, the author often remarks on matters such as: the way schema or structural changes can affect data integrity; when one might create a subtype instead of a separate feature class; how to name group layers so as to reflect their content; the interpretation of error messages and their relative seriousness (can they be ignored?); clear reasons why good metadata is important; and the flexibility gained by combining feature creation tools.

The tutorials are well designed and, having been based on a single case study project, logically well connected, so the reader is guided through the training in an incremental manner. The materials provided for each tutorial are complete and sufficient, and the reader should, in most cases, gain a clear view of both the steps and the goals as they work through each of them. However, in some parts the instructions given are not very clear and do not match with what seems to result from working through the tutorial. In some instances it can be difficult to sort out which of several similarly named geodatabase elements is the one that should be used, or why or how a particular geoprocessing tool should be employed. Sometimes, explanations seem to come later in the book than where they might have been most useful. Occasionally, too, the instructions just seem obscure.

The text layout of the tutorial pages could also use some improvement. Some instructions are in bold text, but it is not always obvious why they are emphasized and others are not. Sometimes, too, the instructions seem to be ordered confusingly, with some paragraphs jumping ahead without any apparent logic.

Finally, the titles of Chapters 3 and 4 are slightly misleading. Chapter 3, "Populating and sharing a geodatabase," does not contain any content about sharing, a topic that is instead covered in Chapter 4, "Extending data formats" (which might be better named "Sharing a Geodatabase and Extending Data Formats").

These concerns notwithstanding, David Allen's *Focus on Geodatabases in ArcGIS Pro* is an excellent aid to understanding how to design a geodatabase in ArcGIS Pro and how to master the editing tools in it, and is a reasonably good investment for both GIS professionals and educators. With some improvements in layout, associated materials, and exercises, however, it could be even better.

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2017 *No eligible papers*

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	Fails to meet expectations	Meets expectations	Exceeds expectations	Greatly Exceeds expectations	Comments	Score
The abstract is a clear and concise description of the paper.	☐ *0*	☐ *3*	☐ *6*	☐ *10*		
The author introduces the research problem succinctly and clearly and explains the purpose of the article.	☐ *0*	☐ *3*	☐ *6*	☐ *10*		
The author addresses how the present research fits into previous research in the appropriate cartographic discipline.	☐ *0*	☐ *3*	☐ *6*	☐ *10*		
The methodology/analysis is technically/scientifically sound and well documented.	☐ *0*	☐ *3*	☐ *6*	☐ *10*		
The results are valid or the design innovation is shown to be useful/effective AND the results or design innovation are presented/illustrated clearly.	☐ *0*	☐ *3*	☐ *6*	☐ *10*		
The discussion addresses the way in which the research aligns with existing knowledge or design practice and its implications for future work.	☐ *0*	☐ *3*	☐ *6*	☐ *10*		
The conclusions state the most important findings of the research.	☐ *0*	☐ *3*	☐ *6*	☐ *10*		
Novelty and significance/potential impact on the field.	☐ *0*	☐ *3*	☐ *6*	☐ *10*		
Maps and illustrations are well designed and communicate effectively.	☐ *0*	☐ *3*	☐ *6*	☐ *10*		
Writing is organized, grammatically correct, clear and concise.	☐ *0*	☐ *3*	☐ *6*	☐ *10*		
TOTAL						

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

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

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**.

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

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