Data Visualization (CIS 490/680)

Geospatial Data

Dr. David Koop
Human Color Perception

[Diagram showing the process of human color perception: Input stimulus, Cone response curves, and the resulting response with SML (short, middle, long) cones.

[via M. Meyer]
Simulating Color Blindness

[Machado et. al, 2009]
Color Spaces and Gamuts

- **Color space**: the organization of all colors in space
  - Often human-specific, what we can see (e.g. CIELAB)

- **Color gamut**: a subset of colors
  - Defined by corners of color space
  - What can be produced on a monitor (e.g. using RGB)
  - What can be produced on a printer (e.g. using CMYK)
  - The gamut of your monitor ≠ the gamut of someone else's or a printer
Luminance

- HSL does not truly reflect the way we perceive color
- Even though colors have the same lightness, we perceive their luminance differently
- Our perception ($L^*$) is **nonlinear**

[Corners of the RGB color cube]
- L from HSL
  - All the same

[Luminance]

[L*$]

[Munzner (ill. Maguire), 2014 (based on Stone, 2006)]
Violations of CIELAB Assumptions

• CIELAB:
  - Approximately perceptually linear
  - 1 unit of Euclidean distance = 1 Just Noticeable Difference (JND)
  - JND: people detect change at least 50% of the time

• Assumptions CIELAB makes:
  - Simple world
  - Isolation
  - Geometric

[D. Szafir, 2017]
Simultaneous Contrast
Project Proposal

• Find an interesting subject or dataset
  - see List of lists of datasets [B. Keegan]
• Understand the data available (format, types, semantics)
• Figure out some interesting questions and tasks
• Start brainstorming about visualizations and interactions
• Inspiration:
  - Information Is Beautiful Awards
  - MBTA Viz
• Due Friday
Midterm

- Thursday, October 17
- Covers material through this week
- Format:
  - Multiple Choice
  - Free Response (often multi-part)
  - CS 680 students will have extra questions related to the research papers discussed
Colormap

- A colormap specifies a mapping from data values to color
- Colormap should follow the expressiveness principle
- Types of colormaps:
  - Binary
  - Categorical
  - Diverging
  - Sequential

[Muñzner (ill. Maguire), 2014]
Categorical Colormap Guidelines

- Don't use too many colors (~12)
- Use other categories or create groups if you have too many values!
- Nameable colors help
- Be aware of luminance (e.g. difference between blue and yellow)
- Think about other marks you might wish to use in the visualization
Continuous Colormap for Ordered Data

US EPA Regional Oxidant Model -- Midwest
Ozone (ppbv): June 26, 1987, 18:00

[Bergman et al., 1995]
Segmented Colormap for Ordered Data

US EPA Regional Oxidant Model -- Midwest
Ozone (ppbv): June 26, 1987, 18:00

[Bergman et al., 1995]
Continuous vs. Segmented Test Results

- "[C]ontrary to the expressiveness principle, no cases were found in which a continuous encoding of 2D scalar field data was advantageous for task accuracy, and for some tasks, specific binned encodings facilitated accuracy."
- "[S]upport for the counterintuitive finding that decisions with binned encoding were slower than those made with continuous encoding"
- Word of caution: single image!
Ordering Color?

(a) Perceptual ordering. (a) We can easily place the gray paint chips in order based on perception, (b) but cannot do this with the colored chips.

(b) Spatial contrast sensitivity function. Frequency increases to the right and contrast increases toward the bottom of both images in the figure. We can see detail at much lower contrast in the (a) luminance-varying gray-scale image than with the (b) rainbow color map.

Ordering Color? [Borland & Taylor, 2007]
Rainbow Colormap

[Bergman et al., 1995]
Artifacts from Rainbow Colormaps

[Borland & Taylor, 2007]
Artifacts from Rainbow Colormaps

[Borland & Taylor, 2007]
Two-Hue Colormap

[Bergman et al., 1995]
"Get It Right in Black and White" - M. Stone

jet colormap

[S. Eddins (Matlab Blog), 2014]
"Get It Right in Black and White" - M. Stone

jet colormap

[S. Eddins (Matlab Blog), 2014]
"Get It Right in Black and White" - M. Stone

parula colormap

[S. Eddins (Matlab Blog), 2014]
"Get It Right in Black and White" - M. Stone

parula colormap

[S. Eddins (Matlab Blog), 2014]
Isoluminant Rainbow Colormap

Original

Isoluminant

[Kindlmann et al., 2002]
Turbo Colormap (August 2019)

Jet

Turbo
Turbo: More Detail in Disparity Maps?
Turbo: Lightness Profiles

Jet

Viridis

Turbo
Turbo Discussion

• Turbo is an improvement over jet
• Some fields (e.g. meteorology) have long used rainbow-like colormaps
• Argument is that segments are more easily located
• Turbo post claims that hue is prioritized in attention, but this seems to misinterpret the study…
• Brightness and saturation are more important than hue in attracting attention [Camgöz et al., 2004 h/t J. Stevens]
D3's color scales

- [https://github.com/d3/d3-scale-chromatic](https://github.com/d3/d3-scale-chromatic)
- In v5, included in default bundle (no separate import)
- D3's built-in color scales
- Derived from ColorBrewer
- Sequential and diverging scales created using interpolation
- Hue can change, but be careful
- Color ramp [M. Bostock]
Bivariate Colormaps

Binary

Categorical

Diverging

Sequential

Diverging

Sequential

Bivariate Colormaps

Diverging

Categorical

Diverging

Sequential

Diverging

Sequential

[27]

[Munzner (ill. Maguire), 2014]
Remember Separable vs. Integral
Remember Separable vs. Integral

The map at right is a product of overlaying the three sets of data. The variation in hue and value has been produced from the data shown above. In general, darker counties represent a more educated, better paid population while lighter areas represent communities with fewer graduates and lower incomes.
What about uncertain data?
Bivariate Colormap (Uncertainty → Saturation)

[Correll et al., 2018]
Value-Suppressing Uncertainty Palette (VSUP)

Same Channels, just binned differently

[Correll et al., 2018]
Bivariate Colormap (Uncertainty $\rightarrow$ Saturation)

[Correll et al., 2018]
Value-Suppressing Uncertainty Palette

[Correll et al., 2018]
Evaluation

- **Tasks:**
  - **Identification:** locate spatial regions
  - **Prediction:** place "safest locations"

![Diagram showing different legend styles and sample data](image)

For examples of each condition, see [Correll et al., 2018].
Identification Results

Figure 6: The 8 conditions from the identification experiment. Juxtaposed maps require participants to make an error-prone connection between areas in two separate maps in order to make a decision that integrates value and uncertainty. Traditional bivariate maps integrate both value and uncertainty. VSUPs attempt to improve on traditional bivariate maps by reducing color resolution as uncertainty increases, discouraging conclusions based on noisy or imprecise data.

Figure 7: Accuracy results for the identification experiment.

Figure 8: The prediction task. The participant has a list of locations, and ought to place their ships on locations with low probability of attack, and high certainty in this probability. Ships above the heatmap have yet to be placed.

For the prediction task, we gave participants the rules of a game similar to Battleship. Greis et al. [18] employ these game-like experimental tasks to assess how different visual designs communicate uncertainty information, which can be abstract or complex, to the general audience. In our task, the participant and a (fictional) adversary have to place tokens representing ships on a 5x5 spatial grid, with the expectation that certain squares will be hit by missiles. Players have to place all their tokens before continuing. The objective is to minimize the number of your own ships that are hit.

In our task, participants were given a map representing the predictions of missile strikes in each location on the grid. The value component was the ship’s danger if placed on the square. The uncertainty component was the confidence in this prediction. Other studies of uncertainty representation, such as in Cox et al. [12], have used “prediction + prediction. [Correll et al., 2018]
We recruited 24 participants for this task: we selected this task in order to promote risk-averse behavior. With 6 replications, for a total of 24 stimuli. Prior to the main task, we limited our study to only 4 types: square and wedge bivariate maps. While participants had at least one "safe" square (low danger, highest expected value), ignoring the uncertainty information.

Tversky & Kahneman [1974] proposed a psychological mechanism that our study used to promote better exclusion purposes. 3 people with unacceptably low accuracy were discarded from the prior experiment (with 12 stimuli) for training and the replication of the identification task, we included a short replication of the identification task placed by the participants.

The results partially support our first hypothesis. We test our belief that VSUP users would avoid highly uncertain information, and encourage better integration by highlighting the ambiguity introduced by uncertain data. In particular:

- A risky player would choose guesses in other quartiles.
- However, as with roulette and other similar games of chance, it would be to place tokens on areas with the lowest predicted danger.
- A more conservative guesser might eschew high-risk, high-certainty, and low-danger areas completely, their low accuracy for our previous information.

By reading the heatmap. Having fewer conditions also afforded the distribution of both guesses in other quartiles. This stimuli design meant that, participants would avoid targets with high uncertainty (bottom left corner). When looking at traditional 2D maps (left), participants favored safe but uncertain locations (bottom left corner). When looking at VSUPs (right), participants favored safe and uncertain locations (bottom left corner). This would result in a tradeoff where they would also choose targets with higher danger when using a VSUP.

The results suggest that wedge- and square-shaped legends produce reliably different outcomes. In particular, there is greater perceived value in avoiding large gains or losses produce reliably different outcomes. In particular, there is greater perceived value in avoiding large gains or losses. A risky player would choose guesses in other quartiles.

In particular, statements regarding the distribution of data, most noticeable for square vs. wedge-shaped legends, but included both as a check against the potential implicit VSUP-like properties of various tasks. We found no significant difference in accuracy between visualizations of uncertainty.

A 2D bivariate map. This resulted in 16 samples. The remaining 9 maps outperformed the other bivariate maps we selected, so patterns of decision-making (for instance, the juxtaposed map).

By limiting the potential effects of learning and fatigue from large interpersonal differences in strategies and risk-aversion, while a within-subjects design that controlled for the variation in exclusion purposes. 3 people with unacceptably low accuracy were discarded from the prior experiment (with 12 stimuli) for training and the replication of the identification task placed by the participants.

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Results & Conclusions

• Legend shape has no significant effect
• Some indication that people avoid high uncertainty with VSUPs
• Tradeoff is that people do choose targets with higher danger when using a VSUP
• VSUPs present uncertainty information \textit{simultaneously} (superimposed) instead of juxtaposed
• VSUPs encode value and uncertainty via \textit{discrete, quantized bins} instead of\textit{ continuously}
Geospatial Data
Geographic Data

- Spatial data (have positions)
- Cartography: the science of drawing maps
  - Lots of history and well-established procedures
  - May also have non-spatial attributes associated with items
  - Thematic cartography: integrate these non-spatial attributes (e.g. population, life expectancy, etc.)

- Goals:
  - Respect cartographic principles
  - Understand data with geographic references with the visualization principles
Map Projection

[P. Foresman, Wikimedia]
Flattening the Sphere?

Central Meridian
(selected by mapmaker)

Great distortion at high latitudes
Examples of two rhumb lines (direction true between any two points)
Equator touches cylinder if cylinder is tangent
Reasonably true shapes and distances within 15 degrees of Equator

[USGS Map Projections]
Lambert Conformal Conic Projection

Two standard parallels
(selected by mapmaker)

Large-scale map sheets can be joined at
edges if they have the same standard
parallels and scales

[USGS Map Projections]
Standard Projections

- Regular Cylindrical
- Regular Conic
- Transverse Cylindrical
- Polar Azimuthal (plane)

[J. P. Snyder, USGS]
Map Projections

[Image of a comic strip by xkcd: It reads, "What your favorite map projection says about you." ]
Projection Classification

Myriahedral projections
Dymaxion map
Goode’s homolosine
equal area
conformal
no interrupts
Lambert cyl. eq. area
Plate carree
Mercator

Angle-preserving

[J. van Wijk, 2008]
Taken together, these constraints imply that $N$ subgraphs connecting two faces instead of two vertices (Figure 2).

Figure 2. (a) Mesh spanning tree of $G$; (b) Dual mesh $H$; (c) Cuts and folds; (d) $f$ and $w$ for each node. The use of $H$ should exist from any node (face of the mesh) to any other node. Should exist from any node (face of the mesh) to any other node. The labelling of edges should be done which strips rarely overlap. The geography of the earth (or whatever image on a spherical surface has to be displayed) is mapped as a texture (examples are shown in http://www.win.tue.nl/vanwijk/myriahedral). When the triangles are large compared with a gnomonic projection here.

D. Koop, CIS 680, Fall 2019

Myriaheiral Projections

The use of $Pape$, $2001$. When the triangles are large compared with a gnomonic projection here.

The new angle is $a$ of $RQS$ (1 gives a flat mesh, use of (for instance) proper anti-aliasing, because regular patterns and very thin gaps have to be dealt with. For the images shown, 100-fold supersampling per pixel with a jittered grid was used, followed by filtering with a Mitchell filter. When the triangles are large compared with a gnomonic projection here.

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Cut along parallels or meridians (graticules)

GRATICULES

The simplest way to define a mesh is to use the graticule itself, and to cut along parallels or meridians. The results can be used as an introduction to map projection. A weight for edges, using the value of $w$ and $l$ of the midpoint of an edge, can be defined as

$$w((w, l)) \sim \left(\frac{W w}{j}, \frac{W l}{min_k} \frac{z}{2} p_k\right),$$

where $W w$ and $W l$ are overall scaling factors, and $w_0$ and $l_0$ denote where a maximal strength is desired. Different values for these lead to a number of familiar looking projections (Figure 3). The use of a high value for $W w$ gives cuts along meridians. Dependent on the value of $w_0$ a cylindrical projection (0°, equator), an azimuthal projection (90°, North pole), or a conical projection (here 25°) is obtained when the meridian strips are unfolded. Use of a negative value for $W w$ gives two hemispheres, each with an azimuthal projection. The meridian at which to be centred can be controlled by using a low value for $W l$ and a suitable value for $l_0$. The use of a high value for $W l$ gives cuts along parallels. Unfolding these parallels gives a result resembling the polyconic projection of Hassler (1820).

The relation between a spatially varying weight $w$ and the decision where to cut and fold can be understood by considering Prim’s algorithm. Suppose, without loss of generality, that we start at a maximum of $w$ and proceed to attach the edges with the highest weight. At some point, edges at the boundary will have approximately the same weight and, after a number of additions, a ring of faces is added, with cuts in between neighbouring faces in this ring. Hence, edges aligned with contours of $w$ typically turn into folds, whereas edges aligned with gradients of $w$ turn into cuts.

Each strip is almost free of angular or area distortion, however, a large number of interrupts occur with varying widths. These gaps visualise, just like the Tissot indicatrix, the distortion that occurs when a non-interrupted map is used, and can be used to explain the basic problem of map projection. If we want to close these gaps, the strips must be broadened. However, to maintain an equal area, they have to be shortened, and to maintain the same aspect ratio they have to be lengthened, which is not possible simultaneously. Also, it is clearly visible that mapping a point (such as a pole) to a line leads to a strong distortion. When the number of strips is increased, the gaps are less visible, and the distortion is shown via the transparency of the map (Figure 4).

Figure 3. Graticular projections, derived from a 5° graticule. 2592 polygons: a) cylindrical; b) conical; c) azimuthal; d) azimuthal, two hemispheres; e) polyconical

[J. van Wijk, 2008]
Subdividing regular polyhedra

For the graticular projections, thin strips of faces are attached to one single strip or face. This is a degenerated tree structure. In this section, we consider what results are obtained when a more balanced pattern is used. To this end, we start with Platonic solids for the projection of the globe, and recursively subdivide the polygons of these solids. This approach has been used before for encoding and handling geospatial data (Dutton, 1996).

At each level \( i \), each edge is split and the new centres, halfway on the greater circle connecting the original endpoints, are connected. As a result, for instance each triangle is replaced at each level by four smaller triangles. Other subdivision schemes can also be used, for instance triangles can be subdivided into nine smaller ones.

The edge weights are set as follows. We associate with each edge three numbers \( w_0, w_1, \) and \( w_c \), where the first two correspond with the endpoints and the latter with the centre position. For new edges, \( w_0, w_1, \) and \( w_c \) are set as follows. If an edge \( e \) is split into two edges \( e' \) and \( e'' \), we use linear interpolation for the new values.

As a result, the weights are highest close to the centre of original edges. Finally, we use \( w_c \) as the edge weight for the edges of the final mesh, plus a graticule weight \( w \) with small values for \( W_l \) and \( W_w \) to select the aspect.

The resulting unfolded maps are, at first sight, somewhat surprising (Figure 5). One would expect to see interesting fractal shapes, however, at the second level of subdivision the gaps are already almost invisible (Figure 6). Indeed, the structure of the cuts is self-similar, however, for higher levels of subdivision and smaller triangles, the surface of the sphere quickly approaches a plane, which has Hausdorff dimension 2. Only when areas would be removed, such as the centre triangles in the Sierpinski triangle, a fractal shape would be obtained.

As a step aside, fractal surfaces and foldouts do not match well either. Unfolding, for instance, a recursively subdivided surface with displaced midpoints leads to a large number of fold-overs (Figure 7).

As another step aside, let us consider optimal mapping on Platonic solids. We consider a map optimal when the cuts do not cross continents. To find such mappings, we assign to each edge a weight proportional to the amount of land cut, computed by sampling the edges at a number of positions (here we used 25) and looking up if land or sea is covered in a texture map of the earth. Next, the map is unfolded using the standard method and the sum of weights of cut edges is determined. This procedure is repeated for a large number of orientations of the mesh, searching for a minimal value. We used a sequence of three rotations to vary the orientation of the mesh, and used steps of 1\( \frac{1}{\text{u}} \) per rotation. Results are shown in Figure 8.
Geographically-aligned

aligned with continents

continents and oceans separated

north-up, south-down

north-up, south-down, graticular mesh

[J. van Wijk, 2008]
Australia-centric

[J. van Wijk, 2008]
## Search Tasks

<table>
<thead>
<tr>
<th>Target known</th>
<th>Target unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Location known</strong></td>
<td><em>Lookup</em></td>
</tr>
<tr>
<td><strong>Location unknown</strong></td>
<td><em>Browse</em></td>
</tr>
<tr>
<td><em>Lookup</em></td>
<td><em>Locate</em></td>
</tr>
<tr>
<td><em>Explore</em></td>
<td></td>
</tr>
</tbody>
</table>

[Munzner (ill. Maguire), 2014]
Lookup
Figure 1: Three route maps for the same route rendered by (left) a standard computer-mapping system, (middle) a person, and (right) LineDrive, our route map rendering system.

The standard computer-generated map is difficult to use because its large, constant scale factor causes the short roads to vanish and because it is cluttered with extraneous details such as city names, parks, and roads that are far away from the route. Both the handdrawn map and the LineDrive map exaggerate the lengths of the short roads to ensure their visibility while maintaining a simple, clean design that emphasizes the most essential information for following the route. Note that the handdrawn map was created without seeing either the standard computer-generated map or the LineDrive map. (Handdrawn map courtesy of Mia Trachinger.)

Abstract

Route maps, which depict a path from one location to another, have emerged as one of the most popular applications on the Web. Current computer-generated route maps, however, are often very difficult to use. In this paper we present a set of cartographic generalization techniques specifically designed to improve the usability of route maps. Our generalization techniques are based both on cognitive psychology research studying how route maps are used and on an analysis of the generalizations commonly found in handdrawn route maps. We describe algorithmic implementations of these generalization techniques within LineDrive, a real-time system for automatically designing and rendering route maps. Feedback from over 2200 users indicates that almost all believe LineDrive maps are preferable to using standard computer-generated route maps alone.

Keywords: Information Visualization, Non-Realistic Rendering, WWW Applications, Human Factors

1 Introduction

Route maps, which depict a path from one location to another, are one of the most common forms of graphic communication. Although creating a route map may seem to be a straightforward task, the underlying design of most route maps is quite complex. Mapmakers use a variety of cartographic generalization techniques including distortion, simplification, and abstraction to improve the clarity of the map and to emphasize the most important information [16, 21]. This type of generalization, performed either consciously or sub-consciously, is prevalent both in quickly sketched maps and in professionally designed route maps that appear in print advertisements, invitations, and subway schedules [25, 13].

Recently, route maps in the form of driving directions have become widely available through the Web. In contrast to handdesigned route maps, these computer-generated route maps are often more precise and contain more information. Yet these maps are more difficult to use. The main shortcoming of current systems for automatically generating route maps is that they do not distinguish between essential and extraneous information, and as a result, cannot apply the generalizations used in hand-designed maps to emphasize the information needed to follow the route.

Figure 1 shows several problems arising from the lack of differentiation between necessary and unnecessary information. The primary problem is that current computer-mapping systems maintain a constant scale factor for the entire map. For many routes, the lengths of roads can vary over several orders of magnitude, from tens of feet within a neighborhood to hundreds of miles along a highway. When a constant scale factor is used for these routes, it forces the shorter roads to shrink to a point and essentially vanish. This can be particularly problematic near the origin and destination of the route where many quick turns are often required to enter or exit a neighborhood. Even though precisely scaled roads might help navigators judge how far they must travel along a road, it is far more important that all roads and turning points are visible. Handdrawn maps make this distinction and exaggerate the lengths of shorter roads to ensure they are visible.

Another problem with computer-generated maps is that they are often cluttered with information irrelevant to navigation. This extraneous information, such as the names and locations of cities, parks, and roads far away from the route, often hides or masks information that is essential for following the route. The clutter makes the maps very difficult to read, especially while driving. Handdrawn maps usually include only the most essential information and are very simple and clean. This can be seen in figure 1 (middle) where even the shape of the roads has been distorted and simplified to improve the readability of the map. Furthermore, distorting
Locate
Adding Data

• Discrete: a value is associated with a specific position
  - Size
  - Color Hue
  - Charts
• Continuous: each spatial position has a value (fields)
  - Heatmap
  - Isolines
Discrete Categorical Attribute: Shape
Discrete Categorical Attribute: Shape
Discrete Quantitative Attribute: Color Saturation
Discrete Quantitative Attribute: Size
Discrete Quantitative Attributes: Bar Chart

[Image: Railway Network Development and Bar Chart of Province Population in Turkey]

[http://mis4gis.com/hgistc.org/]

Northern Illinois University
Continuous Quantitative Attribute: Color Hue

[http://tampaseo.com/2012/02/websites-heat-mapping-users/]
Time as the attribute

[NYTimes]
Isolines

[USGS via Wikipedia]
Isolines

- Scalar fields:
  - value at each location
  - sampled on grids
- Isolines use **derived data** from the scalar field
  - Interpret field as representing continuous values
  - Derived data is **geometry**: new lines that represent the same attribute value
- Scalability: dozens of levels
- Other encodings?
Choropleth (Two Hues)

[M. Ericson, New York Times]
Choropleth Map

- Data: geographic geometry data & one quantitative attribute per region
- Tasks: trends, patterns, comparisons
- How: area marks from given geometry, color hue/saturation/luminance
- Scalability: thousands of regions

Design choices:
- Colormap
- Region boundaries (level of summarization)
Problem?

2008 Popular Vote

Obama: 68 million
McCain: 59 million

[M. Ericson, New York Times]
Problem?

2008 Popular Vote

Obama: 68 million
McCain: 59 million

Amount of red and blue shown on map

Obama: 850,000 mi²
McCain: 2,150,000 mi²

[M. Ericson, New York Times]
Adding Saturation

[Washington Post, 2018]
Aggregation: 2016 Election by Precinct

[Interactive Version, NYTimes] [R. Rohla and Washington Post, 2018]
Aggregation: 2016 Election by State

[Washington Post, 2018]
Aggregation: 2016 Election by Country

[Washington Post, 2018]
Area Marks and Color Hue & Saturation