Title: Intuitive Colormaps for Environmental Visualization

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Intuitive Colormaps for Environmental Visualization

Abstract
Visualizations benefit from the use of intuitive colors, enabling an observer to make use of more automatic, subconscious channels. In this paper, we apply the concept of intuitive color to the generation of thematic colormaps for the environmental sciences. In particular, we provide custom sets of colormaps for water, atmosphere, land, and vegetation. These have been integrated into the online tool: ColorMoves: The Environment to enable the environmental scientist to tailor them precisely to the data and tasks in a simple drag-and-drop workflow.

Categories and Subject Descriptors (according to ACM CCS): H.1.2 [Models and Principles]: User/Machine Systems—Human Factors H.m [User/Machine Systems]: Miscellaneous—Colormapping

1. Introduction

Environmental data is growing in size and complexity, challenging the scientist who needs to communicate effectively at many levels: to peers, to policy makers, and to the general public. Communication is critical to fostering understanding and disseminating the scientific knowledge on which decisions are based.

Color is a critical channel for communicating information. Our scientific understanding of color comes from mathematical models as well as the perceptual and cognitive sciences. A complementary understanding comes from the artistic community based on observing and rendering nature onto a canvas. We tap that artistic expertise to develop sets of sequential custom colormaps that intuitively reflect our perception of water, atmosphere, land, and vegetation. These colormaps draw on the artist’s experience of color contrast and interaction to provide sufficient discriminative power within the narrower hue range intuitively associated with a specific facet of the environment.

We are motivated to apply the concept of intuitive color assignment from researchers who have preceded our efforts (see Section 2). As has been pointed out, “The fist step to developing a systematic approach to characterizing and choosing effective visual representations of data is to look for guidance from our interpretation of the real world.” [Rob90], “User interfaces that model human category judgments might enable more compelling forms of reference and selection.” [HS12], and “Intuition for the meaning of a colormap can be developed through experiencing colors in nature.” [TGH*16].

Research in cognition and color has elucidated important points to consider in colormapping. The natural relation of content and color allows an observer to facilitate automated processes that require less conscious concentration [Baj88]. Conversely, the so-
called "Stroop effect", i.e. if color names are drawn with contradicting colors, like yellow or green, is known to increase the time for a reader to name them [DA72, Mac91]. Additionally, nameable colors tend to be easier to remember [Ber91, RDD00].

The main contribution of this paper is to provide a diverse range of color options for clearer, more intuitive representation and communication of environmental science data. We provide the scientific community with intuitive colormaps and palettes as well as a domain specific colormap customization tool ColorMoves: The Environment, enabling environmental scientists to quickly and easily select and customize colormaps and color systems to meet their observation, exploration, and communication needs.

2. Related Work

2.1. Colormap Design Rules

Colormapping is a very old technique with many rules and guidelines available in the literature [SSM11, ZH16]. Common themes include order [SB79, WF80, Tru81], uniformity [Piz81, Taj83, RO86], and a high discriminative power [PZJ82, Taj83, LH92]. While the first order and uniformity can be satisfied using a straight line through a perceptually uniform color space, high discriminative power requires a long curve through a color space.

2.2. Intuitive Colors in Visualization

Robertson [Rob90], in introducing his natural scene paradigm, states that for the display of multiple variables in complex scenes (such as occur predominantly in the environmental sciences [BM16]), intuitive representations of the data are very important. The important of color names for the design of color palettes is stressed and applied by Brewer et al. [Bre94, HB03]. Havasi et al. [HSH10] provide an algorithm that associates a color to a word. They make use of known associations from databases and interpolate between the concepts related to colors for unknown words.

Heer and Stone stress that the naming of colors strongly influences an observer’s capacity of categorization and judgment of the physical world. They provide a framework for probabilistic color naming [HS12, Sto16]. Lin et al. [LFK13] demonstrate how colors that semantically correspond to the displayed content increase the speed of bar chart reading and develop an algorithm to correlate a set of colors to words.

Despite concerted efforts by the cognitive and visualization communities [RT98, LB04, BTH07], some version of the rainbow remains one of the most frequently used colormaps [BM16, DBW10, MHB14, Win16].

The recent work of Thyng et al. [THG16] and of Samsel et al. [SPG15] are notable exceptions. In the latter an artist was invited to design customized colormaps for the visualization of ocean data with results aligning with the natural colors of the ocean. Thyng et al. [THG16] suggest a set of colormaps, cmoccean, for the visualization of ocean data. They agree with general colormap theory in that uniformity is important and that sequential, diverging, or cyclic colormaps need to be chosen to match the data type. But they also suggest two new rules. One is consistency, by which they mean that within one context two variables should not be represented by the same colormap, just as two variables would also not be assigned the same Greek symbol. The other one is intuition, meaning that cultural implications and the nature of matter and variables can enhance understanding, for example, sea ice should be visualized using blues and whites.

2.3. Colormap Design Tools

The visualization community provides several tools for the guided generation of colormaps. PRAVDA Color [BRT95] suggests colormaps based on the visualization task, data types, and spatial frequency. ColorBrewer [HB03] provides carefully designed discrete color palettes and recommendations based on different data types and goals. ColorCAT [MJSK15] extends the task-based concept of PRAVDA Color to combinations of visualization tasks. The matplotlib [Hun07] extension VisCM (github.com/matplotlib/vism) lets the user design uniform color maps that increase linearly in luminance through adjusting the control points of a spline in the chromaticity plane.

ColorMoves [SKP16] is a tool that provides custom colormaps that can be precisely placed as needed into the data and nested into each other via an intuitive drag-and-drop process. This enables the user to create colormaps that are tailored towards very specific data and visualization goals.

3. Intuitive Environmental Colormaps

Environmental scientists face many challenges when it comes to the visualization of their data [BM16]. They often need to display several variables (temperature, salinity, wind speed, etc.) at once to see and analyze multi-variable correlations. Since the spatial embedding often plays an important role, they must include topographic features (e.g., geopolitical borders, rivers, or terrain information) [BM16] that require both space and colors in a visualization. The ability to see perceptual depth (discriminative power) in the data is usually a key goal. Communication to a broad audience with mixed background knowledge must be considered.
The sets of intuitive colormaps that we provide addresses these challenges while striving to follow some of the more important colormap design rules. They are designed to respect intuitive order and uniformity. These requirements are balanced against the need to create a longer line in color space so as to not sacrifice the discriminative power available in the colormap despite the narrow hue range.

By using intuitive colors, the non-scientific audience is invited to participate in the visualization, while we know from the cognitive sciences that intuitive color choices helps scientists and non-scientists alike to more quickly understand the content of a visualization. These colormaps also help to remedy the other common problems faced by the environmental scientist. When displaying many variables, each can be shown in a different intuitive colormap, emphasizing the contrast between the variables. When spatial context information is crucial for the interpretation of their findings, these colormaps enable sharing the visualization space. A colormap that goes through too broad a spectrum creates issues when insufficient color channels are left for encoding all variables or auxiliary information.

The full set of colormaps, shown in Figure 3, are designed to provide a variety of colormaps that address specific color needs in environmental science. Blues are used for water, ice and sky/air. Greens can be for either land or water. The browns, reds and yellows cover earth and air.

The multiple variants for each hue can be used to address a wide range of data rendering needs. Color contrast theory [Alb09, Itt61, HB03] informs those choices. Colormaps with a wider range of hues (BlueSpectrum, RedSky, GreenFields) can be used to get an overview of data, taking a longer line through colorspace. Colormaps that span a greater luminance range with similar intensities (e.g., BlueIce, GreenPond, YellowFields) work well together in a blended colormap. To create distinct breaks along a dividing line between environments (e.g., water vs. land), use colormaps that extend to the darkest values (BlueWater, BrownEarth). Continuity can be emphasized by combining a series of colormaps, light end to light end, dark to dark.

Considering the warm/cool contrast is also a useful starting point. If two similar hues are needed, choosing one warm and one cool will highlight the differences. e.g., mixing the warm GreenPond and the cool GreenSeas. Across color ranges, a warm green (GreenLagoon) with a cool blue (BlueDeep) will maximize contrast. The yellows can also provide a warm contrast to mix with the cooler greens or blues.

4. Custom Colormapping

No single colormap is optimal for all domains, statistical distributions, or tasks. We extend the previous development of ColorMoves [SKP*16] to include these sets of intuitive colormaps for environmental sciences into a domain specific extension, ColorMoves: The Environment.

ColorMoves, Figure 4 allows the scientist to build custom colormaps, delineating regions of interest with pins and nests. These defined regions in the data can each be given its own colormap.
The ability to interactively adjust the endpoints of these regions in real time enables the scientist to craft very data-specific colormaps. Full details on its use can be found on the ColorMoves site: sciviscolor.org/home/colormoves.

Figure 4: An overview of ColorMoves features: (A) colormap options, (B) Pin splitting tool, a sliding point used to specify data junctures, (C) data histogram, (D) colormap exporter.

Figure 1 illustrates the process of building a custom colormap. Starting from the left, one sees an image of the Wax Lake Delta where brighter colors indicate regions with enhanced vegetation. Flow structures in the coastal ocean correspond to regions of enhanced sediment transport. In the central image, a single pin is dropped and a choice made from the blues for the near-shore ocean and from the greens to evoke the plants in the delta. Alternately, a brown is used in the final image for the earth with blue variants to show greater detail the water.

Using ColorMoves: The Environment, our environmental scientist collaborator notes, "Separation of the ocean and land boundary in the coastal zone, allowing key detail to be manifest, is particularly important because it allows key gradients in the terrestrial aquatic interface to be found. Having these abilities will enable me to more quickly share this information."

The advantages of using intuitive colors and custom colormapping are further illustrated in Figures 2 and 5. The different data sets shown are rendered in common colormaps and in custom colormaps built on the intuitive colors. The custom colormaps allow perceptual depth into the data despite the narrow hue ranges spanned while the colors speak to the natural scene inherent in the dataset.

5. Conclusions

In this paper, we introduced sets of intuitive environmental colormaps that have been incorporated into an online tool, enabling a workflow to customize colormaps.

The different ways in which intuitive colormapping can help to overcome typical challenges in the environmental sciences are summarized in Table 1. ColorMoves: The Environment includes all of the above colormaps plus some starting point option. We invite the community to explore their data with ColorMoves: The Environment and welcome feedback on the newly available colormaps.

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Solution</th>
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<tbody>
<tr>
<td>Broad audience with varying scientific background</td>
<td>Intuitive colormaps work on many levels</td>
</tr>
<tr>
<td>Visualizations need to leave colors for the display of other parameters, spatial context, highlights, or glyphs</td>
<td>Narrow hue range of intuitive colormaps enables clear thematic distinction from other visualization items</td>
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<tr>
<td>Not enough perceptual depth, detail in the data</td>
<td>Artist-designed colormaps provide high discriminative power despite narrow hue range</td>
</tr>
<tr>
<td>The colormaps do not reflect the complicated structure of the data or do not sufficiently emphasize the central statement</td>
<td>The provided tool: ColorMoves: The Environment allows simple and precise fitting of the colormap to data and tasks</td>
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Table 1: Summary of how the suggested colormaps, tool, and workflow help the environmental scientists face typical visualization challenges.

Acknowledgments

Redacted for submission.
References


[Ber91] BERRY L. H.: The interaction of color realism and pictorial recall memory. 2


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