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Visualization-Aware Color Design

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Abstract

Color encoding design currently focuses on the colors themselves: visualization designers choose sets of colors that work well in isolation. However, the effectiveness of a color encoding depends on properties of the visualization it is used for, such as the size or shape of marks. We argue for a new way of thinking about color design in visualizations: designers should choose colors based on a given context rather than in isolation. We identify three categories of design constraints that contribute to the effective color choices in visualization: aesthetic constraints*,* perceptual constraints*, and* functional constraints*. The conceptual framework formed by these constraints helps designers optimize color choices based on known properties of a given visualization. In this poster, we discuss this framework in detail and illustrate how it informs more effective visualization design.*

Categories and Subject Descriptors (according to ACM CCS): H.5.2 [User Interfaces]: Screen Design—Graphics & Color

1. Introduction

Color is a common channel for communicating values in visualizations. The color ramp used to encode data directly influences how accurately people interpret visualized data [BTI07]. A number of systems and guidelines exist for choosing effective colors (see [ZH15] for a survey). However, these approaches focus on color choices in isolation: designers choose swatches that are appealing in the abstract and use guess-and-check to evaluate those choices for a target visualization. This requires designers to iteratively author and apply colors until they find a desirable encoding.

While interactive previews [JMM15] or post-hoc corrections [TFS08] can help in this process, we argue that effective color choices should instead be authored *holistically*, considering characteristics of the visualization, data, and interactions in color design. Many measurable factors can guide effective color choices for a given visualization, such as the type of data [Bre99] or size and shape of marks [SSS14]. Authoring tools can treat these characteristics as constraints to automatically generate color encodings informed by expert designer practices. In this poster, we contribute a framework of design constraints to guide holistic color authoring.

Our framework identifies three types of constraints that collectively enable holistic color design: *aesthetic*, *perceptual*, and *functional*. *Aesthetic constraints* consider how visually pleasing colors appear in a visualization. *Perceptual constraints* model how accurately colors communicate data. *Functional constraints* identify supplemental colors that support specific tasks, such as highlighting or binning outliers. Populating this framework allows designers to optimize color choices for different visualizations.

In this poster, we introduce this framework and discuss its ramifications for improved color choices. We identify several specific constraints within each category (Table 1) and describe how these constraints are formulated to inform new authoring approaches.

2. A Framework of Design Constraints

Our framework formulates design considerations as "constraints" to systematically account for different visualization attributes. We argue that this framework can guide visualization-aware color design using properties of a visualization known by designers *a priori*. This reduces the difficulties designers face in making good color choices. Through this framework, authoring tools can account for critical aspects of visualizations using mathematical constraints.

Type	Constraint
Aesthetic Constraints	Smooth curve through color space Color complementarity Appropriate for mark type Avoid harsh colors Avoid colors that are too light or too dark
Perceptual Constraints	Perceptually uniform distances between colors Equidistant lightness steps between colors Step sizes sufficiently large for minimal mark sizes Avoid crossing color name boundaries Suitable for colorblind users
Functional Constraints	Colors for binning outliers Interpolation colors for low-lighting Salient colors for highlighting Font colors for visible labels Fit mappings to natural structure of the data

Table 1: *A sample of different design constraints in our framework.*

The primary challenge in constructing these constraints is that the three types must each be formulated differently. For example, we can use quantitative models to formulate many perceptual constraints, whereas aesthetic choices are primarily subjective. In this section, we discuss each category of constraints and their formulations to guide visualization-aware color design.

2.1. Aesthetic Constraints

Aesthetic color constraints model visual appeal. For example, heavily saturated colors appear garish on area charts, but help to distinguish scatterplot points [Sto06] (Fig. 1a). These constraints are critical for creating engaging visualizations [CM07], but are predominantly subjective. Some of these constraints (e.g., colors should shift smoothly) can be readily formulated using traditional color spaces. Others (e.g., assembling a visually appealing color set) require extensive expertise and hours of manual adjustment to solve.

Aesthetic constraints can be formulated using a data-driven approach by modeling structural patterns found in successful palettes. For example, ColorBrewer provides appealing color ramps [HB03]; however, the palettes use a fixed set of colors designed for area marks, are not perceptually uniform, and required extensive expertise to create. Prior work has shown that individual Brewer ramps can be approximated computationally [WVVWVDL08]. By modeling recurring structures across the collection of Brewer ramps, we can derive constraints that automatically guide designers towards good color choices. We can apply these models to user-selected colors to recommend color choices that embody expert practices while allowing designers control over specific attributes.

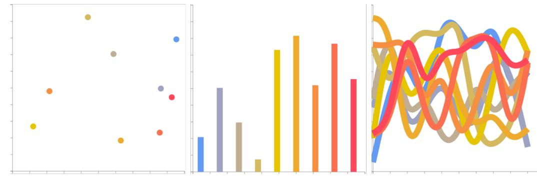
2.2. Perceptual Constraints

Perceptual constraints model how accurately viewers will interpret data in a given visualization. For example, the minimum allowable mark size constrains how well users distinguish encoded values [SSS14] (Fig. 1b). Perceived color differences should mirror value differences. Recent work has explored how perceptual constraints can be resolved at display time (e.g., contrast correction [MK15]). However, many perceptual constraints can be proactively addressed when designing color choices using perceptually uniform colorspaces for basic color constraints (e.g., CIELAB for equidistant lightness steps) and using visualization attributes to parameterize existing probabilistic color models (e.g., [SSG14, SSS14]).

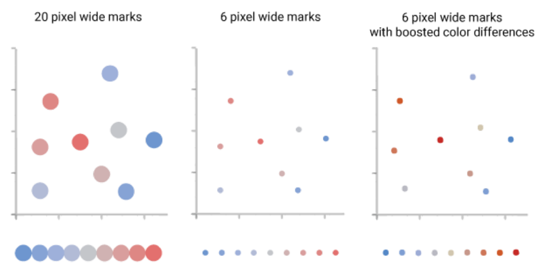
2.3. Functional Constraints

Functional constraints specify colors that augment a data encoding to support specific tasks. For example, visualizations might map outliers to a color that appears related to, but not part of, a primary ramp. Brushing often changes the color of corresponding values to highlight them. Filtering reduces the salience of less relevant data to highlight important values in context.

While functional colors are often chosen through guess-and-check or pseudo-arbitrary conventions (e.g., reduce alpha to lowlight), algorithmic formulations can instead recommend functional colors that better optimize aesthetic and perceptual properties of the resulting visualization (see Fig. 1c for an example). We have designed several candidate algorithms for specifying functional constraints by combining aesthetic and perceptual considerations. Authoring systems can use these algorithms alongside other constraints to recommend function colors that both effectively support specific tasks and complement the primary data encoding.



(a) **Aesthetic** constraints model aspects of visualization context and preference by sampling. For example, colors that work well for scatterplot points may be too bright for line or area charts.



(b) **Perceptual** constraints directly model how visualizations influence how accurately color values are perceived. For example, mark size influences the perceived distance between colors.

(c) **Functional** constraints integrate perceptual and aesthetic considerations to generate colors that supplement values, such as lowlight colors that unambiguously reduce salience.

Figure 1: *Our framework outlines three types of design constraints.*

3. Using Our Framework

Formulating aesthetic, perceptual, and functional considerations as constraints using this framework allows systems to automate color guidance using optimization. An authoring system can query designers for critical information, automatically formulate constraints from this data, optimize a color configuration over these constraints, and output preview visualizations based on these results. Designers can then tweak the input parameters and suggested colors to interactively refine ramps while still preserving important aesthetic and perceptual properties, leading to more effective color choices for visualizations.

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