Perceptually uniform colormaps for data visualization

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Commonly used colormaps, such as those provided with most image display software, tend to be defined as simple functions of device color spaces, usually the Cartesian RGB or the conical HLS or HSV spaces. Though these maps are typically simple to define and have an ordering that is easily interpreted, they are not, in general, perceptually uniform. Thus data variations of a given magnitude get mapped into color variations of different perceptual magnitude, either hiding structure in the data, or exaggerating the perceived contrast, creating artifacts. This problem has been particularly well documented for the still too commonly used "rainbow" colormaps, as is shown, for instance, in a recent review by Borland and Taylor (2007, doi:10.1109/MCG.2007.323435).

This work presents colormaps defined from perceptually uniform colorspaces, designed to optimize the detection and fidelity of the perceived structure in the images. We achieved uniformity by defining the maps in the CIE Lab space, which was defined with the specific objective of having Cartesian distances between points correspond to the perceived color differences between them. We defined completely uniform colormaps by selecting the longest straight lines in these spaces. While these have the desired uniformity, they end up spanning a small length, due to the limitation of being straight lines. Thus we also defined maps that are slightly nonuniform (they are smooth lines with large curvature radius), spanning longer lines to have a wider dynamic range.

Another innovation is the definition of maps for cyclical variables. When one wants to represent a cyclical variable (such as an angle or a time of day), the desired topology for best representation of this variable is no longer a straight line, but is a circle through a uniform space. The circle is cyclical, thus does not introduce an artificial discontinuity in the perceived data, and has the correct perceptual distance between its points. Similarly to the case of the smooth lines used to provide wider dynamical range at the expense of a small nonuniformity, we also defined elliptical maps, to provide wider dynamical range for cyclical variables.

Additional considerations in the development of these colormaps are the number of discrete levels, in order to obtain maps with wider dynamic range than the usual 256 colors, the variation in contrast perception with scale of the structures, and data-dependent colormaps.

We show some examples of the different perceived structures in some astronomical images. Taking data from published papers analyzing structures in astronomical images, we show how these can be misleading, or limited, with poor selection of colormaps. Therefore, the choice of colormaps, often disregarded by

researchers working with images (astronomical or otherwise), can have a significant impact on the use of data in eScience. With increasingly complex and abundant data, lack of efficient visualization means increased risk for missing important subtle features, since researchers no longer spend long times looking at a single image.