Collaboration-Specific Color-Map Design

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Much research in color-map design has focused on appropriate color maps for general categories of datasets for general audiences. For example, David Borland and Russell Taylor demonstrated the rainbow color map's deficiencies and suggested alternatives for different data categories.[1] Also, Kenneth Moreland analyzed the problem of designing an appropriate default color map for a general-purpose scientific-visualization tool.[2]

Although general color-map design is necessary, we argue that designing color maps for domain experts differs fundamentally from designing them for general audiences. The same human-perception issues are at play, but when visualization designers collaborate with domain experts, domain-specific knowledge should inform the design choices. These choices might involve trading decreased general legibility for increased information content displayed for the domain expert's interpretation. Because domain-specific knowledge must inform the color-map design and because domain experts need to understand the design choices, close collaboration between designers and experts is necessary.

Although providing universal principles for such specific color-map designs is problematic, here we present some helpful guidelines derived from collaboration between a visualization designer (David) and a domain expert (Alan). During this collaboration, we created three color maps for three 2D scalar fields extracted from the same underlying 3D vector field, tailoring each map to provide more effective visualization for the expert.

Color-Map Design

A typical LCD display can produce more than 16.7 million distinct colors. How should you arrange them to generate effective visualizations? We offer four guidelines.

First, think of hue and luminance (perceived brightness) as two orthogonal properties to optimize. Consider adjusting the hue as a tool for absolute measurements, such as categorization or localization within a range of values. On the other hand, luminance can be a tool for relative measurements—for example, to reveal fine local detail and introduce perceptual ordering. Always keep in mind that luminance change is necessary for perception of detail but that using luminance alone is a poor choice for making absolute value judgments.

Second, base the colors on existing color maps. Color maps with well-known properties exist. Choose maps that match your needs relatively well and use them as frameworks in which to fine-tune the distribution of hue and luminance (as we'll demonstrate later).

Third, sometimes you can combine multiple existing maps to create a single map (as we'll also demonstrate later). This can be especially useful if you can easily separate the data into larger distinct regions—for example, positive and negative values.

Finally, when in doubt, try the *black-body radiation* (BBR) color map. Borland and Taylor suggested the BBR color map as a suitable alternative to the rainbow color map for 2D ratio scalar fields because of its combination of distinct hues and a luminance gradient.[1] You generate it in RGB color space by increasing red, then green, and finally blue over successive thirds of the color map. You can form a family of color maps by increasing the RGB components in different orders[3] (see Figure 1).

Because of BBR color maps' distinct hues and luminance gradient, they fit nicely with the other

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Figure 1. Black-body radiation (BBR) color maps: (a) the basic BBR color map and (b) a cool variant. BBR color maps provide distinct hues and a luminance gradient.

guidelines we just gave. They provide a good framework in which to experiment with new color maps and a reasonable point of comparison for new creations. Although all three of the maps we designed differ considerably, they're all based at least partly on the BBR color-map family. This wasn't a predetermined design goal, and we introduced each map independently for each dataset.

Because domain-specific knowledge must inform the color-map design and because domain experts need to understand the design choices, close collaboration between designers and experts is necessary.

The Collaborative Process

We generated our maps in a highly collaborative process in which we designed and discarded many maps before achieving satisfactory results. Each color map evolved from a relatively standard color map to a highly tailored one. Here are four guidelines.

First, listen to the domain expert. The domain expert is just that—an expert, who knows his or her field much better than you do. One job of the visualization designer is to translate from domain-specific language into constructs that can guide color-map design. (For example, sharp downdrafts mean high-frequency data, indicating the need for a luminance change.)

Second, speak to the domain expert. Explain your design choices. Explain the properties of the human visual system that led to those choices. The domain expert will be using the final product, so the more he or she knows about it, the better. Having a close collaborator who understands the color map's properties and how to interpret the map gives you more freedom to design effectively than if you were designing for a general audience.

Third, prioritize properties. Sometimes you might need to lose a beneficial property, such as perceptual ordering, to effectively display data features the domain expert needs (as we'll show later). The expert can help with this prioritization, and making the expert explicitly aware of such choices can help his or her interpretation of the color map.

Finally, rinse and repeat. Keep iterating until you converge on a satisfactory result.

The Data

We visualized 3D unstructured grids of 3D vectors simulating airflow in downtown Manhattan. Owing to the geometry of the buildings in the urban environment, complex wind patterns emerge from even simple wind inlet conditions. We addressed the color mapping of scalar fields on 2D slices through the data, using the convention of the z-axis being perpendicular to the ground plane. We extracted these 2D scalar data fields: the xy velocity magnitude, xy angle, and z component.

For the images in this article, we used xy slice planes. The "holes" in the planes are the intersections with buildings, the interiors of which contain no data points.

The xy Magnitude Color Map

The magnitude of the velocity in the xy-plane forms a ratio scalar field with all positive values. The domain expert wished to identify areas of velocity magnitude in certain ranges and observe detailed patterns in these ranges.

In our first attempt, we applied the standard BBR color map, but starting at dark blue instead of black, so that the data would stand out from the background. We chose this map because the luminance gradient across it displays detail and because the distinct hues help separate data into ranges of values. Although this choice initially seemed reasonable to the visualization designer, the domain expert wasn't satisfied.

Because of the difference in the range of velocity magnitudes at different altitudes, a given altitude would often use only a small section of the color map. Figure 2a illustrates this issue for a slice plane at a height of 300 meters. The vast majority of that plane uses only a small range of hue and luminance, causing it to appear washed out.

The visualization designer first had the color-map range automatically adjust to match the current slice's range. However, this was unacceptable to the domain expert, who needed to directly compare images of slices at different altitudes. This necessitated a consistent color-map range across all slices.

After numerous iterations, we created the color map in Figure 2b. This map evolved from the BBR color map, mimicking its ordering of hues (again replacing black with blue at the low end to differentiate the data from gray values at the high end). This map uses five bands of constant hue,

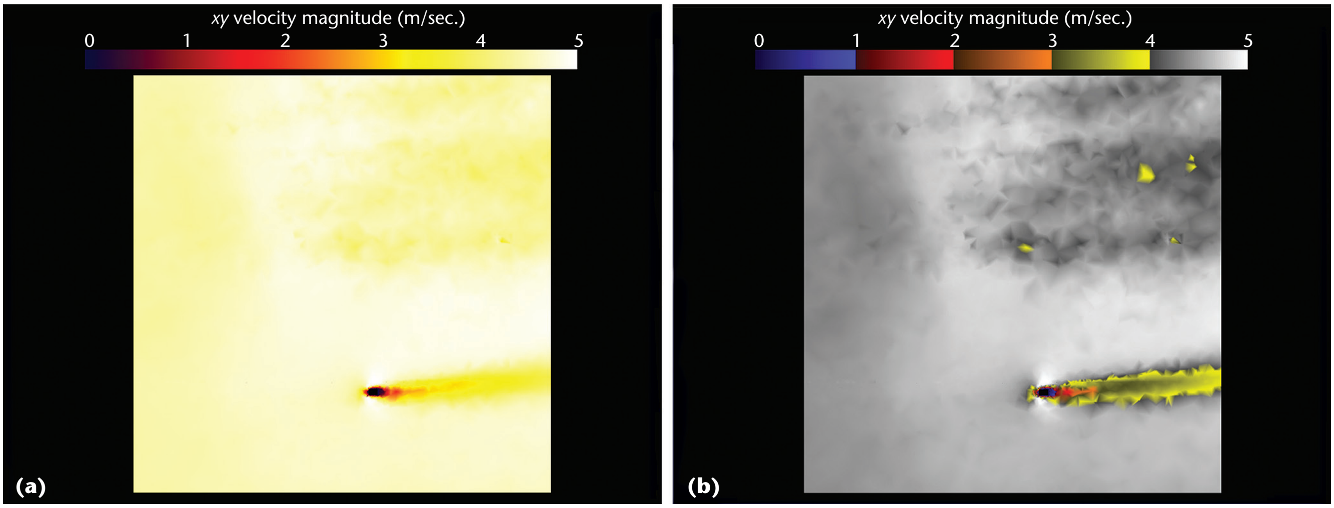
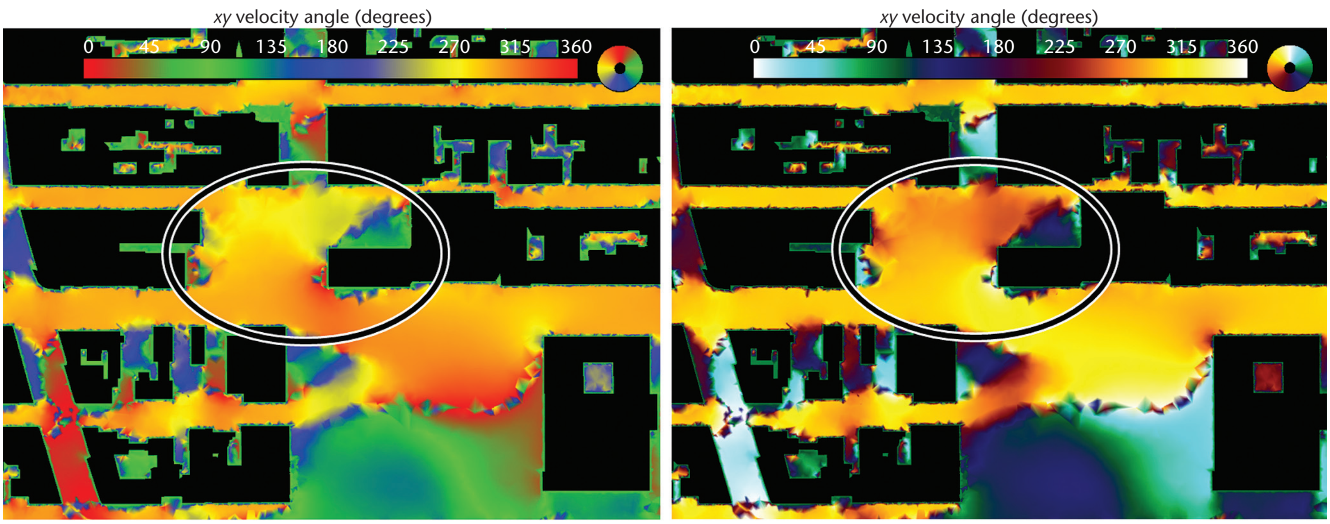


Figure 2. An *xy* magnitude color map. (a) An early version used a small range of hue and luminance for the vast majority of the slice plane, causing the map to appear washed out. (b) The final design rearranges the color map's luminance profile while maintaining its hue profile. It shows more detail and segments the data ranges more effectively.



(a) **(b)**

Figure 3. An *xy* angle color map. (a) An early map tried to correct inconsistent angular ranges of windflow but didn't provide high-enough resolution. (b) The final design shows more detail (see the circled area) and more effectively maps hue to direction.

which form implicit contours at the borders between hues. This enables easy visual segmentation into distinct ranges of velocity magnitude. Because visualization of the detail in each band was also necessary, we increased the luminance linearly in each band. In essence, we rearranged the color map's luminance profile while maintaining its hue profile.

Although such a rearrangement loses perceptual ordering across the whole color map, it maintains this ordering in each band. And, more important for the domain expert, it enables much better perception of the detail in each band.

This color map is a good example of an unorthodox color map that might be somewhat confusing at first glance for a naive user but that matches the domain expert's needs well. It enables the expert to gain more insight into the data than was possible with the standard color map we began with.

The xy Angle Color Map

The domain expert was also interested in the complex patterns of wind directions formed in urban environments. To study these phenomena, we computed the incoming wind direction on the *xy*-plane. The initial thought was to show direction directly through techniques such as vector glyphs and streamlines.[3] However, this produced too much visual clutter and the inability to perceive high-frequency patterns in the data.

Figure 3 shows a slice plane at a height of 10 meters, zoomed in to show more detail. For this data,

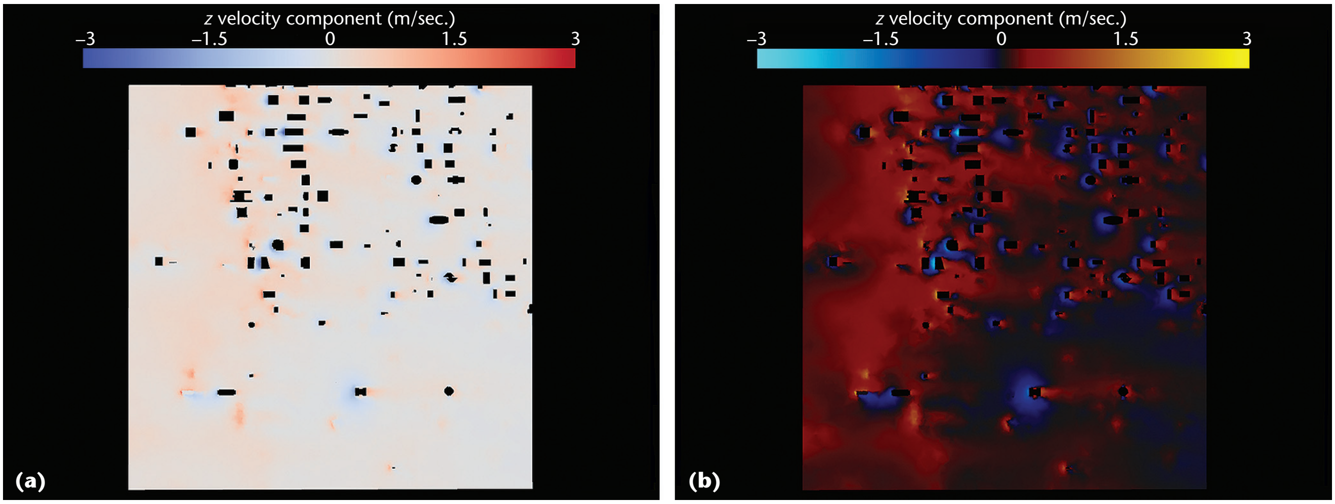


Figure 4. A *z* component color map. (a) Our first attempt used the double-ended color map that Kenneth Moreland suggested.[2] (b) The final design uses dark gray to de-emphasize values near zero. It shows more detail, and brighter areas highlight high velocities.

the domain expert wished to assign distinct zones of airflow into angular ranges of consistent size without losing the ability to see the detail in these zones.

For such angular data, a circular color map is appropriate because 0 degrees and 360 degrees are equal. Previous research has applied the rainbow spectrum to such maps for visualizing orientation.[4] However, if we used the rainbow spectrum in this case, the detail in many areas would be difficult to see. Also, because some hues take up more space than others, the hues' angular ranges would be inconsistent.

To produce consistent ranges, we reordered four hues from their position in the rainbow color map (see Figure 3a). This let us assign a hue to each cardinal direction: red for north, blue for south, yellow for east, and green for west. However, the domain expert still found this color map insufficient because it provided insufficient resolution in mapping hue to direction and didn't allow observation of finer details in the data.

After numerous revisions, we arrived at the color map in Figure 3b. A distinct hue occurs every 45 degrees to allow categorization into ranges, and the luminance gradient throughout enables perception of detail. This color map is based on dual BBR color maps that begin at dark purple and end at white. Warm and cool colors enable differentiation between easterly and westerly winds; dark and bright colors enable differentiation between southerly and northerly winds.

Again, this color map is somewhat unorthodox but matches the domain expert's needs well.

The z Component Color Map

This component represents the vertical airflow due to building faces diverting the input horizontal flow. It forms a ratio scalar field with positive and negative values (upward and downward flow). Because understanding the direction is important, we can consider zero a "special value," and a double-ended color map around zero is an appropriate choice.[3]

Figure 4 shows two such color maps applied to a slice plane at a height of 150 meters. The domain expert wished to locate high-magnitude downdrafts and updrafts and examine the structure of large areas of upward and downward flow.

Our first attempt used the double-ended color map that Moreland suggested,[2] from blue to white to red (see Figure 4a). In this case, the colors appear washed out, such that the features of interest aren't apparent. These deficiencies are due largely to a relatively small luminance gradient.

The final color map design (see Figure 4b) uses dark gray to de-emphasize values near zero. We use two versions of the BBR (with white removed from both ends to avoid confusion) to divide negative and positive values into cool and warm colors. Owing to the BBR's properties, we can see much more detail than with the first color map. Also, this map maintains the perceptual ordering of magnitude (the brighter the color, the higher the magnitude).

This map is relatively straightforward compared to the *xy* magnitude and angle maps. However, it still illustrates the benefit of performing collaborative color-map design to improve upon default color maps.

Color mapping is one of the most common visualization techniques, and selecting a color map appropriate for specific datasets and questions about the data can greatly enhance a visualization's effectiveness. Close collaboration between visualization designers and domain experts maximizes the information content the visualization can convey to end users. As we mentioned before, it also enables greater flexibility than when you're designing for generic datasets and general audiences.

We hope that our guidelines will help you design your own effective color maps.

References

1. D. Borland and R.M. Taylor II, "Rainbow Color Map (Still) Considered Harmful," *IEEE Computer Graphics and Applications*, vol. 27, no. 2, 2007, pp. 14–17.
2. K. Moreland, "Diverging Color Maps for Scientific Visualization," *Proc. 5th Int'l Symp. Visual Computing* (ISVC 09), Springer, 2009, pp. 92–103.
3. C. Ware, *Information Visualization: Perception for Design*, 2nd ed., Morgan Kaufmann, 2004.
4. A. Johannsen and R.J. Moorhead II, "AGP: Ocean Model Flow Visualization," *IEEE Computer Graphics and Applications*, vol. 15, no. 4, 1995, pp. 28–33.

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