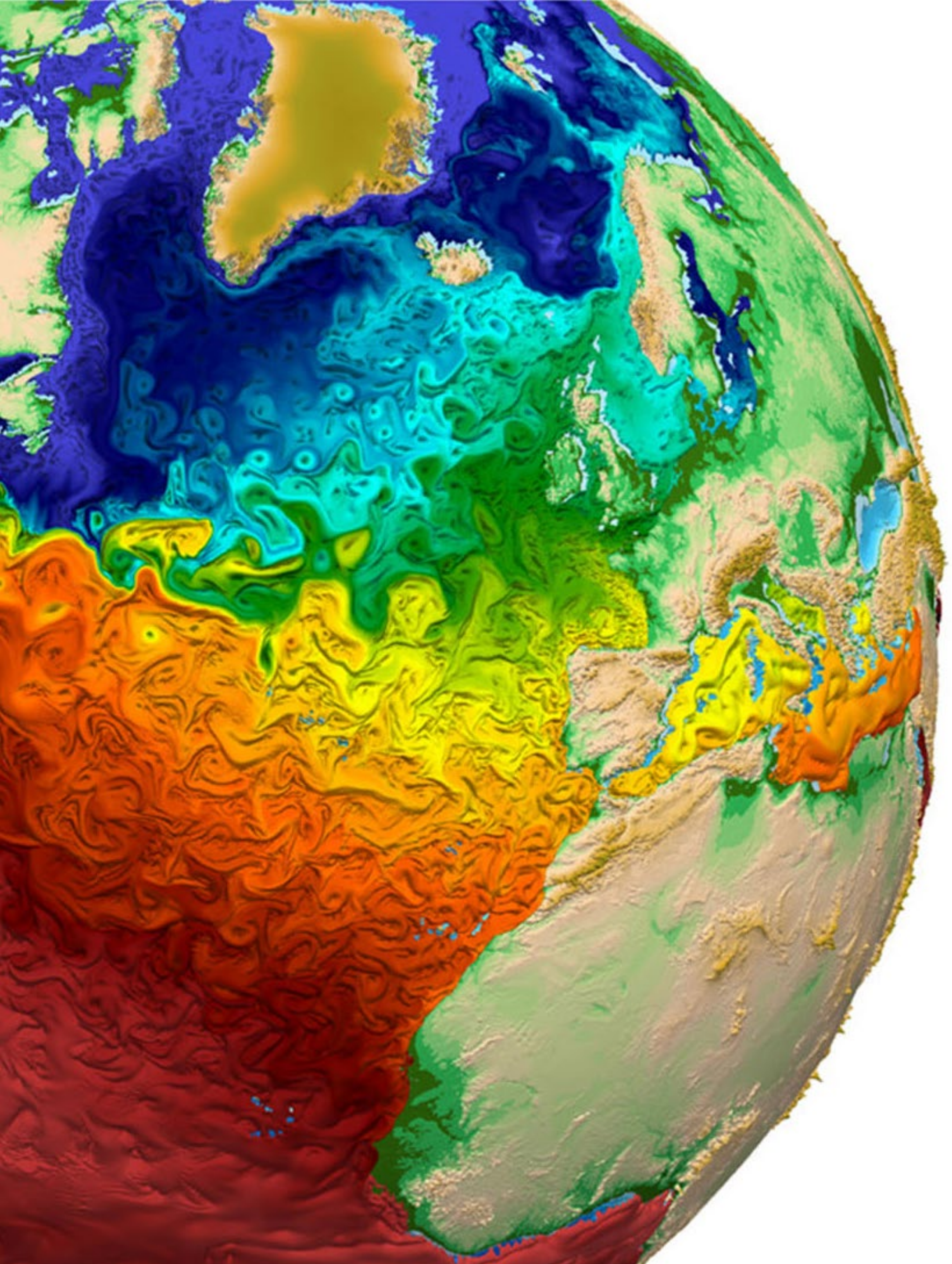

Scalar Field Visualization

Colormaps

Scientific Visualization

Professor Eric Shaffer

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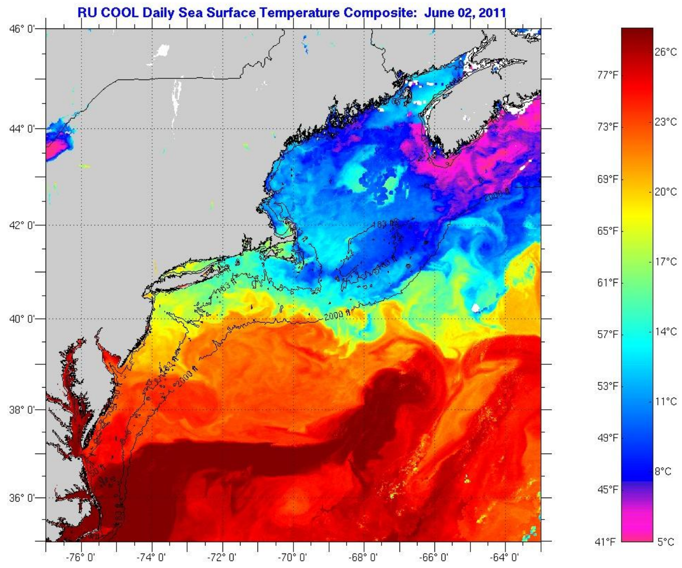
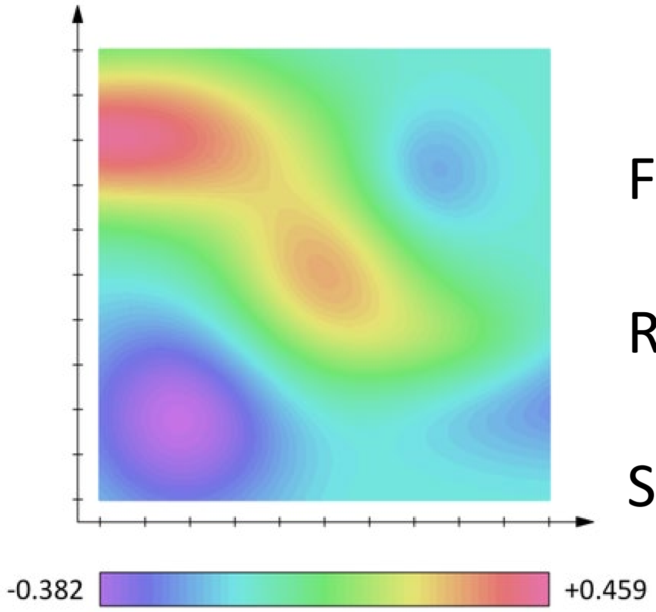
What is a Scalar Field?

A scalar is a single quantity…a number

A scalar field assigns a scalar to every point in a given space





For a 2D space, a scalar field is often visualized using color

Render a representation of domain and assign a color to each pixel

Seemingly simple task…just need to construct a colormap

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Coloring Continuous Data

Coloring to denote continuous data is called ***pseudo-coloring***

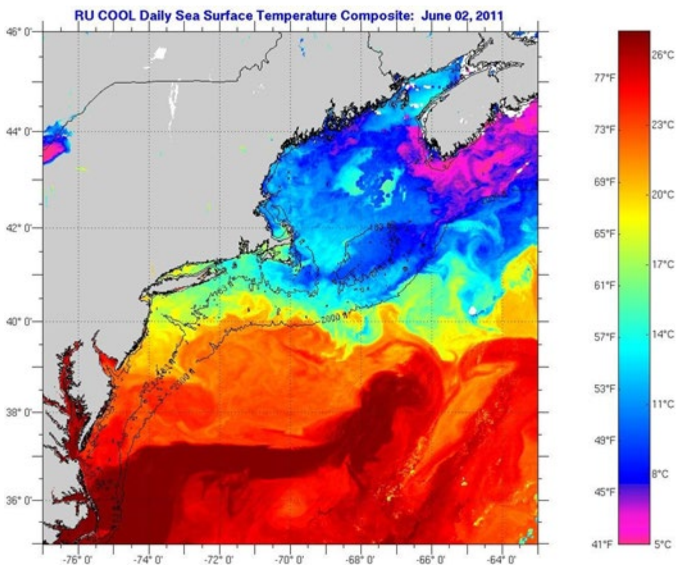
Such a mapping from value to color is called a ***choropleth***

Anyone know the standard weather map colors?

How about elevation in geography?

What is the most used colormap?

Is it any good?



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Coloring Continuous Data

Coloring to denote continuous data is called ***pseudo-coloring***

Such a mapping from value to color is called a ***choropleth***

Anyone know the standard weather map colors?

blue-cyan-green-yellow-orange-red

How about elevation in geography?

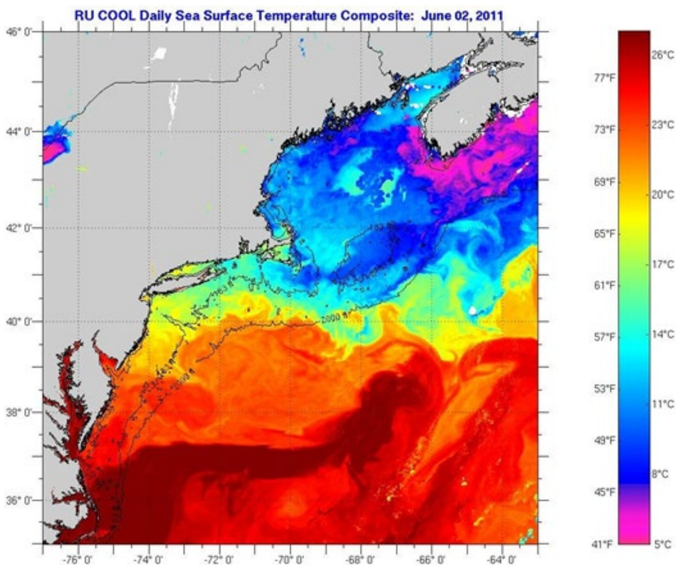
blue-green-brown-white

What is the most used colormap?

rainbow

Is it any good?

probably not



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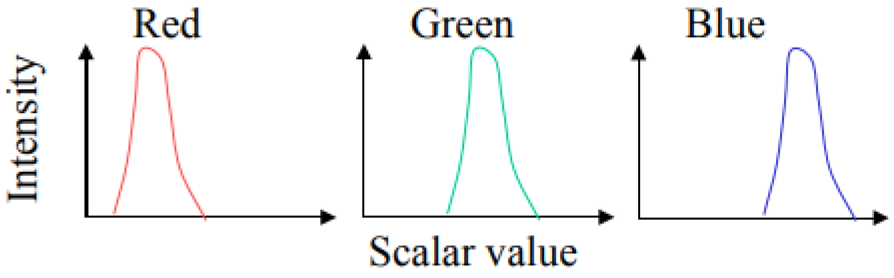
Designing a Color Map: Two Options

- Color Table
  - Pre-compute colors and store colors

- Transfer Function



Designing a Colormap : Generate a Color Table

Map each scalar value $x \in R$ at a point to a color via a table lookup

Assume that we know $x \in [x_{min}, x_{max}]$

Color Tables

- precompute colors and save results into a table of colors $\{c_1,\ldots,c_N\}$
- index table by mapping ranges to integers

Suppose we have N colors in a table and we index them [0,N-1]

Typically a color mapping function might generate an index i:

$$i = \min\left(\left\lfloor \frac{x - x_{min}}{\frac{x_{max} - x_{min}}{N}} \right\rfloor, N-1\right)$$

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Transfer Functions

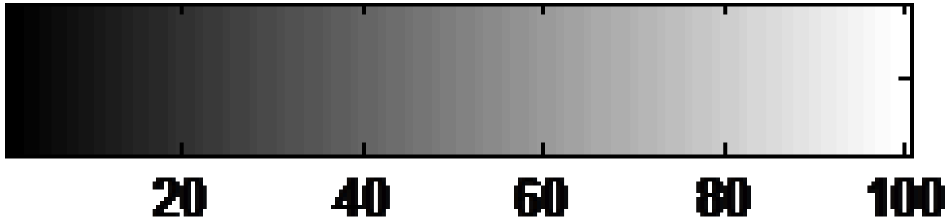
A transfer function defines colors at certain scalar values

- These points are sometimes called knots

Interpolation is then used to define colors for values in between the knots

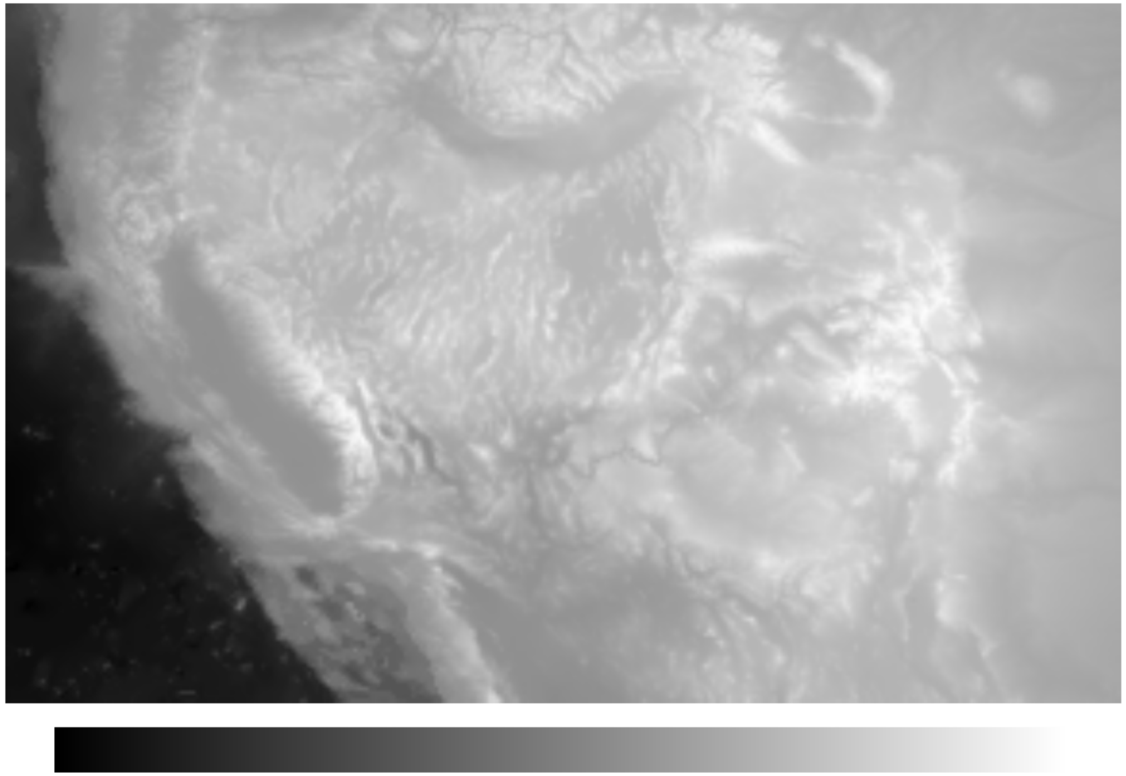
Example:

- Consider a function with a range of [0,100]
- c(0) = (0,0,0) and c(100)=(1,1,1) and use linear interpolation in between

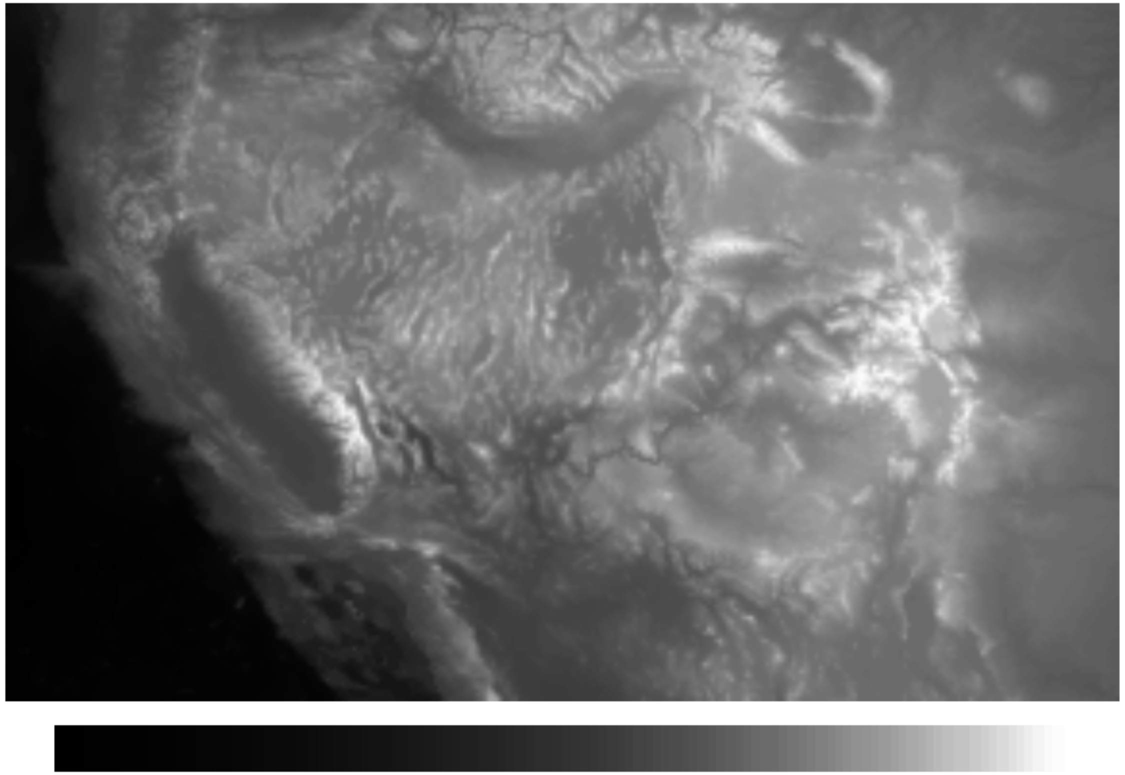


This is a simple but super effective colormap!

Perceptually Linearized Grayscale

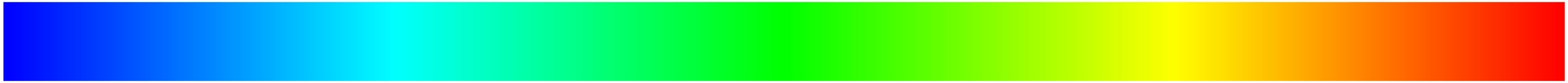


Regular Grayscale



Perceptually Linearized Grayscale

Rainbow Colormap

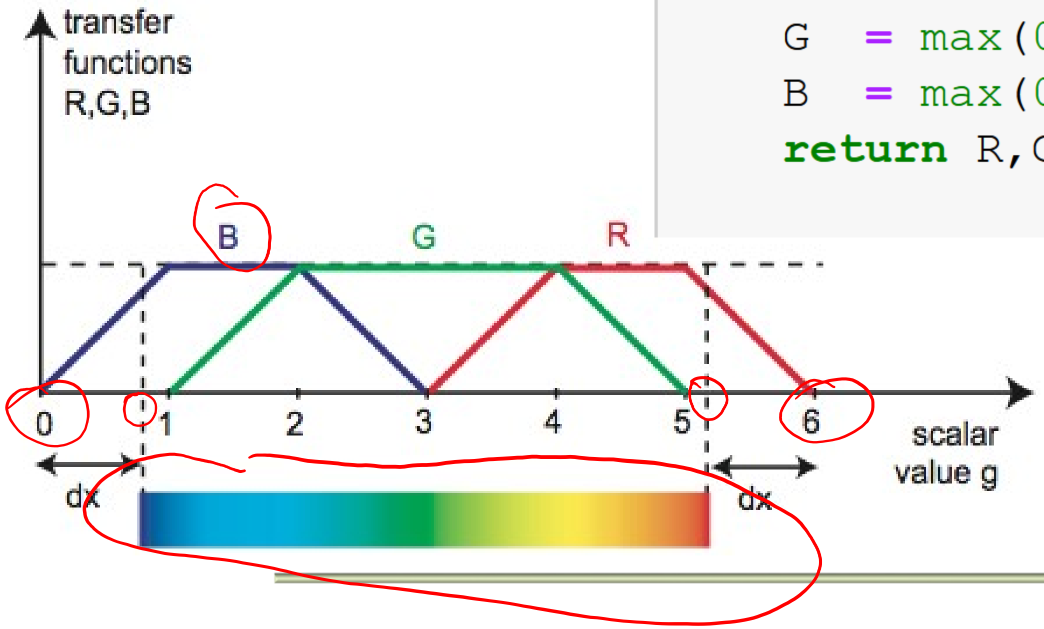


- Probably most (in)famous colormap in visualization
  - “Cold colors” → Low values
  - “Warm colors” → High values
- People like it…think they can use it well…studies say they do not

Example: Implementing the Rainbow Colormap

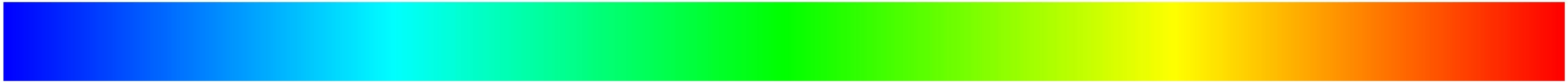
```python
import numpy as np
import math
```

```python
def cm_rainbow(x):
    x   = min(max(x,0),1)      #clamp x to expected range [0,1]
    offset = 0.8               #magic number...like a step size
    c   = (6-2*offset)*x + offset #scale x to [offset,6-offset]
    R   = max(0,(3-math.fabs(c-4)-math.fabs(c-5))/2.0)
    G   = max(0,(4-math.fabs(c-2)-math.fabs(c-4))/2.0)
    B   = max(0,(3-math.fabs(c-1)-math.fabs(c-2))/2.0)
    return R,G,B
```

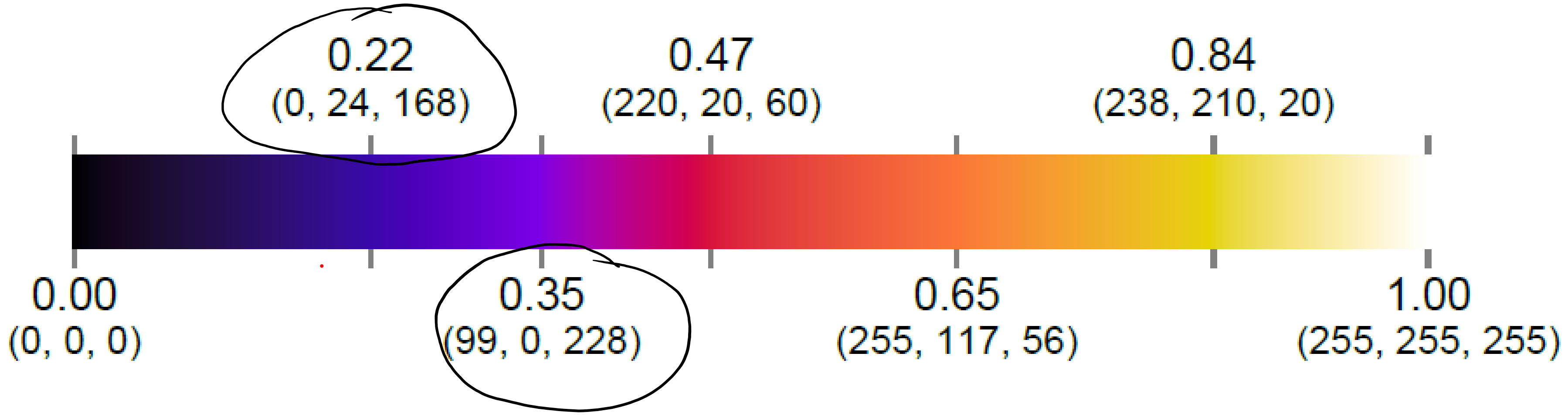


Criticism

- The user is conceptually mapping a linear scale in hue onto a scalar variable
  - Perceptually, however, this scale does not appear linear
  - Equal steps in the scale do not correspond to equal steps in color.
  - The colors appear to change much faster in yellow region than green region.
- Gives impression that the data are organized into discrete regions
  - This can lead the user to infer structure which is not present in the data
    …and to miss details that lie completely within a single color region
- Rainbow color map is sensitive to deficiencies in vision
  - Roughly 5% of the population has deficiencies in distinguishing these colors



Alternatives to the Rainbow



Perceptually linear color map

A change in the underlying metric is matched by similar perceptual change in color

[Python code, etc.: https://www.kennethmoreland.com/color-advice/](https://www.kennethmoreland.com/color-advice/)

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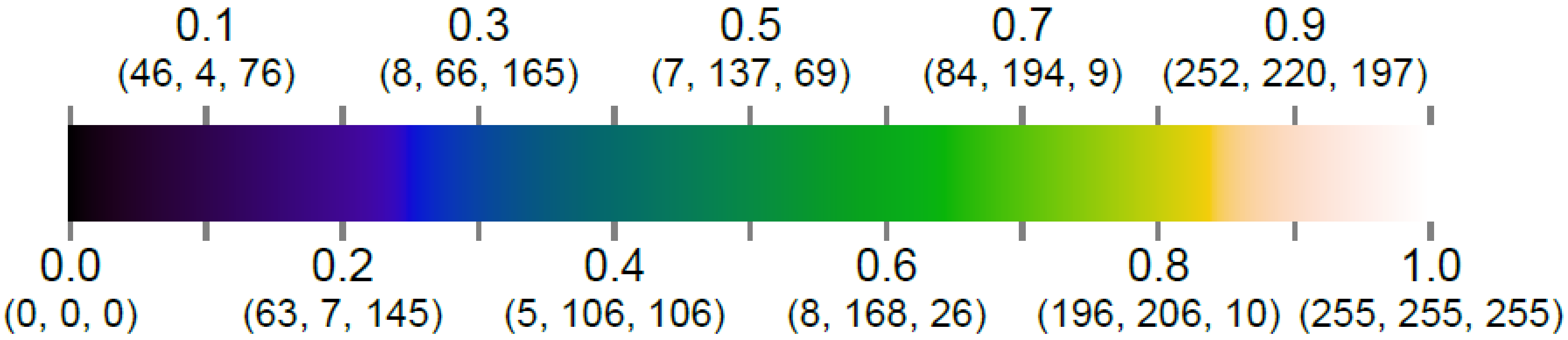
Kindlmann Colormap



Also perceptually linear….or at least close

[Python code, etc.: https://www.kennethmoreland.com/color-advice/](https://www.kennethmoreland.com/color-advice/)

Gordon Kindlmann, Erik Reinhard, and Sarah Creem. Face-based luminance matching for perceptual colormap generation. In *Proceedings of IEEE Visualization*, pages 299–306, October 2002. DOI 10.1109/VISUAL.2002.1183788.

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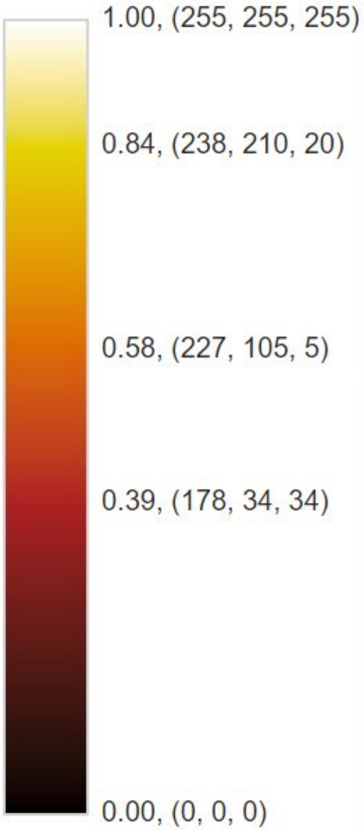
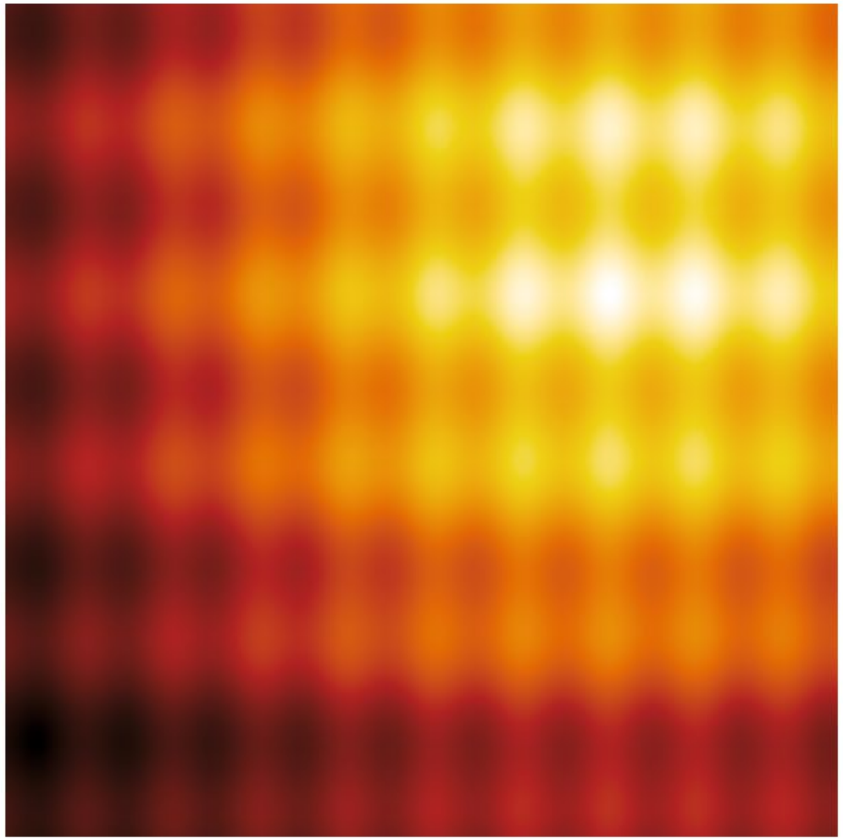
Black Body Colormap





Based on colors from black body radiation.
Designed to have a constant increase in brightness throughout.

[Python code, etc.: https://www.kennethmoreland.com/color-advice/](https://www.kennethmoreland.com/color-advice/)

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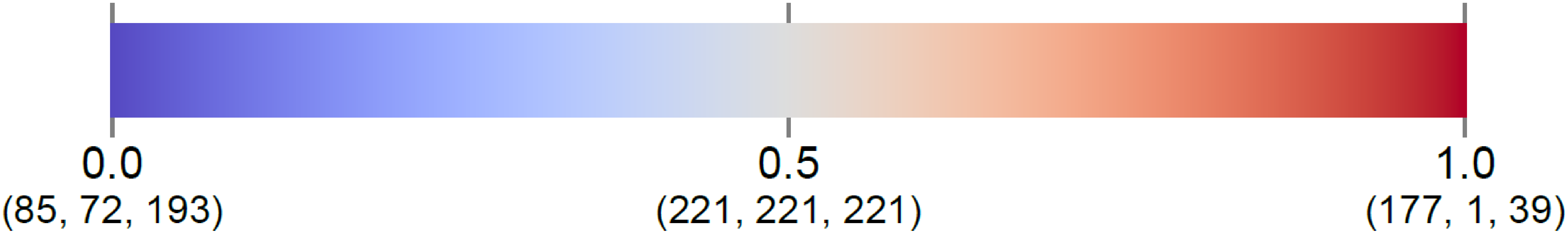
Diverging Colormaps

The underlying data can inform your choice…

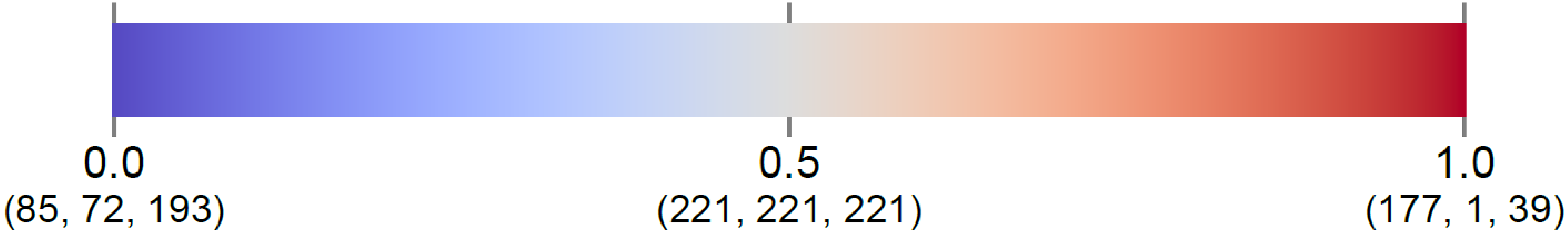
- Is there critical value the viewer should be aware of?
- A ***diverging colormap*** would be appropriate



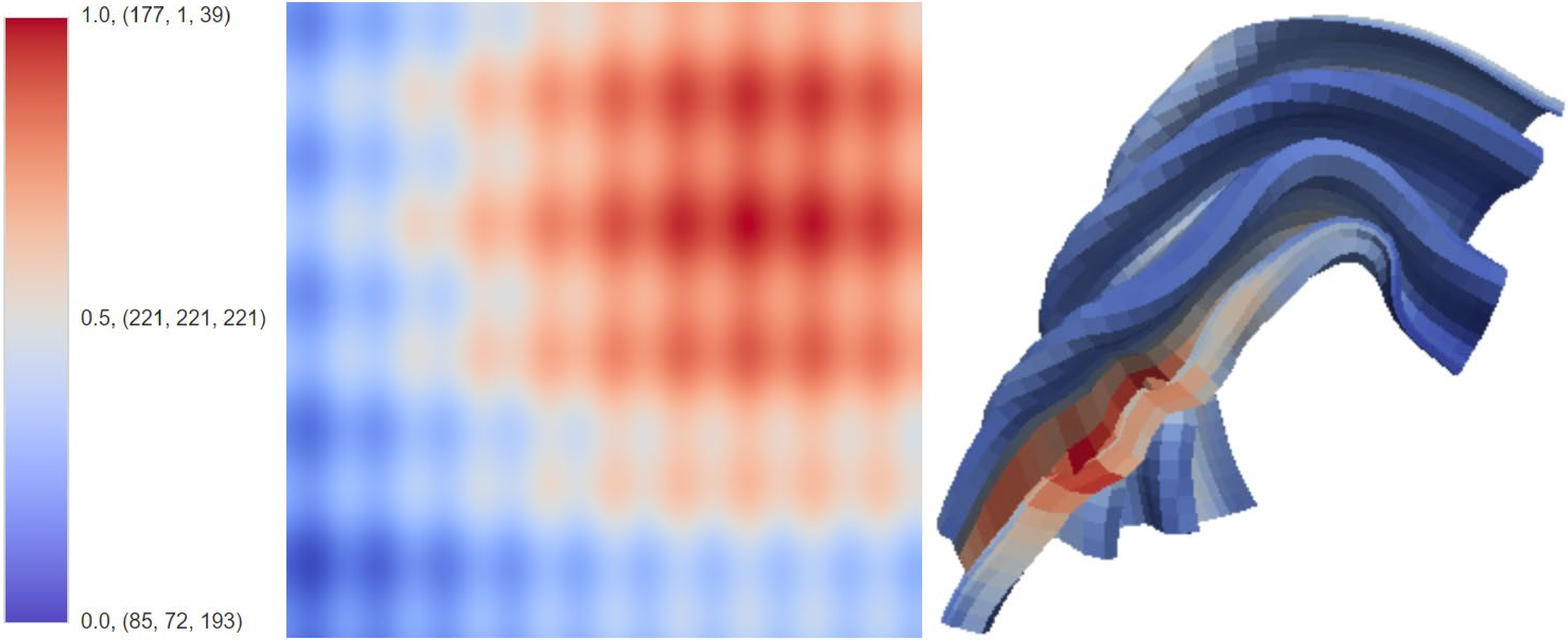
Diverging: change in lightness and possibly saturation of two different colors that meet in the middle at an unsaturated color; should be used when the information being plotted has a critical middle value, such as topography or when the data deviates around zero. - https://matplotlib.org/tutorials/colors/colormaps.html

Colormaps for 3D Surfaces

- Ideally, colormap should use change in luminance to display changes in value.
- However, in 3D scene, shading cues are vital to understanding shapes.
- Need to avoid colormap and shading from interfering
- Achieve this by limiting the color map to bright colors.
  - Reduces the total range of brightness in the color map

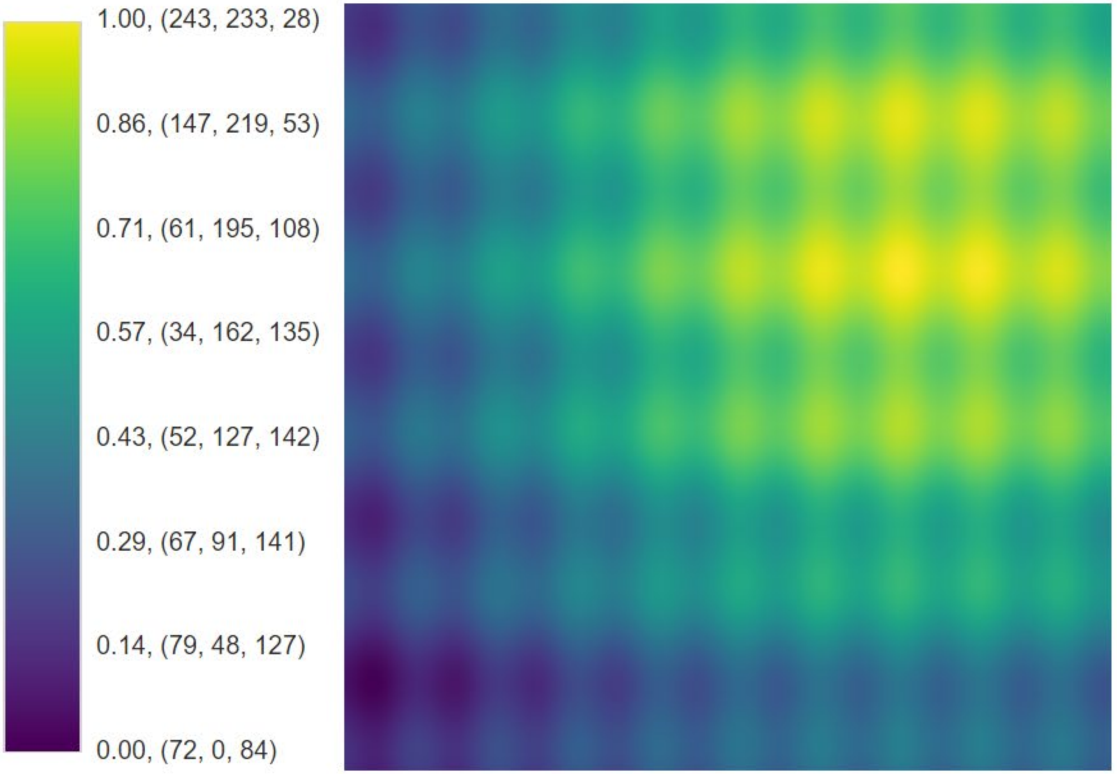


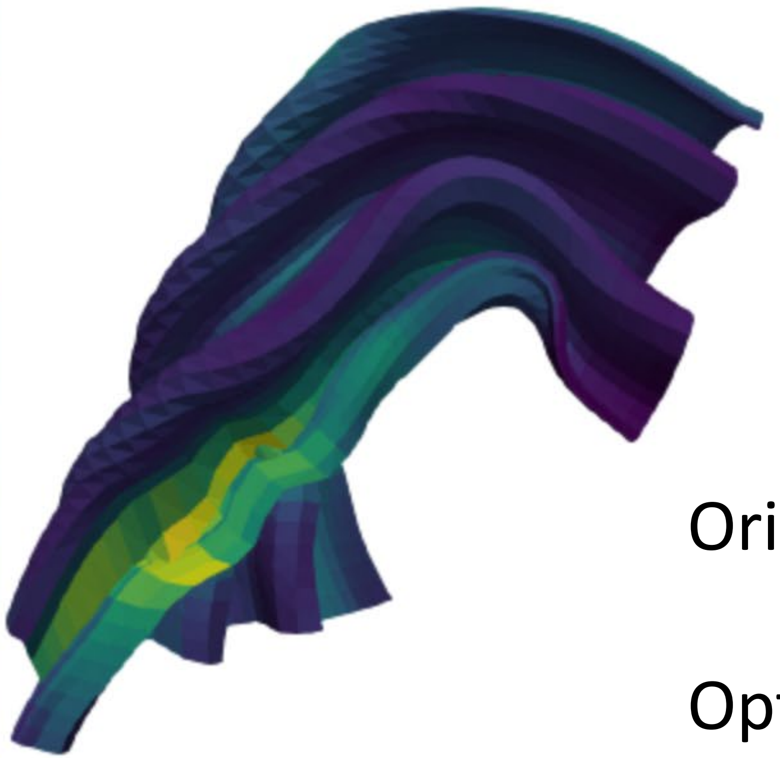
Colormaps for 3D Surfaces



[Python code, etc.: https://www.kennethmoreland.com/color-advice/](https://www.kennethmoreland.com/color-advice/)

Colormaps for 3D Surfaces





Original: Viridis

Optimized: Cividis

Optimizing colormaps with consideration for color vision deficiency to enable accurate interpretation of scientific data

Jamie R. Nuñez, Christopher R. Anderton, Ryan S. Renslow

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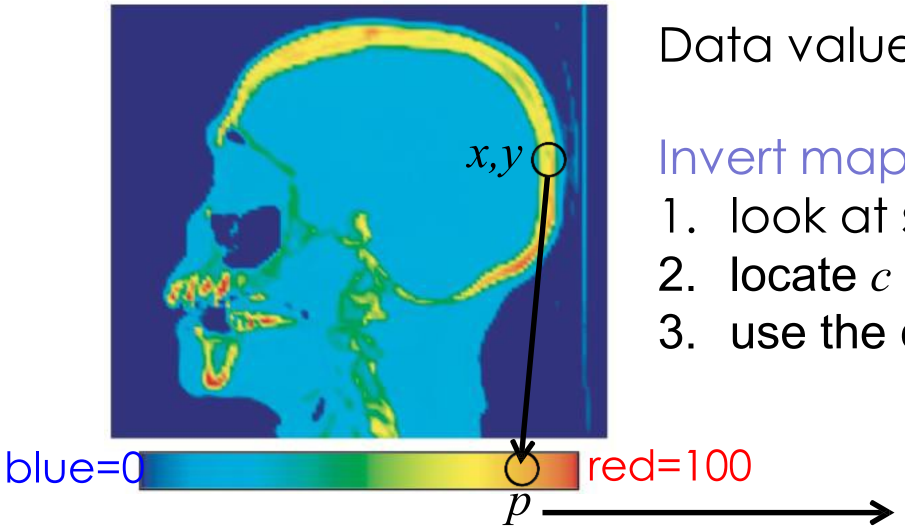
Keyed Lookup Tasks

Keyed Lookup: User wants to estimate specific data value from color

Some colormaps better than others for this task

Banded maps like rainbow (but don’t use it) better than linear maps such as grayscale



Data values mapped to RGB colors via a colormap

Invert mapping:

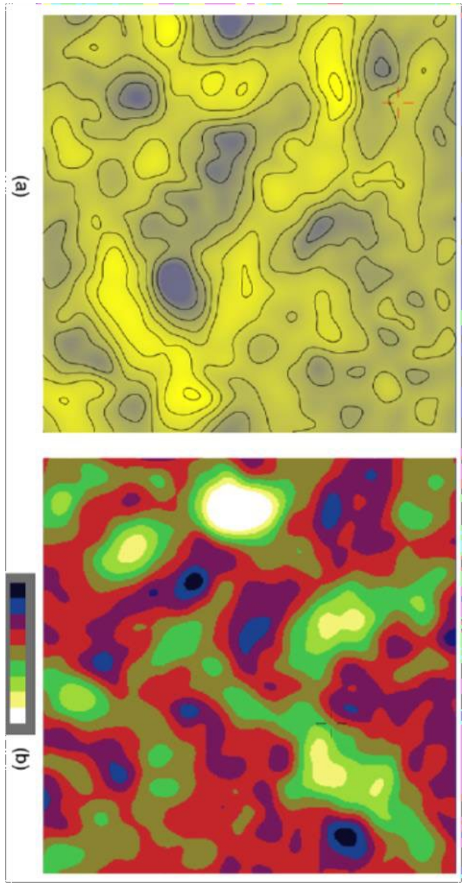
1. look at some point (x,y) in the image $\rightarrow$ color c
2. locate c in colormap at some position p
3. use the colormap legend to derive data value s from p

answer: $s = 90$

Keyed Lookup Tasks

Keyed Lookup: User wants to estimate specific data value from color

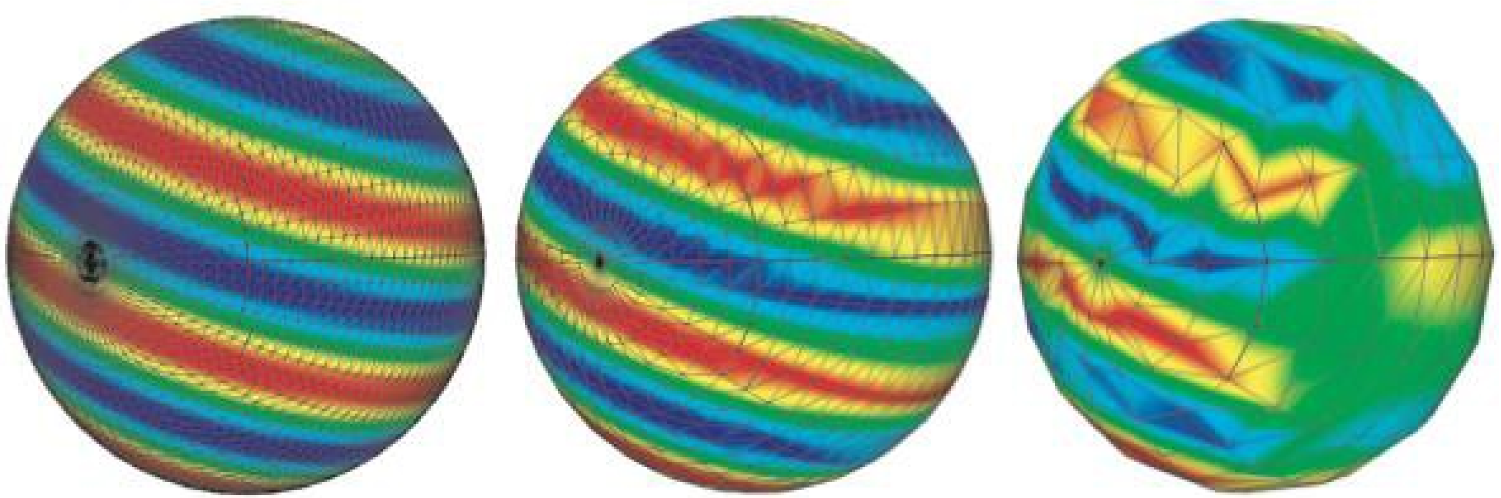
Contours help as well…..



Prefer Interpolating Values to Interpolating Colors

Where to apply the colormap?

- per pixel – better results than per-vertex colormapping



64x64 points | 32x32 points | 16x16 points

color interpolation can fall outside the colormap!

Explanation

- per-vertex: $f \to c(f) \to$ interpolation$(c(f))$
- per-pixel: $f \to$ interpolation$(f) \to c($interpolation$(f))$ colors always stay in colormap

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Colormap Design Advice

- Design for accessibility
  - minimally, don't depend on red-green differentiation
- Use your knowledge of the data set (*e.g.*, is there a critical value?)
- If there is a standard in the field the audience may be expecting?
- Often a perceptually uniform colormap is the best choice
  - equal steps in data are perceived as equal steps in the color space
- We perceive change in lightness as changes in the data pretty well
  - better than changes in hue.
- Use colormaps with monotonically increasing lightness