COSE436

Lecture 25:
Scalar Visualization

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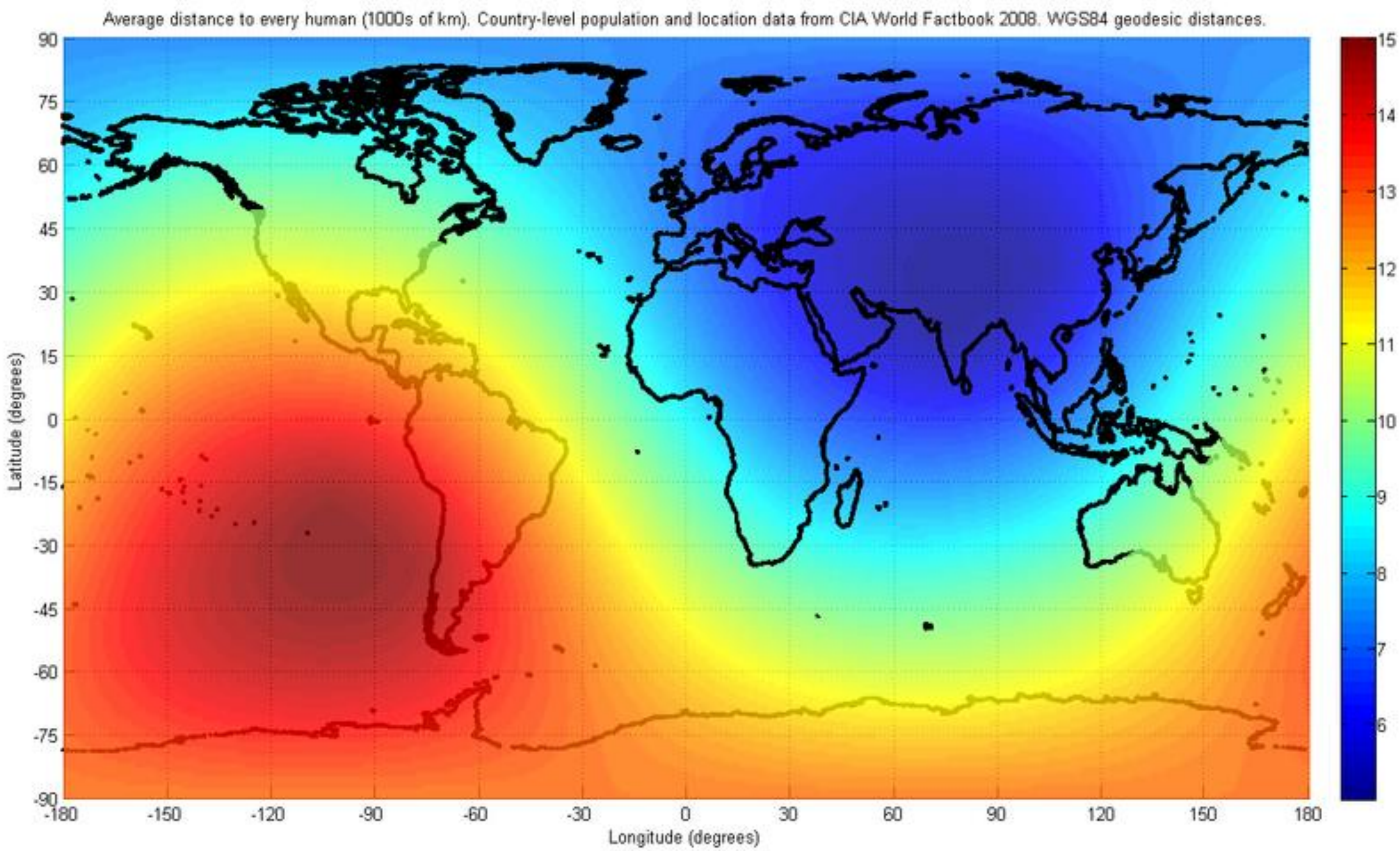
KOREA UNIVERSITY

Outline

- Color mapping
- Contouring
- Height / displacement plots

Color Mapping

- Associate a color with a scalar value



Wikipedia

Color Tables

- Precompute c and save results into a table $\{c_i\}_{i=1..N}$
- Index table by normalized scalar values

input data — scalar value f

determine input range — scalar value range $[f_{min}, f_{max}]$

normalize input to [0,N] — $$i = N \frac{f - f_{min}}{f_{max} - f_{min}}$$

Color mapping

$$c_i = c\left(\frac{i}{N}\right)$$

color table

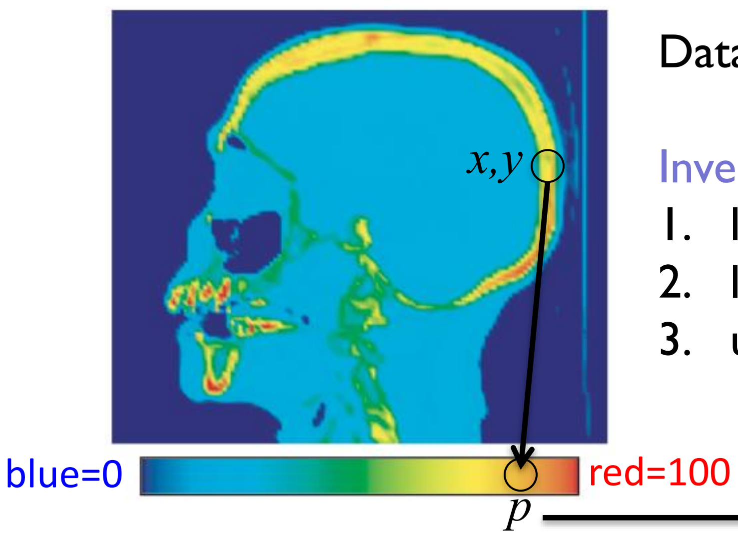
$$c : [0,1] \rightarrow [0,1]^3$$

desired color transfer function

f is color-mapped to c_i

Color Map Design

- Good color map
  - Color map is invertible
  - Different values are separated by different colors



answer: $s = 90$

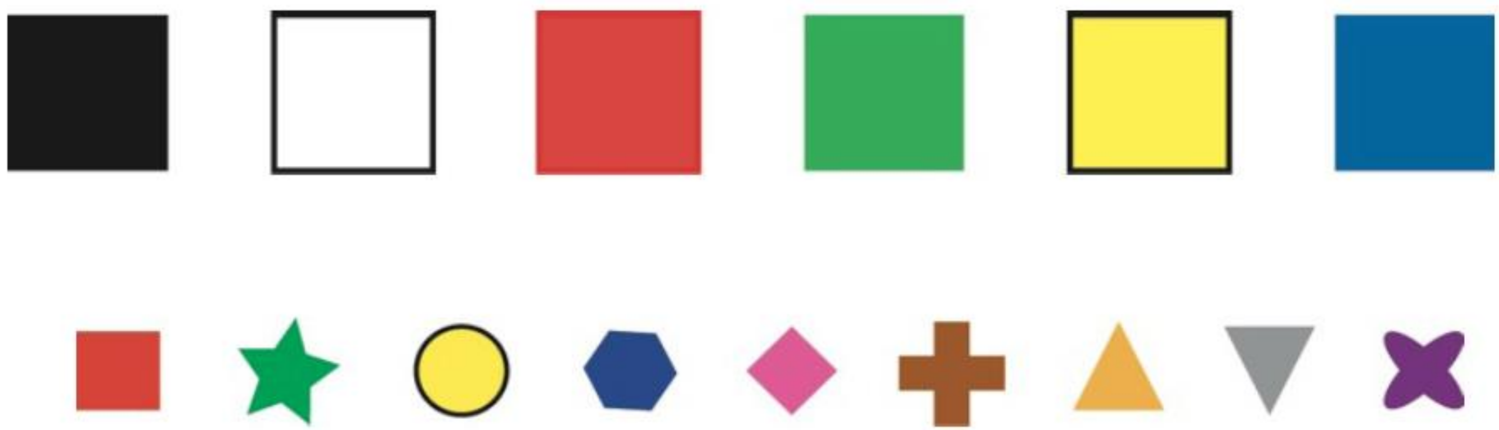
Data values mapped to RGB colors via a colormap

Invert mapping:

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

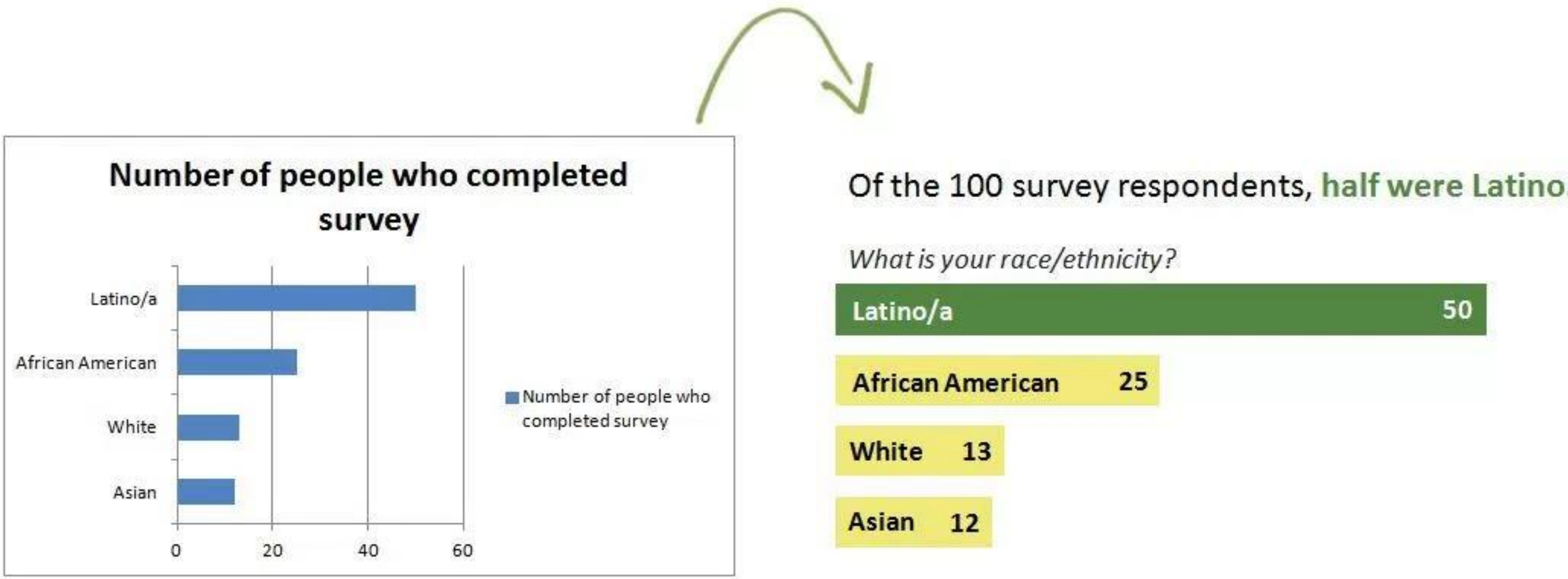
Nominal Colors

- Red, green, yellow, blue, black, white
- Pink, cyan, grey, orange, brown, purple



Used for visualizing categorical data, e.g., race/ethnicity/genders…

Nominal Colors Example



https://annkemery.wordpress.com/2013/08/07/chart-colors/

Sequential Colors

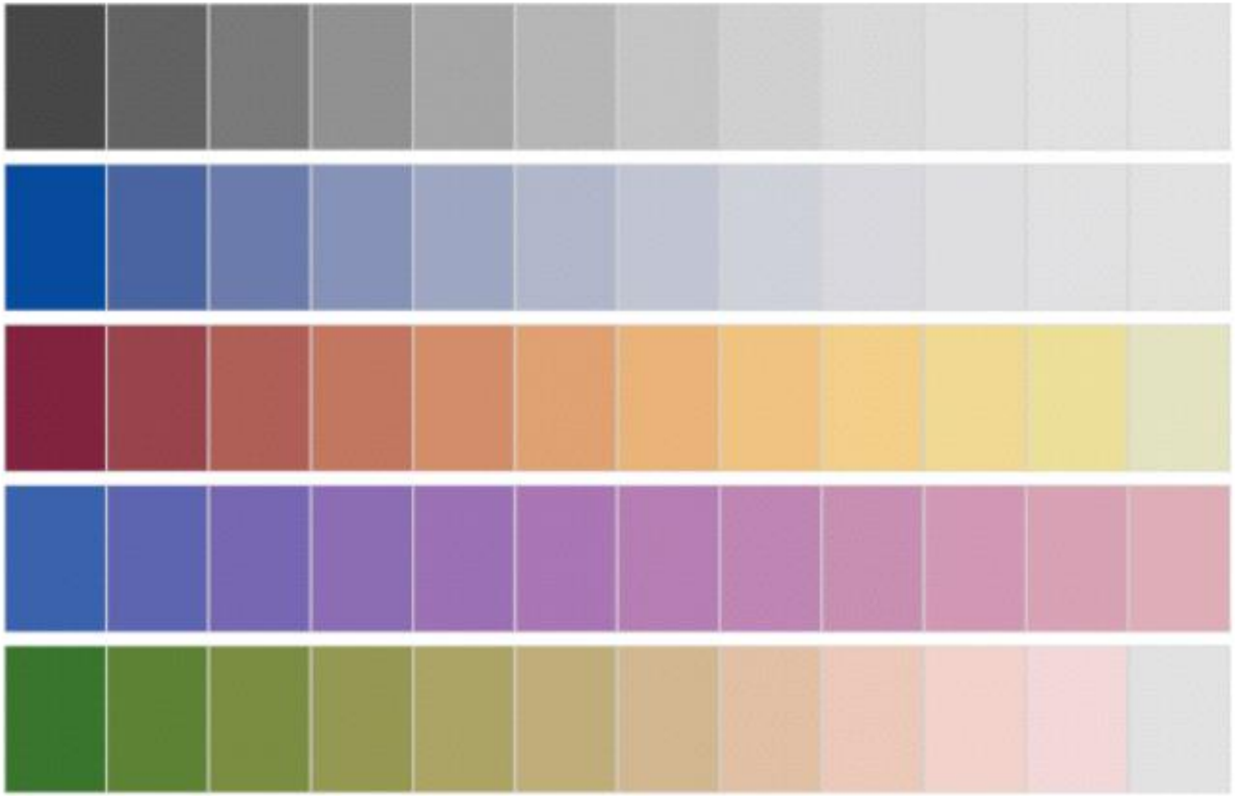
- Vary luminance, saturation, hue

L only

L and S

L, S, and H

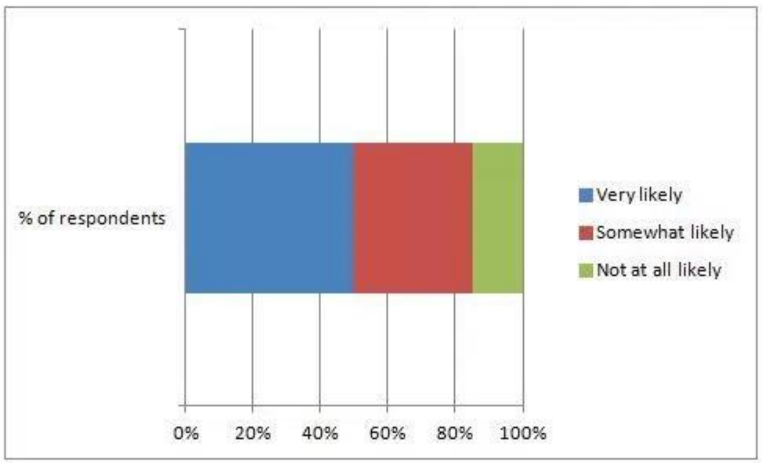
Hue is used to increase contrast

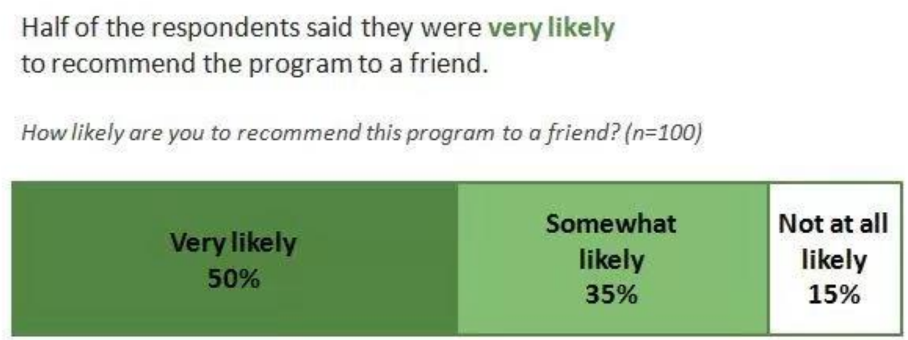


Used for visualizing orders, e.g., range of ages/years

Hanspeter Pfister

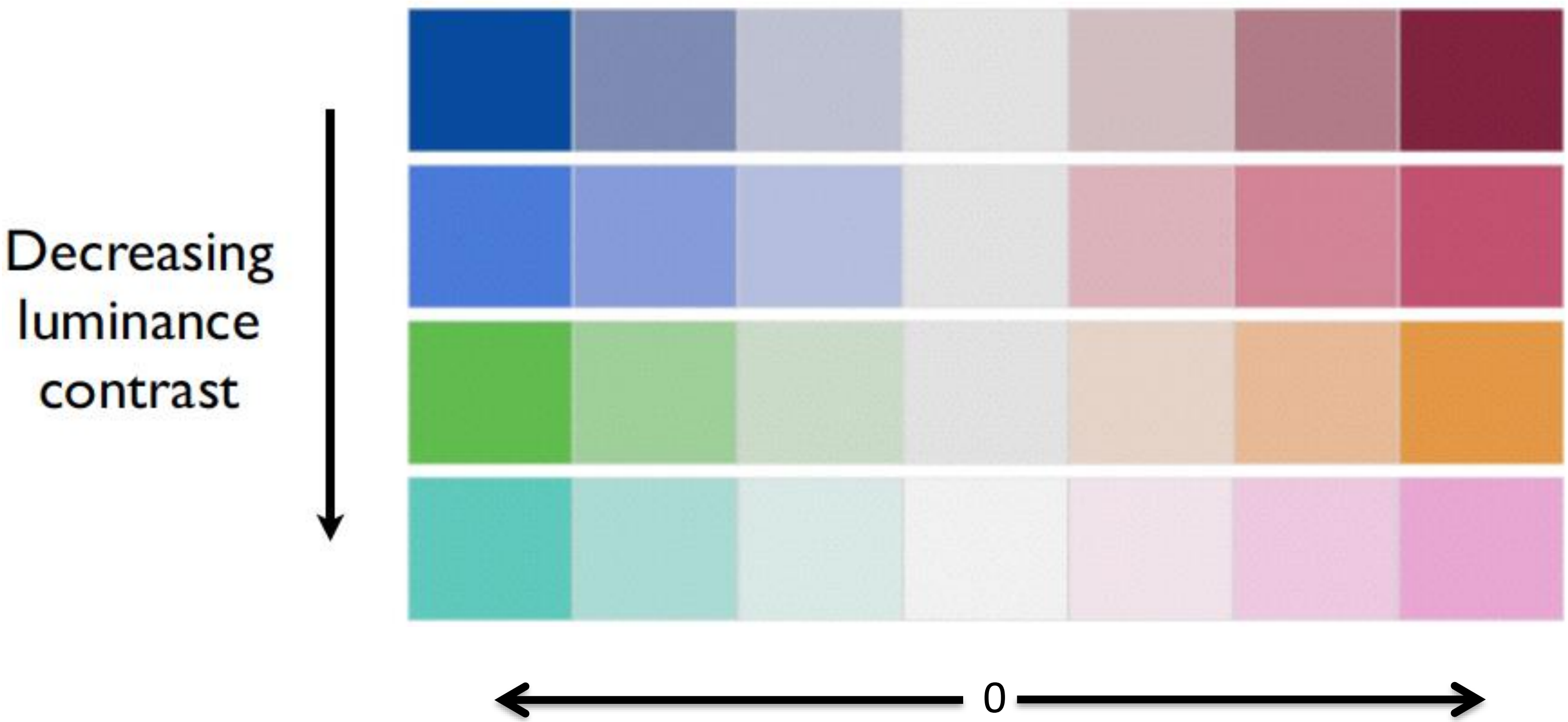
Sequential Colors Example





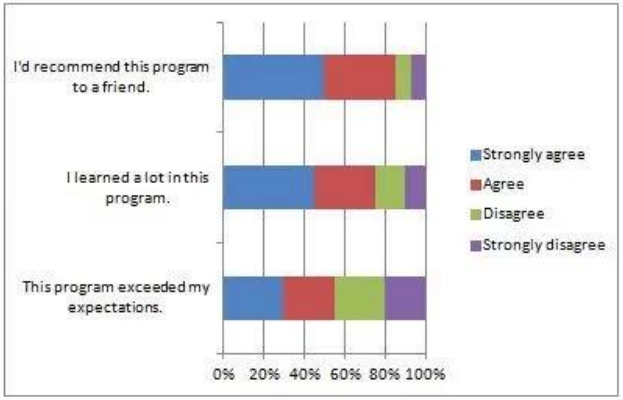
https://annkemery.wordpress.com/2013/08/07/chart-colors/

Diverging Colors



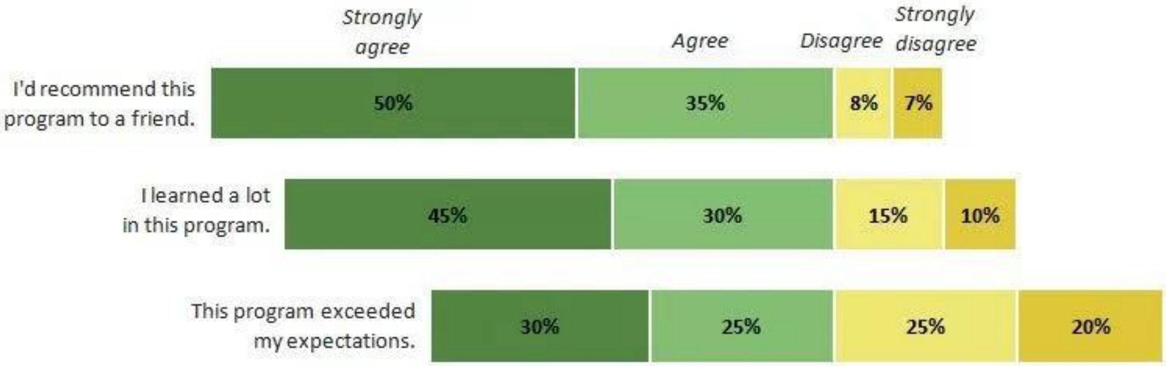
Used for visualizing opposite data, e.g., agree/disagree

Diverging Colors Example



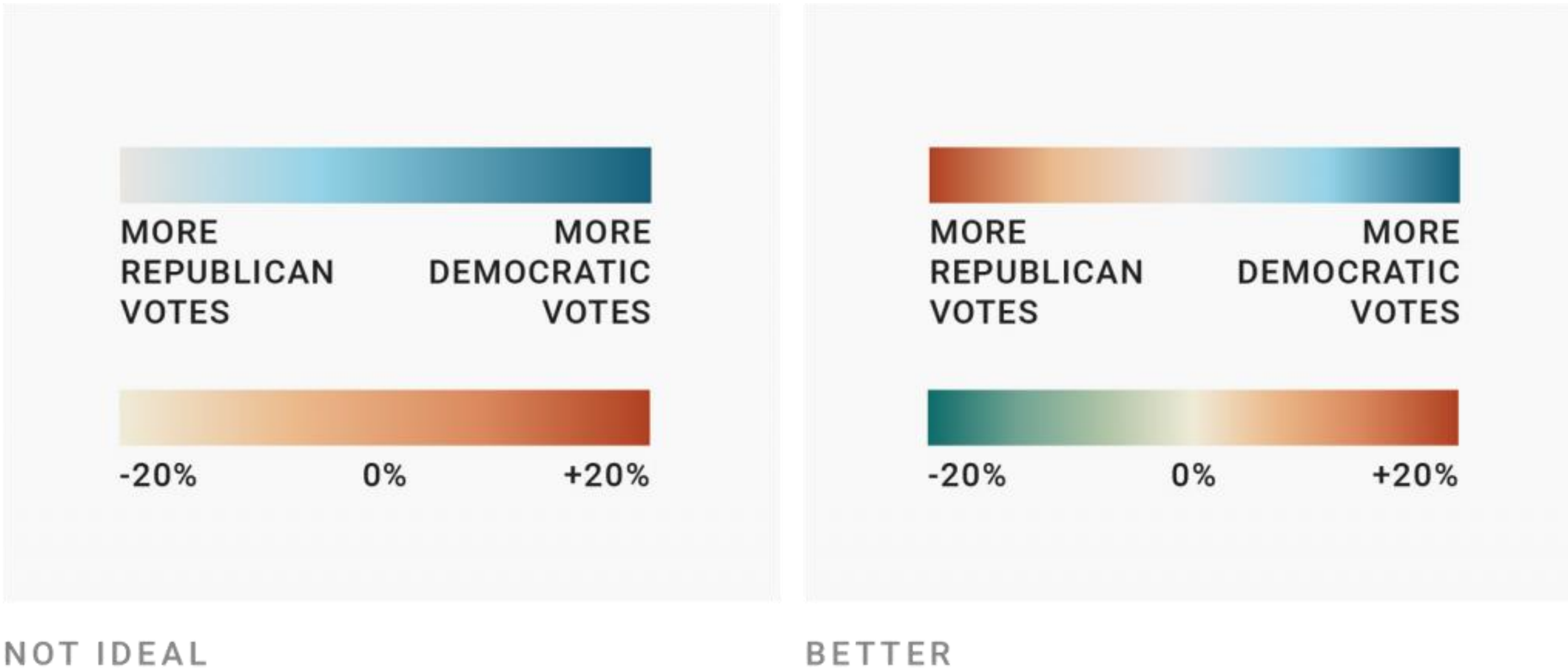
A majority of participants **would recommend this program to a friend** (85% strongly agreed or agreed). Three-quarters (75%) strongly agreed or agreed that they **learned a lot in this program**, but only half (55%) felt the program **exceeded their expectations**.

Please indicate how much you agree or disagree with the following statements. (n=100)



Diverging Colors Example

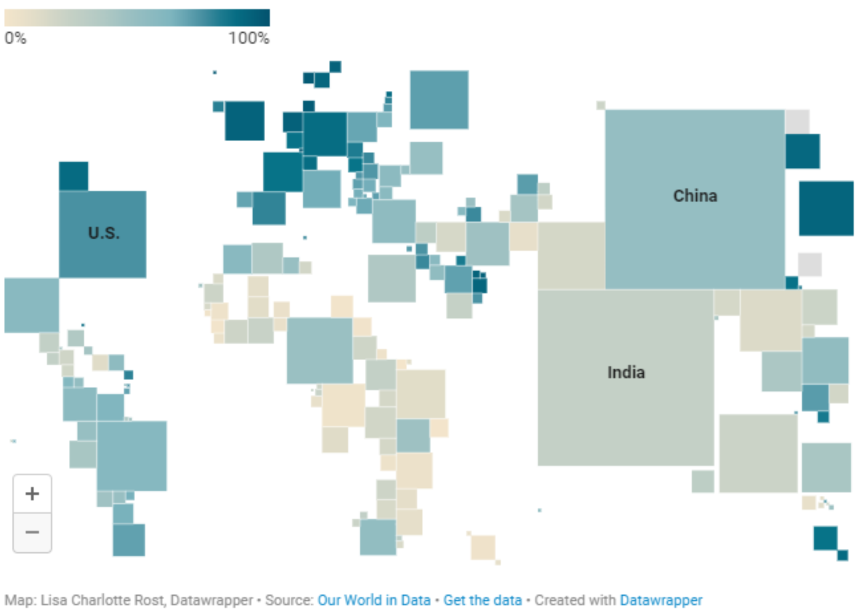
Diverging color is useful if there is a meaningful middle value



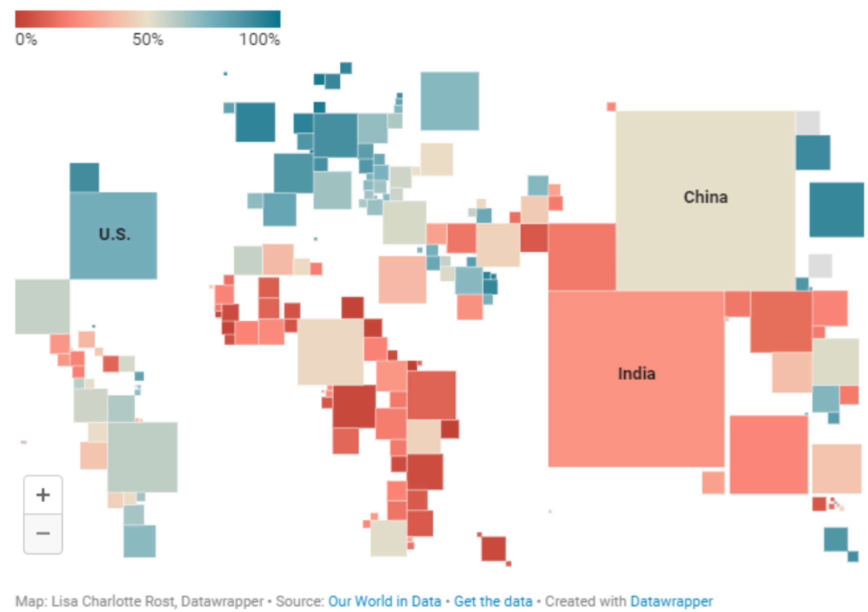
https://blog.datawrapper.de/diverging-vs-sequential-color-scales/

Diverging Colors Example

Diverging color is useful to emphasize the extremes



The internet was mostly used by the Western World in 2015

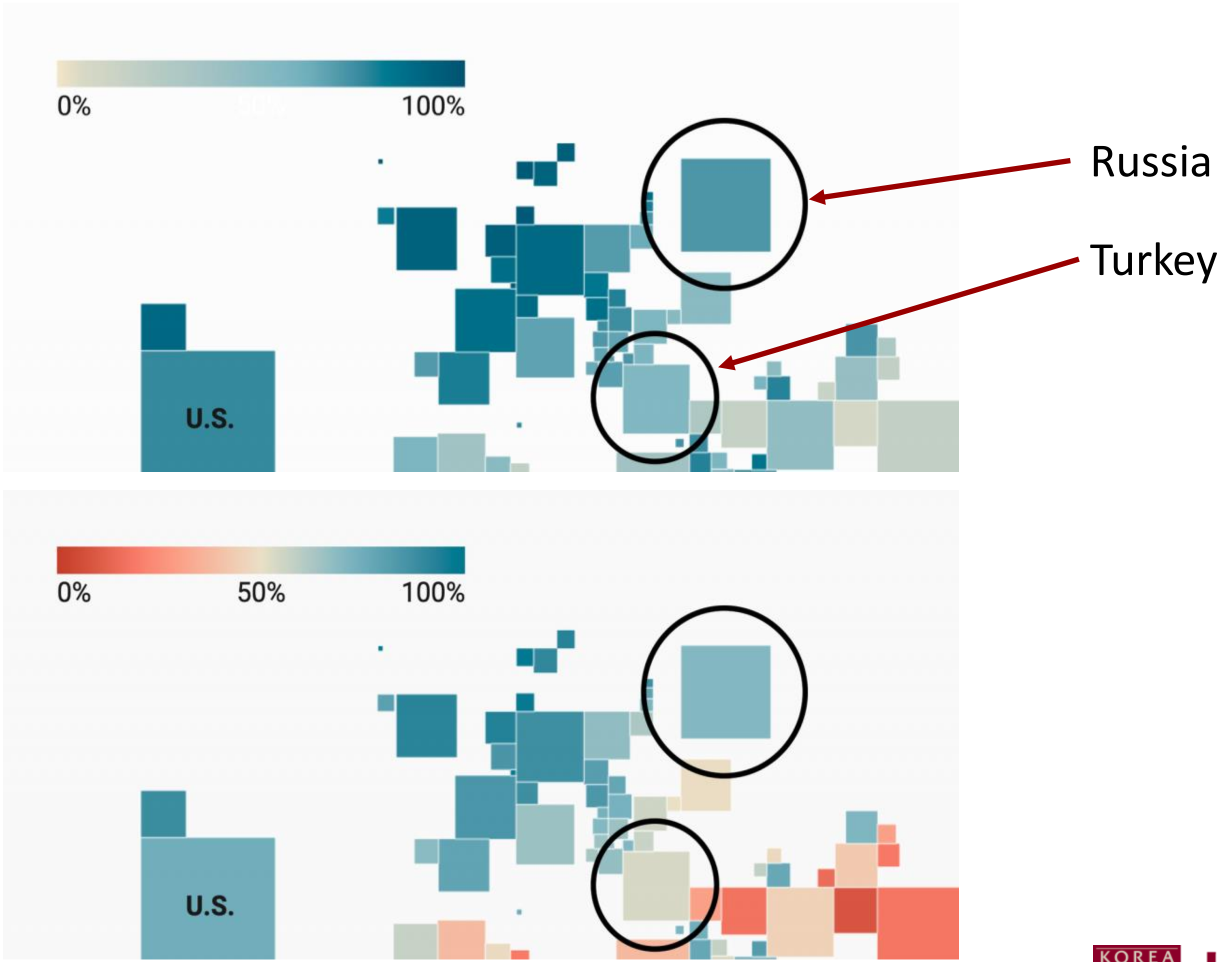


In most African and Asian countries, less than half of the population was using the internet in 2015.

https://blog.datawrapper.de/diverging-vs-sequential-color-scales/

Diverging Colors Example

Diverging color is useful to express more differences in the data

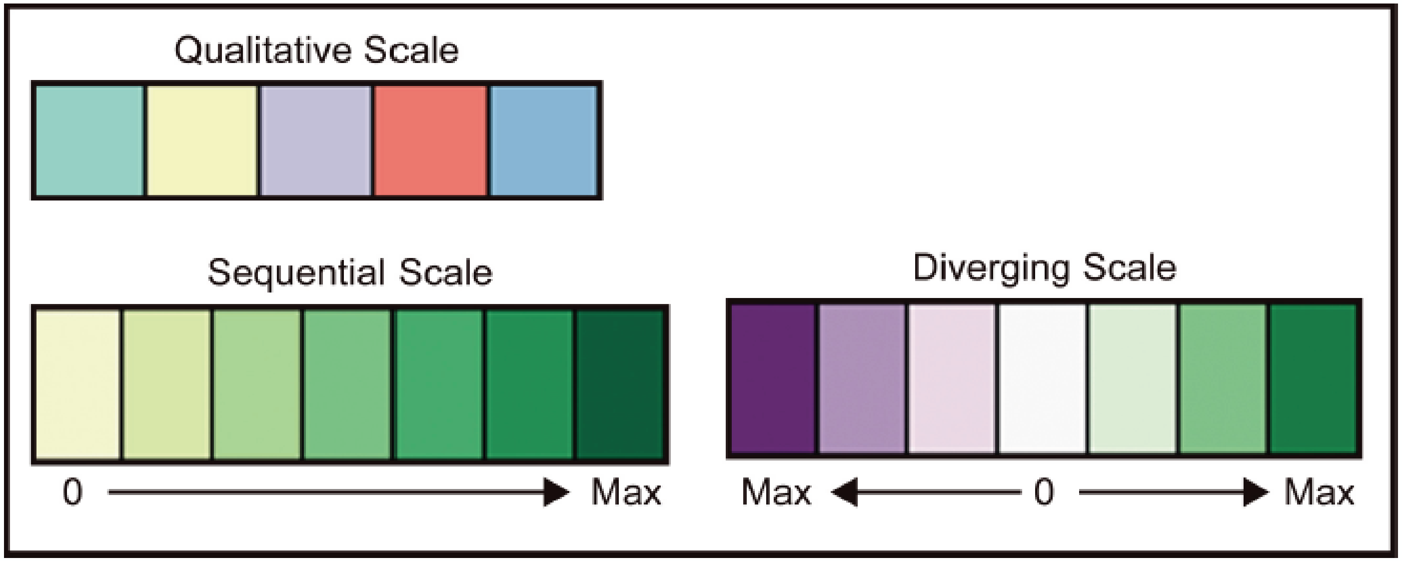


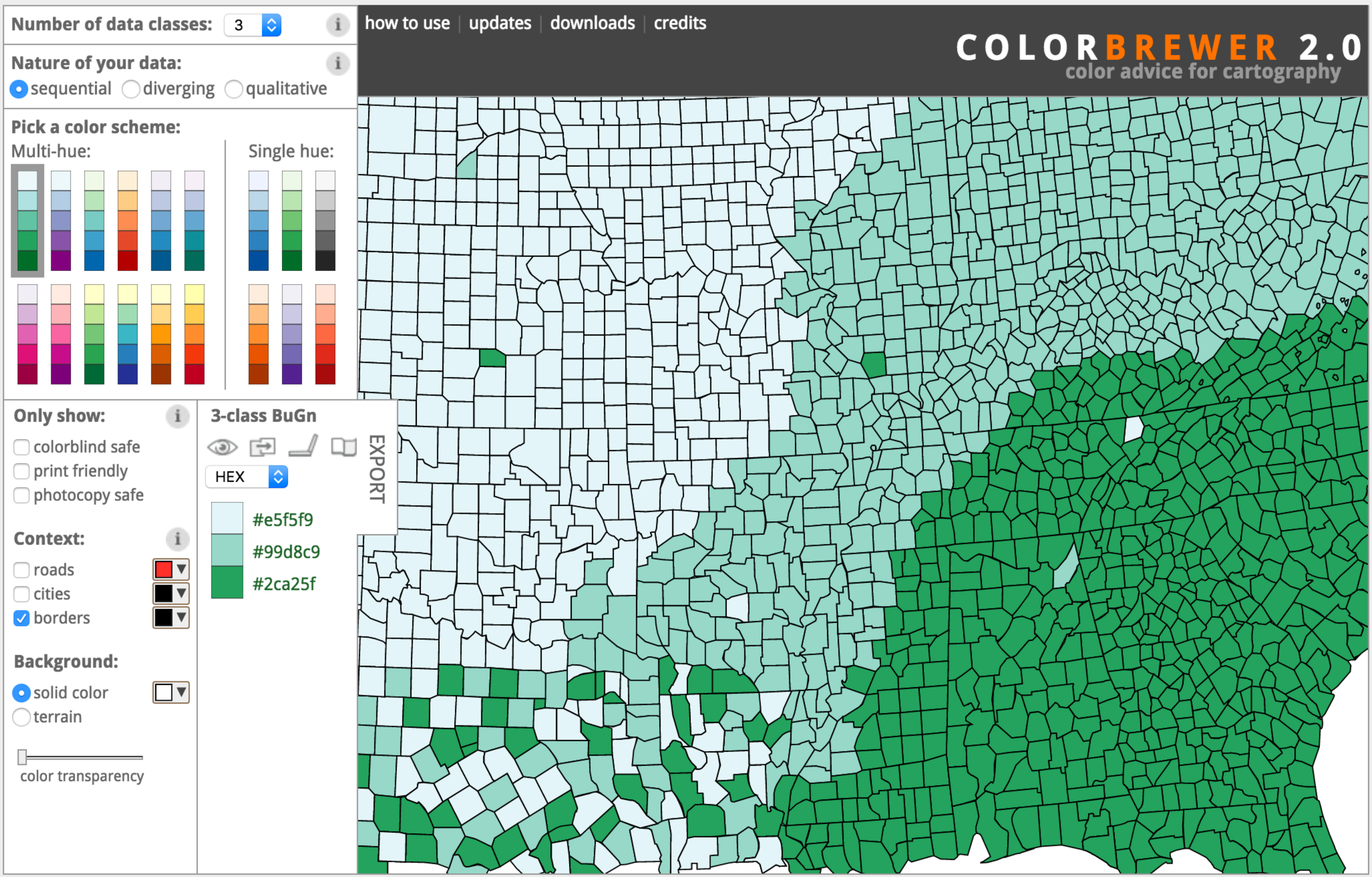
https://blog.datawrapper.de/diverging-vs-sequential-color-scales/

Color Brewer

Nominal

Ordinal

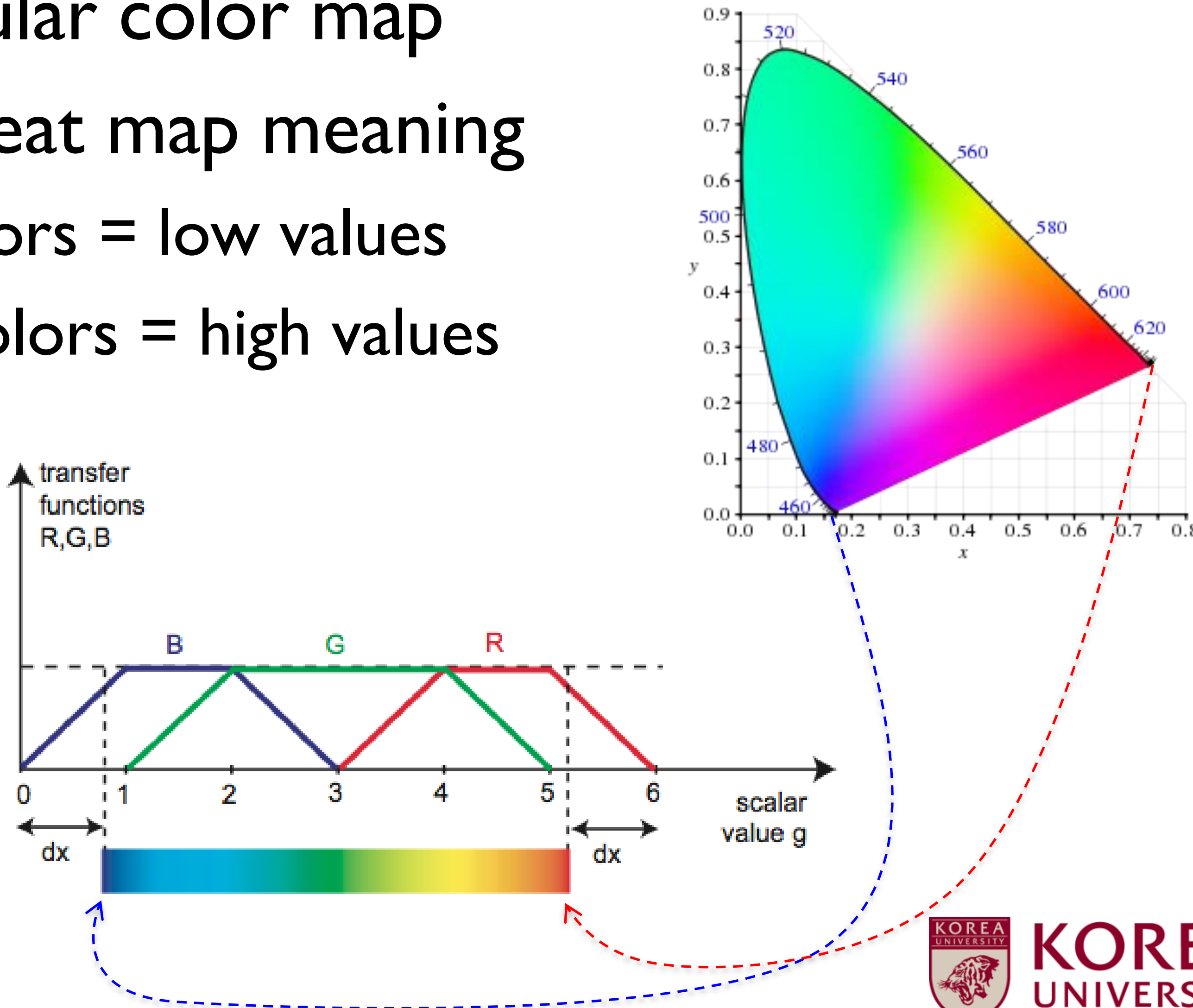




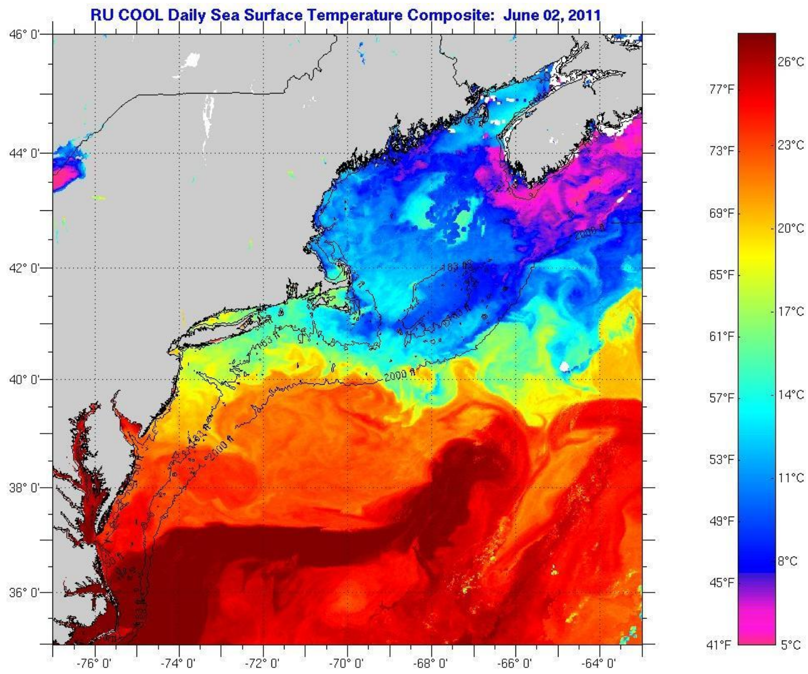
http://colorbrewer2.org/

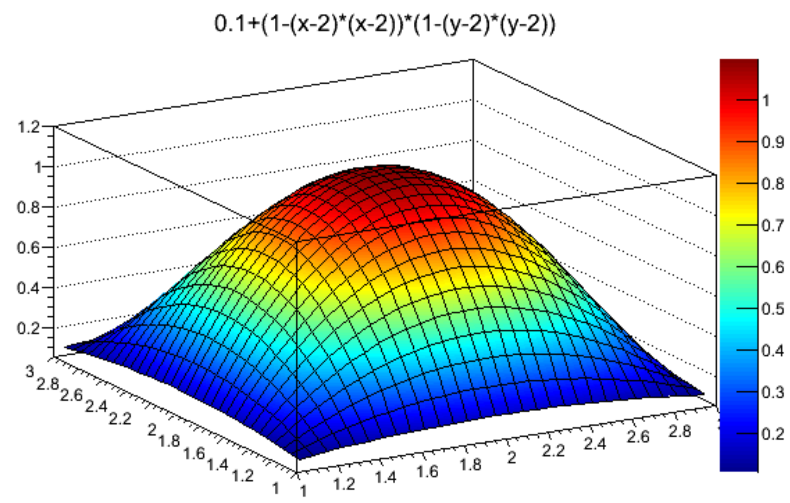
Rainbow Color Map

- Most popular color map
- Intuitive heat map meaning
  - Cold colors = low values
  - Warm colors = high values



Rainbow Color Map





~50% IEEE VIS papers use rainbow color map (in 2001~2005)

Visualization Viewpoints

Editor: Theresa-Marie Rhyne

Rainbow Color Map (Still) Considered Harmful

David Borland and Russell M. Taylor II
University of North Carolina at Chapel Hill

Research has shown that the rainbow color map is rarely the optimal choice when displaying data with a pseudocolor map. The rainbow color map confuses viewers through its lack of perceptual ordering, obscures data through its uncontrolled luminance variation, and actively misleads interpretation through the introduction of non-data-dependent gradients.

Despite much published research on its deficiencies, the rainbow color map is prevalent in the visualization community. We present survey results showing that the rainbow color map continues to appear in more than half of the relevant papers in IEEE Visualization Conference proceedings; for example, it appeared on 61 pages in 2005. Its use is encouraged by its selection as the default color map used in most visualization mercials, weather forecasts, and even the IEEE Visualization Conference 2006 call for papers, just to name a few. The problem with this wide use of the rainbow color map is that research shows that it is rarely, if ever, the optimal color map for a given visualization.[1-6] Here we will discuss the rainbow color map's characteristics of confusing the viewer, obscuring data, and actively misleading interpretation.

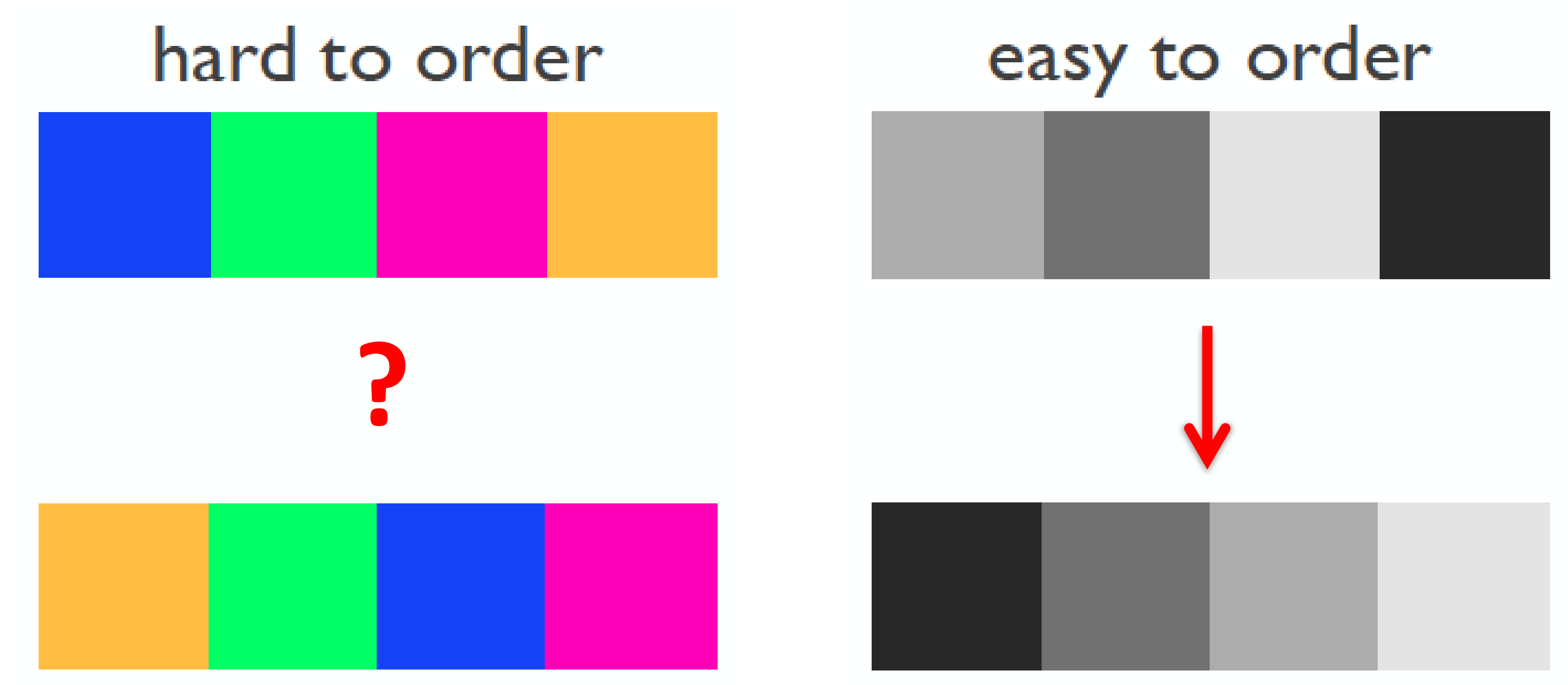
Confusing

For all tasks that involve comparing relative values, the color map used should exhibit perceptual ordering. A simple example of a perceptually ordered color map is the gray-scale color map. Increasing luminance from black to white is a strong perceptual cue that indicates

Borland et al. (2007), Rainbow color map (still) considered harmful, IEEE Computer Graphics and Applications 27(2):14-17.

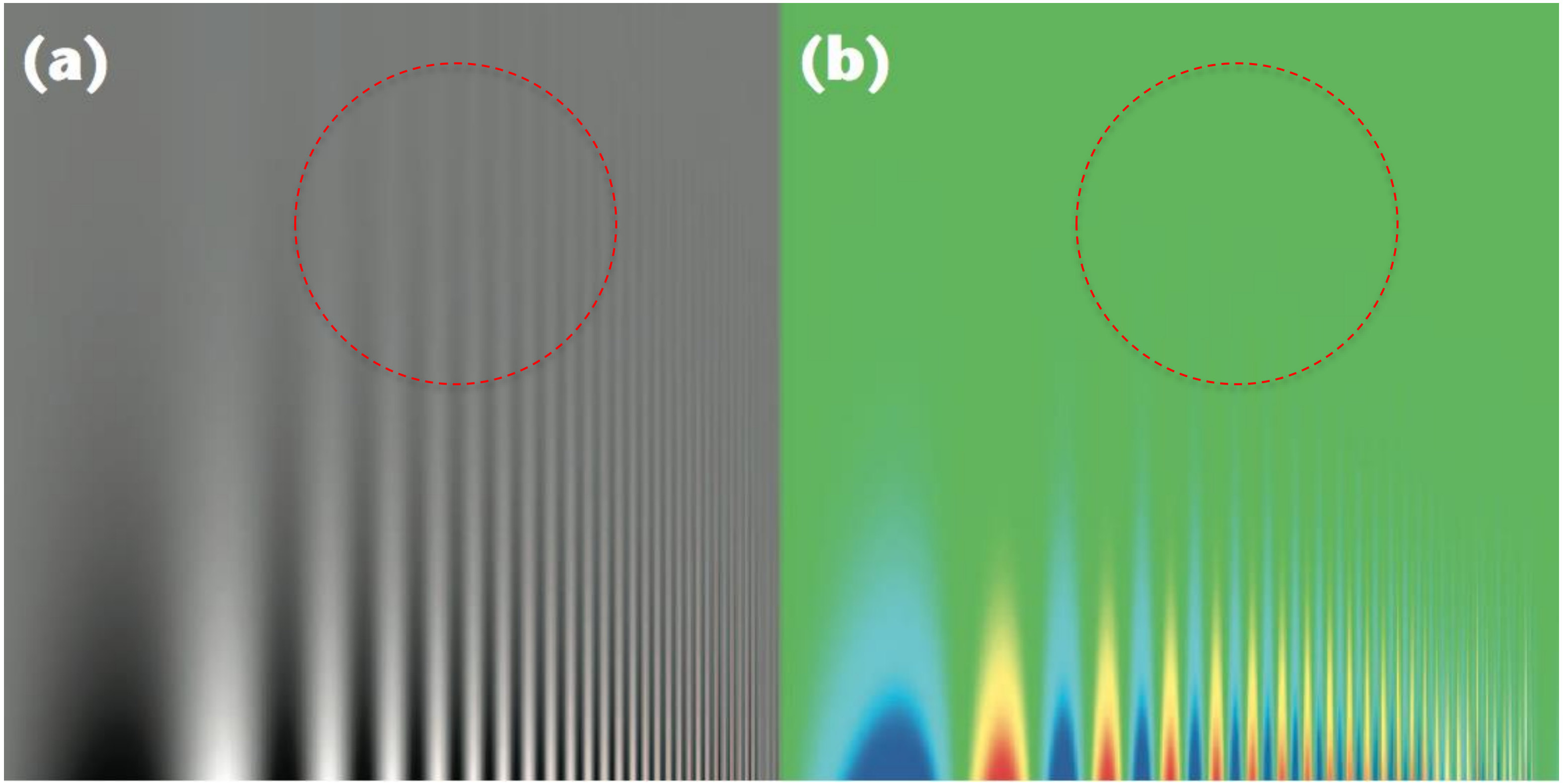
Problem of Rainbow Color Map

- Not perceptually ordered



Problem of Rainbow Color Map

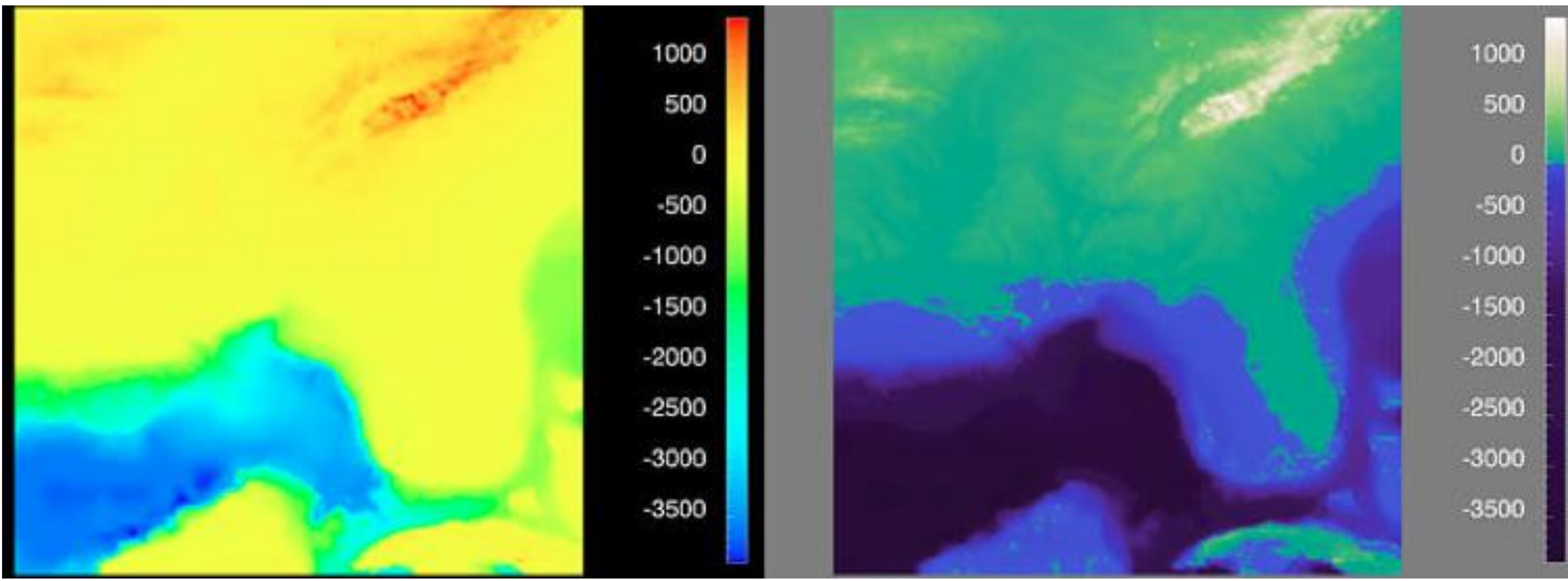
- Human perceives high-spatial frequencies through changes in luminance



Borland et al.

Problem of Rainbow Color Map

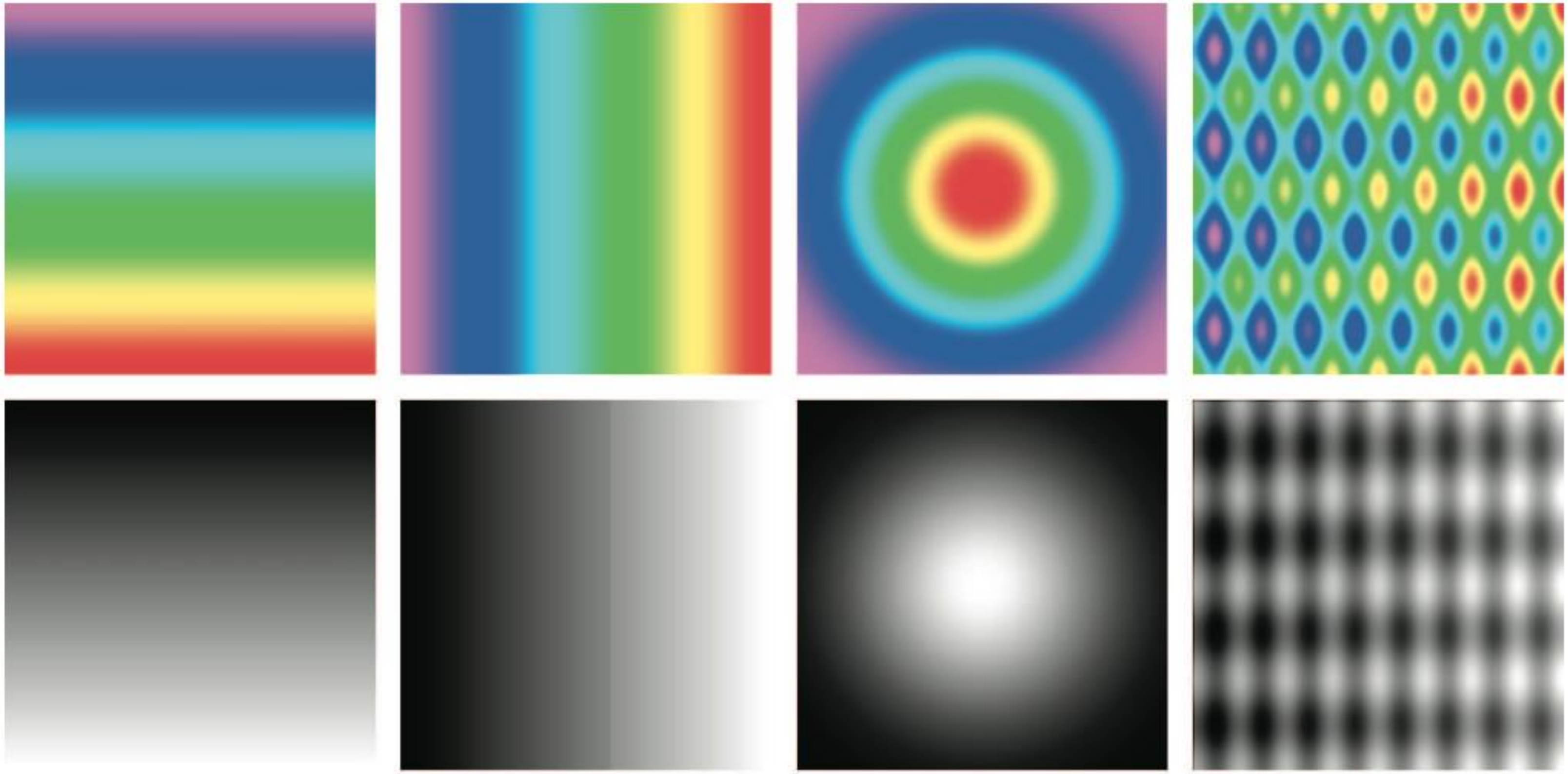
- Human perceives high-spatial frequencies through changes in luminance



http://root.cern.ch/drupal/content/rainbow-color-map

Problem of Rainbow Color Map

- Introducing artifacts
  - Banding with constant hue

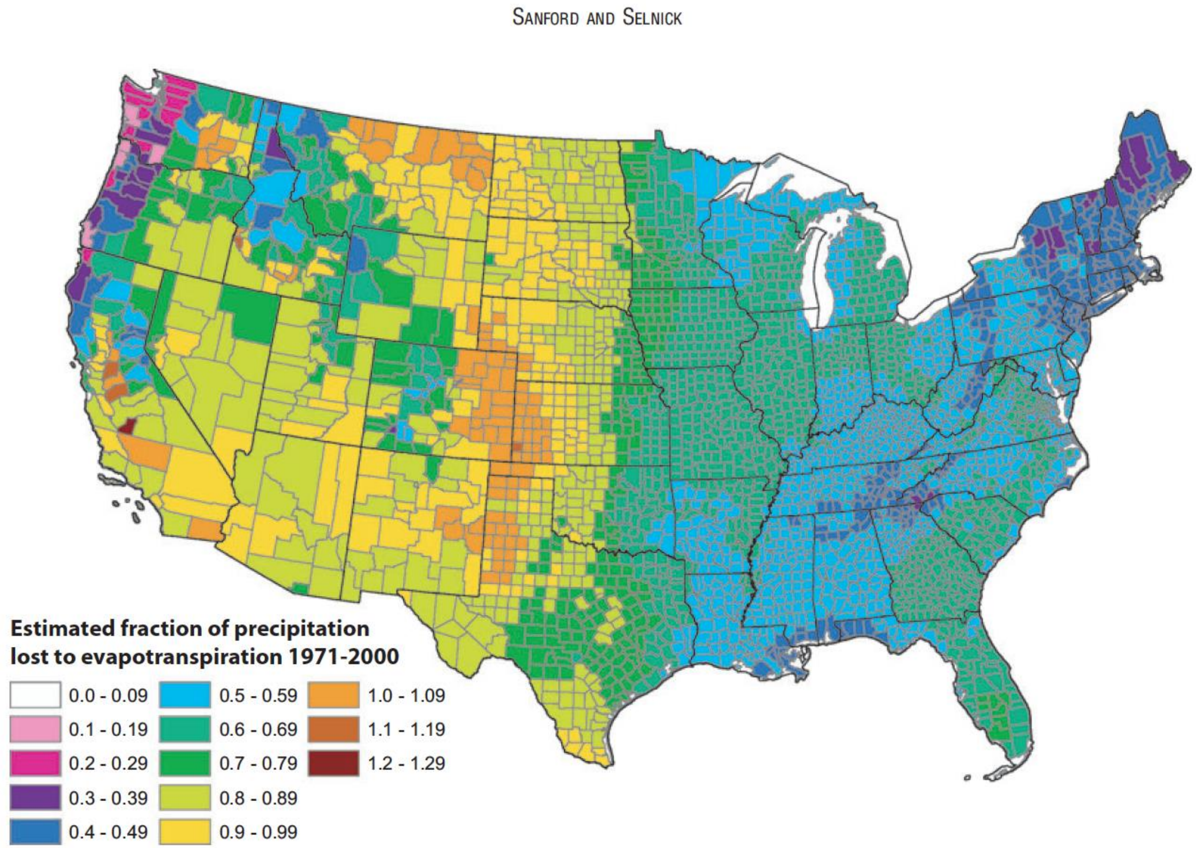


Borland et al.

Problems of Rainbow Color Map

- Misleading

Sharp discontinuity in the middle.
Actually, they are changing smoothly (green->bright green->yellow)



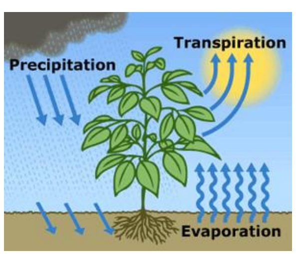


FIGURE 13. Estimated Mean Annual Ratio of Actual Evapotranspiration (ET) to Precipitation (P) for the Conterminous U.S. for the Period 1971-2000. Estimates are based on the regression equation in Table 1 that includes land cover. Calculations of ET/P were made first at the 800-m resolution of the PRISM climate data. The mean values for the counties (shown) were then calculated by averaging the 800-m values within each county. Areas with fractions >1 are agricultural counties that either import surface water or mine deep groundwater.

http://tagteam.harvard.edu/hub_feeds/1977/feed_items/217812

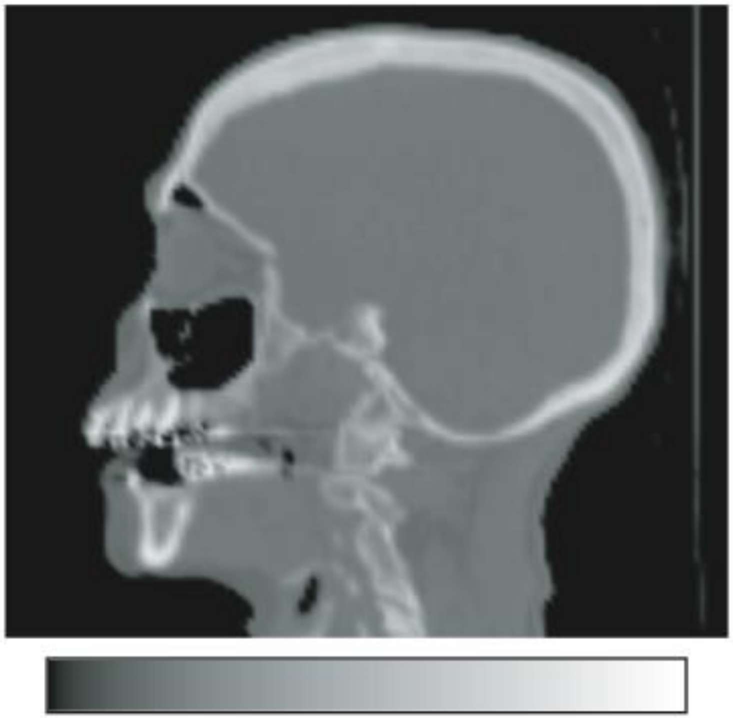

L

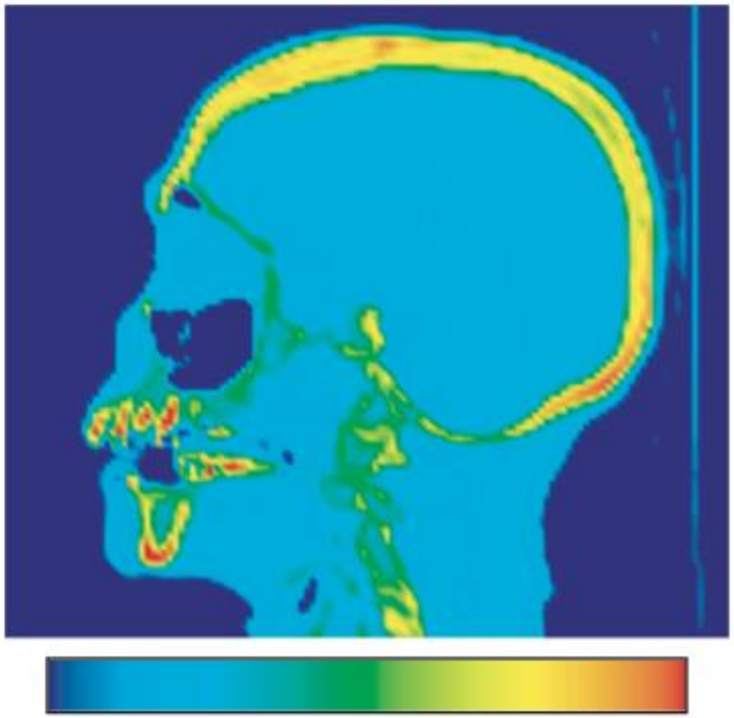

L

Grayscale Color Map

- Brightness = value, natural in some domains
  - X-ray, angiography

2D slice in 3D CT dataset
Scalar value: tissue density





Gray-value colormap
- white = hard tissues (bone)
- gray = soft tissues (flesh)
- black = air

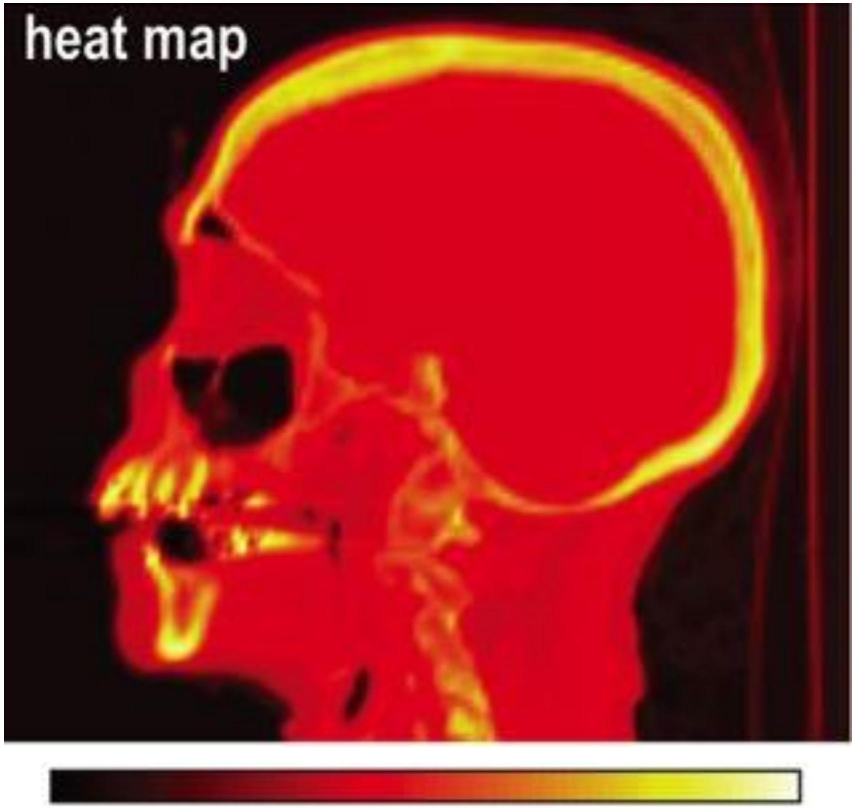
Rainbow colormap
- red = hard tissues (bone)
- blue = air
- other colors = soft tissues

Two-hue Color Map

- Interpolate between two colors
- Generalization of grayscale color map
- Hue + Luminance increases contrast

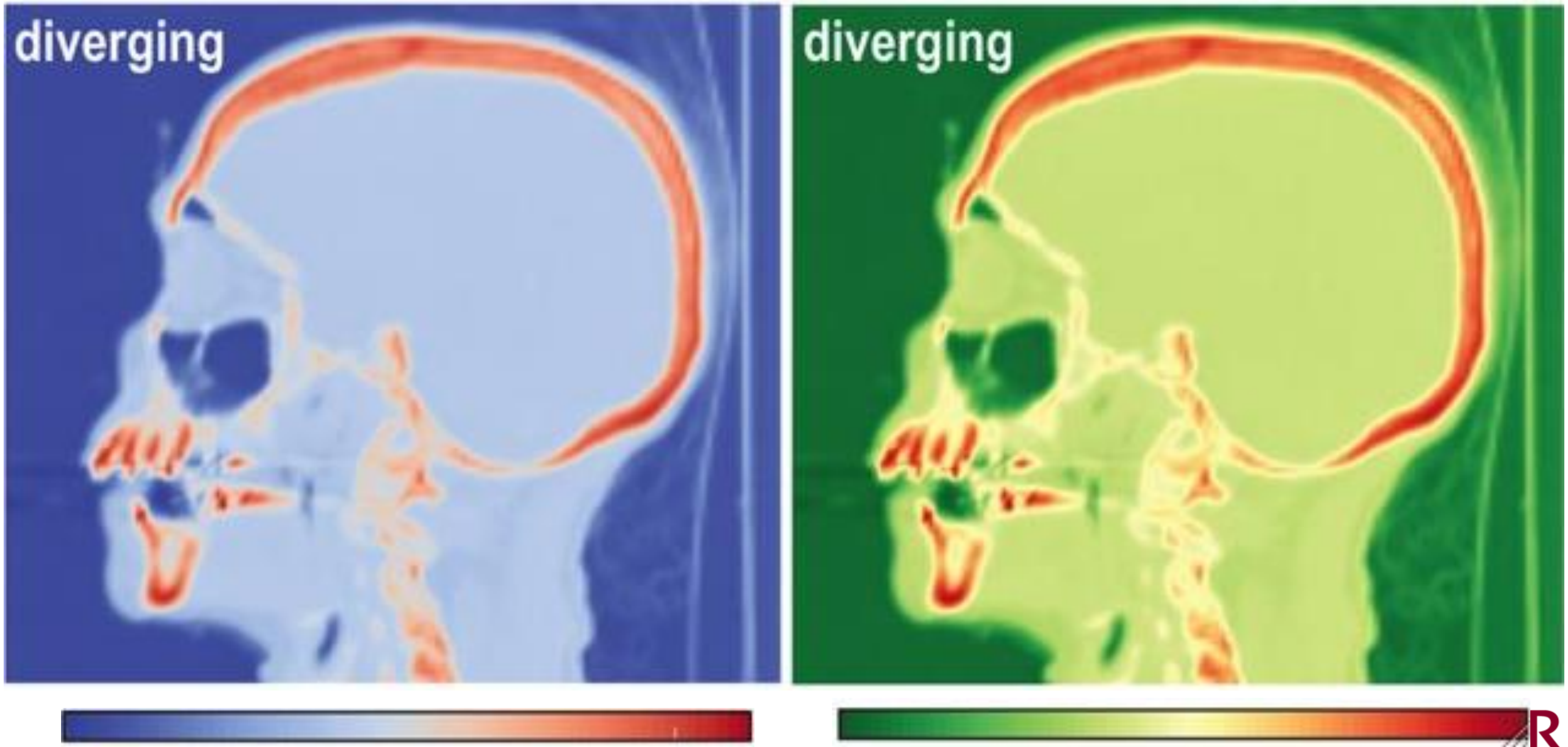
Heat Map

- More luminance than rainbow
- More hues than two-hue color map



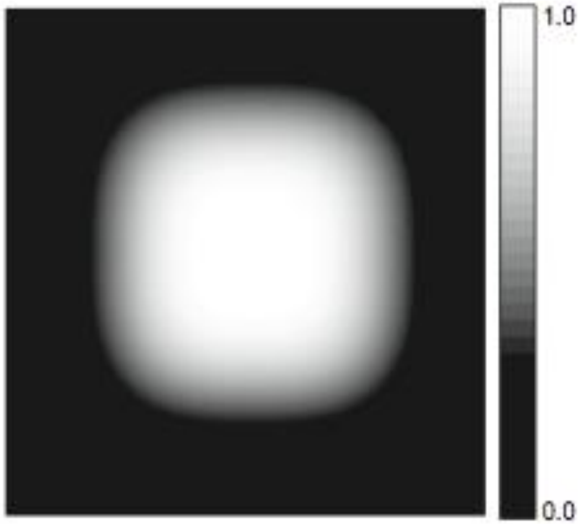
Diverging Color Map

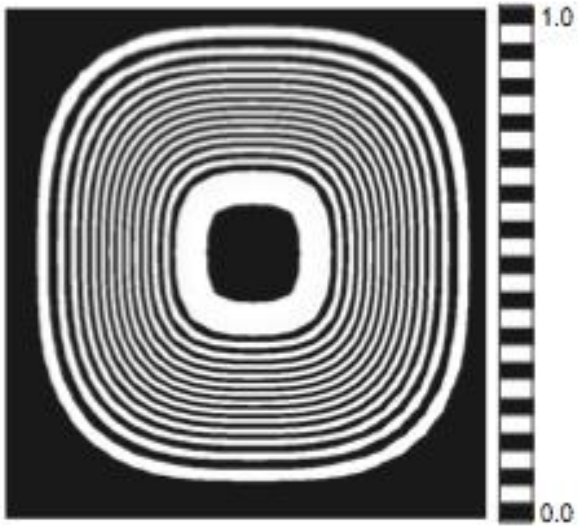
- Three colors : left, middle, right
  - Easy to detect deviation from center



Zebra Color Map

2D function $f(x,y) = e^{-10(x^4+y^4)}$





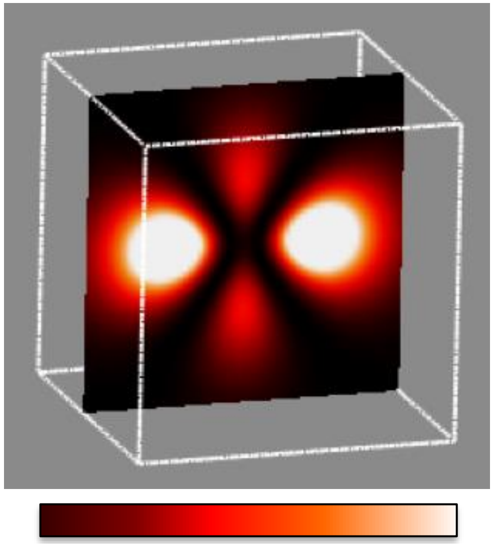
Gray-scale colormap

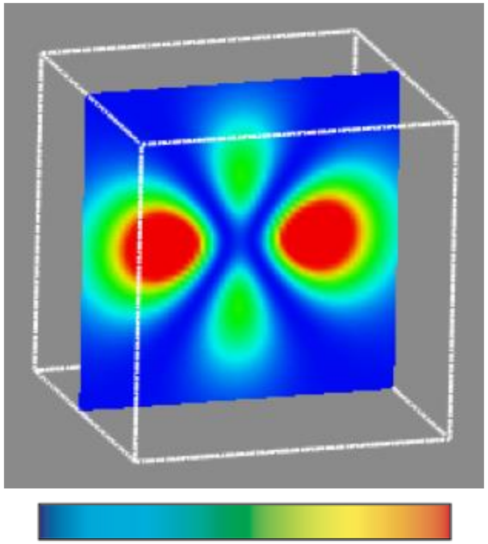
- highlights plateaus
- value transitions hard to see

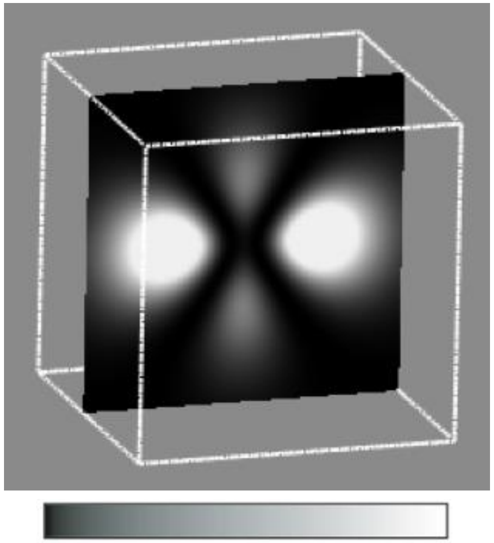
Zebra colormap

- highlights value variations (1st derivative)
- dense, thin bands: fast variation
- thick bands: slow variation

Color Map Comparison







Heat colormap
- maxima highlighted well
- lower values better separable than with gray-value colormap

Rainbow colormap
- maxima not prominent
- lower values better separable

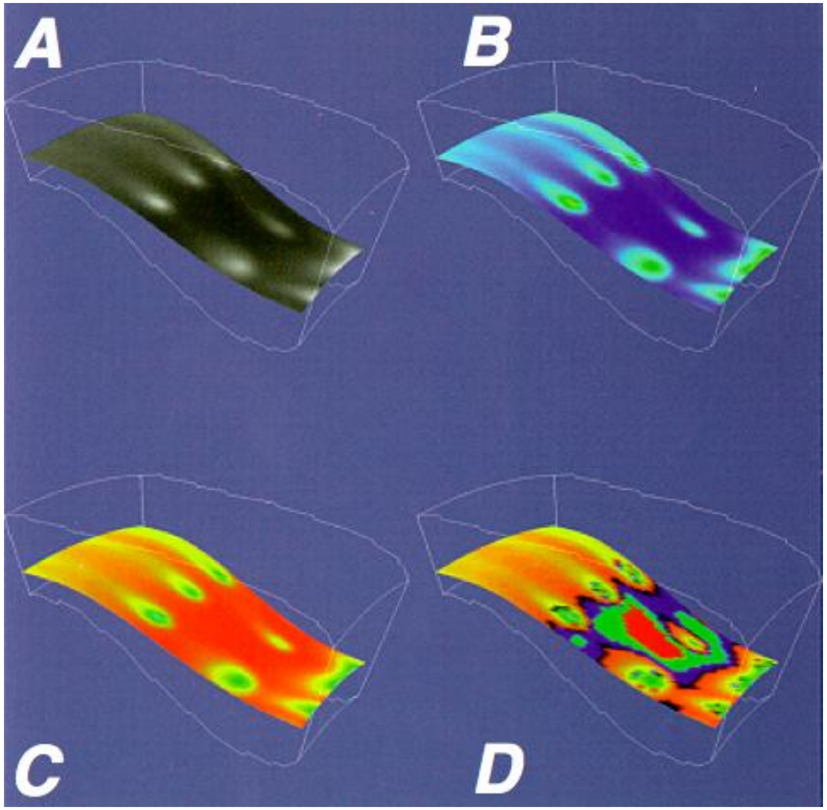
Grayscale colormap
- maxima are highlighted well
- lower values are unclear

Color Map Comparison

2D slice in 3D pressure field in an engine

A. Grayscale colormap
- maxima highlighted well
- low-contrast

B. Purple-to-green colormap
- maxima highlighted well
- good high-low separation

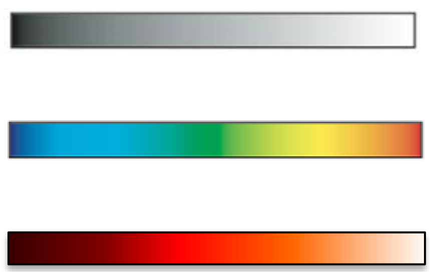


C. Red-to-green colormap
- luminance not used
- color-blind problems..

D. 'Random'
- equal-value zones visible
- little use for the rest

More about Color Map Design

- Fully use the perceptual spectrum
  – Color map entries should differ in more HSV components



scalar value ~ V; H,S not used

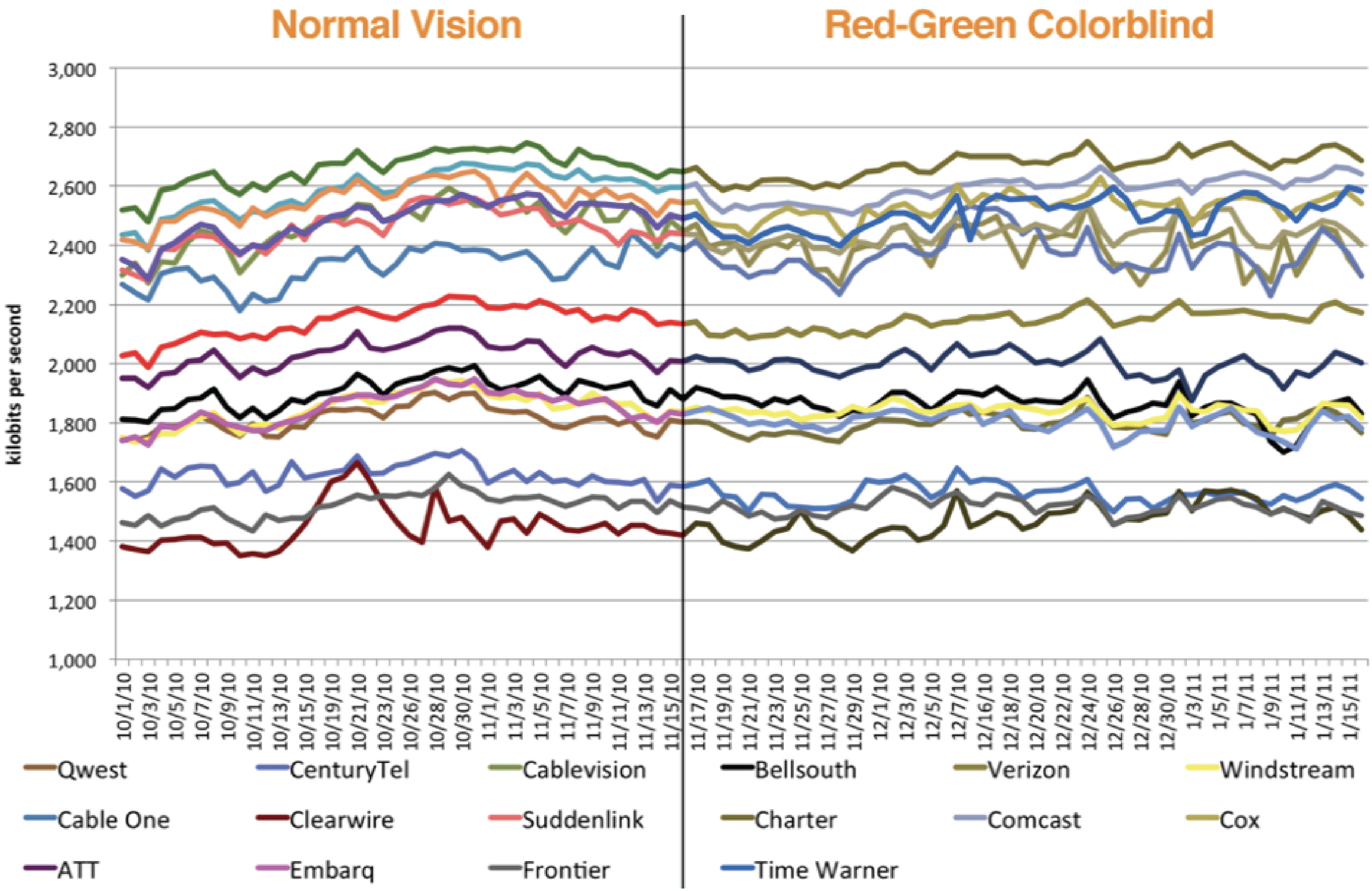
scalar value ~ H; S,V not used

scalar value ~ H,V; S not used

More about Color Map Design

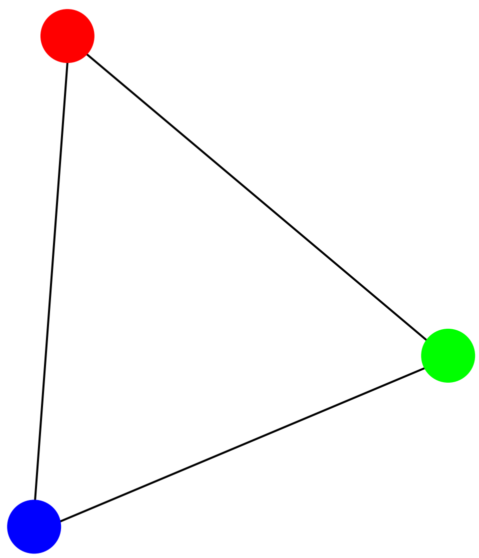
- Color map should be easily invertible
- Avoid color map entries with
  - Similar HSV entries
  - Perceived as similar
    - color blindness issue
  - Hard to perceive
    - Dark or strongly desaturated colors

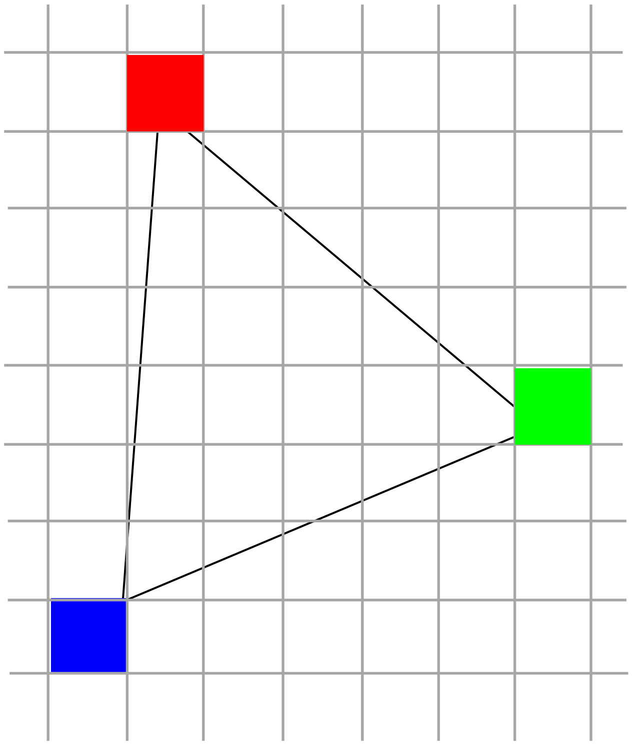
Color Blind


Normal Vision
Red-Green Colorblind
kilobits per second
3,000
2,800
2,600
2,400
2,200
2,000
1,800
1,600
1,400
1,200
1,000
Qwest
CenturyTel
Cablevision
Bellsouth
Verizon
Windstream
Cable One
Clearwire
Suddenlink
Charter
Comcast
Cox
ATT
Embarq
Frontier
Time Warner

Colormap Implementation

- Where to apply colormap?
  - Vertex? Pixel?

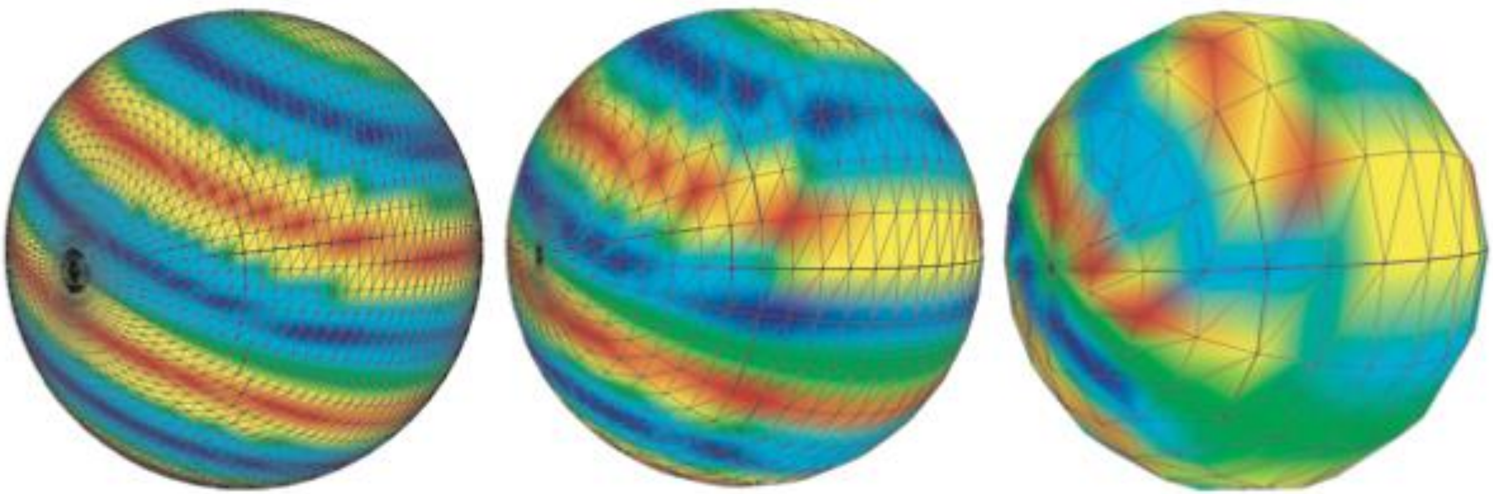




Colormap Implementation

- Where to apply colormap?
  - Per-vertex (pre-classification)

2D periodic high-frequency function

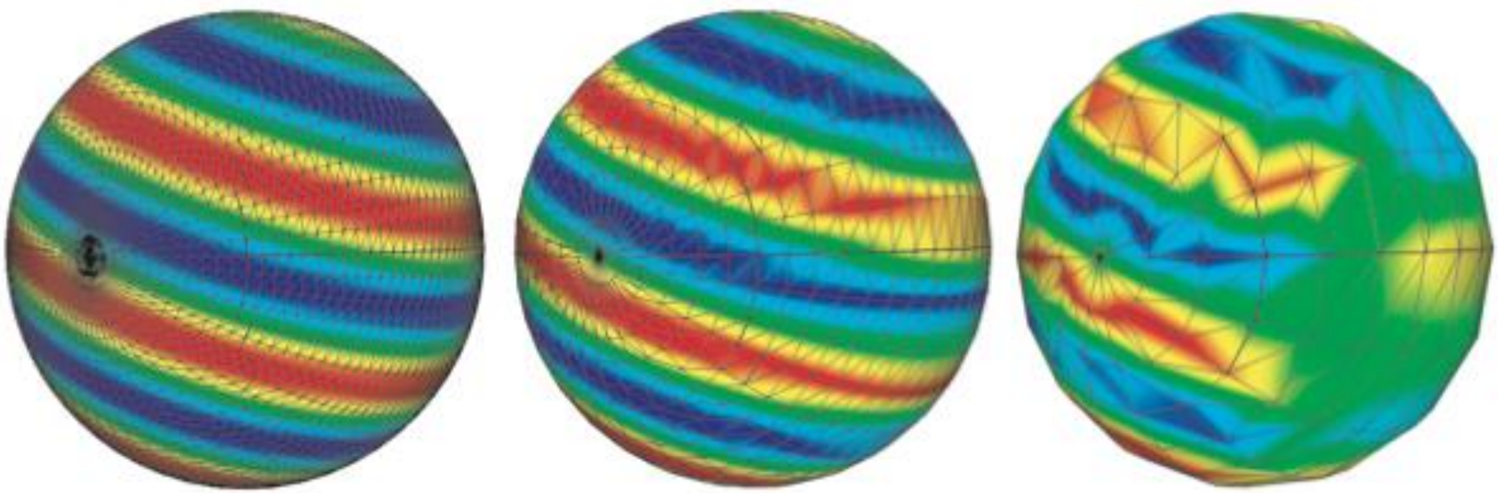


64x64 points 32x32 points 16x16 points

Colormap Implementation

- Where to apply colormap?
  - Per-pixel (post-classification)

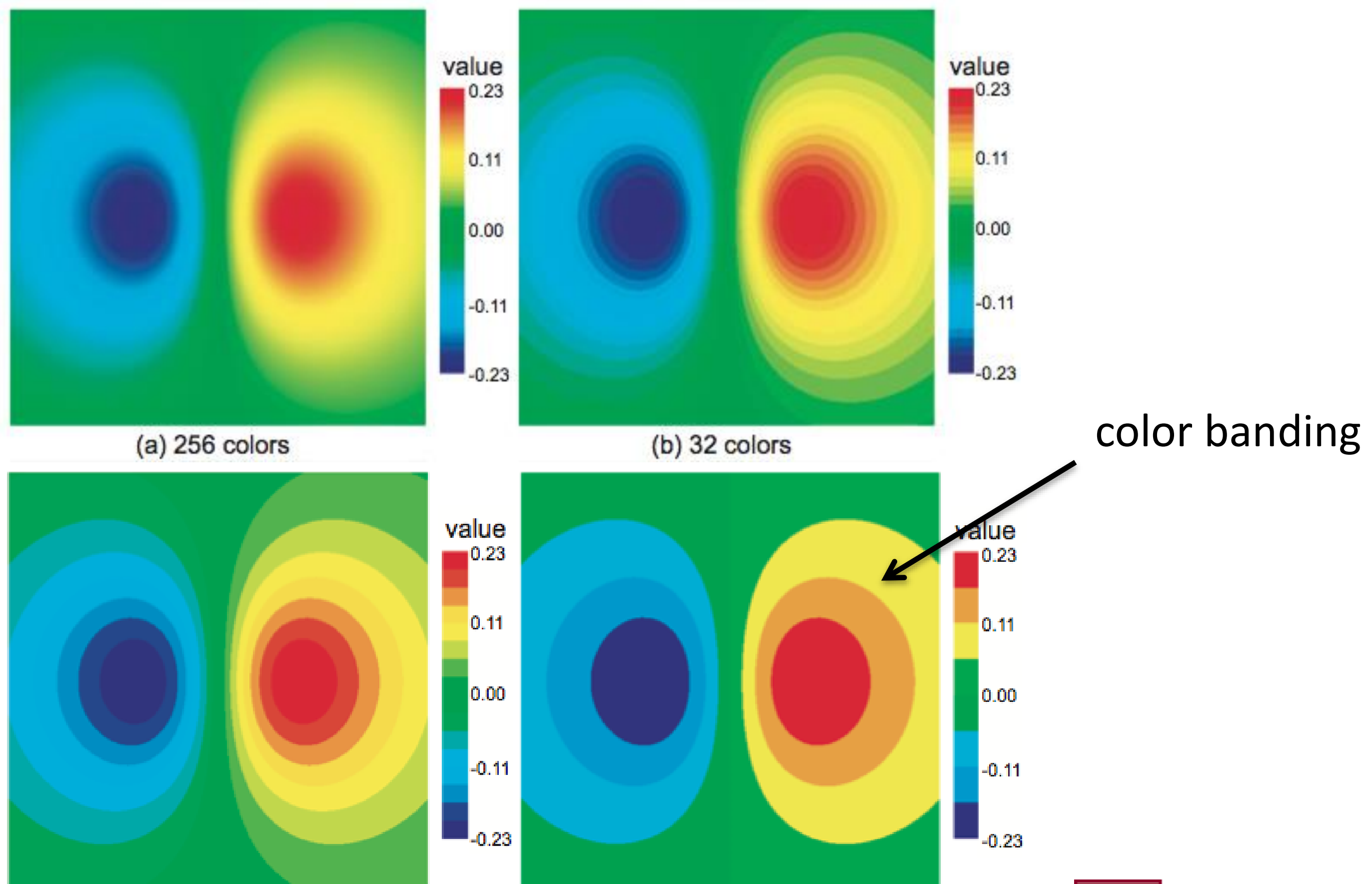
2D periodic high-frequency function



64x64 points | 32x32 points | 16x16 points

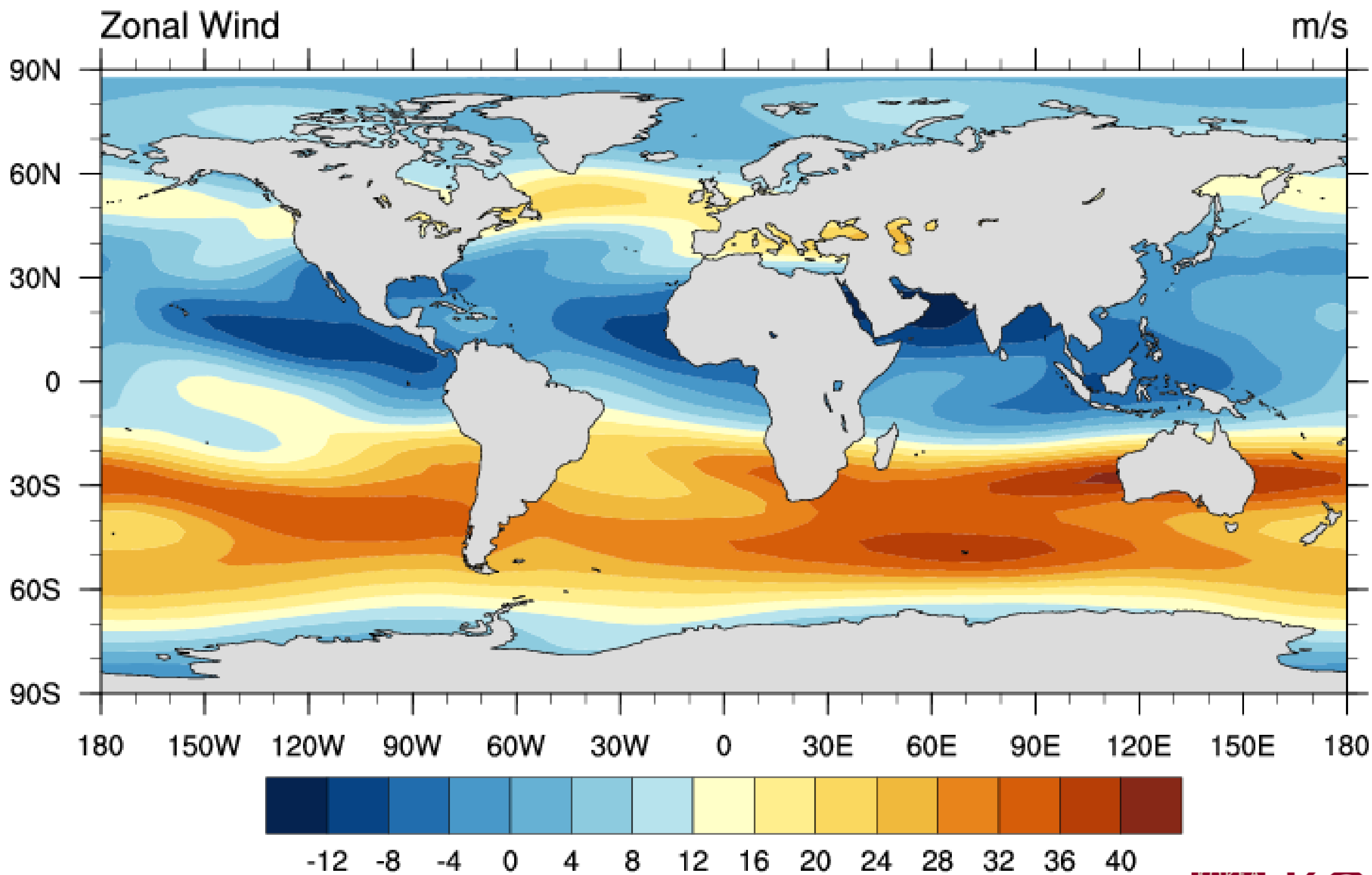
Color Banding

- How many distinct colors N used in color table



(a) 256 colors
(b) 32 colors
(c) 16 colors
(d) 8 colors

Color Banding Example



https://www.ncl.ucar.edu/

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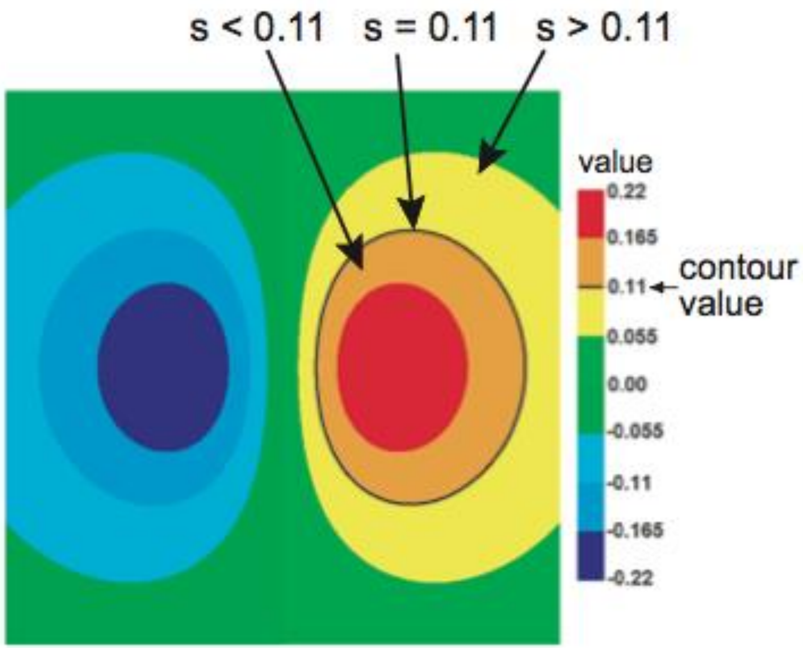
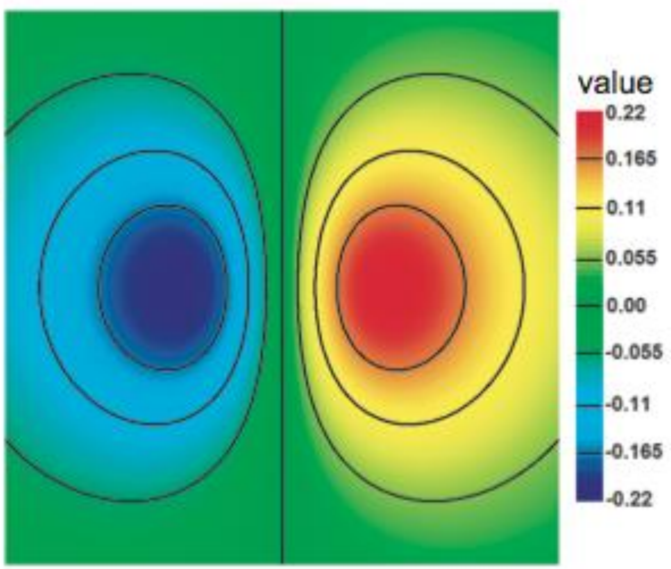
Contouring

- How to see where some given values appear in a dataset?
  - a transition separating two consecutive bands



contour = all points having the scalar value $s = 0.11$



seven different contours, equidistant in value space

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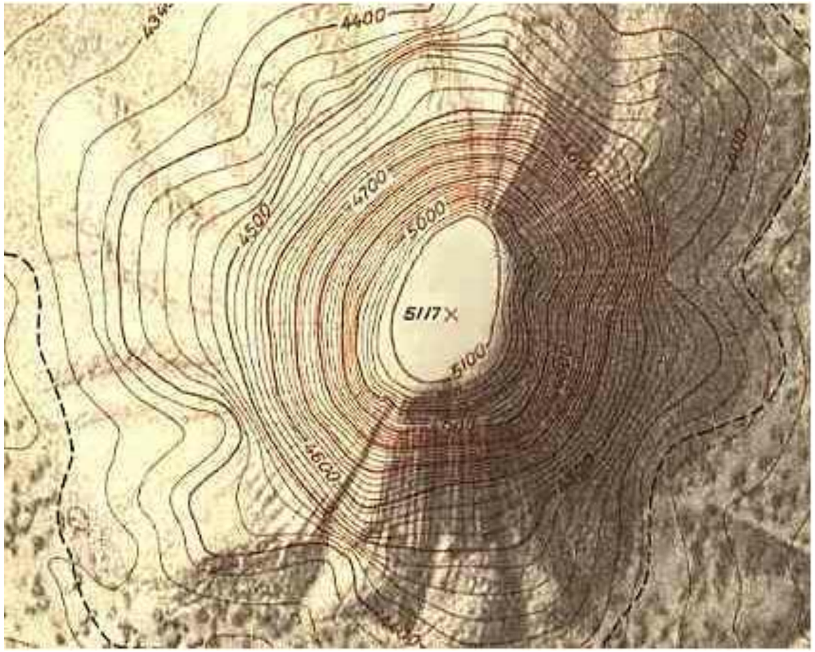
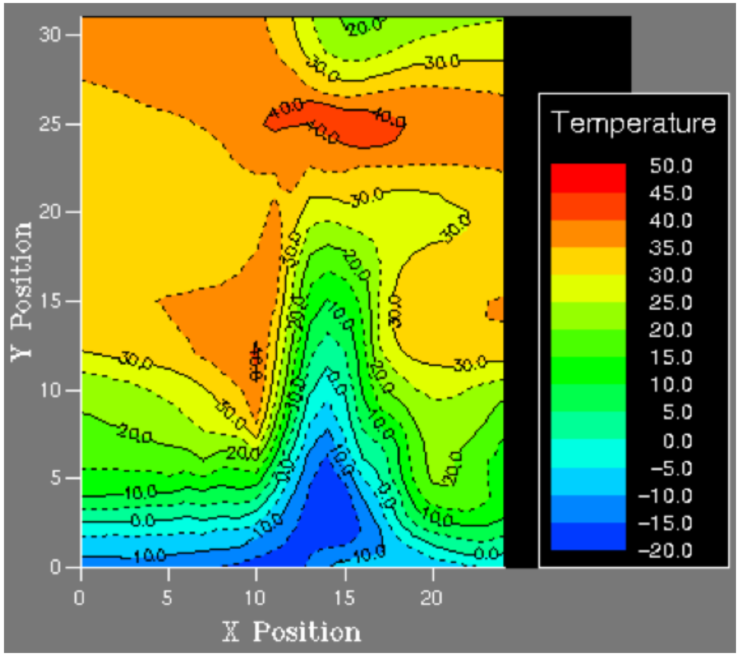
Contouring

- Isolines
  - Lines of equal values





Contour Properties

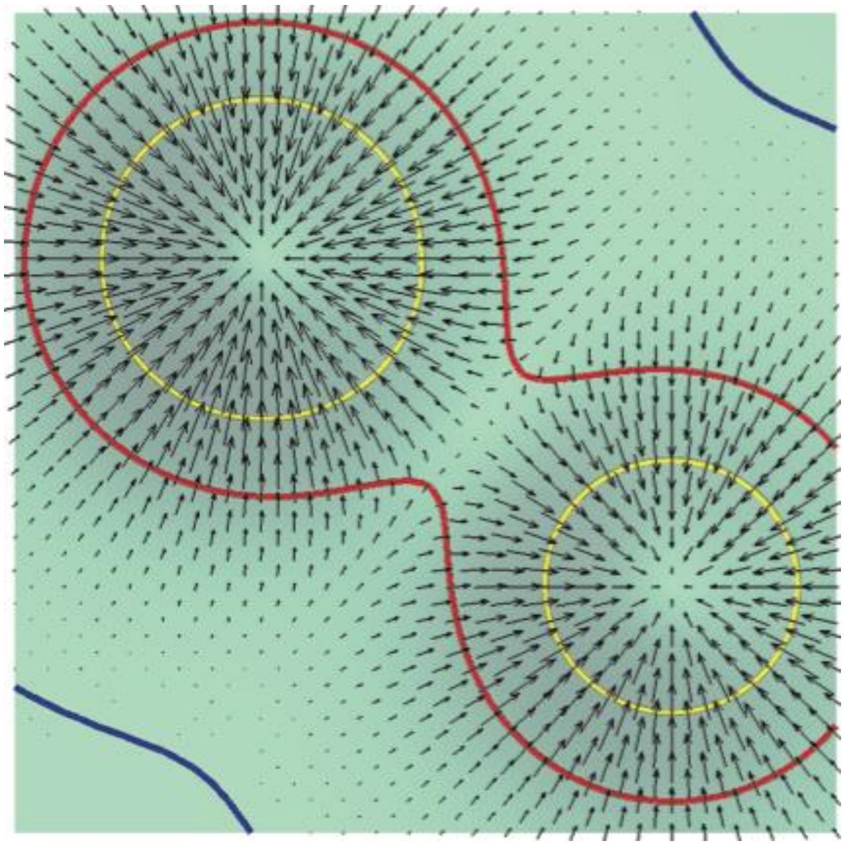
- Definition

$$I(f_0) = \left\{ x \in D \middle| f(x) = f_0 \right\}$$

- Properties
  - Contours are closed curves (except when exit D)
  - Contours never self-intersect, so nested
  - Contours cut D into two regions with smaller / larger than isovalue

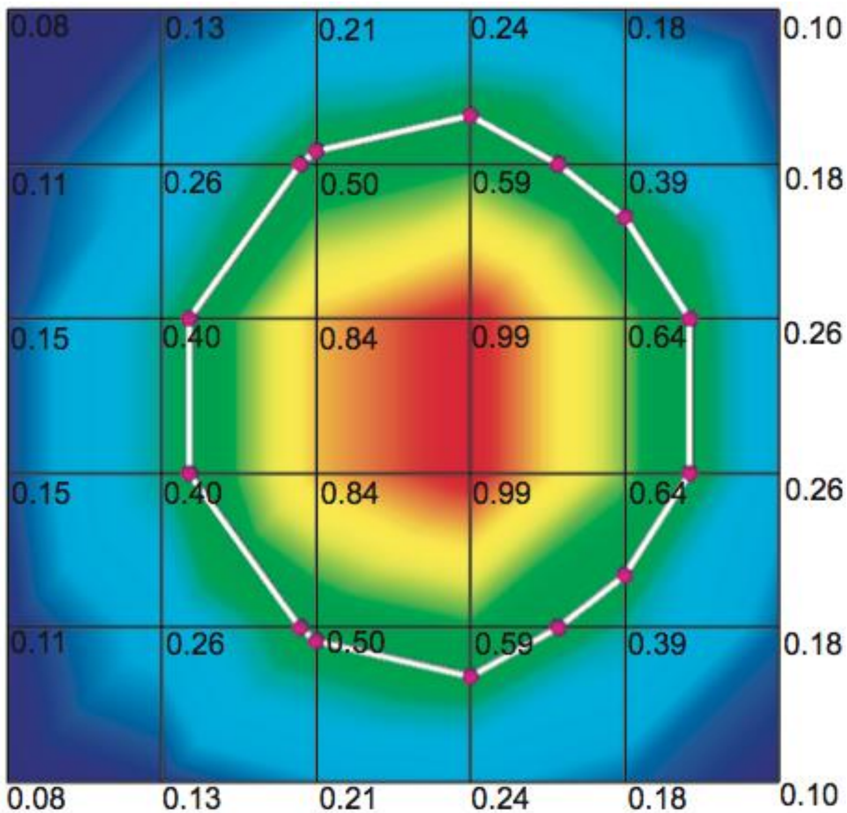
Contour Properties

- Contours are orthogonal to gradient



gradient of a scalar field (drawn with arrows) is orthogonal to contours

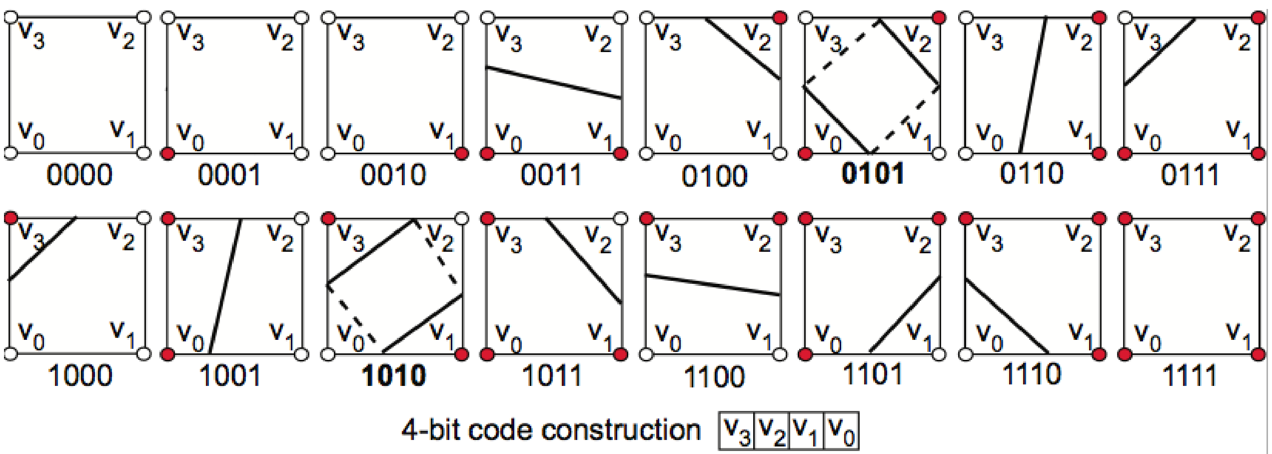
Contouring Algorithm



for(each cell c in D)
{
  $S = \text{Æ}$ //no contour-edge cuts
  for(each edge $e=(p_i,p_j)$ of c)
  {
    if($f_i < f < f_j$) //e cuts contour
    {
$$q = \frac{p_i(f_j - f) + p_j(f - f_i)}{f_j - f_i}$$
$$S = S \text{ È } q$$
    }
  }
  connect points in S with lines to build contour;
}

Marching Squares

- Fast Implementation of 2D contouring
- Encore inside/outside using 4 bits

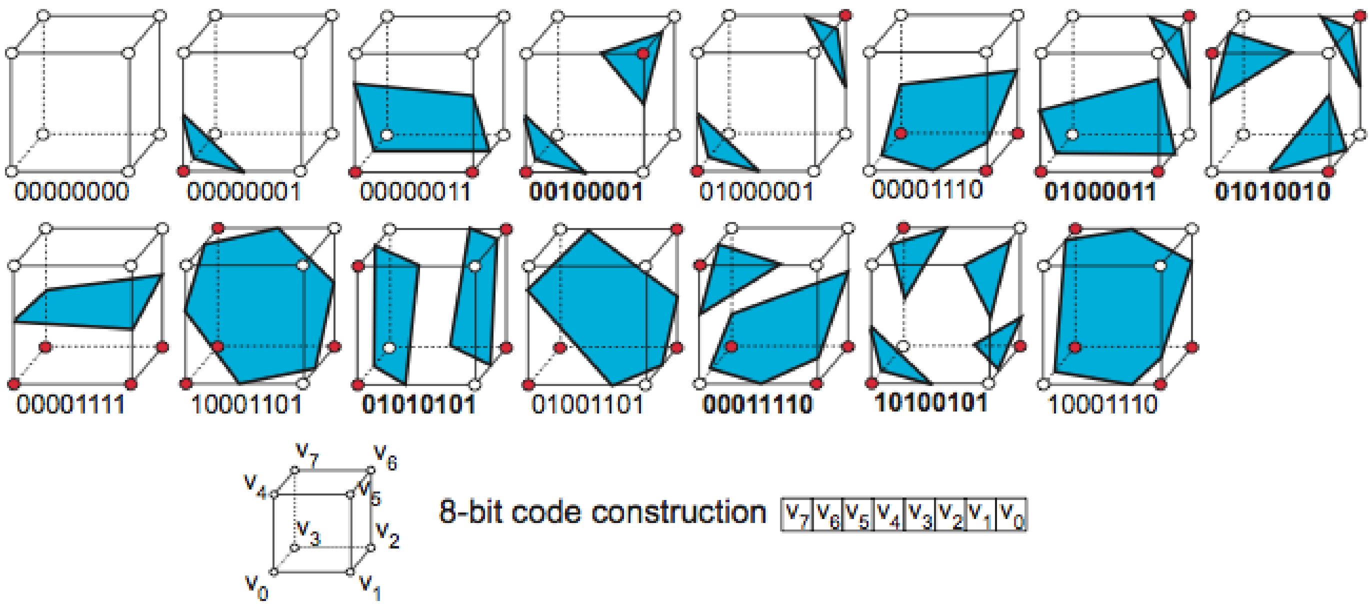


e.g.
inside: $f > f_0$
outside: $f \leq f_0$

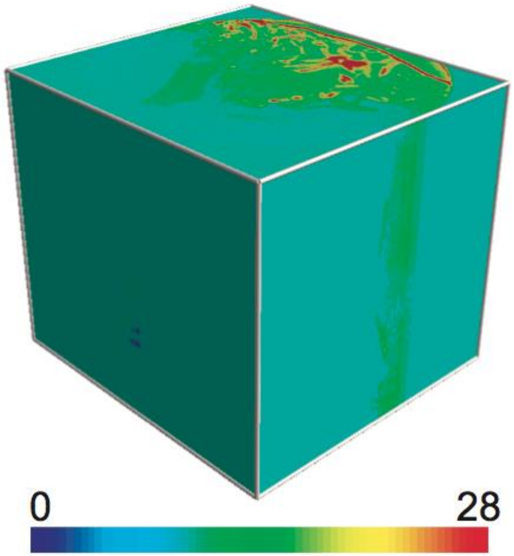
- For each cell, use the code to determine case
  – Compute only intersected edge
  – Reuse already-computed contour vertex

Marching Cubes

- Extension to 3D
  - 15 unique cases (out of 256 cases)

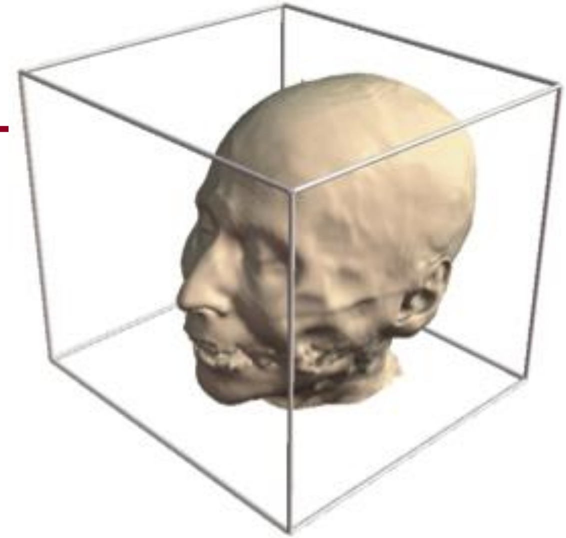


Marching Cube

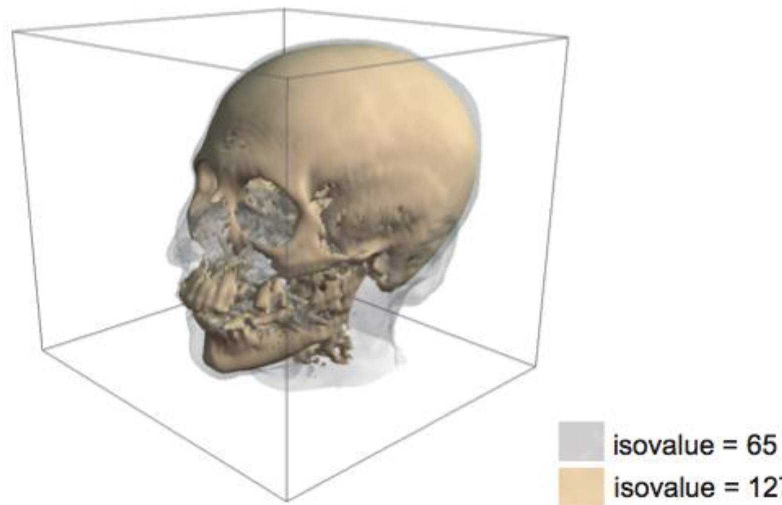


scalar CT volume
(tissue density)

isosurfaces

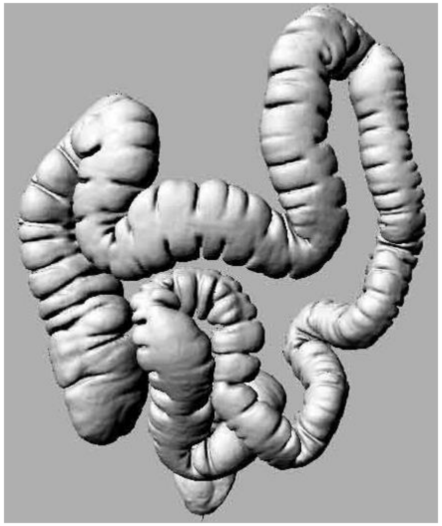


isosurface for scalar value
corresponding to skin

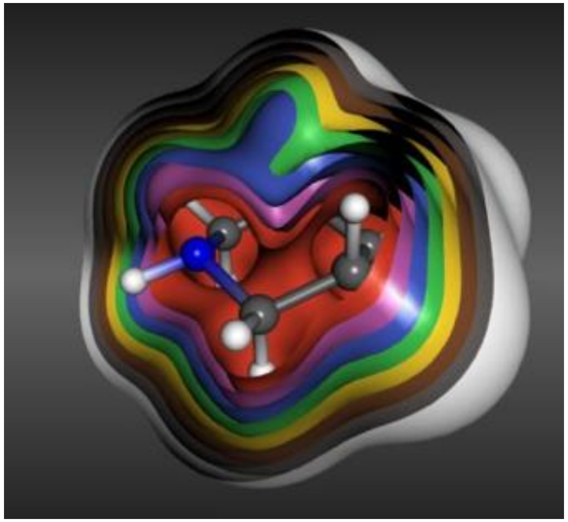


isosurfaces for skin and bone

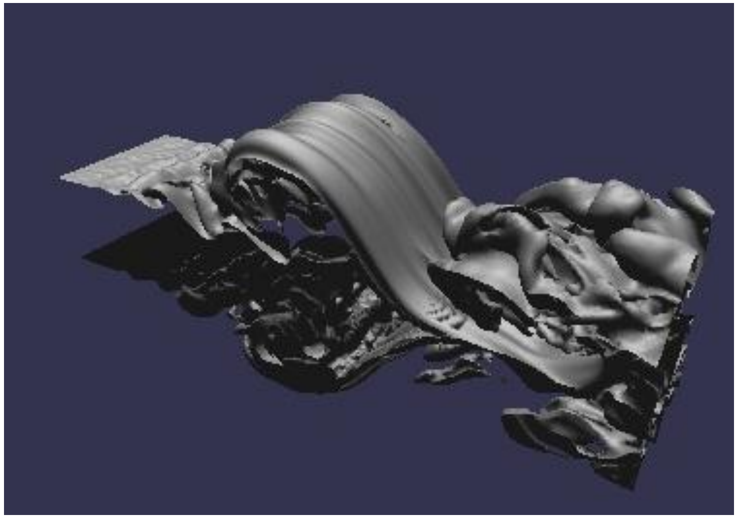
- extremely simple to use tool
- insightful results



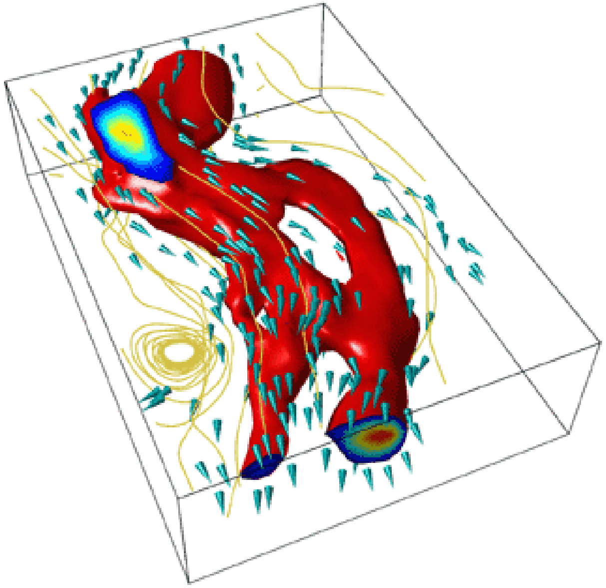
colon (CT dataset)



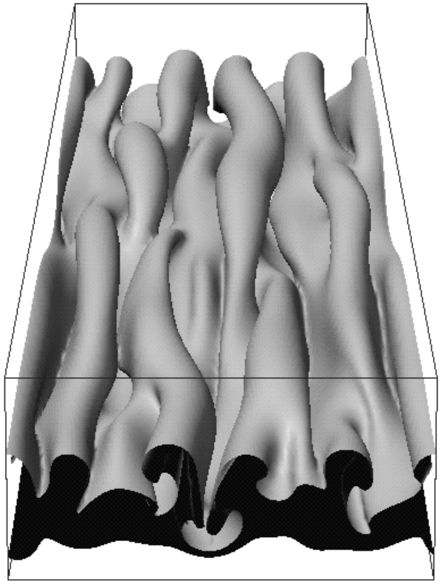
electron density in molecule



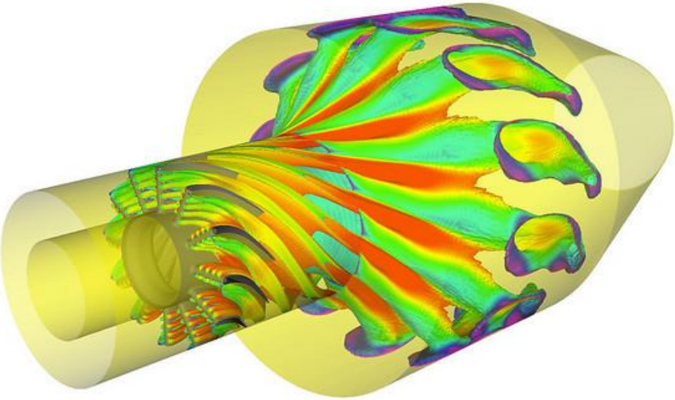
velocity in 3D fluid flow



velocity in 3D fluid flow



magnetic field in sunspots

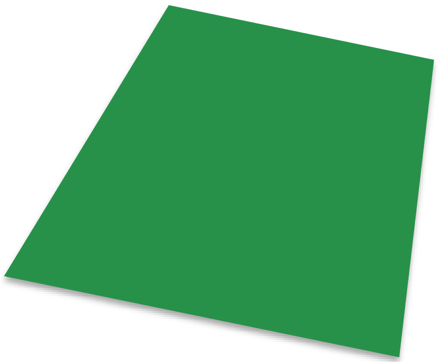


fuel concentration, colored
by temperature in jet engine

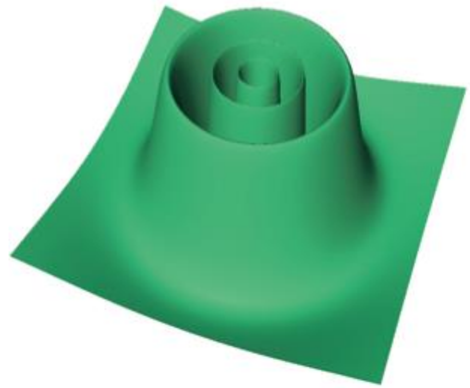
Alexandru C. Telea

Height / Displacement Plots

$S_{displ}(x) = x + \mathbf{n}(x) f(x), \ \forall x \in S$ f: displacement value, n : normal direction



input surface S

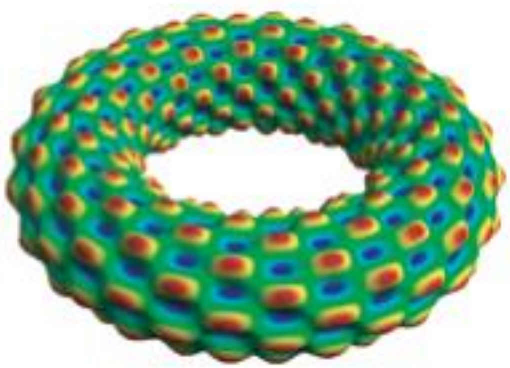


displaced surface S_{displ}

Height plot

- $S = xy$ plane
- displacement always along z

input surface S



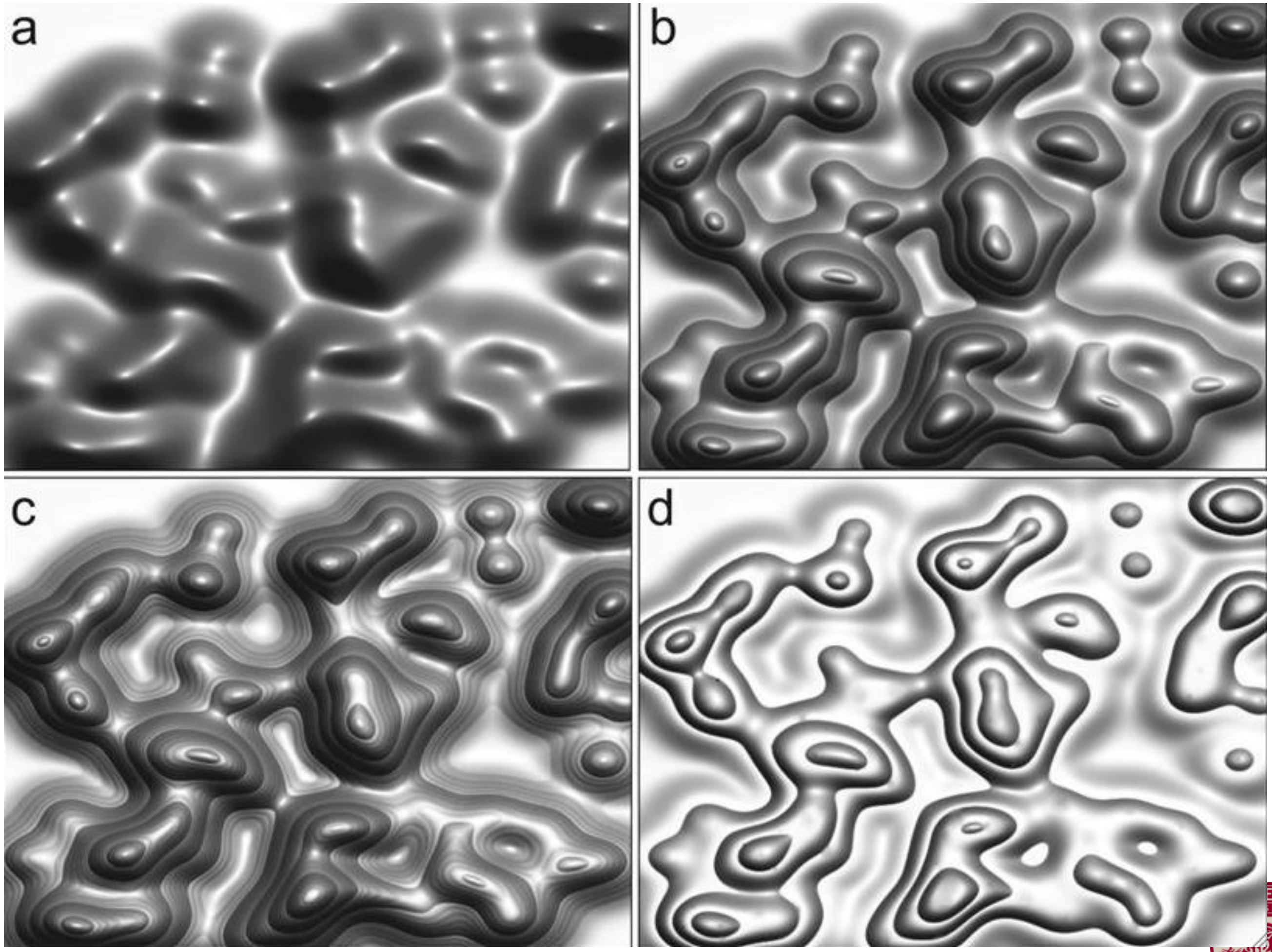
displaced surface S_{displ}

Displacement plot

- S = any surface in $\mathbf{R}^3$
- useful to visualize 3D scalar fields

Enridged Contour Maps

- Contour + shading



Questions?

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