Data Visualization Principles: Other Perceptual Channels

CSC444

Acknowledgments for today's lecture:
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History Time!

Gustav Fechner, 1801–1887

Founder of psychophysics

(What?)

Psychophysics

- Some stuff that happens in the “external world” (outside your own body) causes stuff to happen “in your head”

- Some of it is simple enough to study: that’s psychophysics
    - “the scientific study of the relation between stimulus and sensation"

Stephens's Power Law

have been made to scale their magnitudes. In the years since 1953 more than three dozen continua have been examined, always with the same outcome: the sensation magnitude ψ grows as a power function of the stimulus magnitude ϕ. In terms of a formula, we may write

$$\psi = k\phi^{\beta}$$

The constant k depends on the units of measurement and is not very interesting; but the value of the exponent β serves as a kind of signature that may differ from one sensory continuum to another. As a matter of

Source: Stephens's "Psychophysics"

There exist stimuli
other than colors

From Stephens's Psychophysics:

Table 1. Representative exponents of the power functions relating subjective magnitude to stimulus magnitude

Continuum	Measured exponent	Stimulus condition
Loudness	0.67	Sound pressure of 3000-hertz tone
Vibration	0.95	Amplitude of 60 hertz on finger
Vibration	0.6	Amplitude of 250 hertz on finger
Brightness	0.33	5° Target in dark
Brightness	0.5	Point source
Brightness	0.5	Brief flash
Brightness	1.0	Point source briefly flashed
Lightness	1.2	Reflectance of gray papers
Visual length	1.0	Projected line
Visual area	0.7	Projected square
Redness (saturation)	1.7	Red-gray mixture
Taste	1.3	Sucrose
Taste	1.4	Salt
Taste	0.8	Saccharine
Smell	0.6	Heptane
Cold	1.0	Metal contact on arm
Warmth	1.6	Metal contact on arm
Warmth	1.3	Irradiation of skin, small area
Warmth	0.7	Irradiation of skin, large area
Discomfort, cold	1.7	Whole body irradiation
Discomfort, warm	0.7	Whole body irradiation
Thermal pain	1.0	Radiant heat on skin
Tactual roughness	1.5	Rubbing emery cloths
Tactual hardness	0.8	Squeezing rubber
Finger span	1.3	Thickness of blocks
Pressure on palm	1.1	Static force on skin
Muscle force	1.7	Static contractions
Heaviness	1.45	Lifted weights
Viscosity	0.42	Stirring silicone fluids
Electric shock	3.5	Current through fingers
Vocal effort	1.1	Vocal sound pressure
Angular acceleration	1.4	5-Second rotation
Duration	1.1	White noise stimuli

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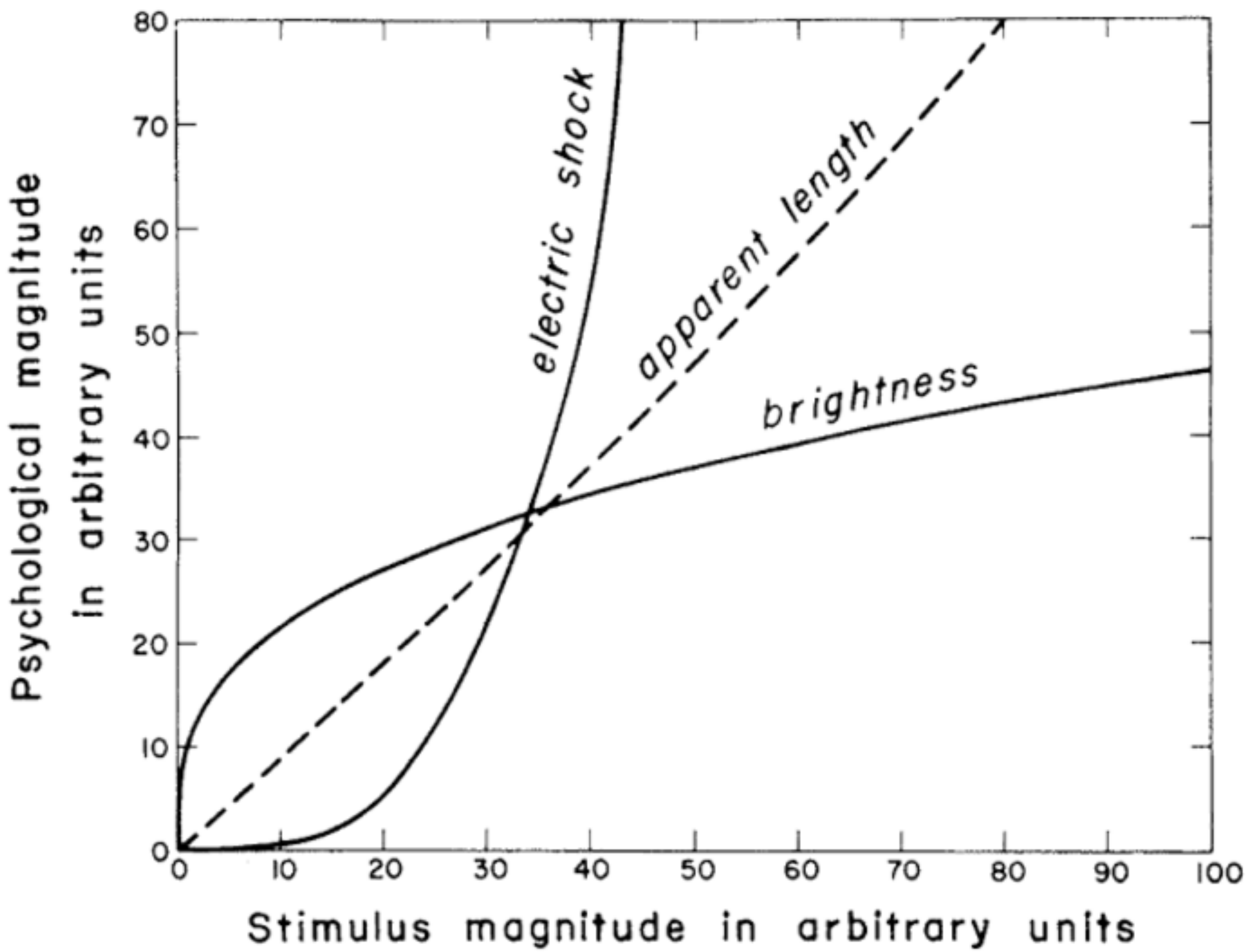

80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
electric shock
apparent length
brightness
Psychological magnitude in arbitrary units
Stimulus magnitude in arbitrary units

So what is data visualization?

The art and science of matching the “features” of a data set to the “features” of visual perception

Why visualization?

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An Introduction to Interactive Sonification

Thomas Hermann
Bielefeld University, Germany

Andy Hunt
University of York, UK

The research field of sonification, a subset of the topic of auditory display, has developed rapidly in recent decades. It brings together interests from the areas of data mining, exploratory data analysis, human–computer interfaces, and computer music. Sonification presents information by using sound (particularly nonspeech), so that the user of an auditory display obtains a deeper understanding of the data or processes under investigation by listening.[1]

We define *interactive sonification* as the use of sound within a tightly closed human–computer interface where the auditory signal provides information about data under analysis, or about the interaction itself, which is useful for refining the activity.

work processes. For the newer applications, the data often have a high dimensionality. This has led to two trends:

- the development of techniques to achieve dimensionality reduction without losing the available information in the data, and
- the search for techniques to represent more dimensions at the same time.

Regarding the latter point, auditory displays offer an interesting complement to visual displays. For example, an acoustic event (the audio counterpart of the graphical symbol) can show variation in a multitude of attributes such as pitch, modulations, amplitude envelope over time, spatial location, timbre, and brightness simultaneously.

Human perception, though, is tuned to process a combined audiovisual (and often also tactile and olfactory) experience that changes instantaneously as we perform actions. Thus we can increase the dimensionality further by using different modalities for data representation. The more we understand the interaction of these different modalities in the context of human activity in the real world, the more we learn what conditions are best for using them to present and interact with high-dimensional data.

Interacting with musical interfaces

Throughout history humankind has developed tools that help us shape and understand the world. We use these in a close action-perception loop, where physical interaction yields continuous visual, tactile, and sonic feedback. Musical instruments are particularly good examples of systems where the acoustic feedback plays an impor-

Why visualization?

- It has been studied more deeply
- It appears to have more "bandwidth" than alternatives (though not as much as you think it does)
- It is **richer**

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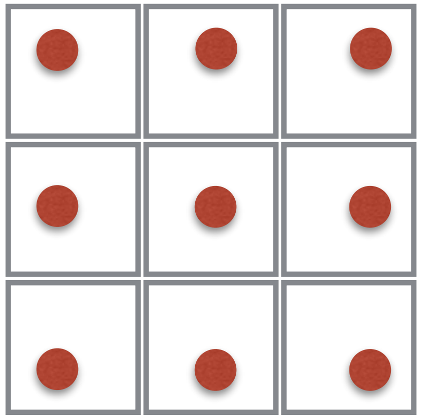

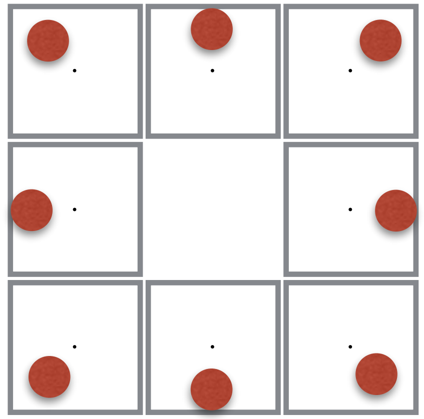

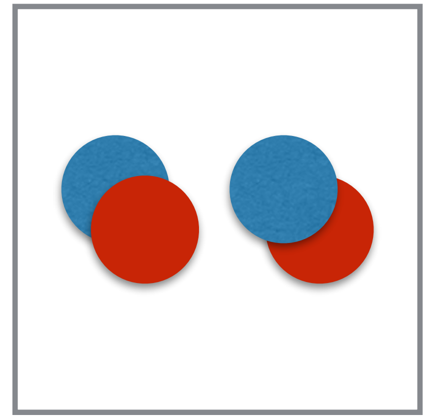

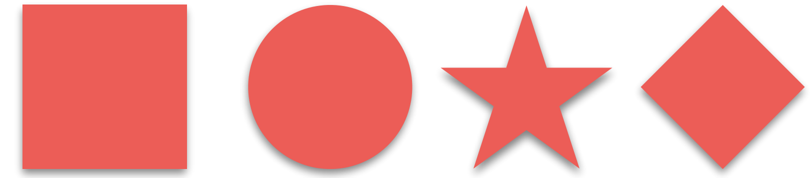

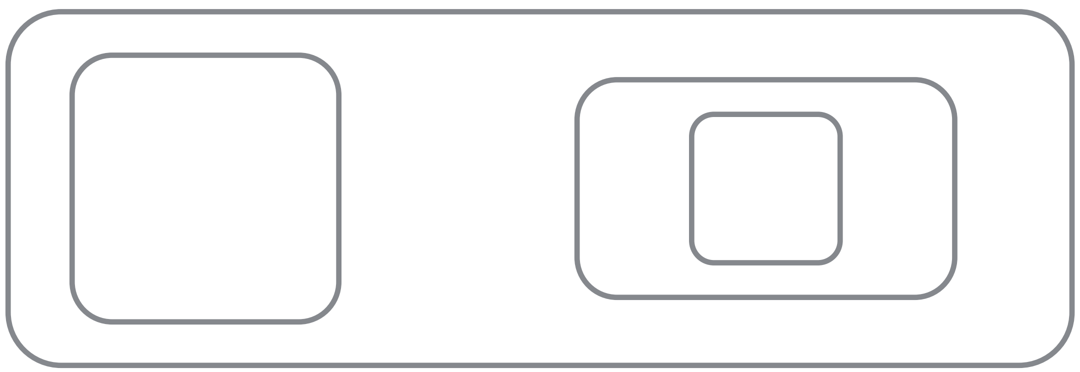

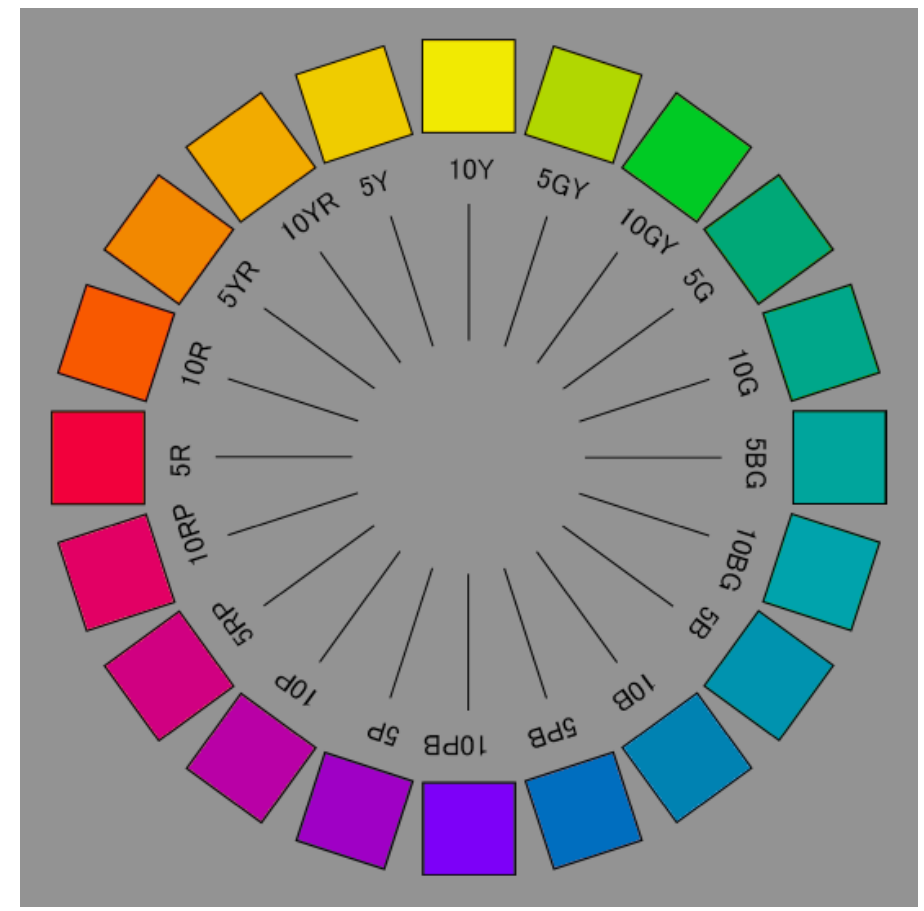

(c) PlusMinus, GFDL

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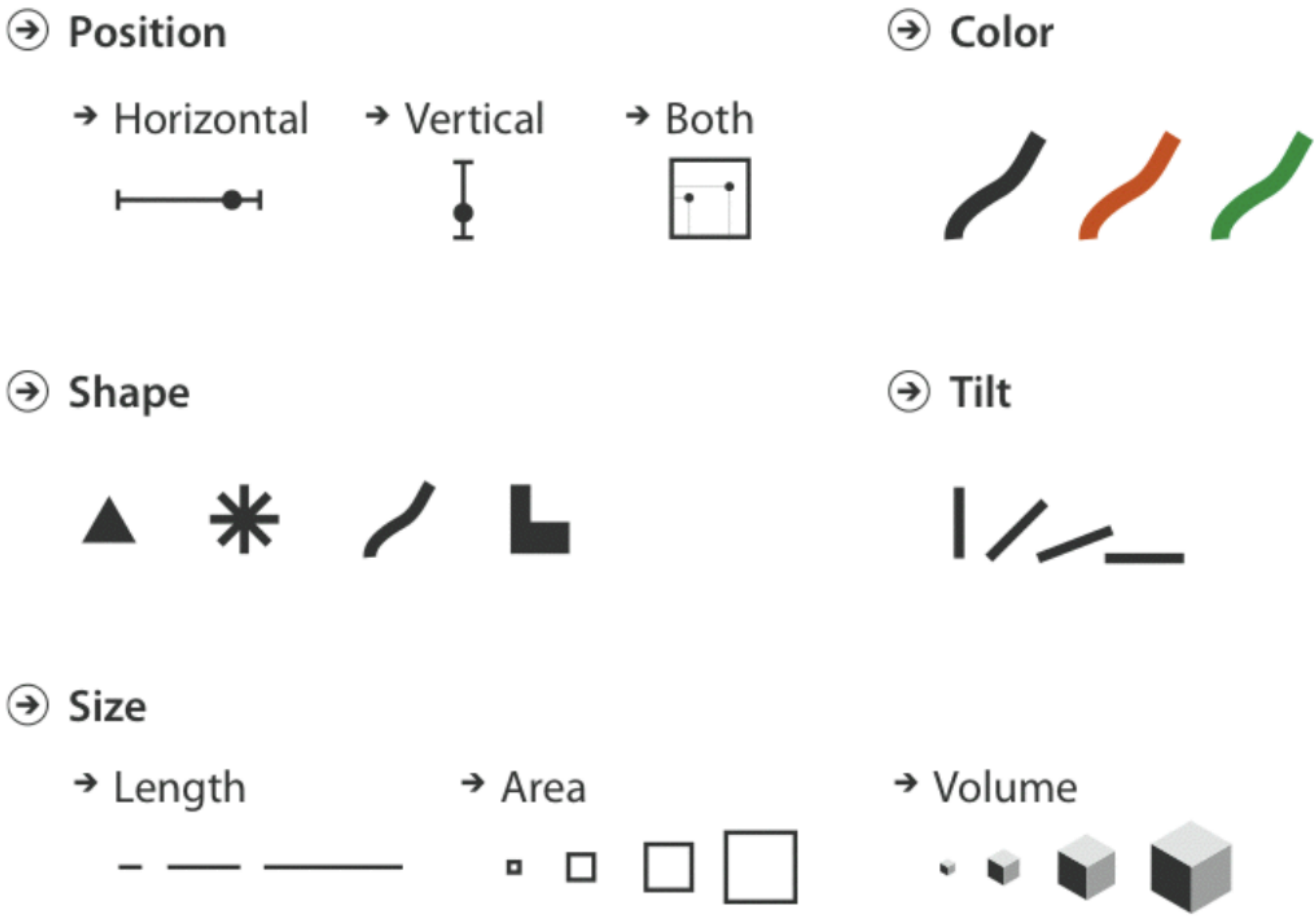
THE STANDARD VISUAL CHANNELS


Position
Horizontal
Vertical
Both
Color
Shape
Tilt
Size
Length
Area
Volume

Cleveland/McGill perception papers

- The beginning of visualization as an experimental science
- **Required reading for ALL students!**

Graphical Perception: Theory, Experimentation, and Application to the Development of Graphical Methods

WILLIAM S. CLEVELAND and ROBERT McGILL*

The subject of graphical methods for data analysis and for data presentation needs a scientific foundation. In this article we take a few steps in the direction of establishing such a foundation. Our approach is based on *graphical perception*—the visual decoding of information encoded on graphs—and it includes both theory and experimentation to test the theory. The theory deals with a small but important piece of the whole process of graphical perception. The first part is an identification of a set of

largely unscientific. This is why Cox (1978) argued, "There is a major need for a theory of graphical methods" (p. 5), and why Kruskal (1975) stated "in choosing, constructing, and comparing graphical methods we have little to go on but intuition, rule of thumb, and a kind of master-to-apprentice passing along of information. . . . there is neither theory nor systematic body of experiment as a guide" (p. 28–29).

There is, of course, much good common sense about

Cleveland/McGill perception papers

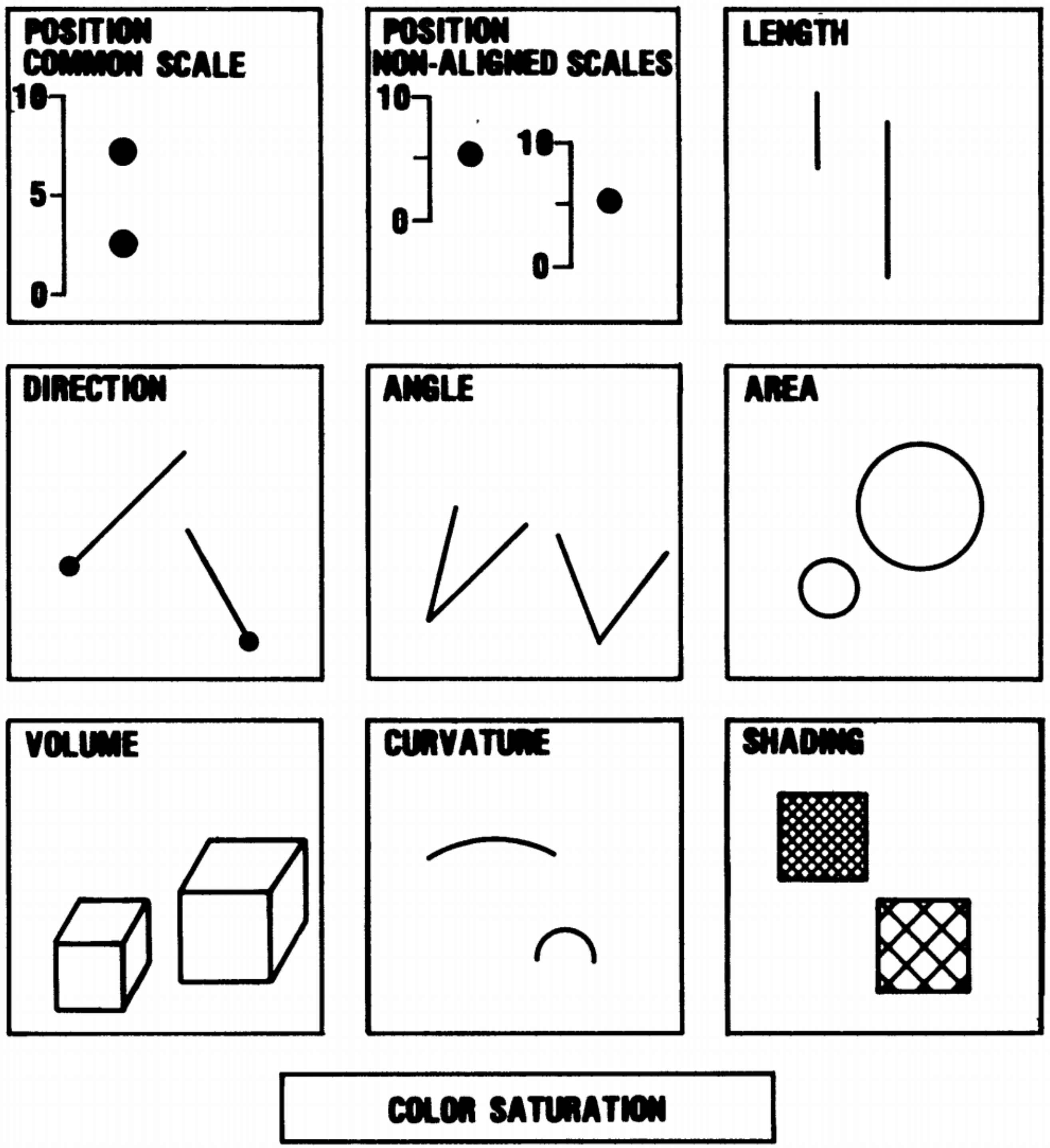


Figure 1. Elementary perceptual tasks.

Better to worse:

1. Position along a common scale
2. Positions along nonaligned scales
3. Length, direction, angle
4. Area
5. Volume, curvature
6. Shading, color saturation

Pie Chart Bad, Scatterplot Good

Integral vs. Separable Channels

- Do humans perceive values “as a whole”, or “as things that naturally split”?

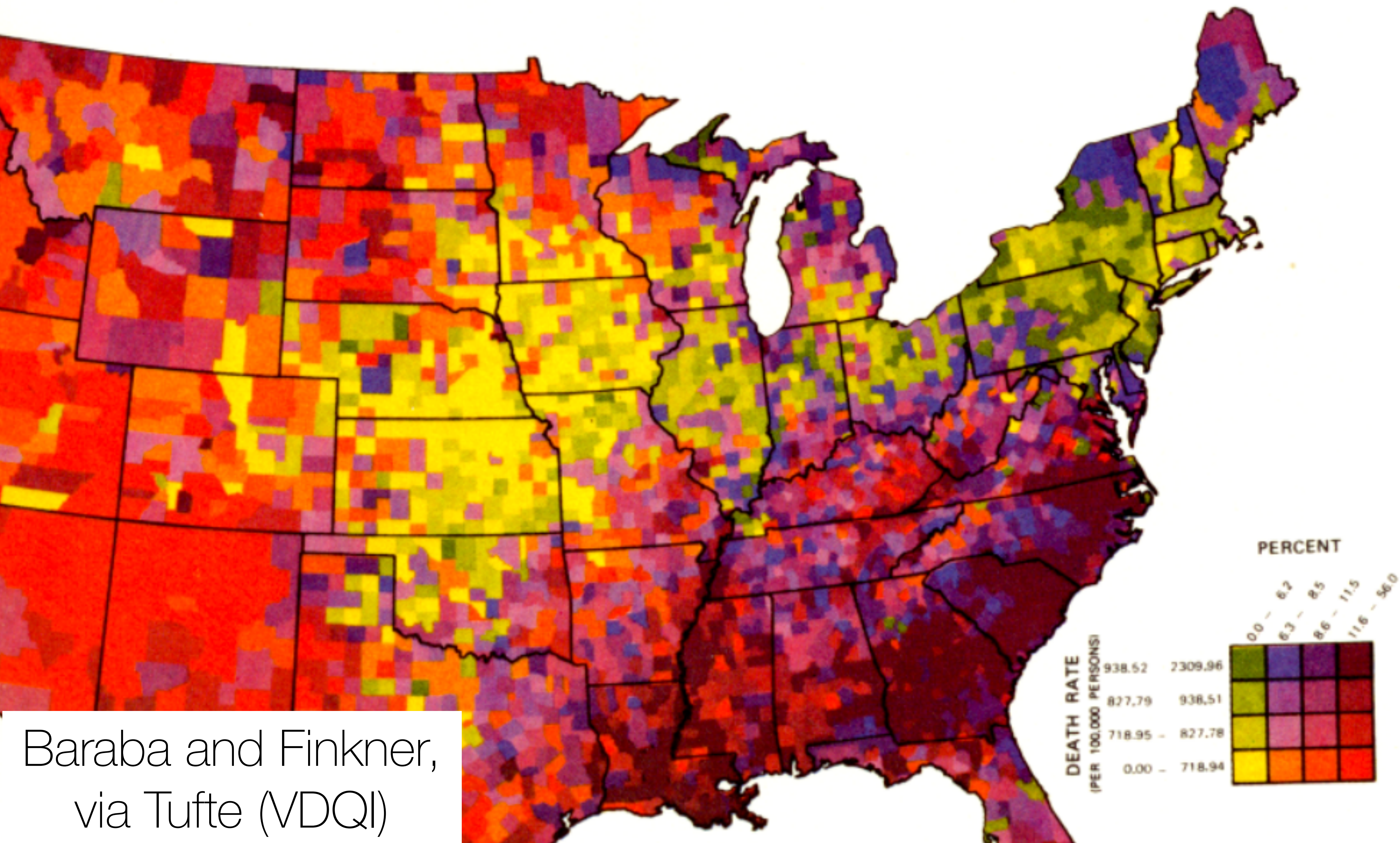
Integral vs. Separable Channels

Separable ⟷ Integral

(color, location) (color, motion) color x shape size x orientation x-size x y-size r-g x y-b

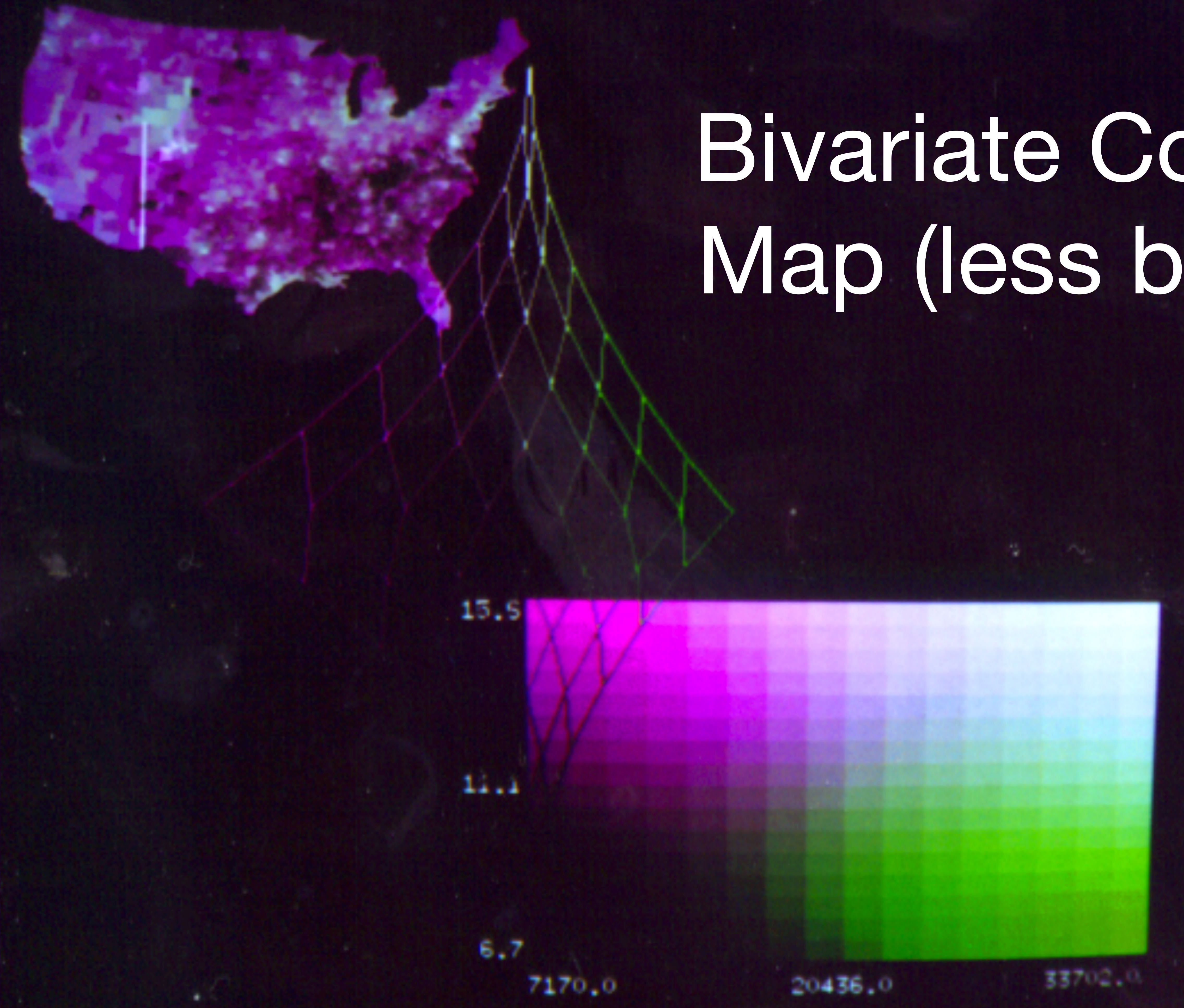
Colin Ware, 2004, p180

Bivariate Color Map (Bad)

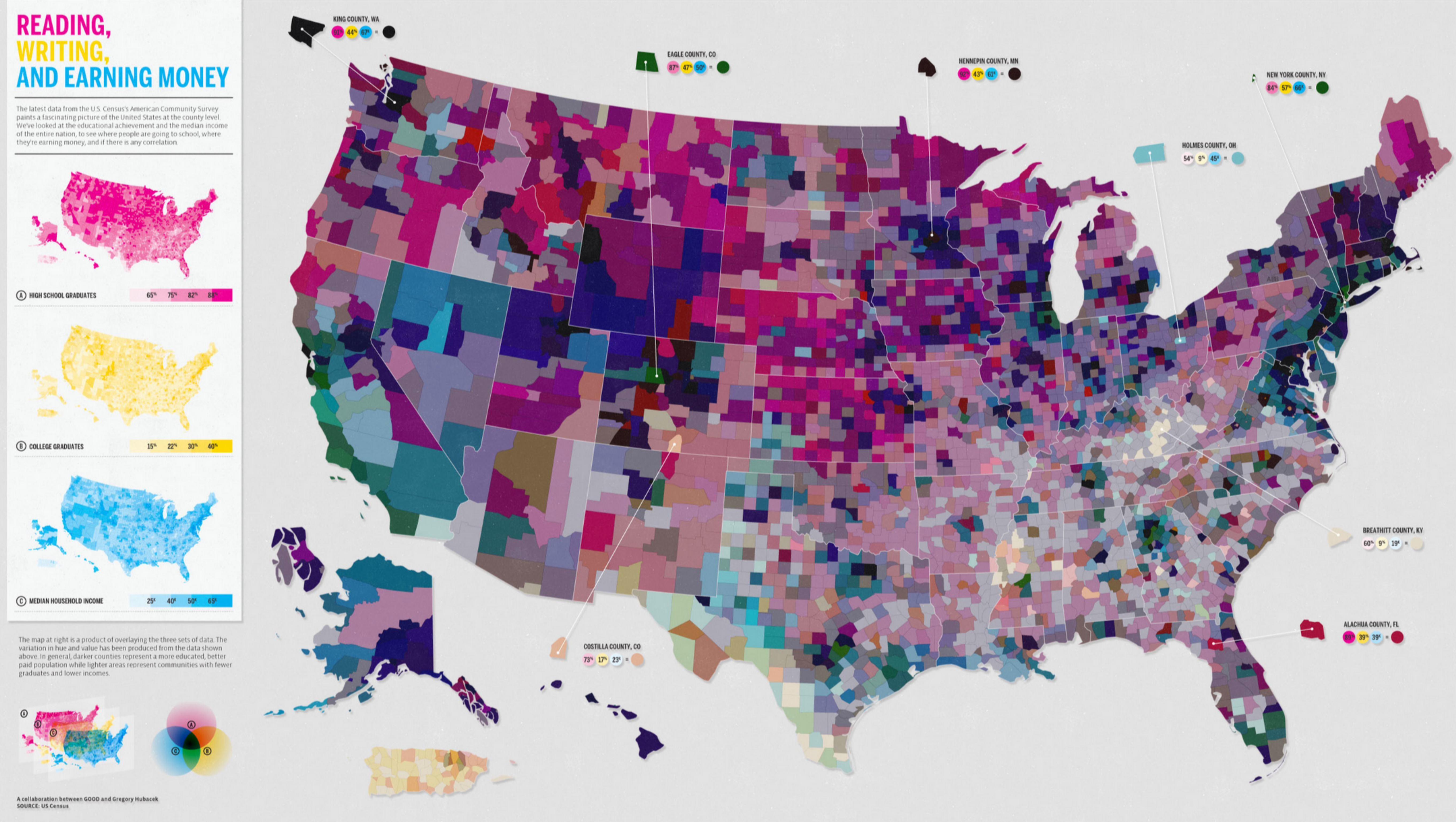


Baraba and Finkner,
via Tufte (VDQI)

Bivariate Color Map (less bad)



http://www.csee.umbc.edu/~rheingan/636/color.pdf

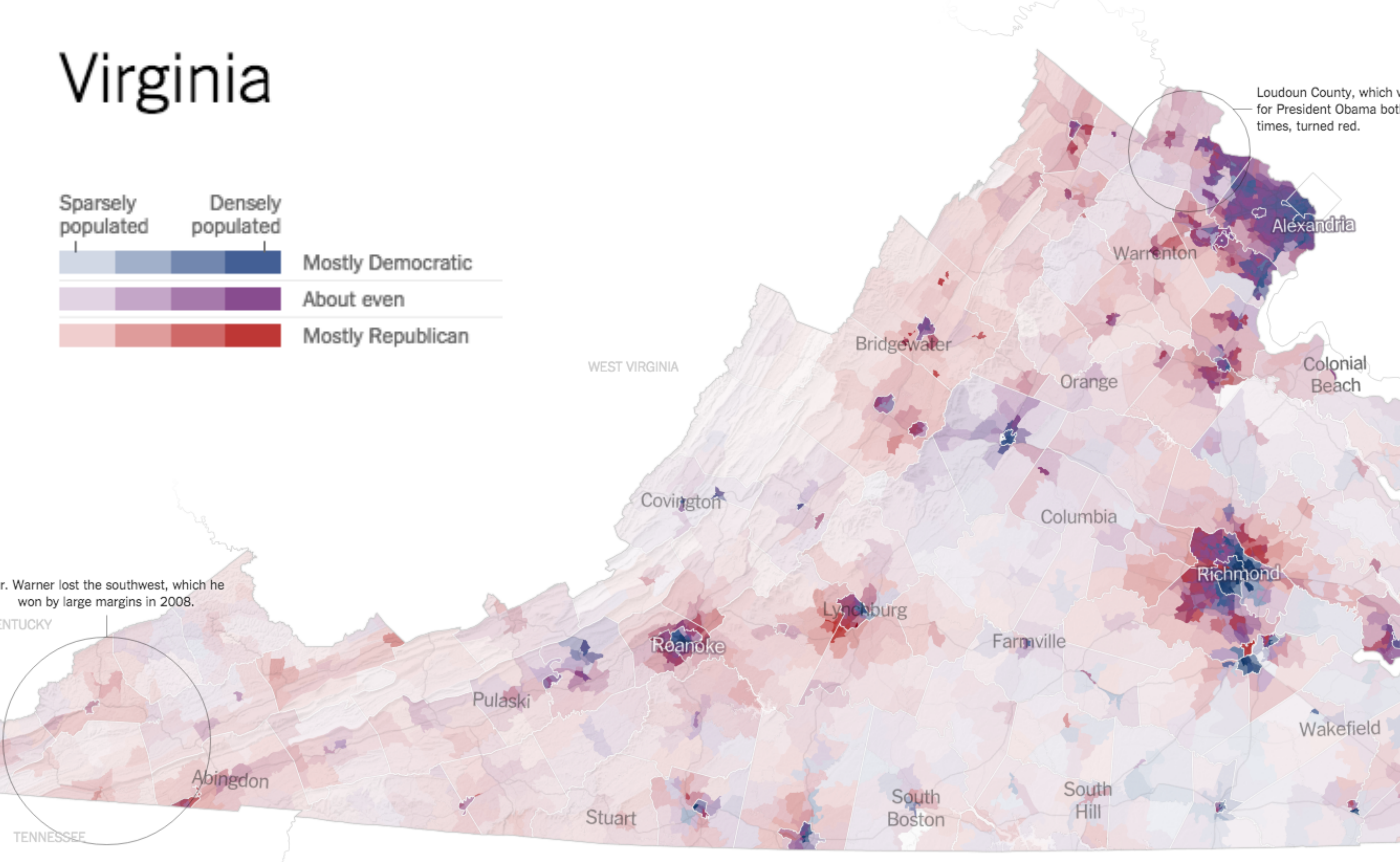


Trivariate (!) Color Map (terrible, terrible idea)

http://magazine.good.is/infographics/america-s-richest-counties-and-best-educated-counties#open

The best bivariate colormap I know

http://www.nytimes.com/interactive/2014/11/04/upshot/senate-maps.html



Bivariate Color Maps are Possible, but Hard

pay attention to the **behavior of the variables** you're mapping from, and the **behavior of the channels** you're mapping to.