

Data Visualization Principles: Other Perceptual Channels

CSC444

Acknowledgments for today's lecture:

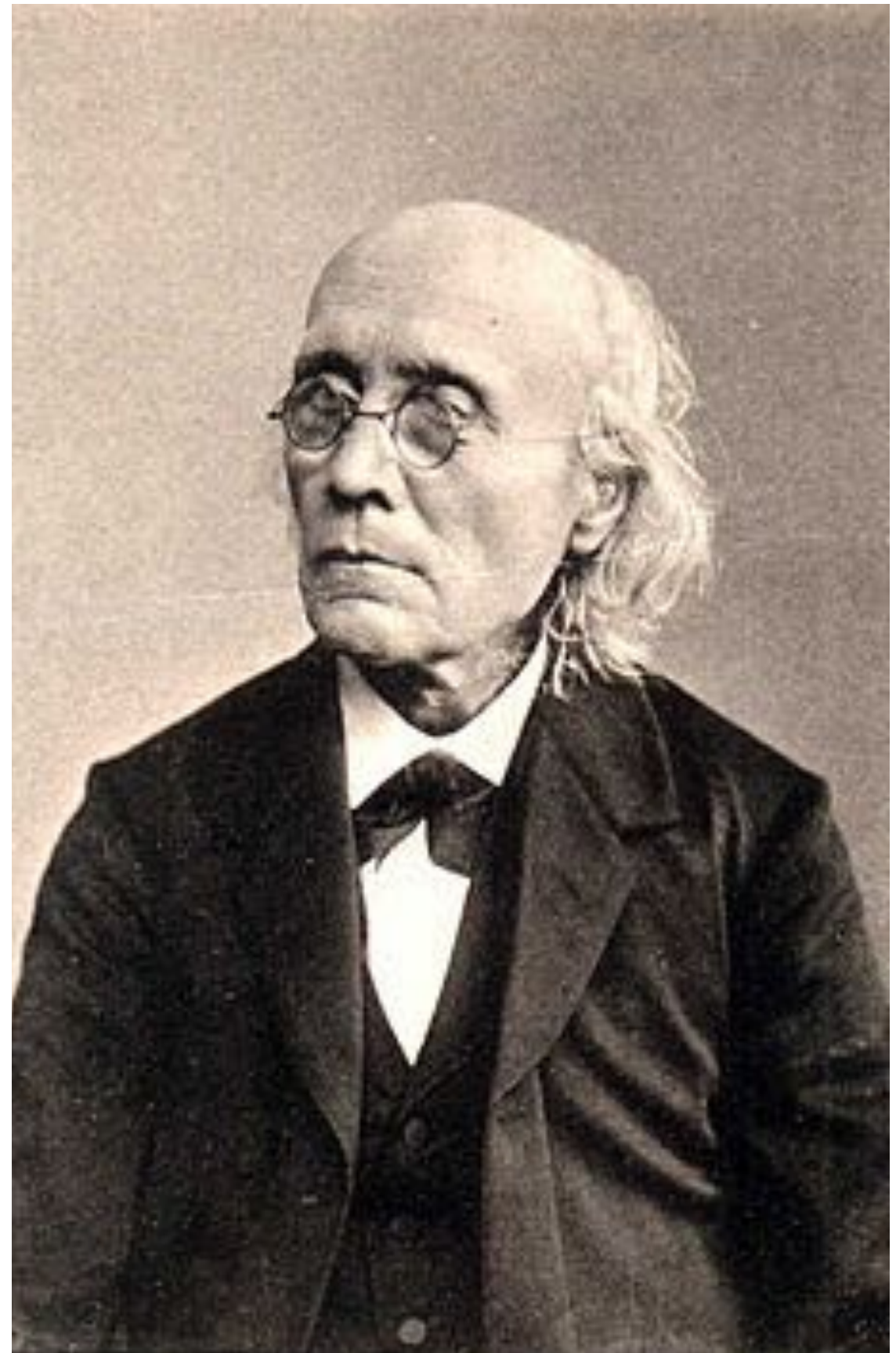
Tamara Munzner, Miriah Meyer, Colin Ware, Penny Rheingans

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"

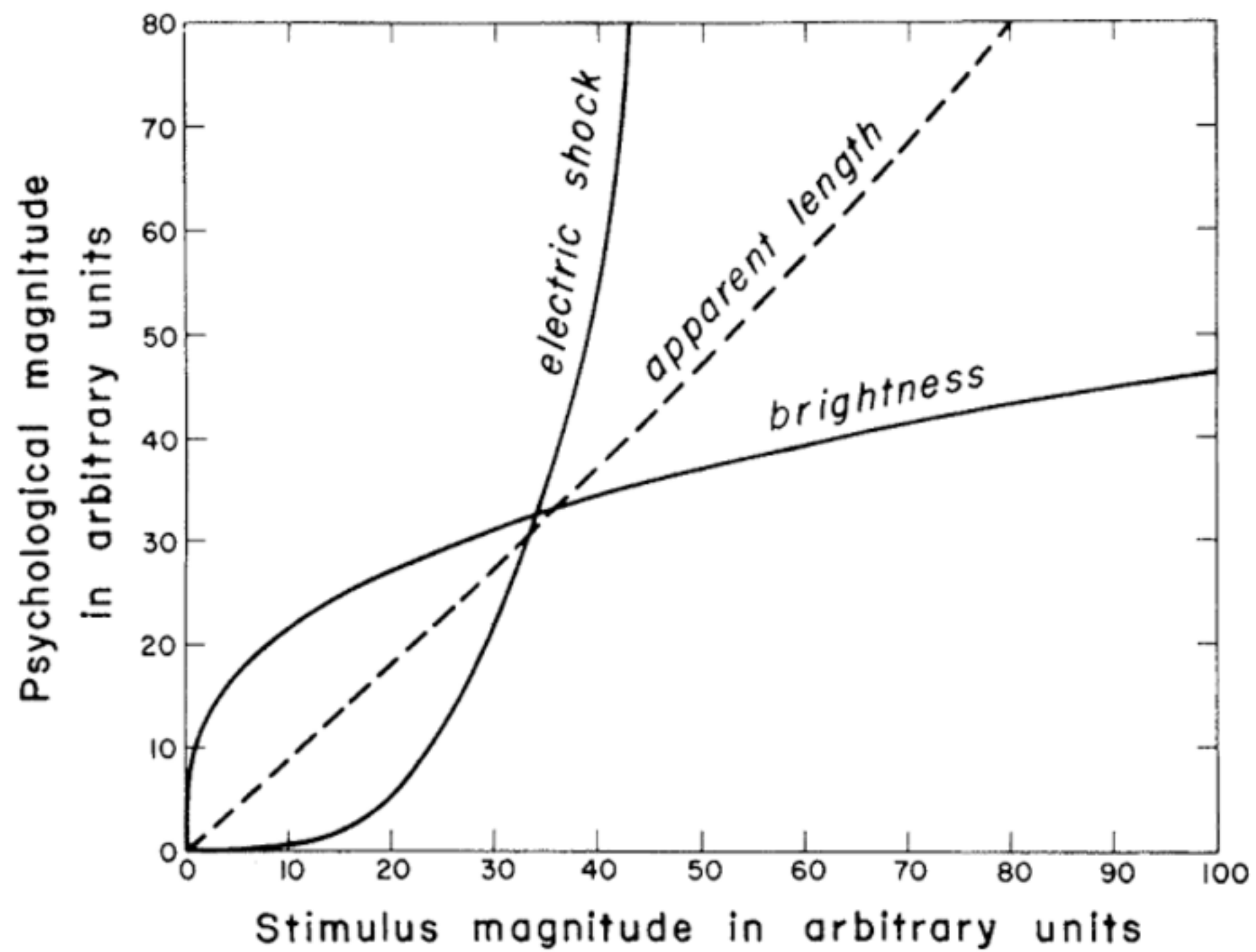
There exist stimuli
other than colors

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	Smell	0.6	Heptane
Vibration	0.95	Amplitude of 60 hertz on finger	Cold	1.0	Metal contact on arm
Vibration	0.6	Amplitude of 250 hertz on finger	Warmth	1.6	Metal contact on arm
Brightness	0.33	5° Target in dark	Warmth	1.3	Irradiation of skin, small area
Brightness	0.5	Point source	Warmth	0.7	Irradiation of skin, large area
Brightness	0.5	Brief flash	Discomfort, cold	1.7	Whole body irradiation
Brightness	1.0	Point source briefly flashed	Discomfort, warm	0.7	Whole body irradiation
Lightness	1.2	Reflectance of gray papers	Thermal pain	1.0	Radiant heat on skin
Visual length	1.0	Projected line	Tactual roughness	1.5	Rubbing emery cloths
Visual area	0.7	Projected square	Tactual hardness	0.8	Squeezing rubber
Redness (saturation)	1.7	Red-gray mixture	Finger span	1.3	Thickness of blocks
Taste	1.3	Sucrose	Pressure on palm	1.1	Static force on skin
Taste	1.4	Salt	Muscle force	1.7	Static contractions
Taste	0.8	Saccharine	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

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
Electric shock	3.5	Current through fingers



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?

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
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An Introduction to Interactive Sonification

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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

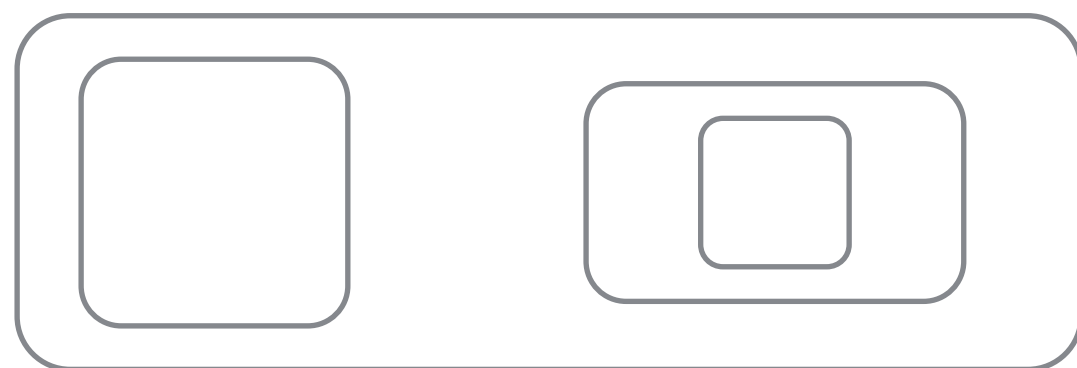
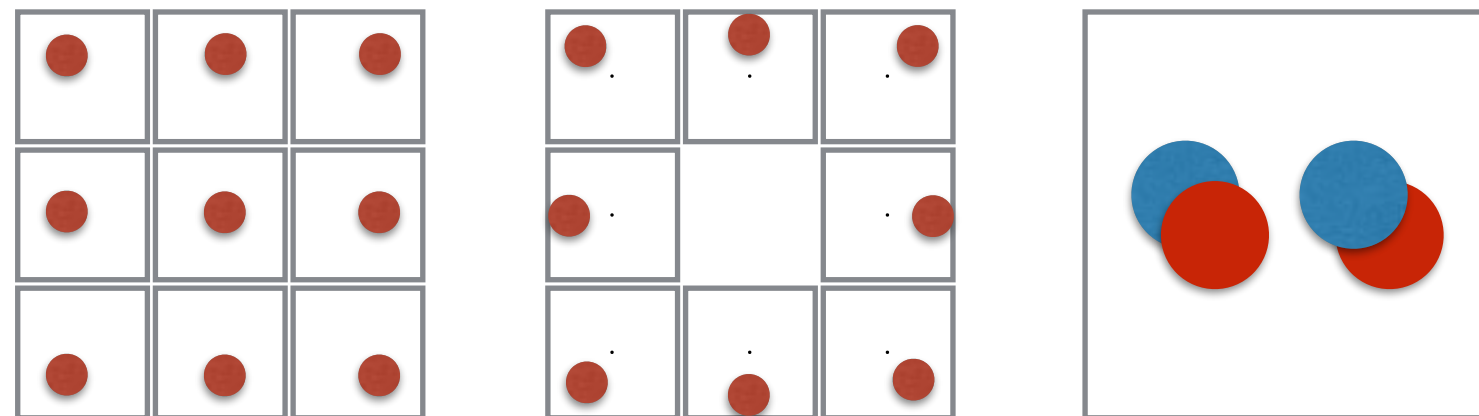
Throughout history humankind has developed tools that help us shape and understand the world. We use these in a close action-perception loop, where physical interaction yields continuous visual, tactile, and sonic feedback. Musical instruments are particularly good examples of systems where the acoustic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

Why visualization?

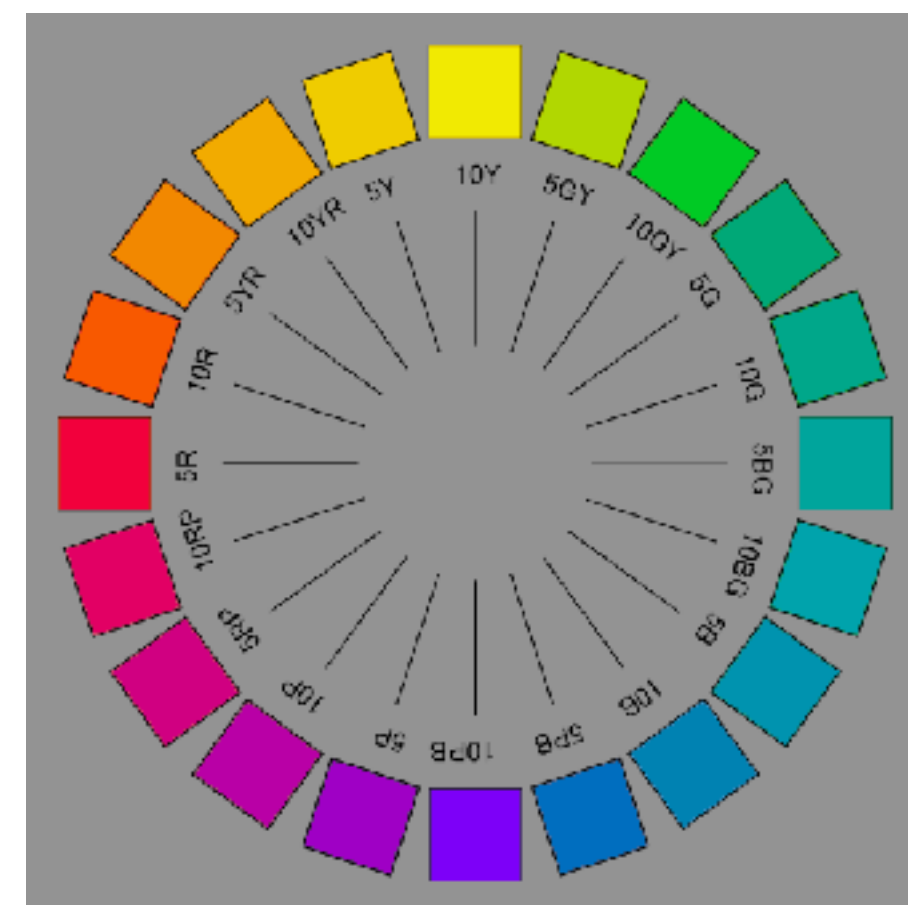
- It has been studied more deeply
- It appears to have more “bandwidth” than alternatives (though not as much as you think it does)

- It is **richer**

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
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Cold	1.0	Metal contact on arm
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(c) PlusMinus, GFDL

THE STANDARD VISUAL CHANNELS

➔ Position

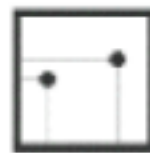
➔ Horizontal



➔ 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

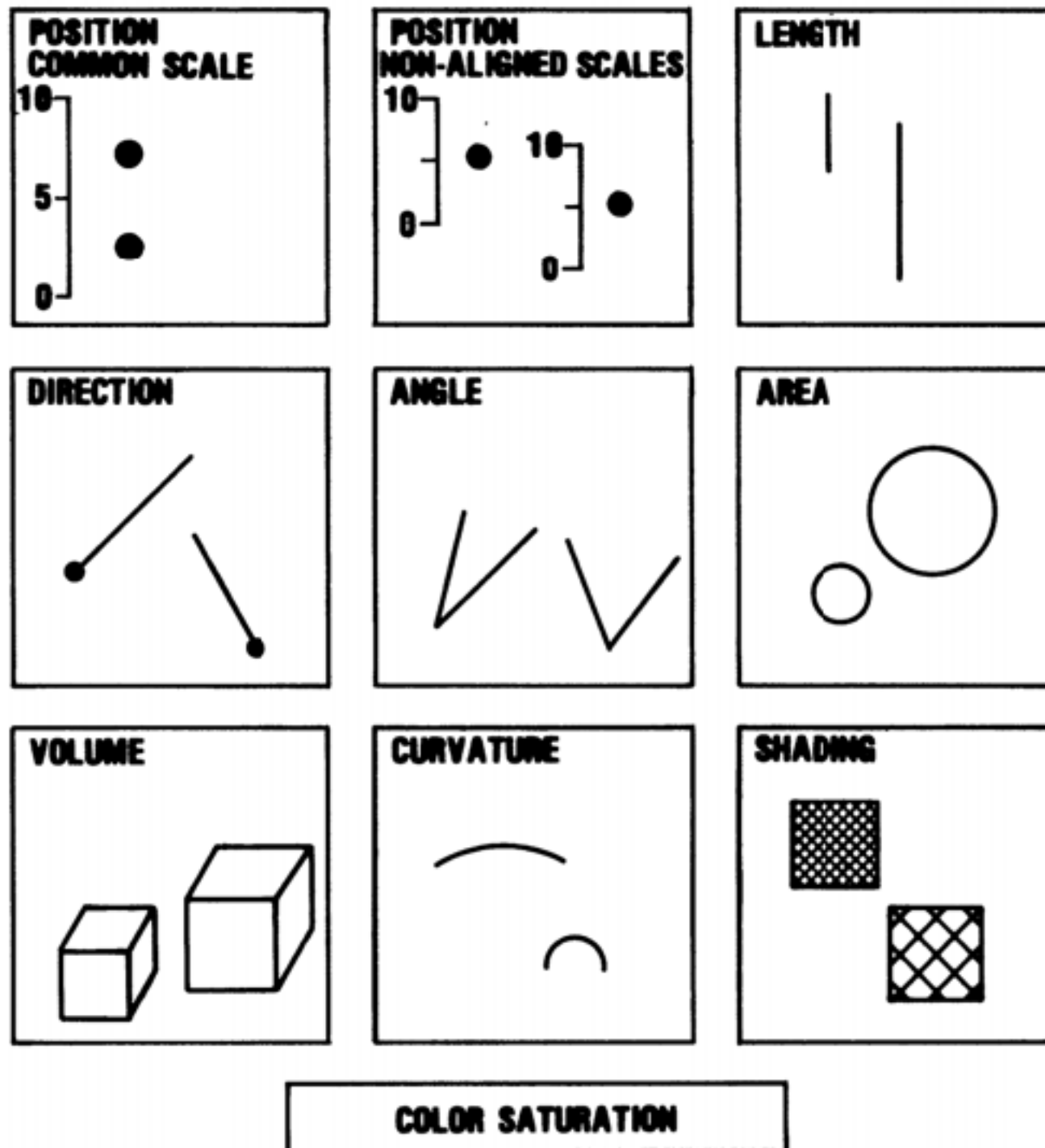
WILLIAM S. CLEVELAND and ROBERT MCGILL*

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



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

Figure 1. Elementary perceptual tasks.

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)

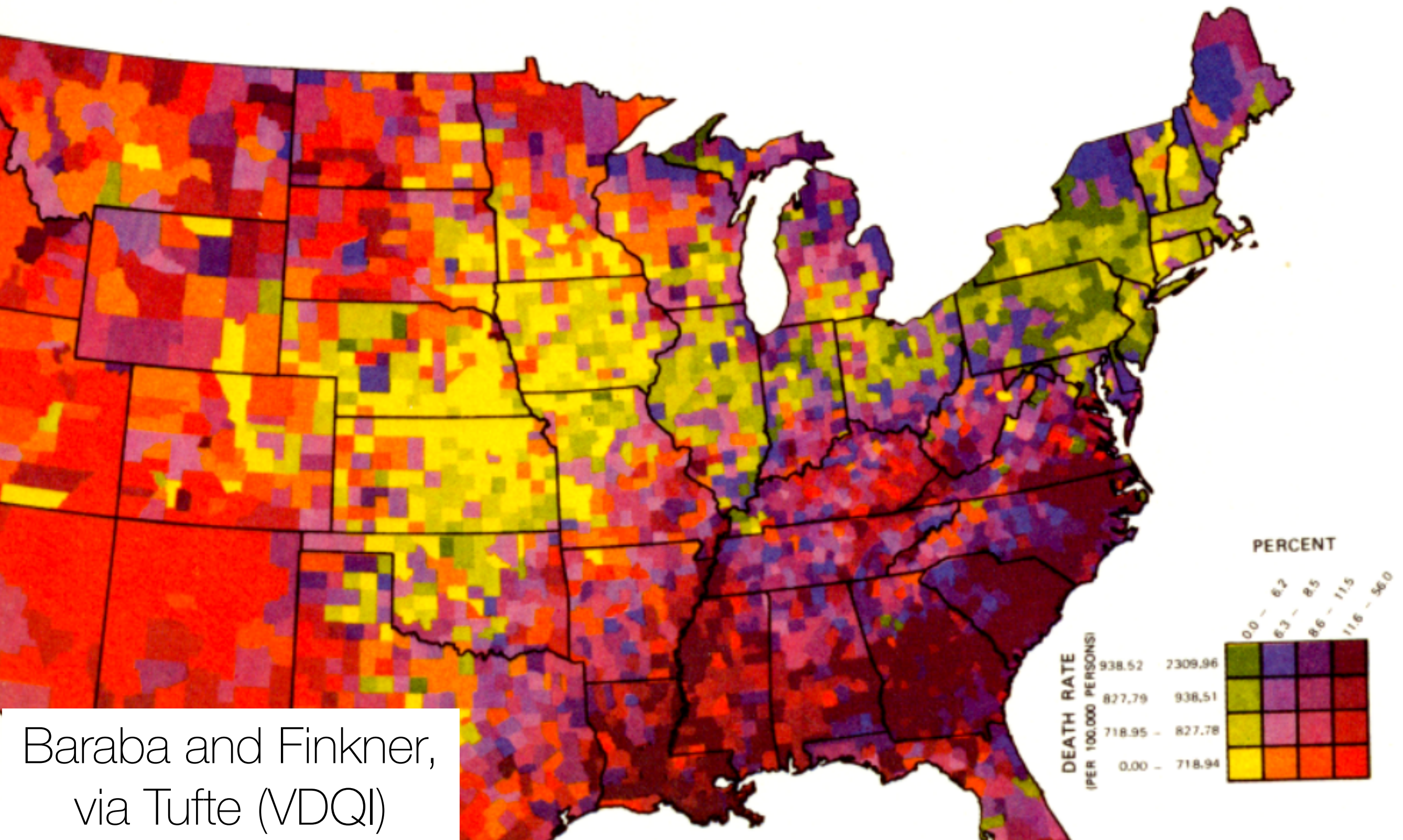
color x shape

size x orientation

x-size x y-size

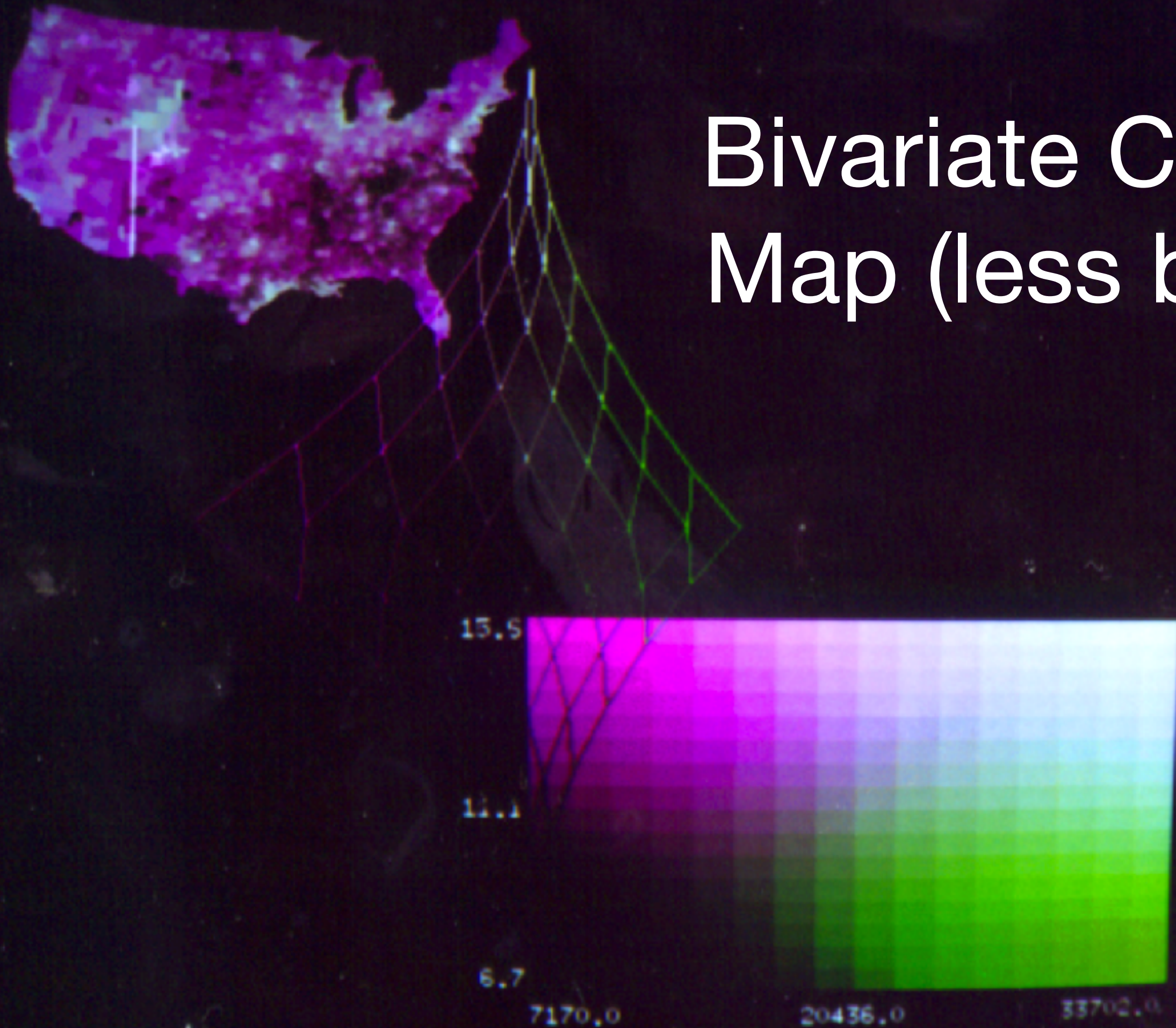
r-g x y-b

Bivariate Color Map (Bad)



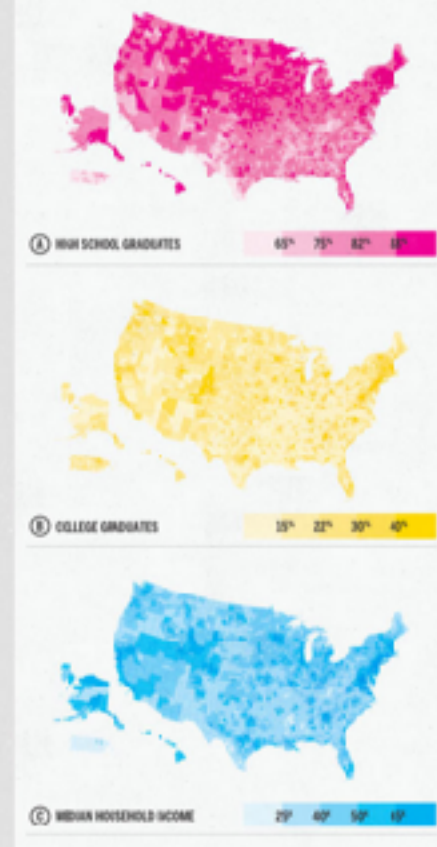
Baraba and Finkner,
via Tufte (VDQI)

Bivariate Color Map (less bad)



READING, WRITING, AND EARNING MONEY

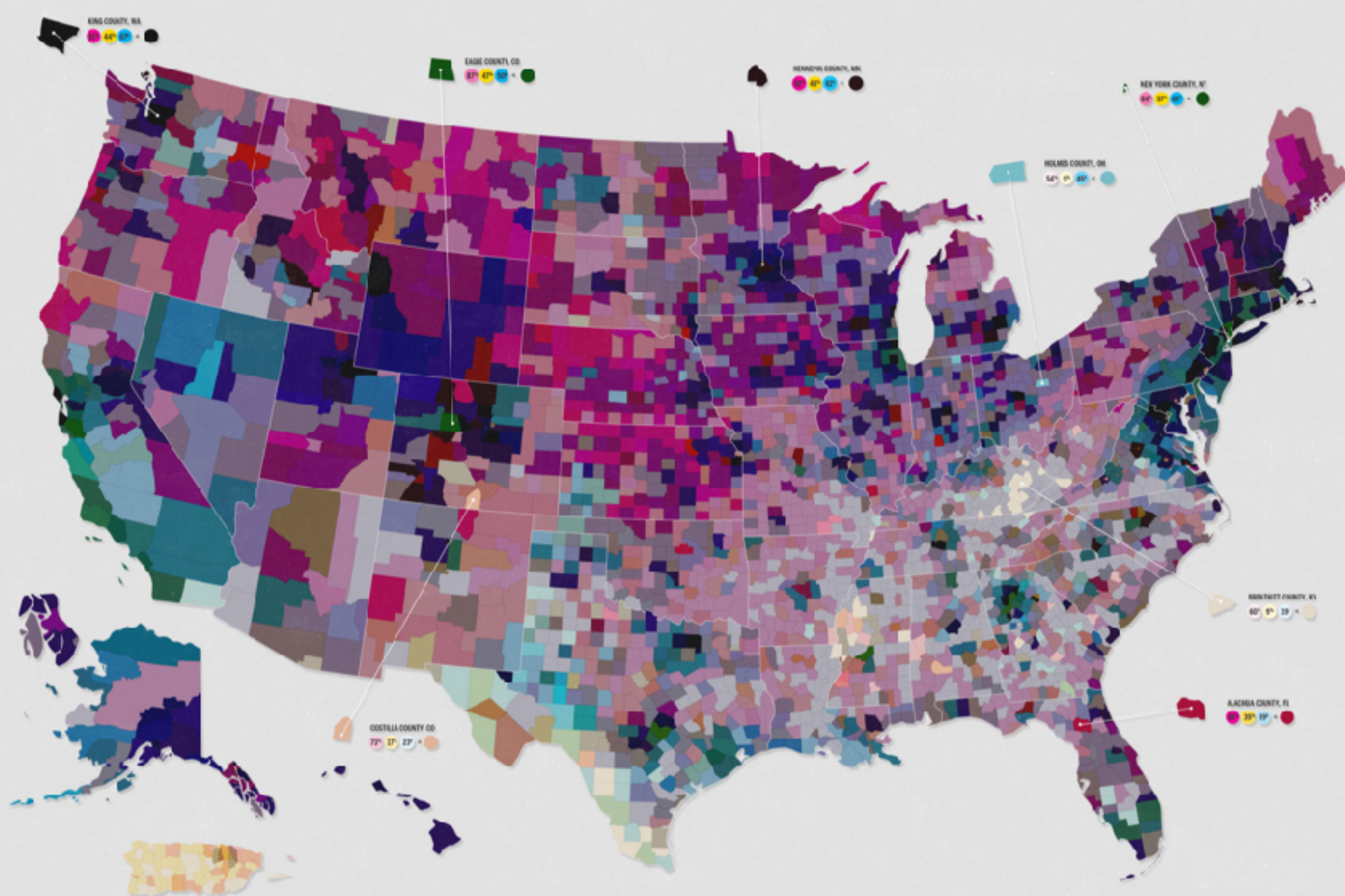
The latest data from the U.S. Census's American Community Survey paints a fascinating picture of the United States at the county level. We've looked at the educational achievement and the median income of the entire nation, to see where people are going to school, where they're earning money, and if there is any correlation.



The map at right is a product of overlaying the three sets of data. The variation in hue and value has been produced from the data shown above. In general, darker counties represent a more educated, better paid population while lighter areas represent communities with fewer graduates and lower incomes.



A collaboration between NOOD and Gregory M. Hackett
Illustration: Greg M. Hackett



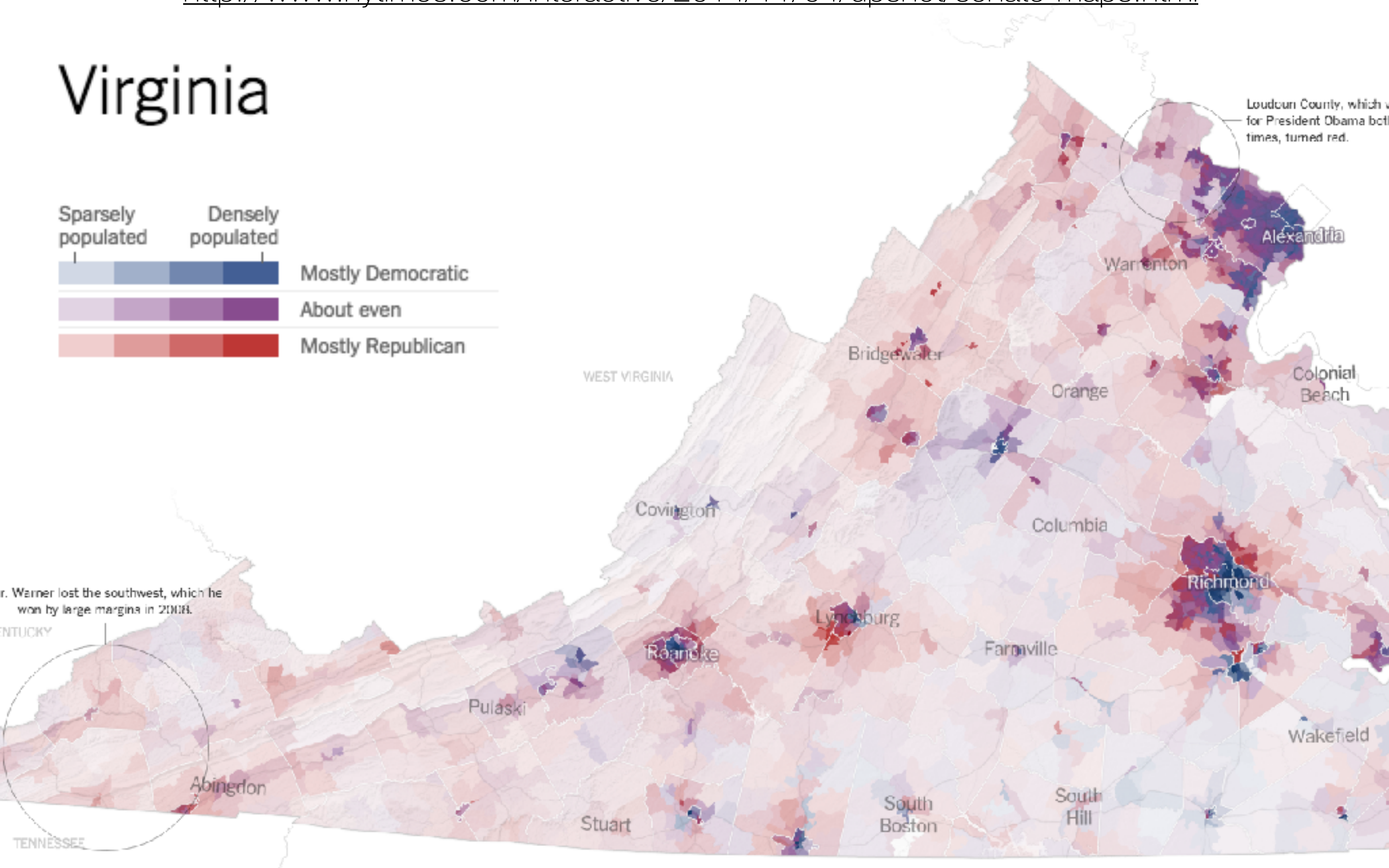
Trivariate (!) Color Map (terrible, terrible idea)

<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>

Virginia



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.