04

# Visualization Foundations

# Notice

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# Bibliography

- **Many examples are extracted and adapted from**
  - **Interactive Data Visualization: Foundations, Techniques, and Applications,**

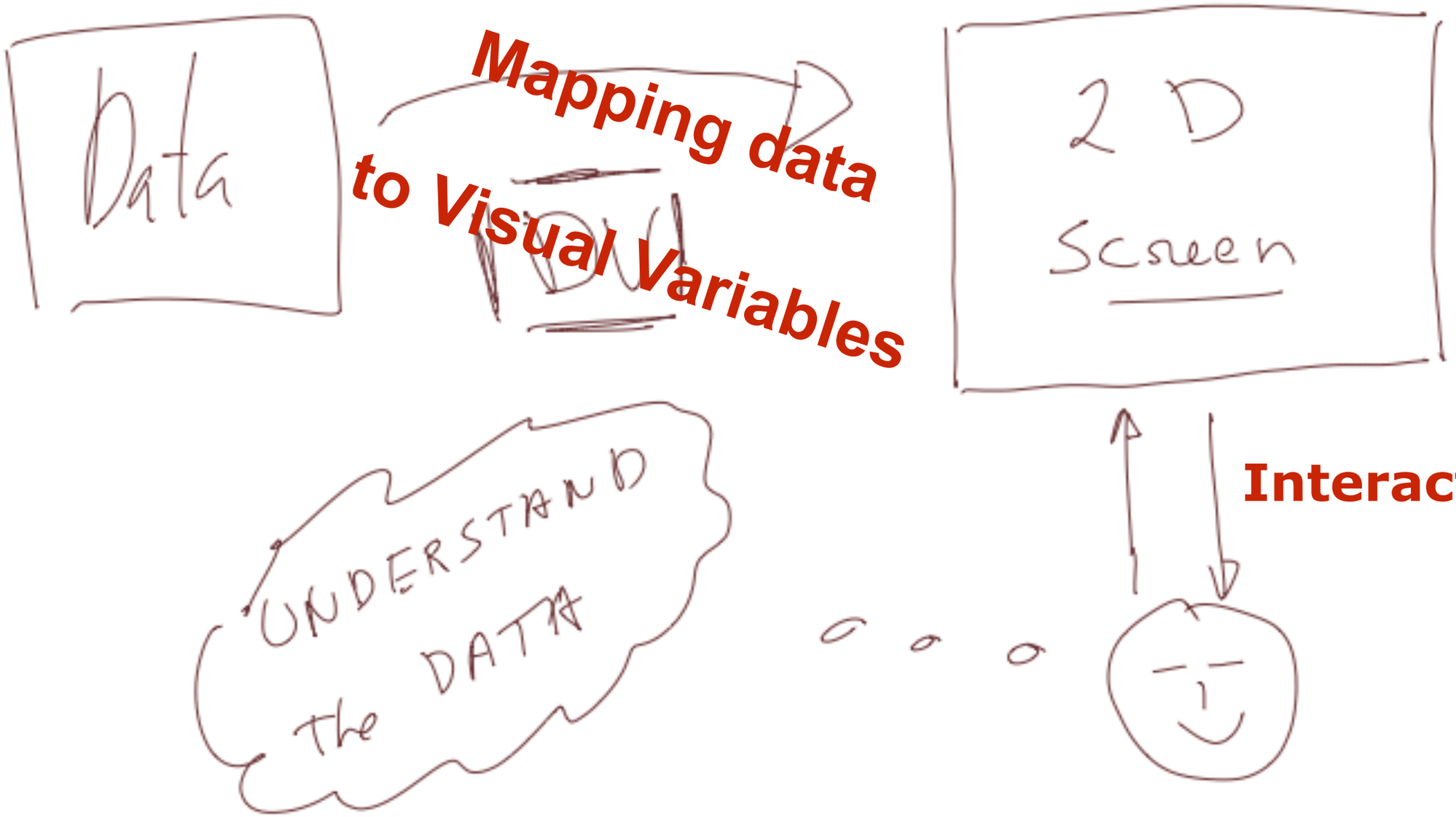
    **Matthew O. Ward, Georges Grinstein, Daniel Keim, 2015**

  - **Visualization Analysis & Design,**

    **Tamara Munzner, 2015**

# Never Forget

# What is the core idea of Interactive Data Visualization?



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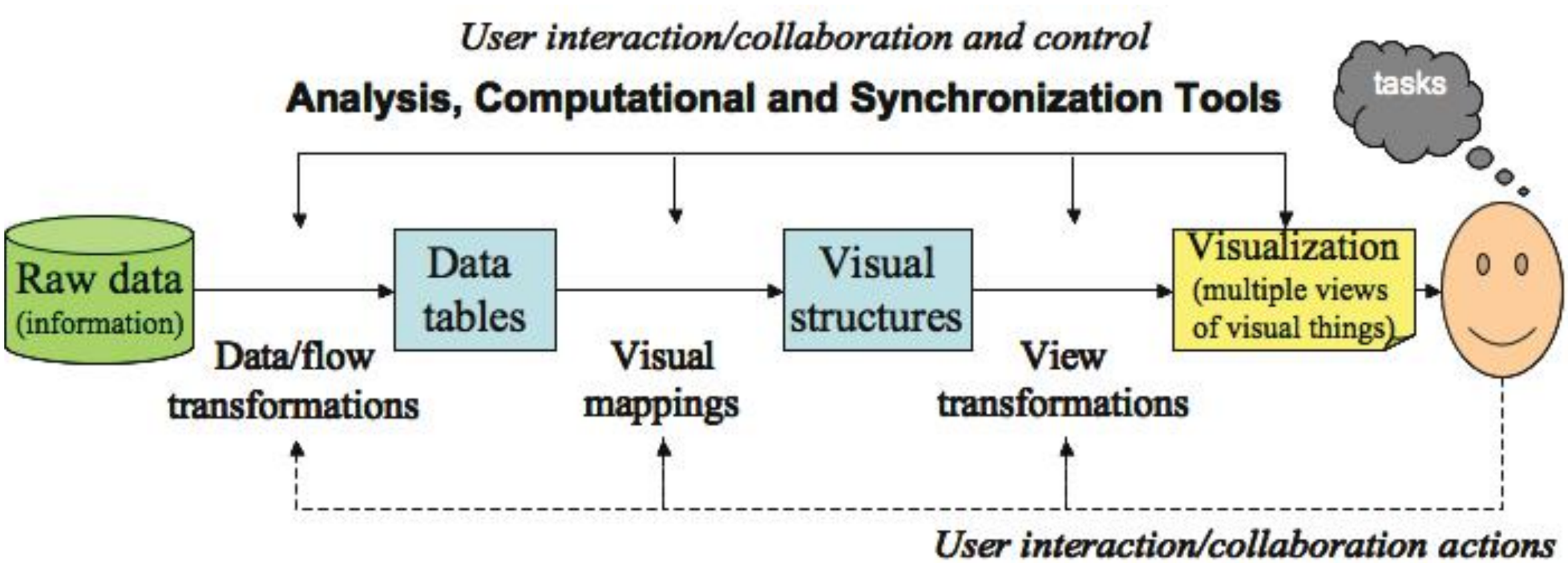
# The Visualization Process in Detail

# The Visualization Process in Detail



# The Visualization Process in Detail

- **Data preprocessing and transformation**
  - **Process the raw data into something usable by the visualization system.**
    - The first part is to make sure that the data are mapped to fundamental data types
    - The second step entails dealing with specific application data issues.
- **Mapping for visualizations**
  - **Decide on a specific visual representation.**
    - This requires representation mappings: geometry, color, and sound, for example.
- **Rendering transformations.**
  - **The final stage involves mapping from geometry data to the image**
    - This stage of the pipeline is very dependent on the underlying graphics library.

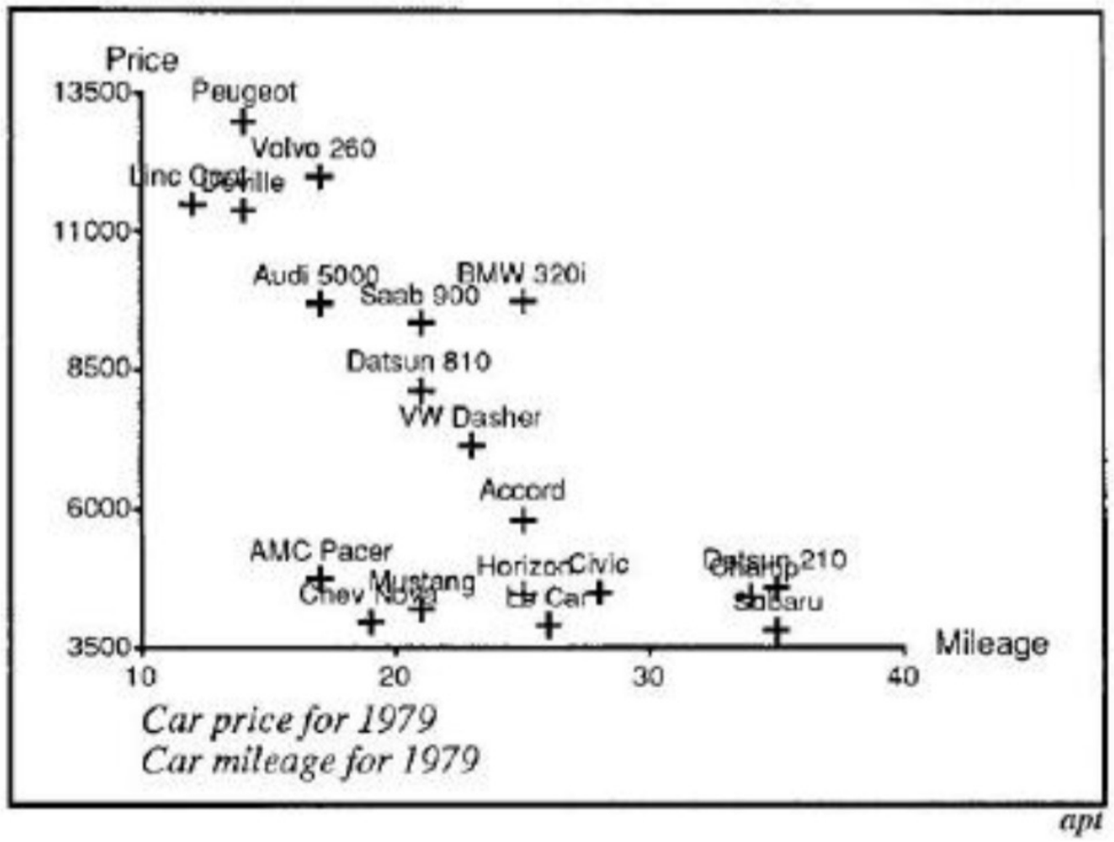
# **Expressiveness** and Effectiveness

- **Expressiveness**
  - **An expressive visualization presents all the information, and only the information**
  - ***M*$_{exp}$ = The information that we actually display to the user / information we want to present to the user**
  - **$0 \leq M_{exp} \leq 1$.**
  - **If $M_{exp} = 1$, we have ideal expressiveness**
  - **If the information displayed is less than that desired, then $M_{exp} < 1$.**
  - **If $M_{exp} > 1$, we are presenting too much information.**
    - Expressing additional information is potentially dangerous, because it may not be correct and may interfere with the interpretation of the essential information.

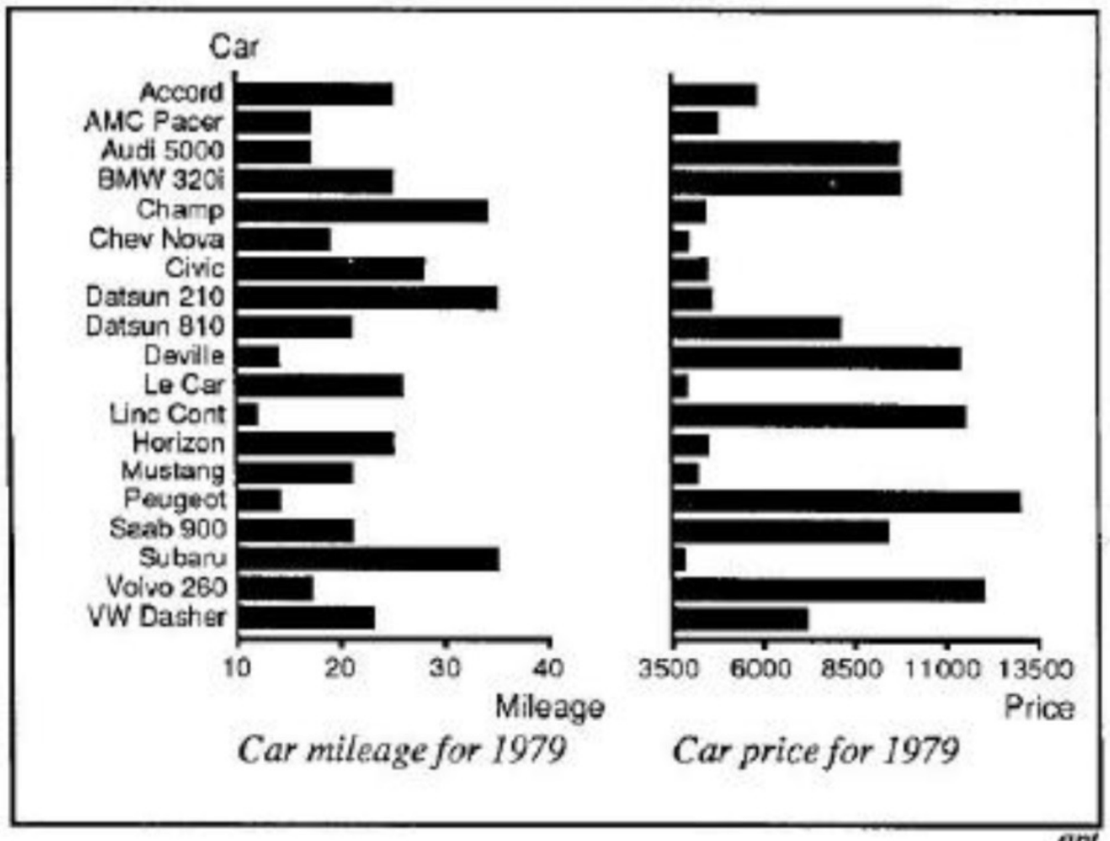
# Expressiveness and **Effectiveness**

- **Effectiveness**
  - **A visualization is effective when it can be interpreted accurately and quickly and when it can be rendered in a cost-effective manner.**
  - **Effectiveness thus measures a specific cost of information perception.**
  - $M_{eff} = 1 / (1 + time_{interpret} + time_{render})$.
  - $0 < M_{eff} \leq 1$.
  - **The larger $M_{eff}$ is, the greater the visualization's effectiveness.**
  - **If $M_{eff}$ is small, then either the interpretation time is very large, or the rendering time is large.**
  - **If $M_{eff}$ is large (close to 1), then both the interpretation and the rendering time are very small.**

# Expressiveness and Effectiveness



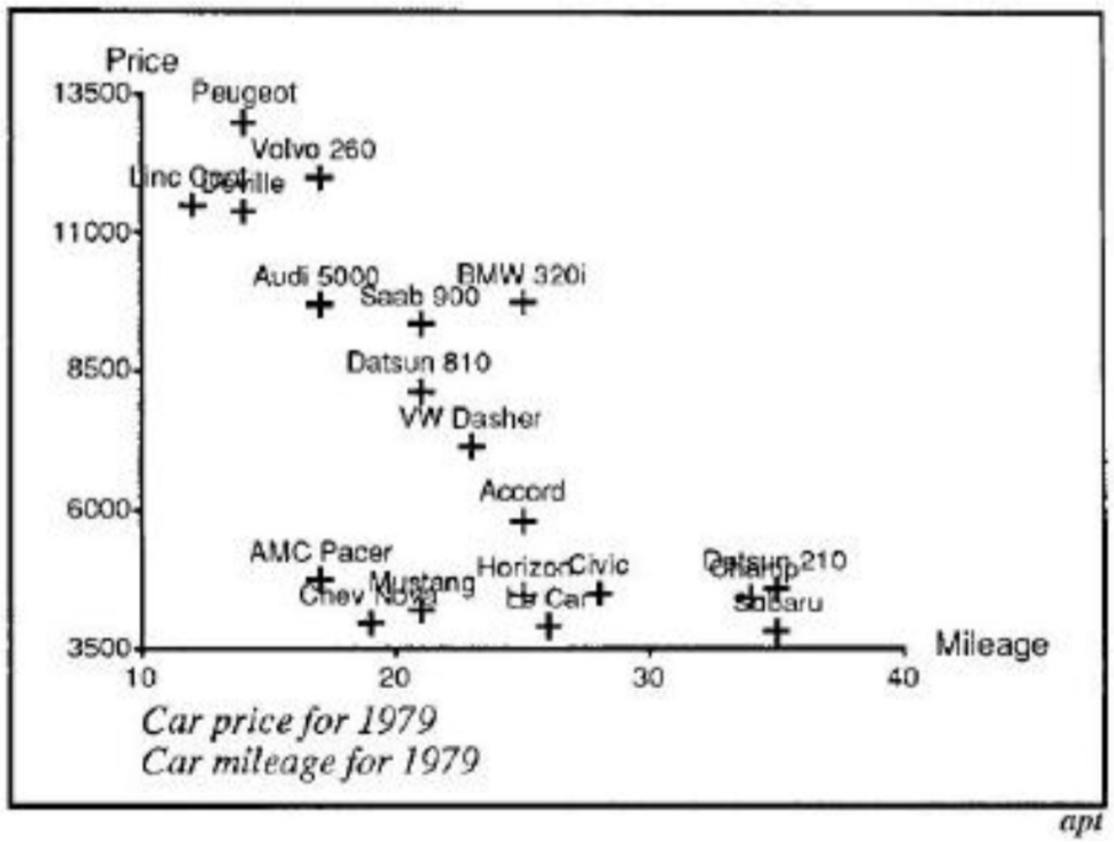

(a)



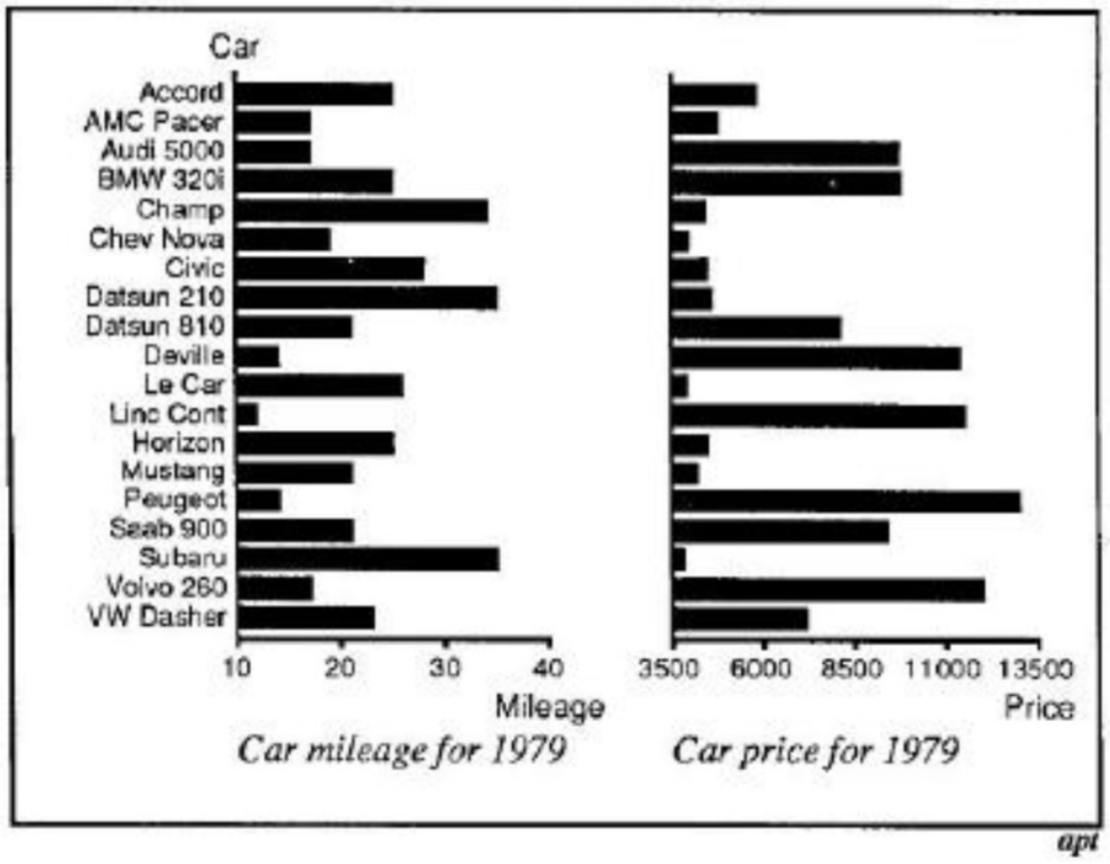

(b)

$$M_{exp}(\text{a}) \approx M_{exp}\ (\text{b})$$

# Expressiveness and Effectiveness




(a)

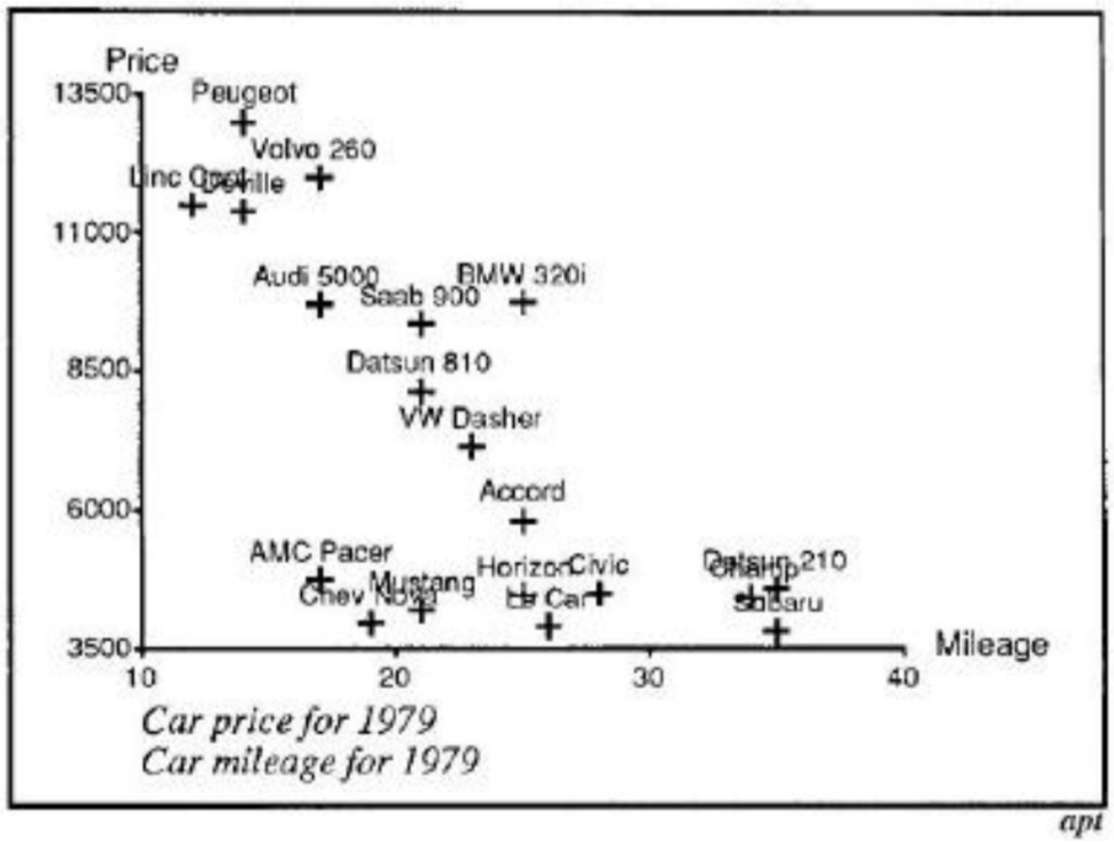



(b)

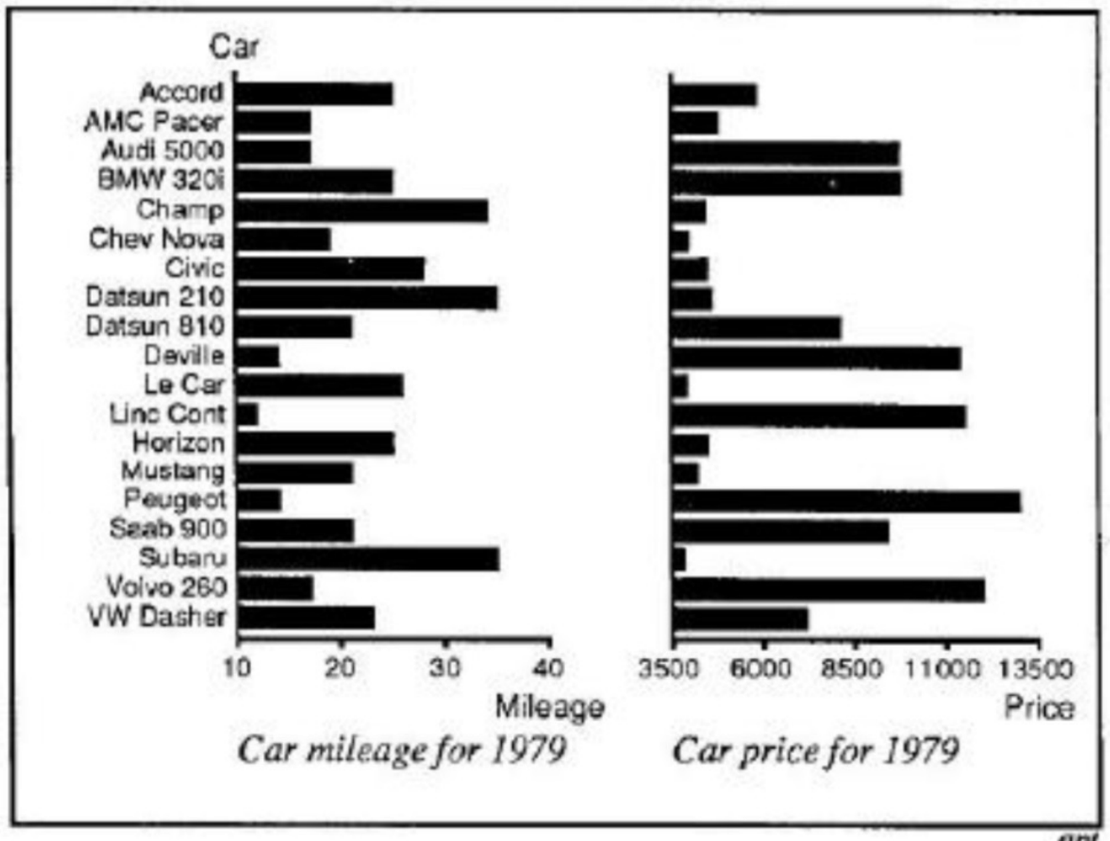
The information in (b) can be interpreted more accurately or more quickly than that in (a) for some questions. For example, which car has the best mileage?

However, if we ask which car has the best mileage under $11,000?

# Expressiveness and Effectiveness



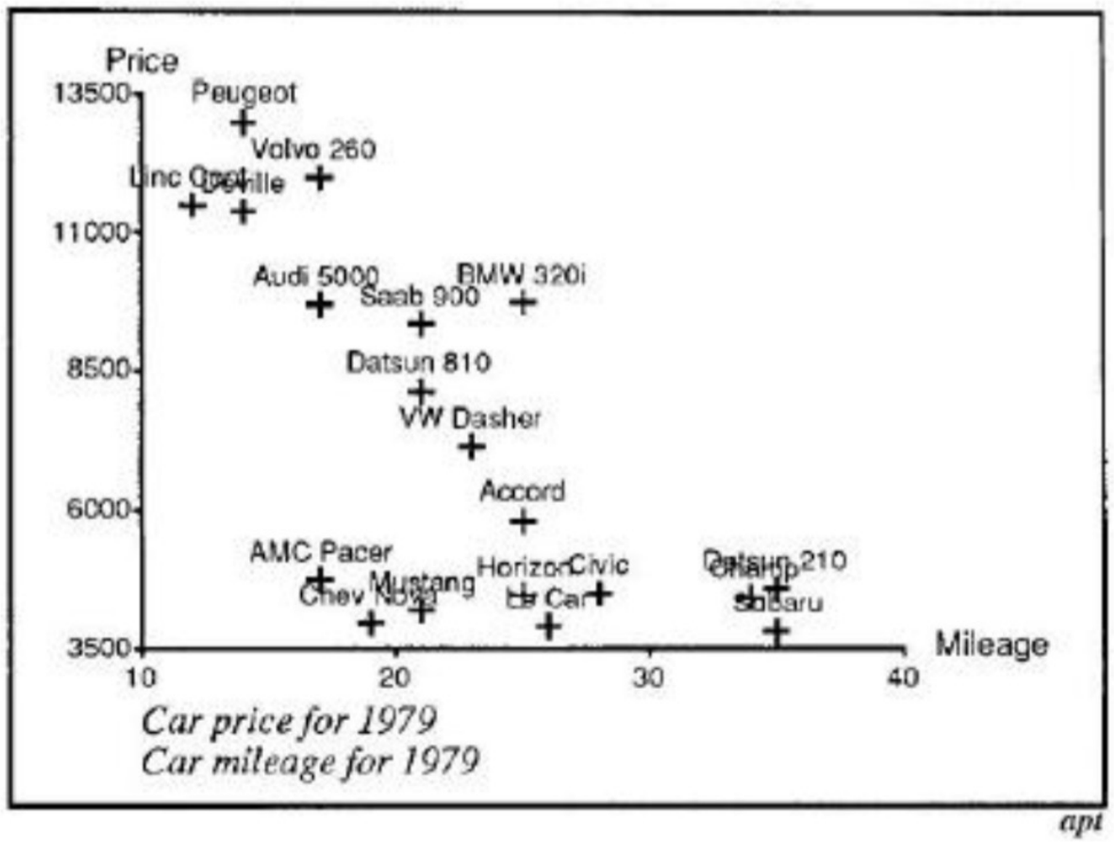

(a)



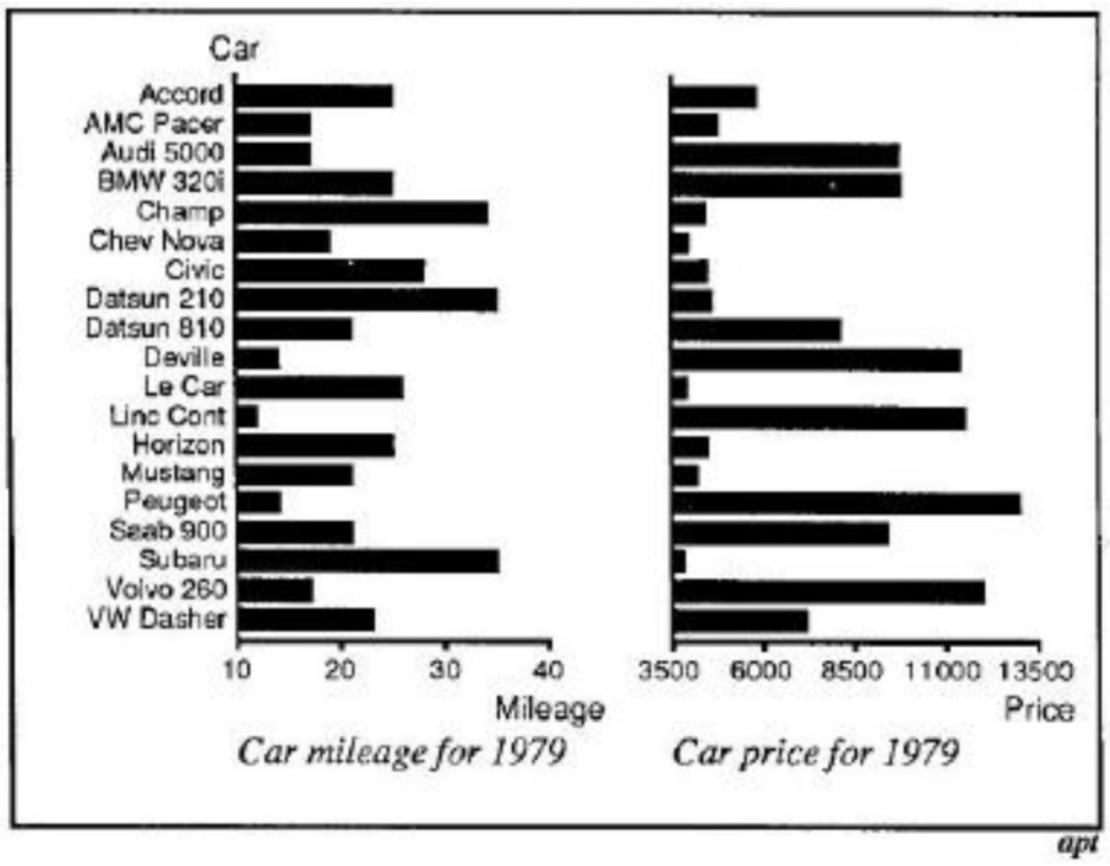

(b)

**Figure 4.3.** (a) Scatterplot using plus as symbol provides good query-answering capabilities, but is slower for simple one-variable queries. (b) Bar charts clearly display cost and mileage, but don't provide as much flexibility in answering some other queries.

# Expressiveness and Effectiveness




(a)




(b)

**Figure 4.3.** (a) Scatterplot using plus as symbol provides good query-answering capabilities, but is slower for simple one-variable queries. (b) Bar charts clearly display cost and mileage, but don't provide as much flexibility in answering some other queries.

# Semiology of Graphical Symbols

# Semiology of Graphical Symbols

- **The science of graphical symbols and marks is called semiology.**

- **Every possible construction in the Euclidean plane is a graphical representation made up of graphical symbols (diagrams, networks, maps, plots, and other common visualizations).**

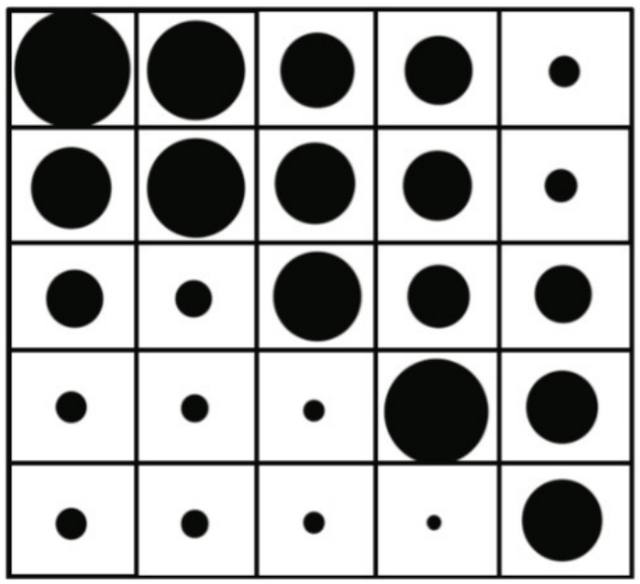
- **Semiology uses the qualities of the plane and objects on the plane to produce similarity features, ordering features, and proportionality features of the data that are visible for human consumption.**

# Semiology of Graphical Symbols

- **Discovery of relations or patterns occurs through a mapping between any relationship of the graphic symbols and the data that these symbols represent.**
  - **any pattern on the screen must imply a pattern in the data.**
    - **If it does not, then it is an artifact of the selected representation (and is disturbing).**
  - **Similarly, any perceived pattern variation in the graphic or symbol cognitively implies such a similar variation in the data.**
  - **Any perceived order in graphic symbols is directly correlated with a perceived corresponding order between the data, and vice versa**

# Features of Graphics

- **Graphics have three (or more) dimensions.**

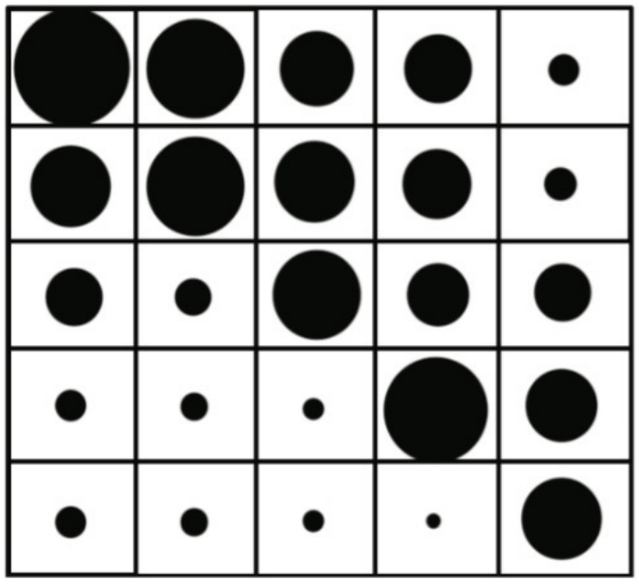


Matrix representation of a set of relationships between nodes in a graph. The size represents the strength of the relationship.

- **Every point of the graphic can be interpreted as a relation between a position in x and a position in y. The points vary in size, providing a third dimension or variable to interpret.**

# Rules of Graphics

- **The aim of a graphic is to discover groups or orders in x, and groups or orders in y, that are formed on z-values;**



Matrix representation of a set of relationships between nodes in a graph. The size represents the strength of the relationship.

# Rules of Graphics

- **The aim of a graphic is to discover groups or orders in x, and groups or orders in y, that are formed on z-values;**
- **(x, y, z)-construction enables in all cases the discovery of these groups;**
- **Within the (x,y,z)-construction, permutations and classifications solve the problem of the upper level of information;**
- **Every graphic with more than three factors that differs from the (x, y, z)-construction destroys the unity of the graphic and the upper level of information;**
- **Pictures must be read and understood by the human.**

# The Eight Visual Variables

# Spatial arrangement of marks

- For the most part, all graphic primitives will be termed **marks**.
- One way to encode data for display is to **map different data values to different marks and their attributes**.
- However, marks by themselves do not define informative displays, since all the marks would simply obscure all previously drawn marks; **it is only through the spatial arrangement of marks that informative displays are created**.
- Once the layout and types of marks are specified, then additional graphical properties can be applied to each mark.
  - Marks can vary in **size**, can be displayed using different **colors**, and can be mapped to different **orientations**, all of which can be **driven by data to convey information.**

# Eight visual variables

**See the slides from lecture 1**

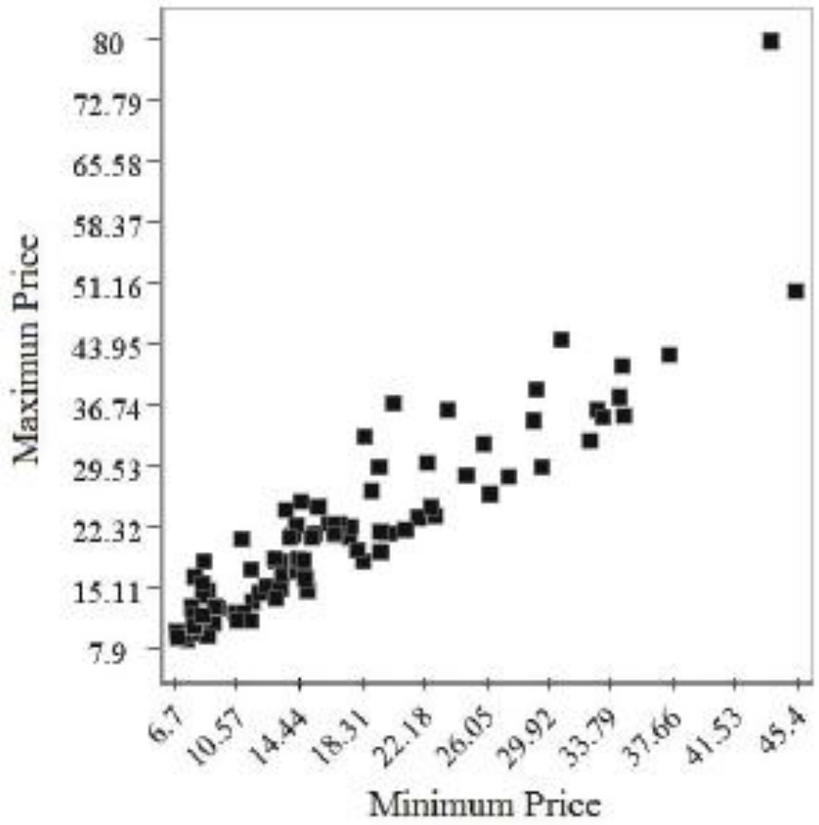
- **eight visual variables:**
  - **position,**
  - **shape,**
  - **size,**
  - **brightness,**
  - **color,**
  - **orientation,**
  - **texture,**
  - **motion**

The first and The first and **most important visual variable is that of position** is that of position

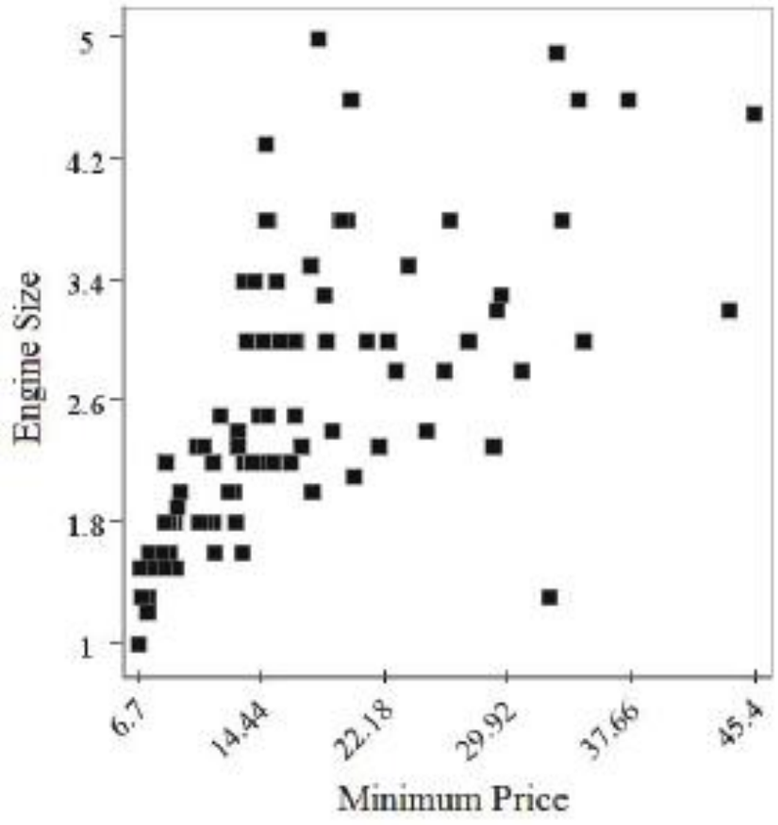
# Eight visual variables: Position

- **The first and most important visual variable is that of position, the placement of representative graphics within some display space, be it one-, two-, or three-dimensional.**
- **Spatial arrangement of graphics is the first step in reading a visualization:**
  - **The maximization of the spread of representational graphics throughout the display space maximizes the amount of information communicated, to some degree.**
  - **Worst case positioning scheme maps all graphics to the exact same position**
  - **Best positioning scheme maps each graphic to unique positions, such that all the graphics can be seen with no overlaps.**

# Eight visual variables: Position - Scales




(a)

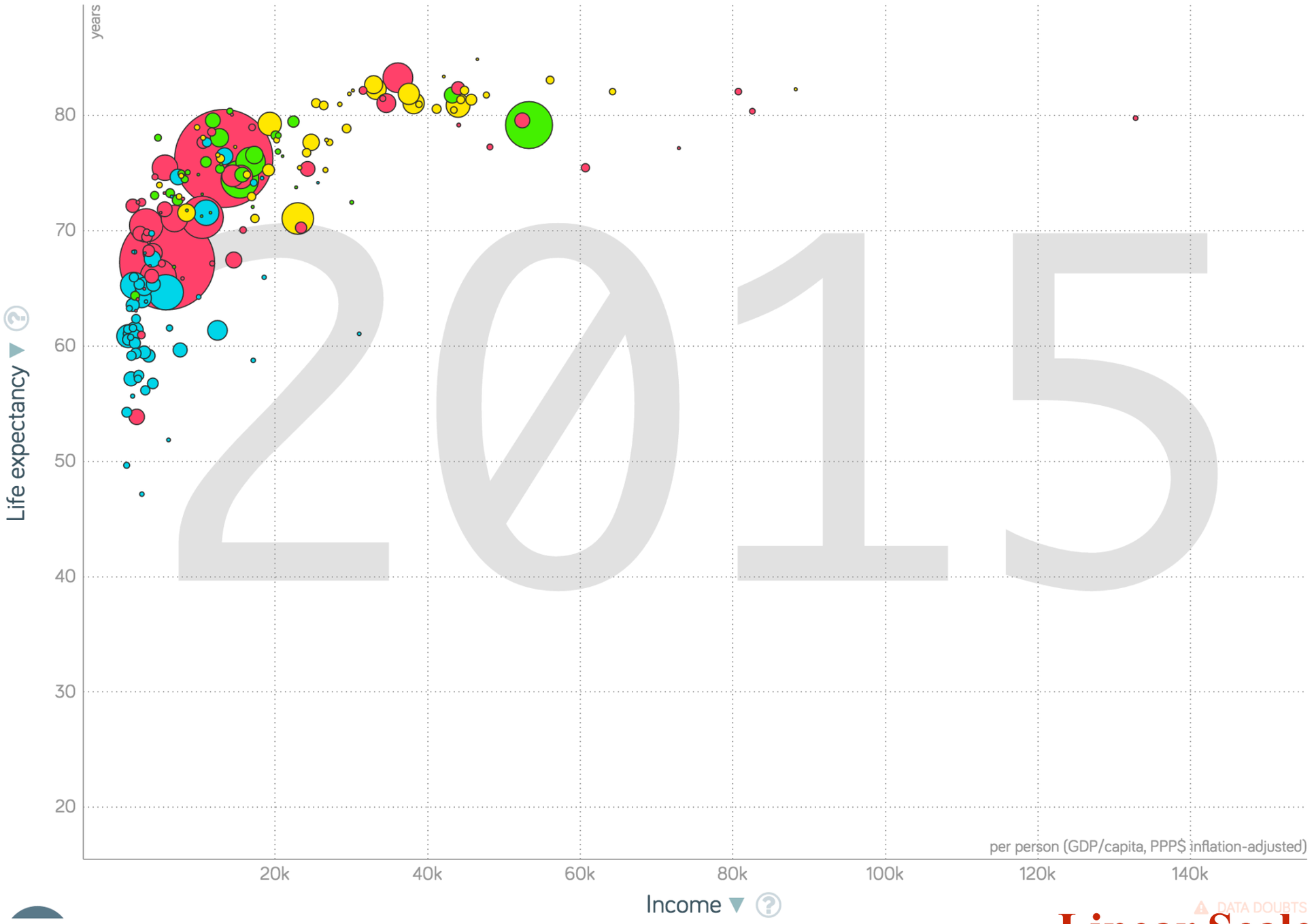



(b)

Example visualizations: (a) using position to convey information. Displayed here is the minimum price versus the maximum price for cars with a 1993 model year. The spread of points appears to indicate a linear relationship between minimum and maximum price; (b) another visualization using a different set of variables. This figure compares minimum price with engine size for the 1993 cars data set. Unlike (a), there does not appear to be a strong relationship between these two variables.

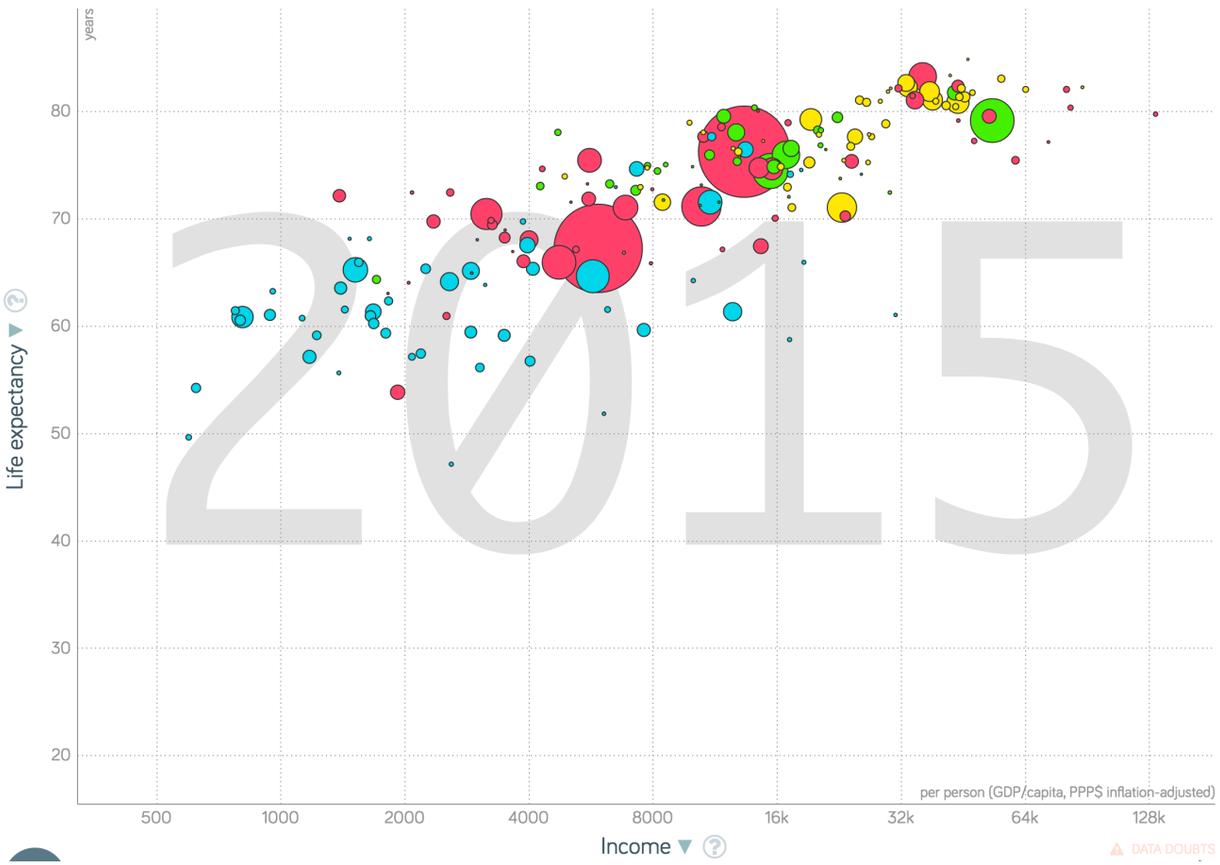
# Eight visual variables: Position - Scales

**Linear Scale**

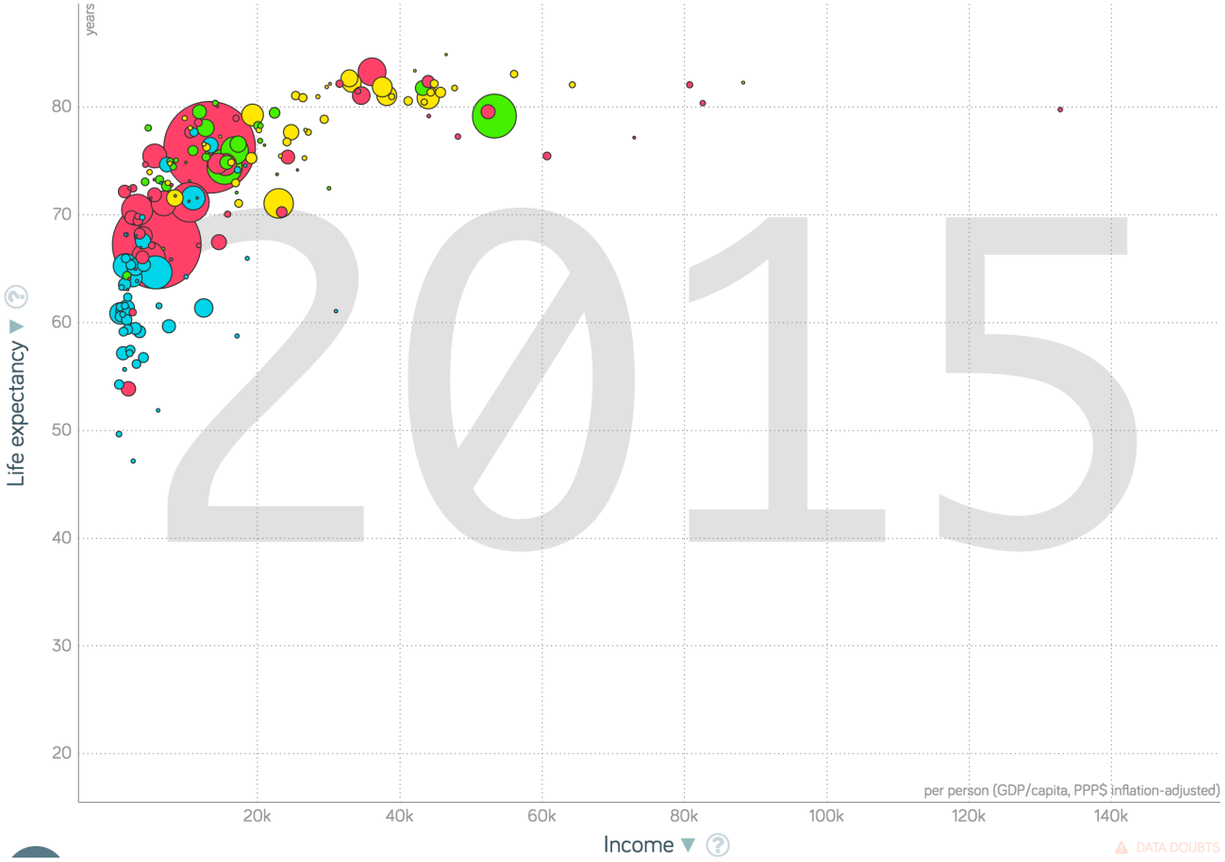



**Linear Scale**

# Eight visual variables: Position - Scales




**Log Scale**



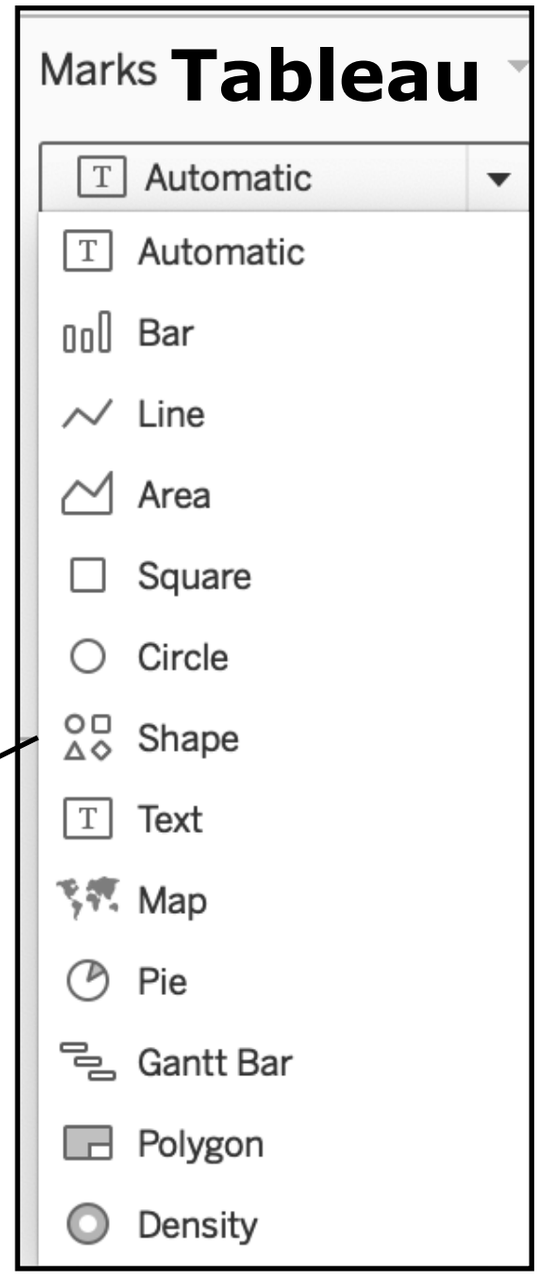

**Linear Scale**

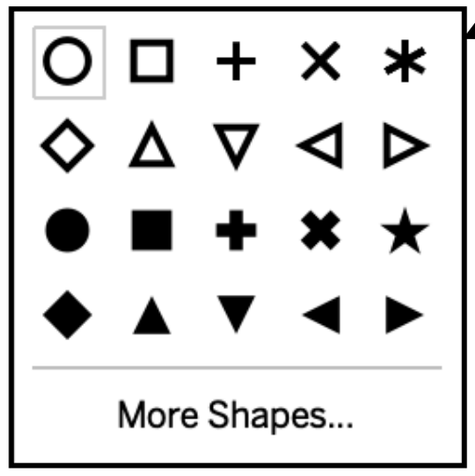
# Eight visual variables: Mark (or shape)

- **The second visual variable is the mark or shape: points, lines, areas, volumes, and their compositions.**
- **Marks are graphic primitives that represent data:**

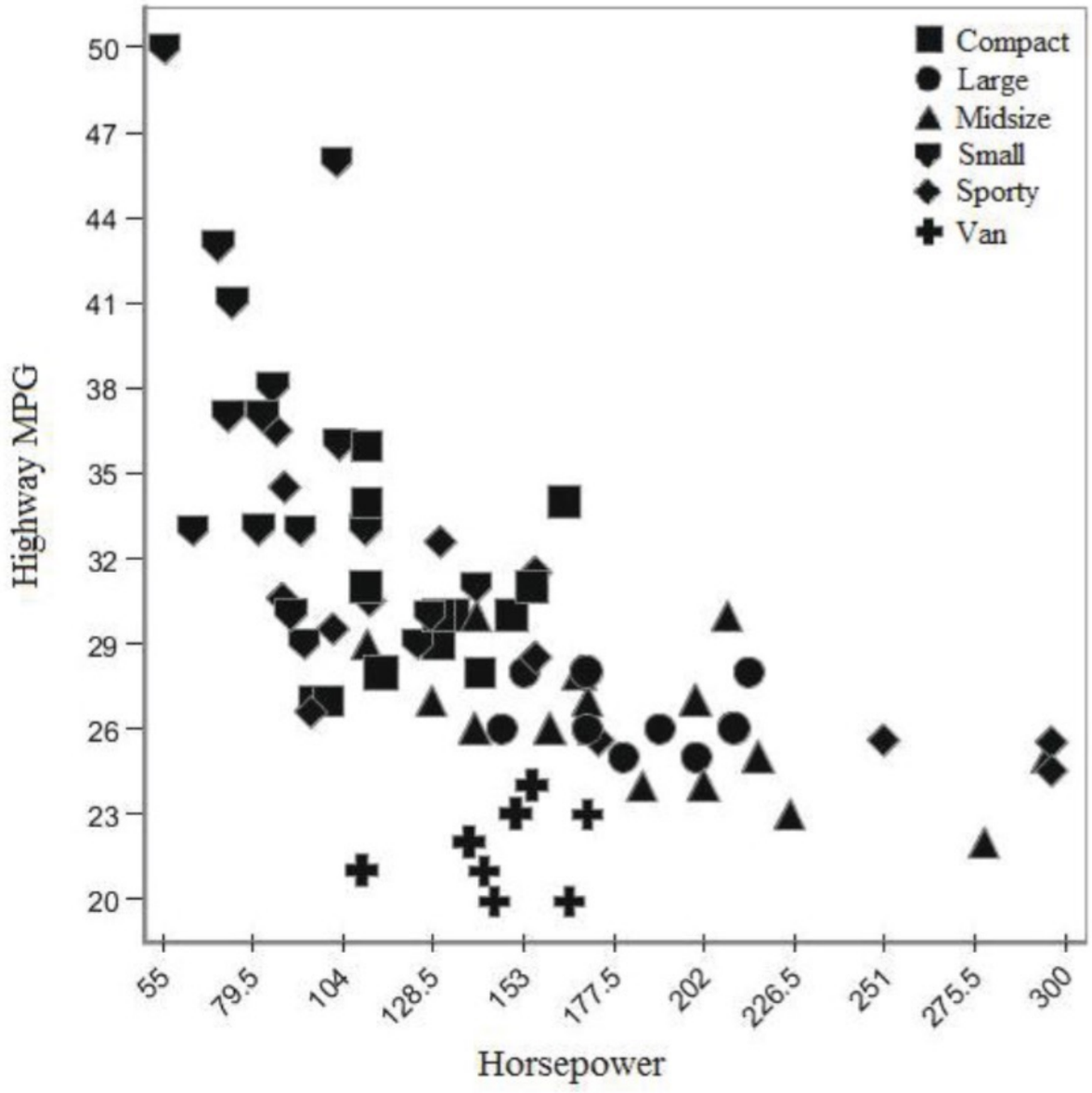
Several examples of different marks or glyphs that can be used.

- When using marks, it is important to consider how well one mark can be differentiated from other marks



# Eight visual variables: Mark (or shape)




This visualization uses shapes to distinguish between different car types in a plot comparing highway MPG and horsepower. Clusters are clearly visible, as well as some outliers.

# Eight visual variables

- **The position and marks, are required to define a visualization. Without these two variables there would not be much to see !**

- **The remaining visual variables affect the way individual representations are displayed;**

- **These are the graphical properties of marks other than their shape.**

# Eight visual variables: Size

Example sizes to encode data.

- **Size easily maps to interval and continuous data variables, because that property supports gradual increments over some range.**
- **It is more difficult to distinguish between marks of near similar size, and thus size can only support categories with very small cardinality.**
- **A confounding problem with using size is the type of mark.**
  - **For points, lines, and curves the use of size works well**
  - **when marks are represented with graphics that contain sufficient area, the quantitative aspects of size fall, and the differences between marks becomes more qualitative.**

**Stevens' Law**

# Eight visual variables: Size

**Stevens' Law**

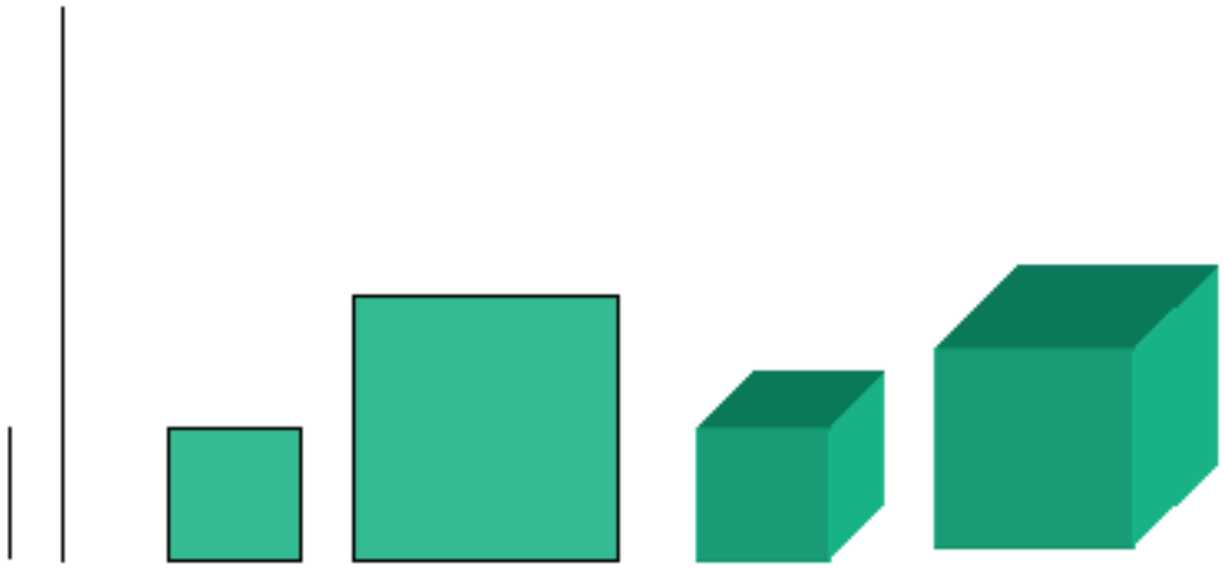
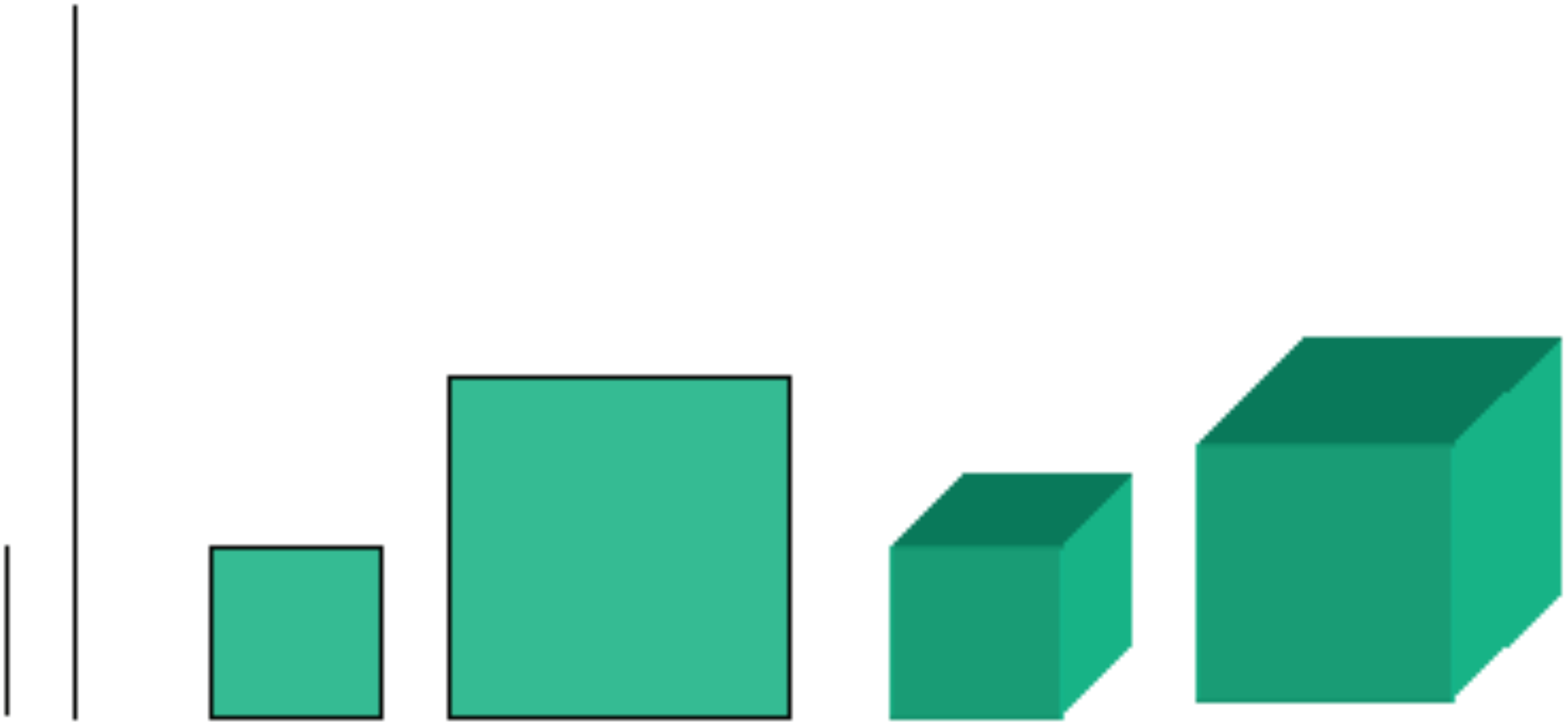
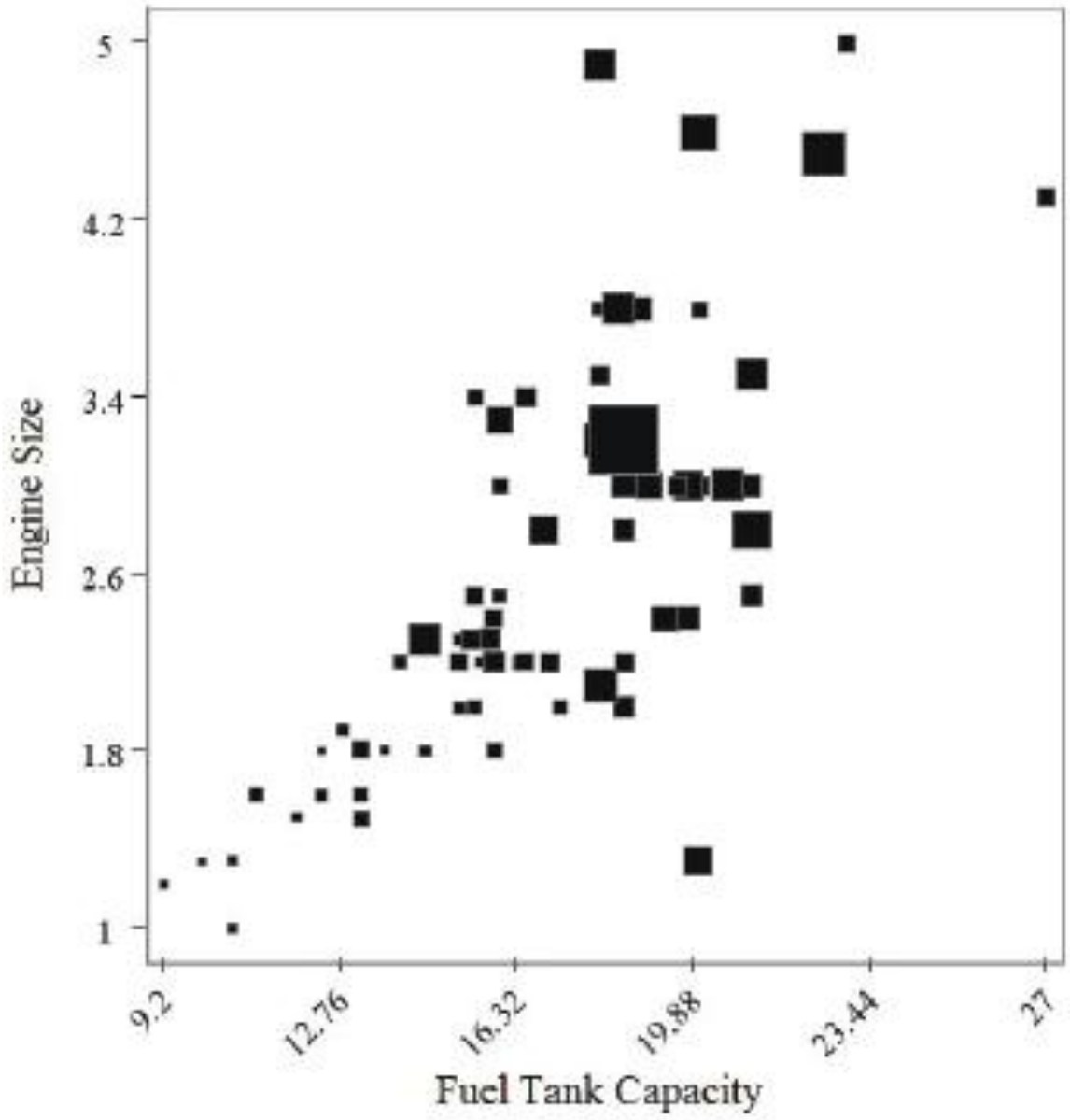


Illustration of Stevens' Law. The size ratio for each pair is 1:4. This magnitude is readily apparent in the lines, but it is easily underestimated in the squares and cubes.

# Stevens' Law



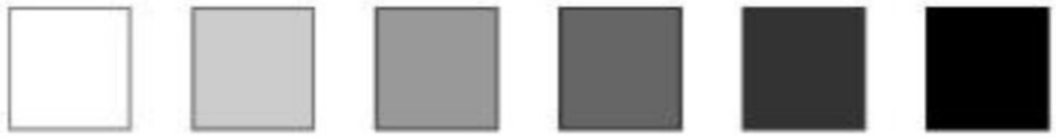
# Eight visual variables: Size




This is a visualization of the 1993 car models data set, showing engine size versus fuel tank capacity. Size is mapped to maximum price charged.

# Eight visual variables: Brightness (ou luminance)

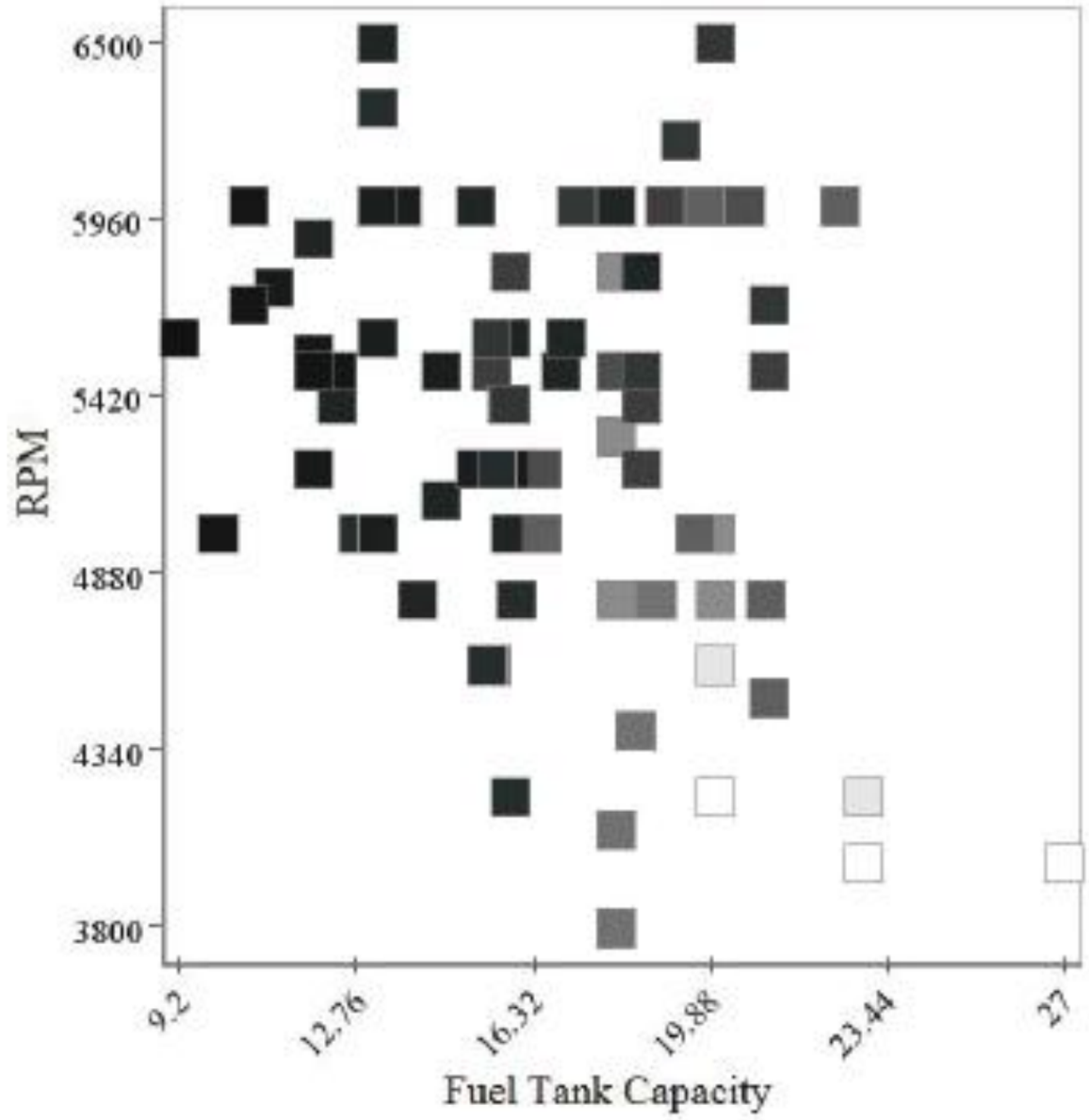
- **Brightness is the second visual variable used to modify marks to encode additional data variables.**



Brightness scale for mapping values to the display.

- **While it is possible to use the complete numerical range of brightness values, human perception cannot distinguish between all pairs of brightness values.**
- **Brightness can be used to provide relative difference for large interval and continuous data variables,**
- **or for mark distinction for marks drawn using a reduced sampled brightness scale.**

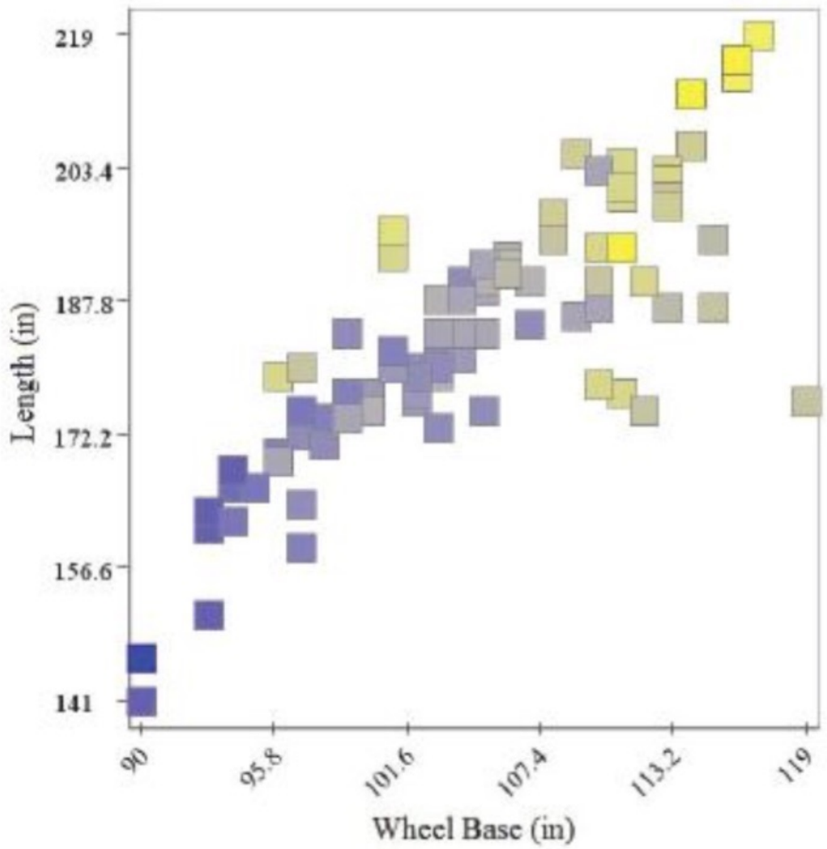
# Eight visual variables: Brightness (ou luminance)




Another visualization of the 1993 car models data set, this time illustrating the use of brightness to convey car width (the darker the points, the wider the vehicle).

# Eight visual variables: Color

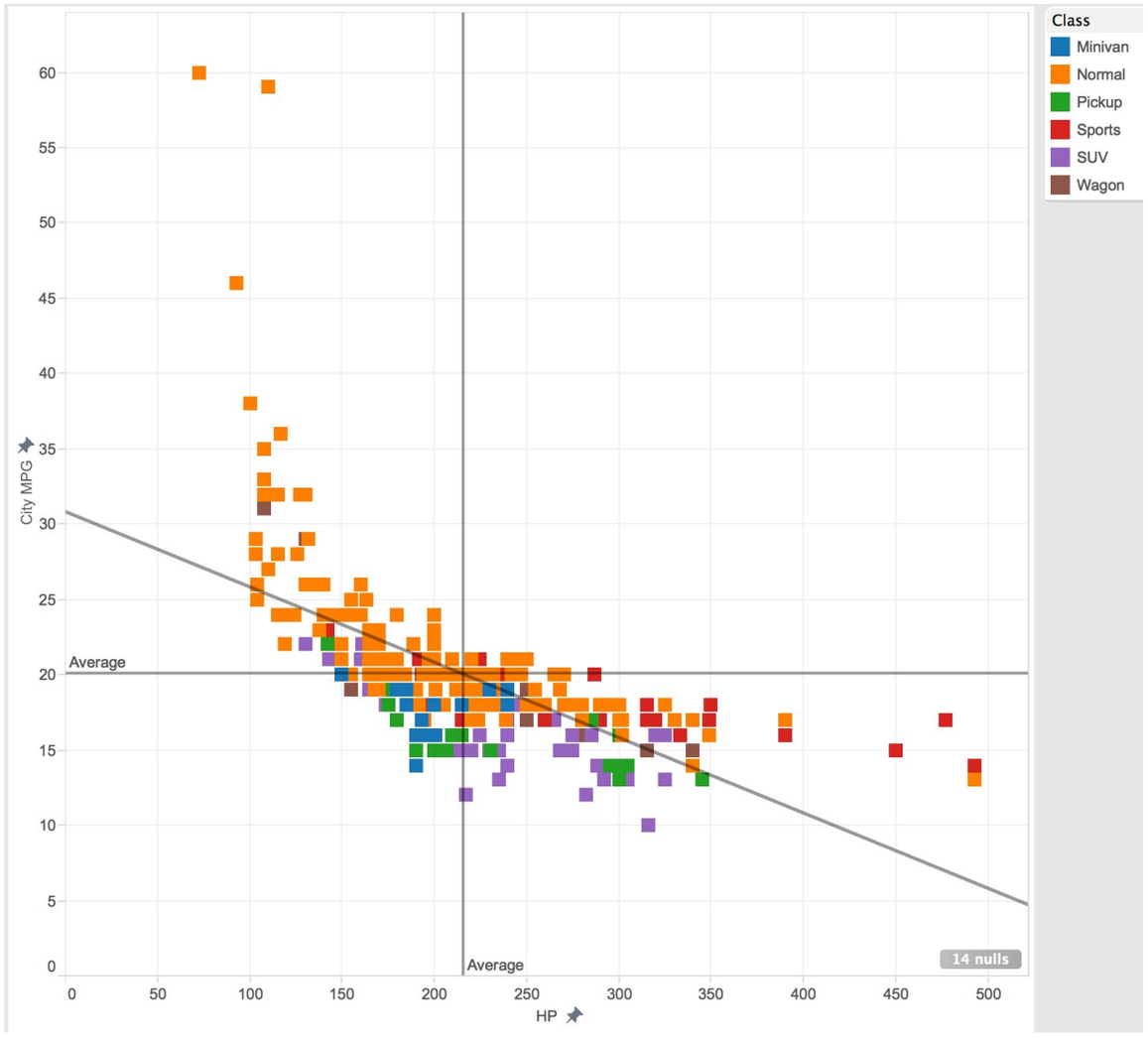
- **Color maps are useful for handling both interval and continuous data variables, since a color map is generally defined as a continuous range of hue and saturation values**



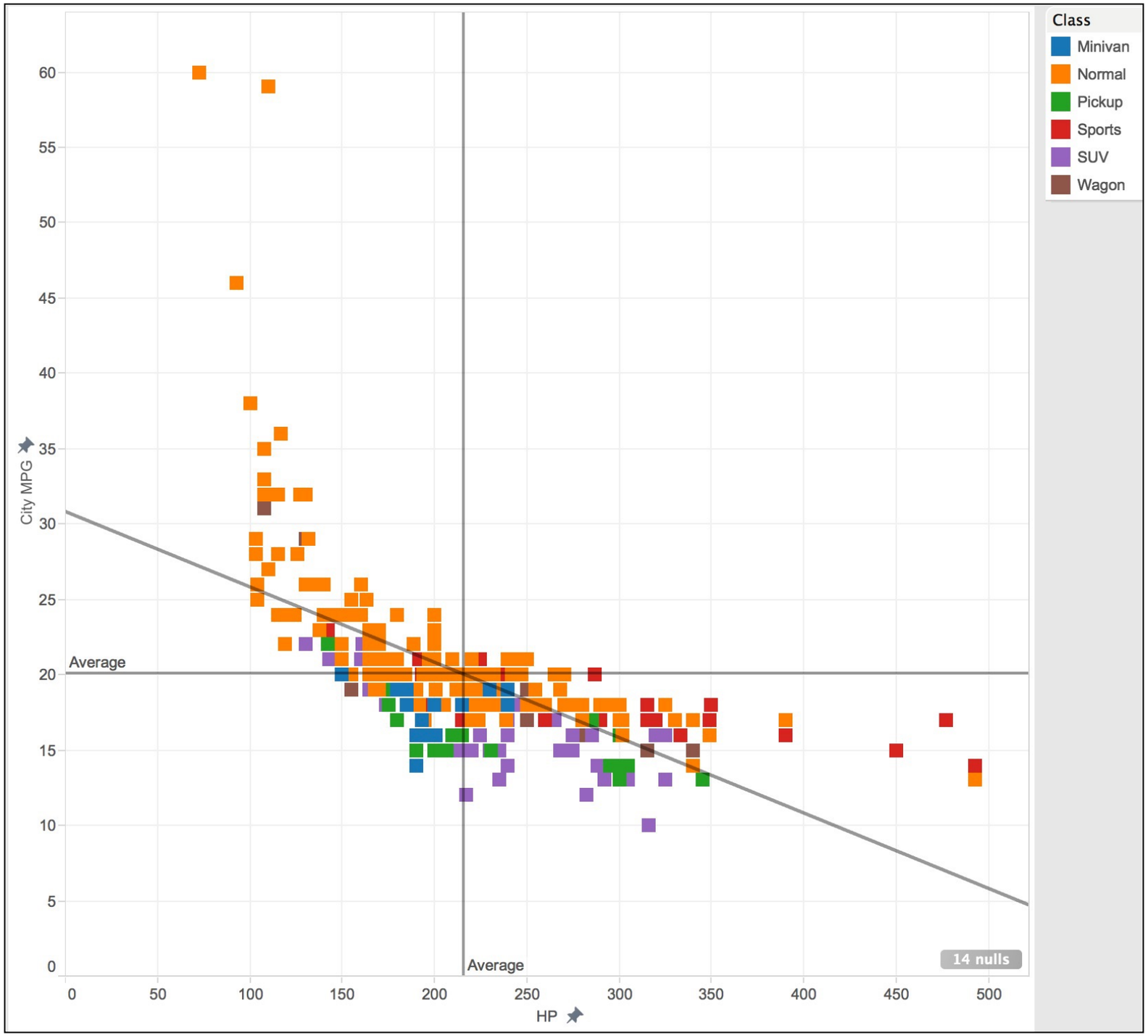

A visualization of the 1993 car models, showing the use of color to display the car's length. Here length is also associated with the $y$-axis and is plotted against wheelbase. In this figure, blue indicates a shorter length, while yellow indicates a longer length.

# Eight visual variables: Color

- **When working with categorical or interval data with very low cardinality, it is generally acceptable to manually select colors for individual data values, which are selected to optimize the distinction between data types**

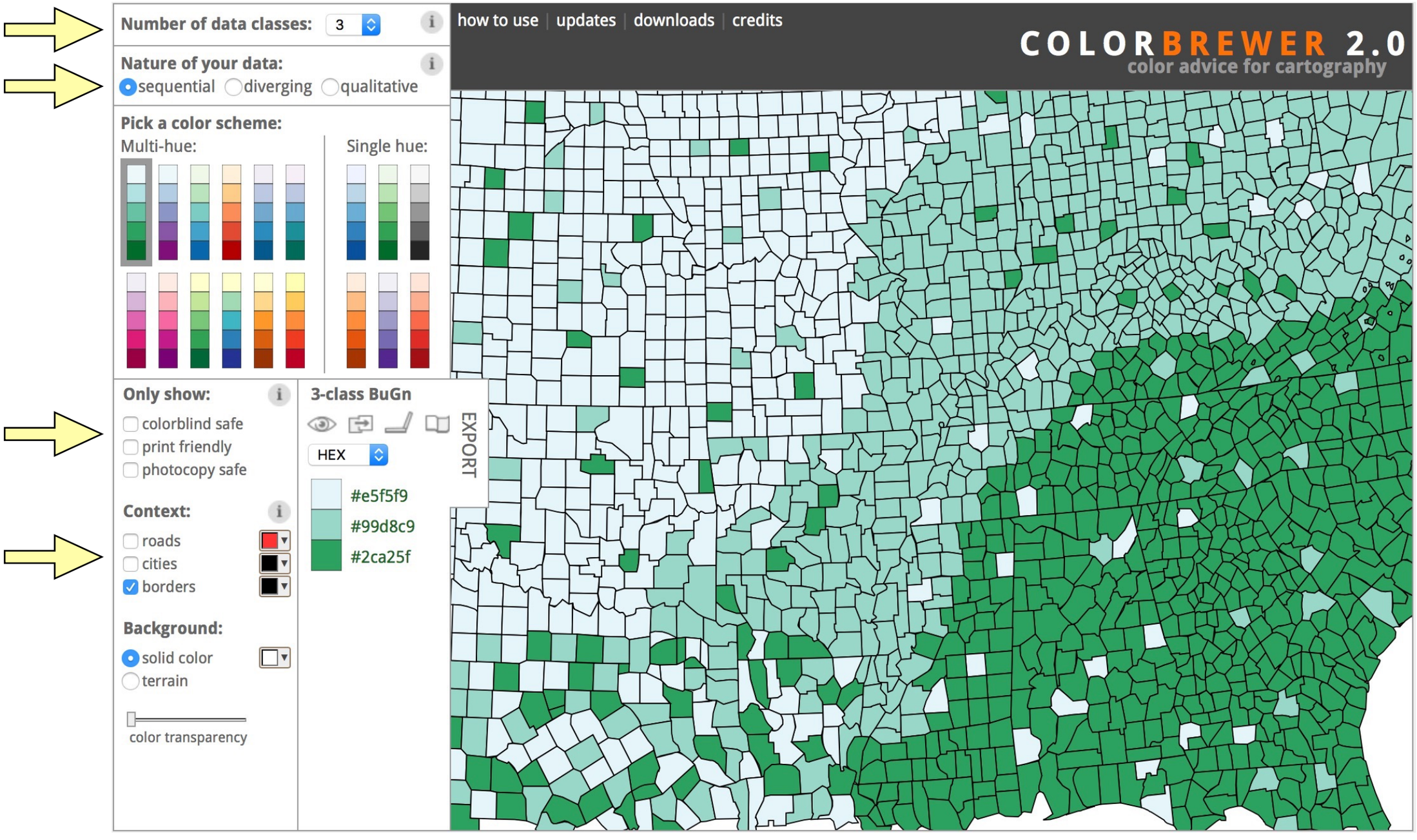


# Eight visual variables: Color



# Eight visual variables: Color

- **Check and try with: www.colorbrewer2.org**

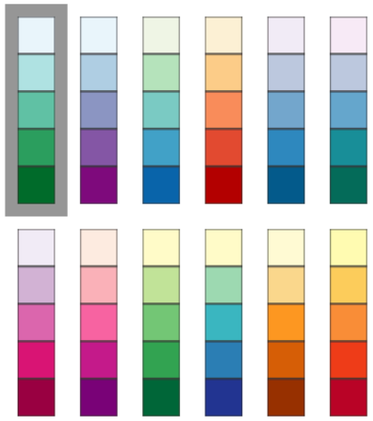


Number of data classes: 3

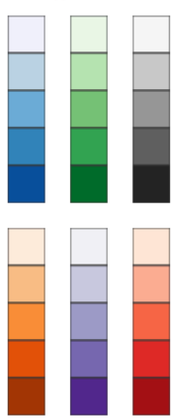
Nature of your data:
(•) sequential ( ) diverging ( ) qualitative

Pick a color scheme:

Multi-hue:



Single hue:



Only show:
- [ ] colorblind safe
- [ ] print friendly
- [ ] photocopy safe

Context:
- [ ] roads
- [ ] cities
- [x] borders

Background:
(•) solid color
( ) terrain

color transparency

3-class BuGn

EXPORT

HEX

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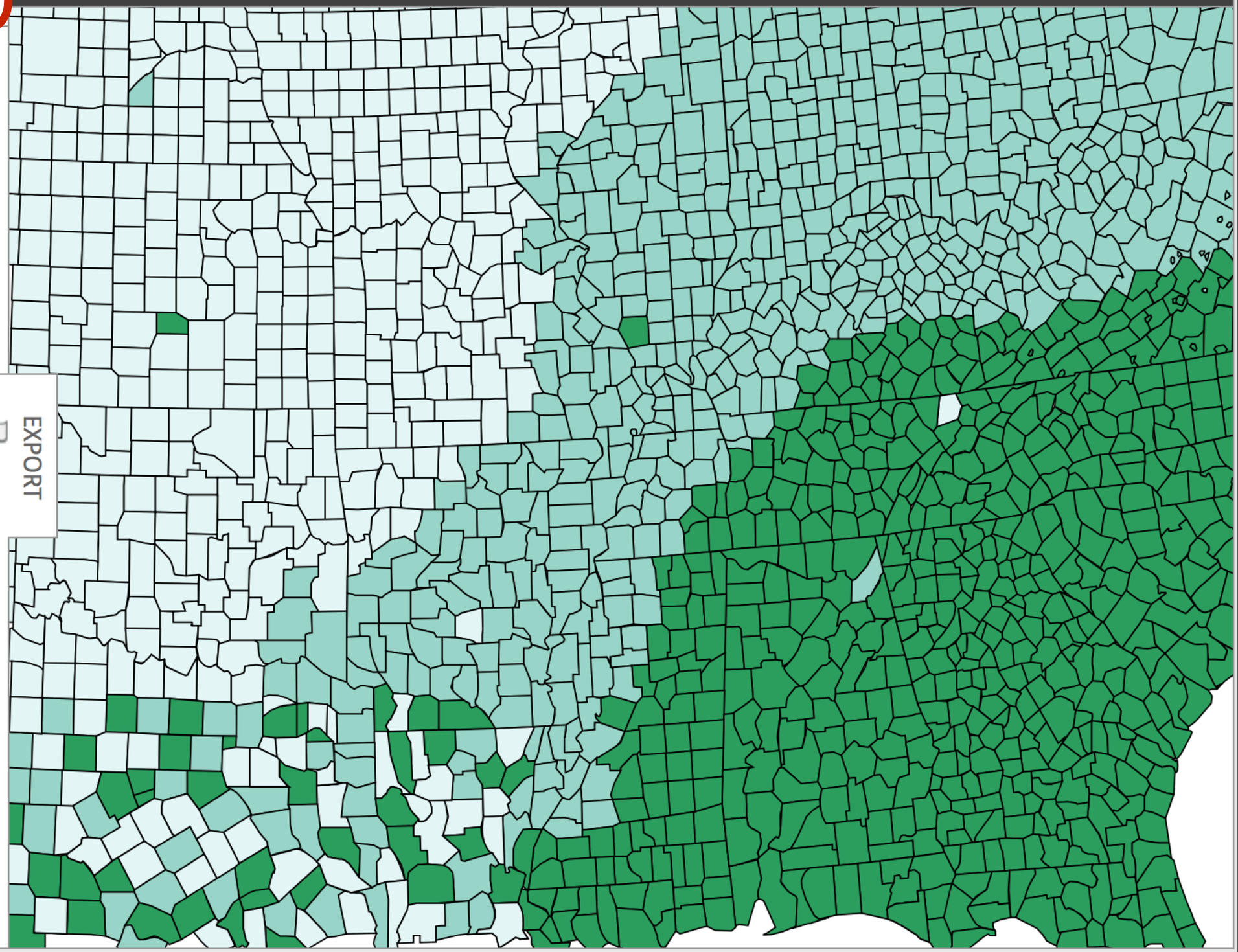
how to use | updates | downloads | credits

COLORBREWER 2.0
color advice for cartography

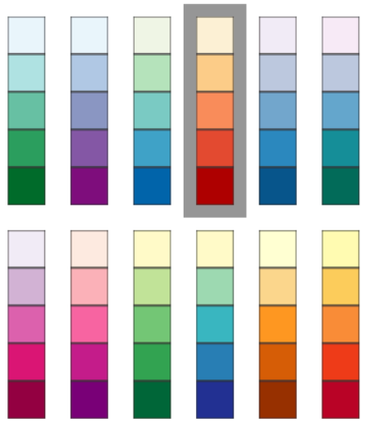


Number of data classes: 3

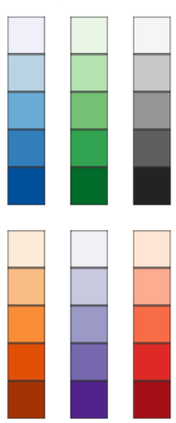
Nature of your data:
(•) sequential ( ) diverging ( ) qualitative

Pick a color scheme:

Multi-hue:



Single hue:



Only show:
- [ ] colorblind safe
- [ ] print friendly
- [ ] photocopy safe

Context:
- [ ] roads
- [ ] cities
- [x] borders

Background:
(•) solid color
( ) terrain

color transparency

3-class OrRd

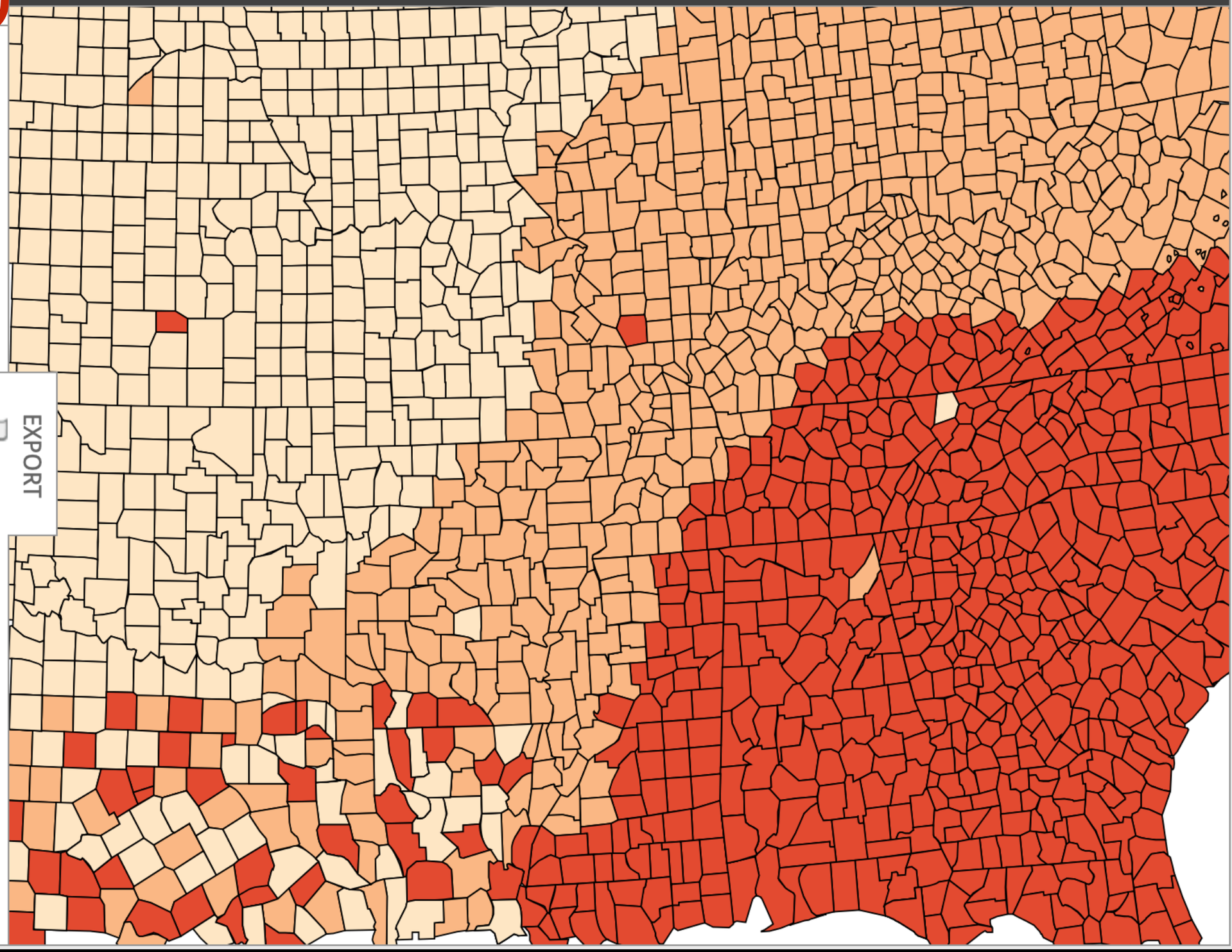
HEX

#fee8c8
#fdbb84
#e34a33

EXPORT

how to use | updates | downloads | credits

COLORBREWER 2.0
color advice for cartography



Number of data classes: 3

Nature of your data:
(•) sequential ( ) diverging ( ) qualitative

Pick a color scheme:

Multi-hue:

Single hue:

Only show:
- [ ] colorblind safe
- [ ] print friendly
- [ ] photocopy safe

Context:
- [ ] roads
- [ ] cities
- [x] borders

Background:
(•) solid color
( ) terrain

color transparency

3-class Greens

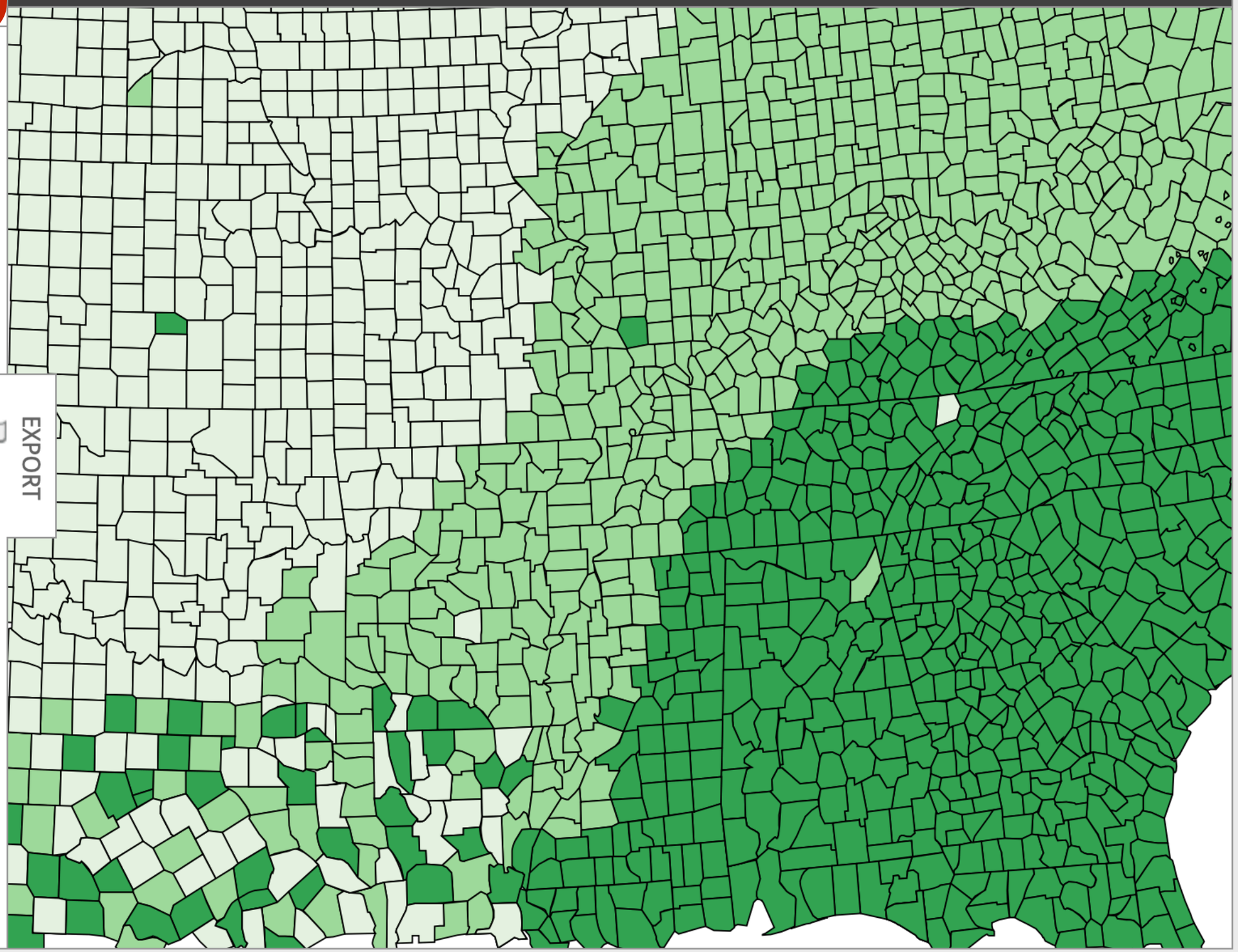
HEX

#e5f5e0
#a1d99b
#31a354

EXPORT

how to use | updates | downloads | credits

COLORBREWER 2.0
color advice for cartography



Number of data classes: 3

Nature of your data:
sequential diverging qualitative

Pick a color scheme:

how to use | updates | downloads | credits

COLORBREWER 2.0
color advice for cartography

Only show:
colorblind safe
print friendly
photocopy safe

Context:
roads
cities
borders

Background:
solid color
terrain

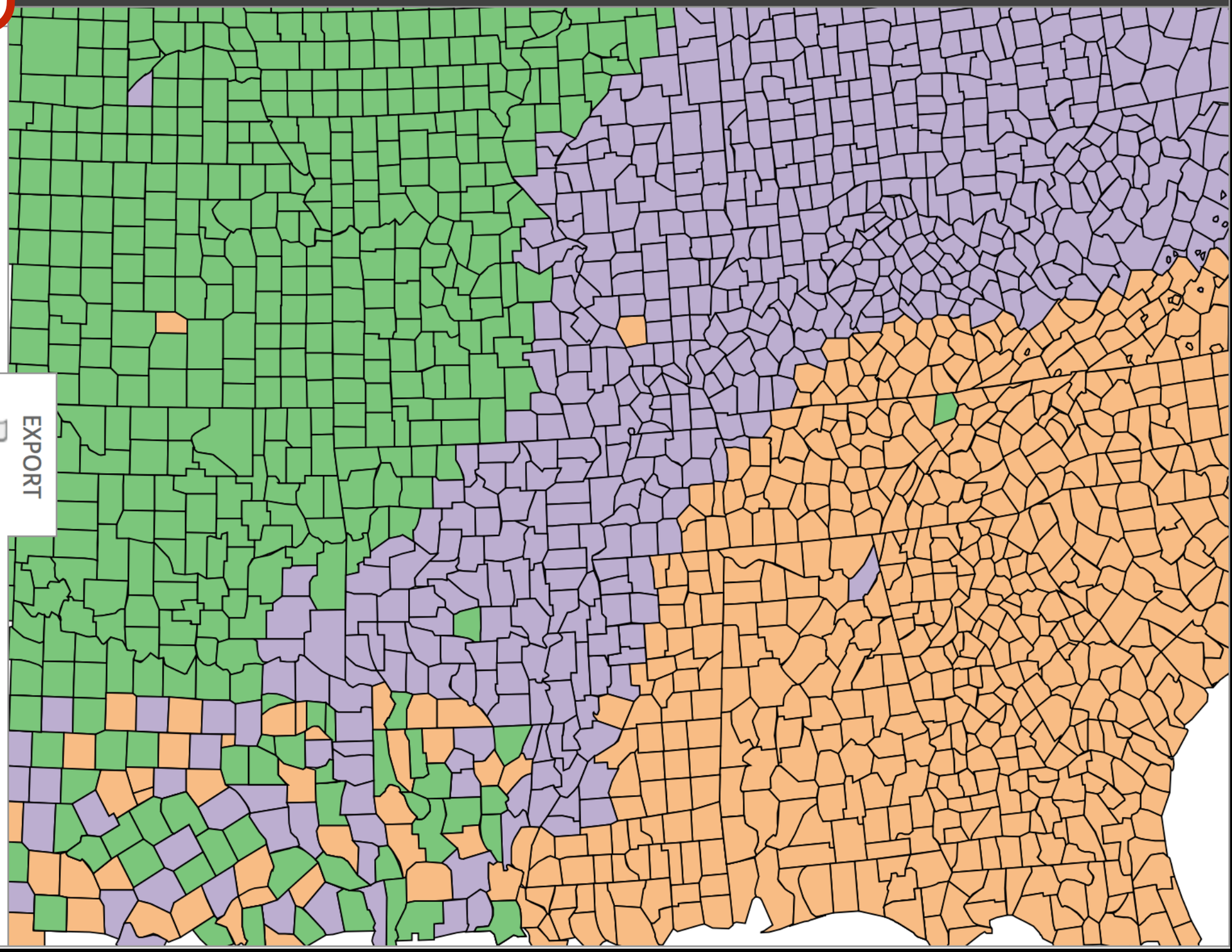
color transparency

3-class Accent

HEX

#7fc97f
#beaed4
#fdc086

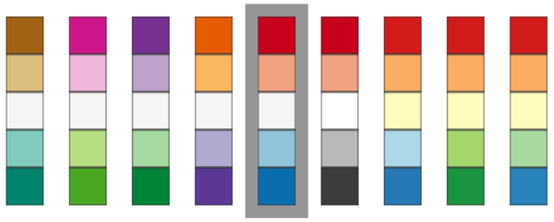
EXPORT



Number of data classes: 7

Nature of your data:
sequential | diverging | qualitative

Pick a color scheme:



how to use | updates | downloads | credits

COLORBREWER 2.0
color advice for cartography

Queen — A Kind of

Only show:
- colorblind safe
- print friendly
- photocopy safe

Context:
- roads
- cities
- borders

Background:
- solid color
- terrain

color transparency

7-class RdBu

HEX

#b2182b
#ef8a62
#fddbc7
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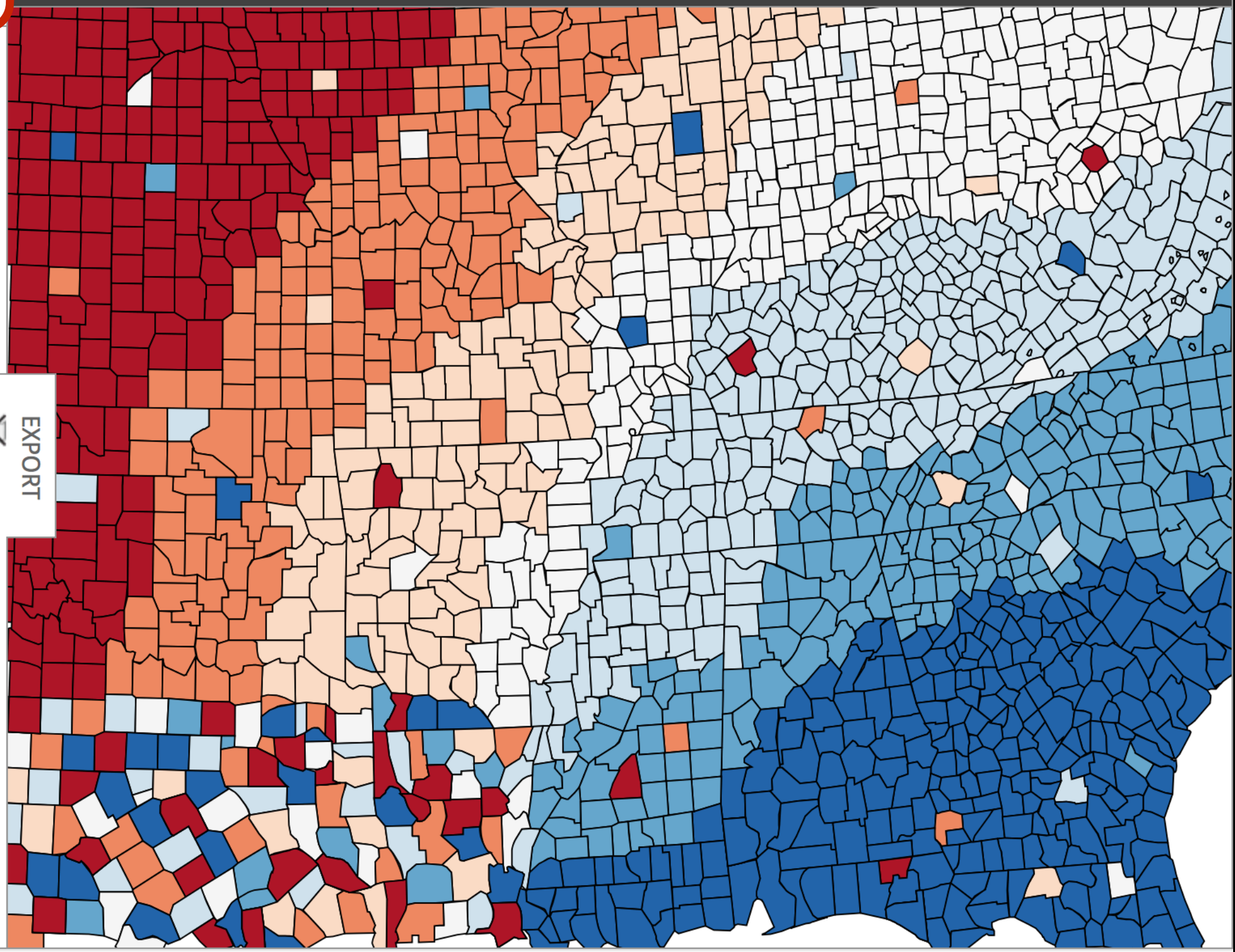
#d1e5f0
#67a9cf
#2166ac

EXPORT



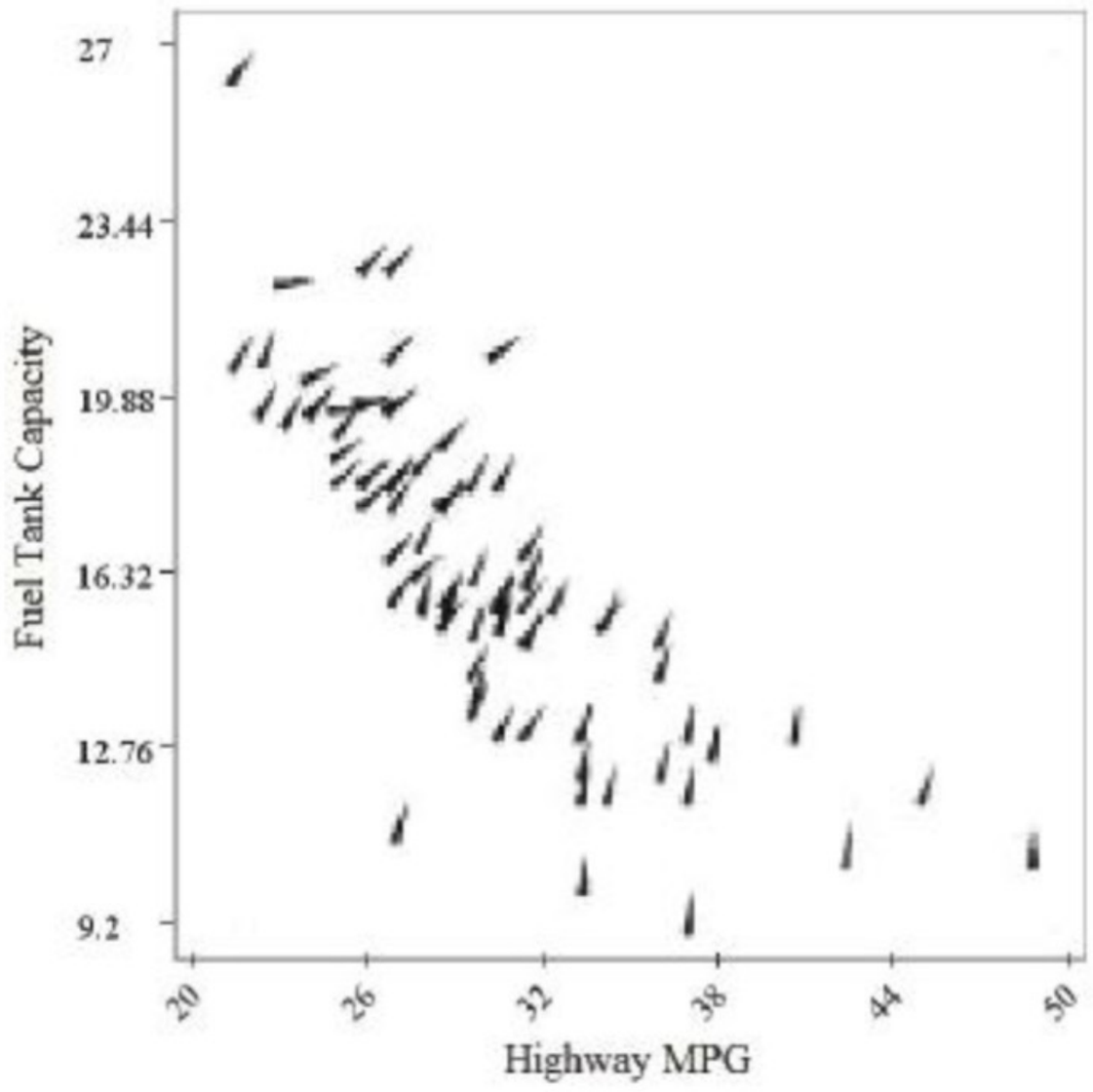
# Eight visual variables: Orientation

- **Orientation is a principal graphic component behind iconographic stick figure displays, and is tied directly to preattentive vision.**

Example orientations of a representation graphic, where the lowest value maps to the mark pointing upward and increasing values rotate the mark in a clockwise rotation.

- **The best marks for using orientation are those with a natural single axis; the graphic exhibits symmetry about a major axis.**

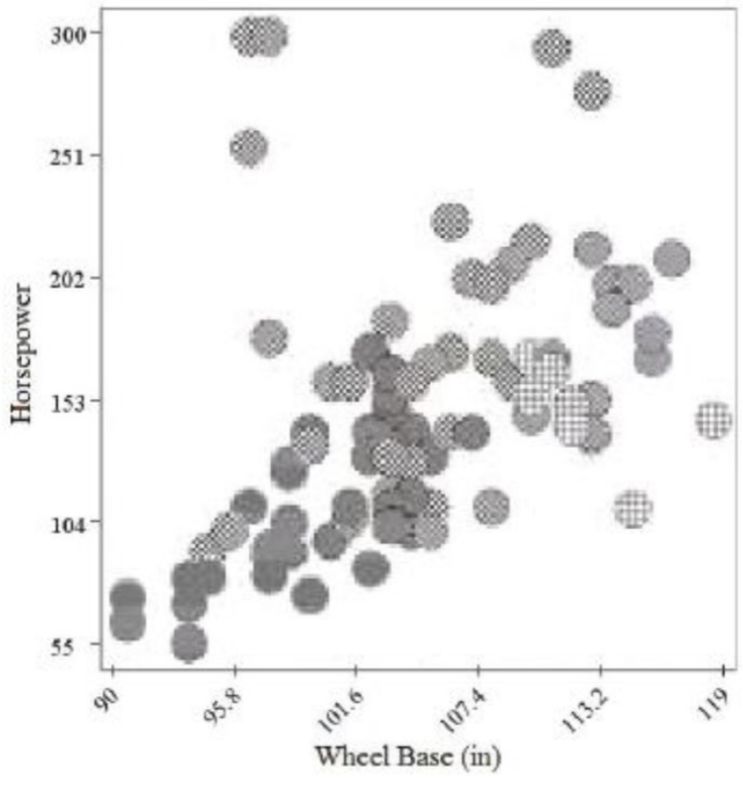
# Eight visual variables: Orientation




Sample visualization of the 1993 car models data set depicting using highway miles-per-gallon versus fuel tank capacity (position) with the additional data variable, midrange price, used to adjust mark orientation.

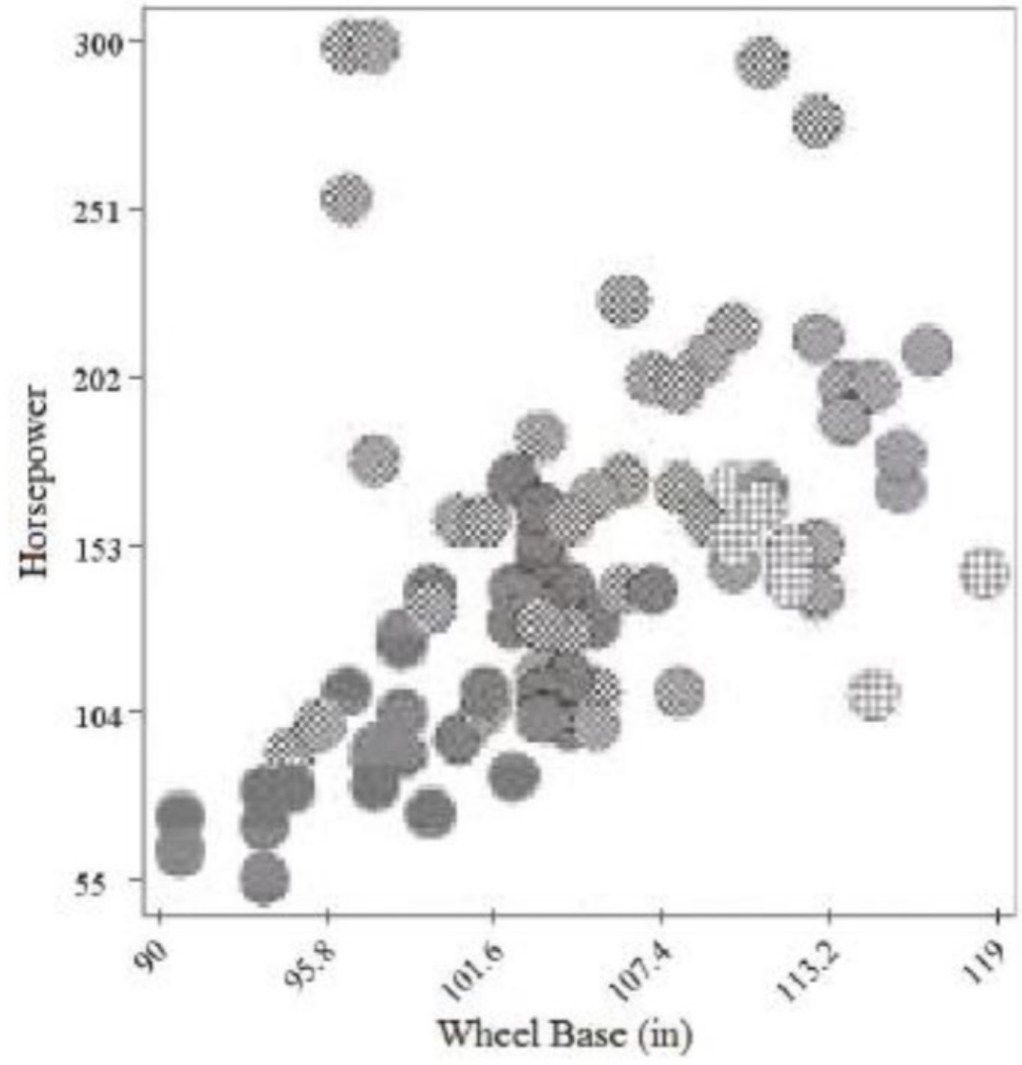
# Eight visual variables: Texture

- **Texture can be considered as a combination of many of the other visual variables, including marks (texture elements), color (associated with each pixel in a texture region), and orientation (conveyed by changes in the local color).**
- **Texture is most commonly associated with a polygon, region, or surface.**




Example visualization using texture to provide additional information about the 1993 car models data set, showing the relationship between wheelbase versus horsepower (position) as related to car types, depicted by different textures.

# Eight visual variables: Texture




Example visualization using texture to provide additional information about the 1993 car models data set, showing the relationship between wheelbase versus horsepower (position) as related to car types, depicted by different textures.

# Eight visual variables: Motion

- **Motion can be associated with any of the other visual variables, since the way a variable changes over time can convey more information.**

- **One common use of motion is in varying the speed at which a change is occurring (such as position change or flashing, which can be seen as changing the opacity).**

- **The other aspect of motion is in the direction for position, this can be up, down, left, right, diagonal, or basically any slope, while for other variables it can be larger/ smaller, brighter/dimmer, steeper/shallower angles, and so on.**

# Effects of Visual Variables

- **Selective visual variables:**
  - **After coding with such variables, different data values are spontaneously divided by the human into distinguished groups (e.g., for visualizing nominal values).**
- **Associative visual variables:**
  - **All factors have same visibility (e.g., for visualizing nominal values).**
- **Ordinal visual variables:**
  - **After coding with such variables, different data values are spontaneously ordered by the human into distinguished groups (e.g., for visualizing ordinal and quantitative data).**

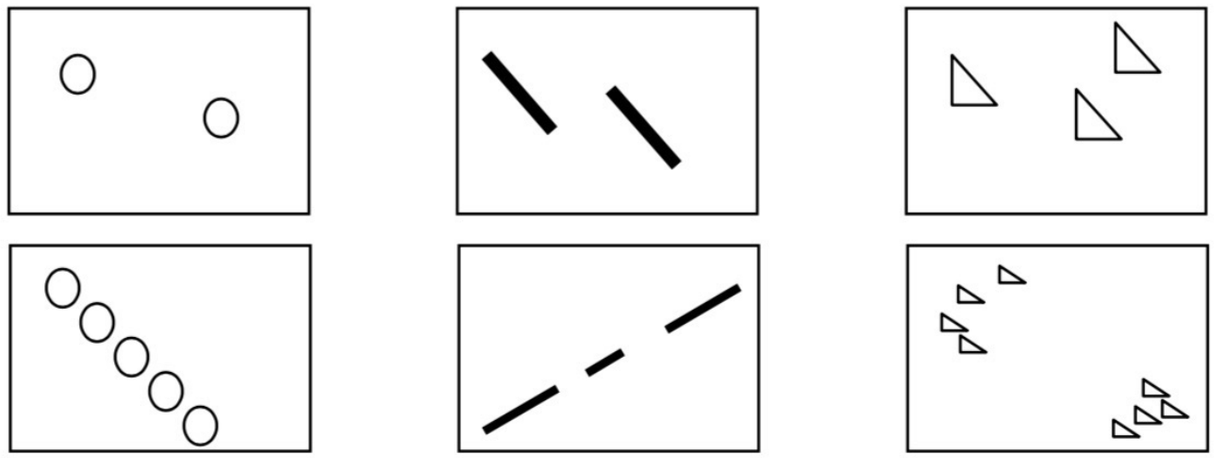
# Effects of Visual Variables

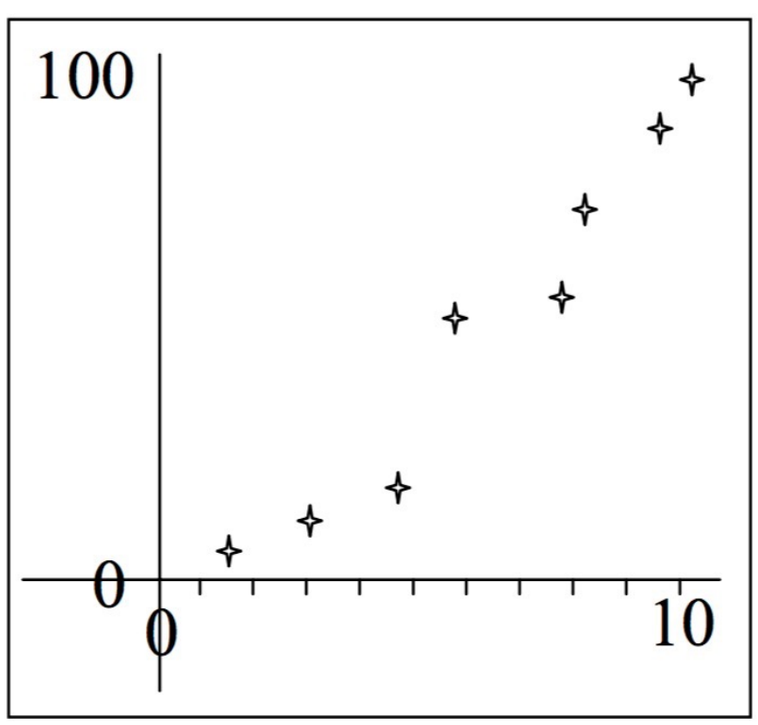
- **Check the slides by Sheelagh Carpendale, University of Calgary**
  - **https://pages.cpsc.ucalgary.ca/~saul/hci_topics/pdf_files/visual-variables.pdf**
- **For each graphic attribute evaluates its use for each visual variable:**
  - **selective (is a change enough to allow us to select it from a group?)**
  - **associative (is a change enough to allow us to perceive them as a group?)**
  - **quantitative (is there a numerical reading obtainable from changes in this variable?)**
  - **order (are changes in this variable perceived as ordered?)**
  - **length (across how many changes in this variable are distinctions perceptible?)**

# Effects of Visual Variables (by Sheelagh Carpendale)

## Position

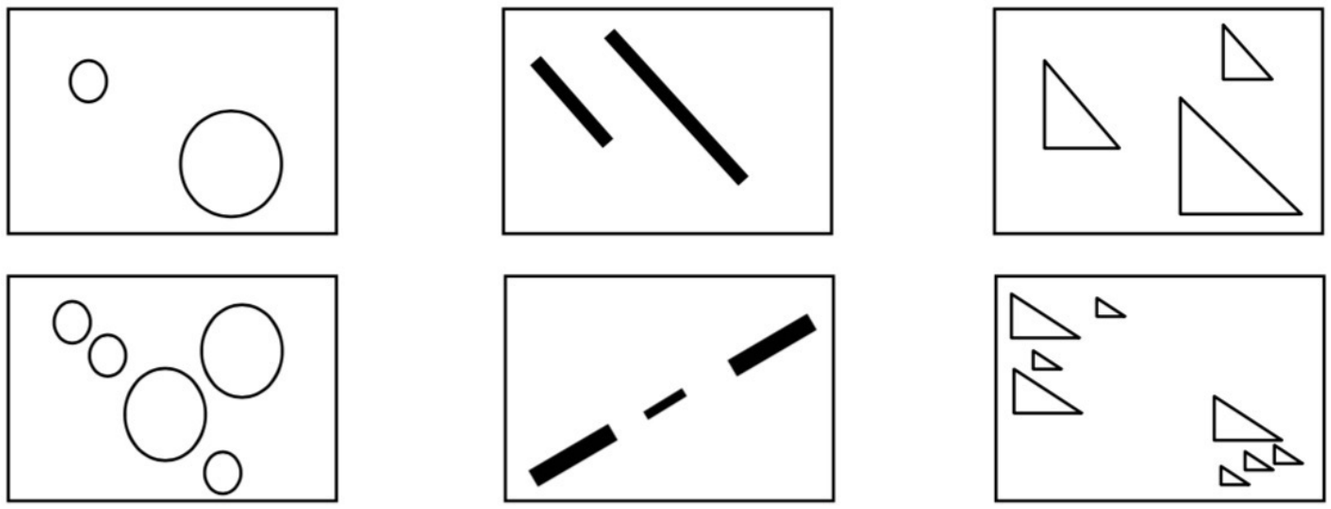
- ✓ selective
- ✓ associative
- ✓ quantitative
- ✓ order
- ✓ length





# Effects of Visual Variables (by Sheelagh Carpendale)

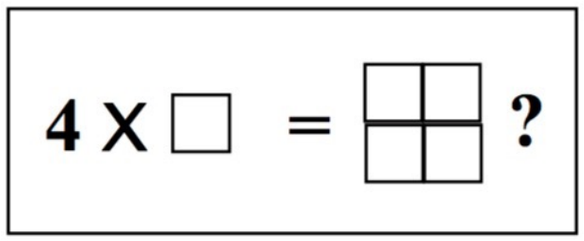
## Size



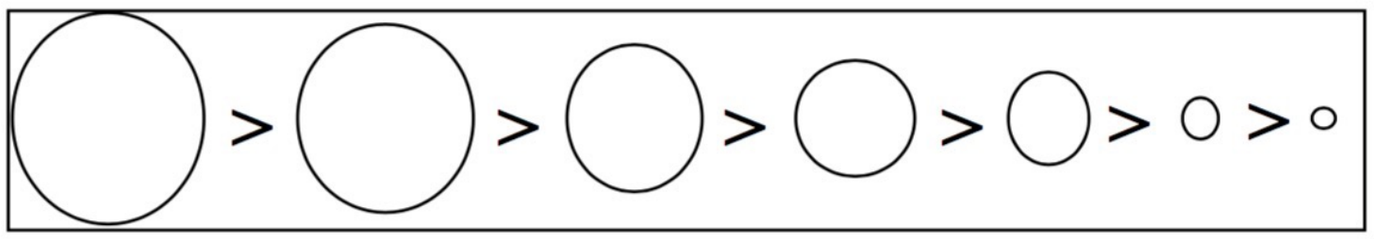
✓ selective

✓ associative

≃ quantitative




✓ order



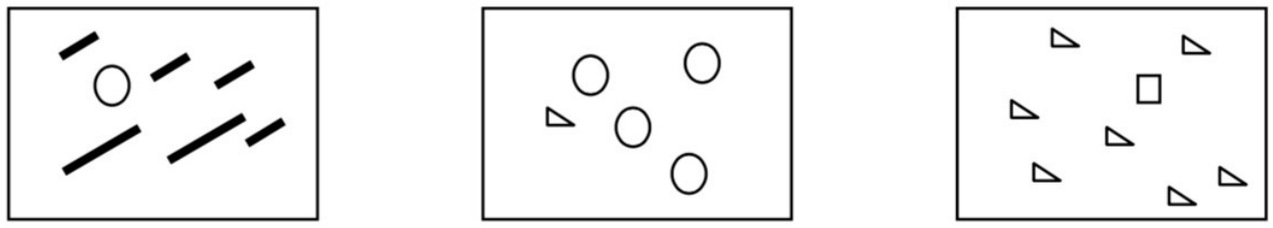
✓ length

- theoretically infinite but practically limited
- association and selection ~ 5 and distinction ~ 20

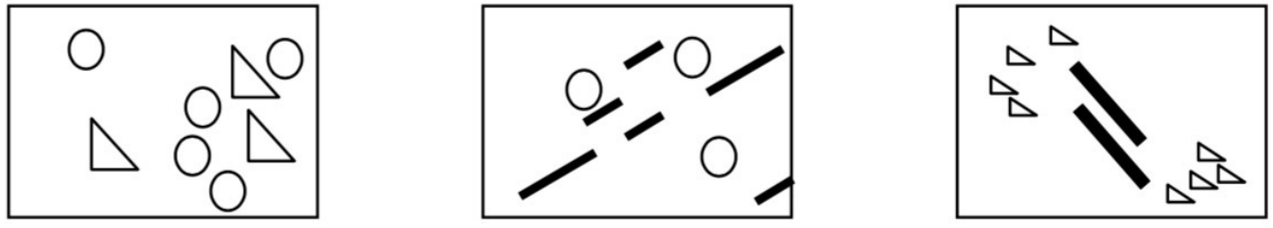
# Effects of Visual Variables (by Sheelagh Carpendale)

**Shape**

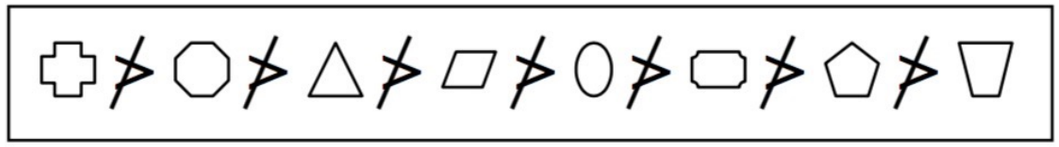
≂ selective



≂ associative



≠ quantitative



≠ order

✓ length - infinite variation

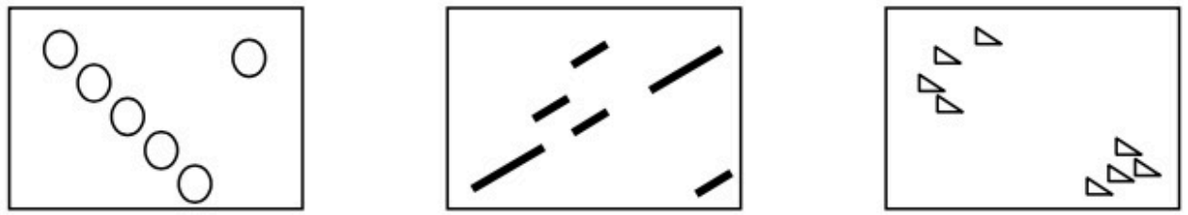
# Effects of Visual Variables (by Sheelagh Carpendale)

**Value**

(Brightness)

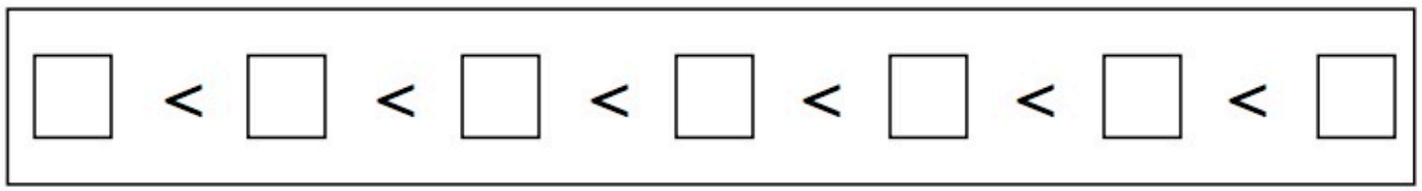
✓ selective

✓ associative



≠ quantitative

✓ order




✓ length

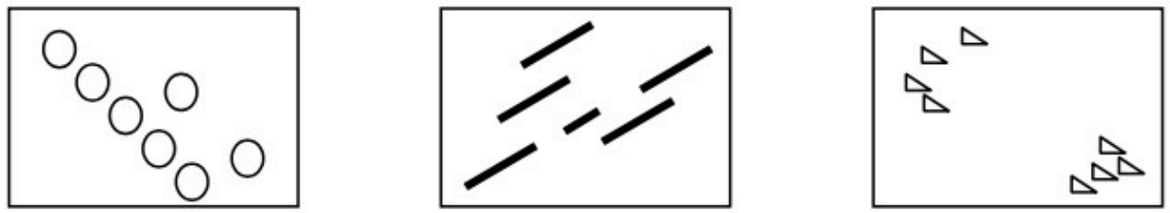
- theoretically infinite but practically limited
- association and selection ~ < 7 and distinction ~ 10

# Effects of Visual Variables (by Sheelagh Carpendale)

**Color**

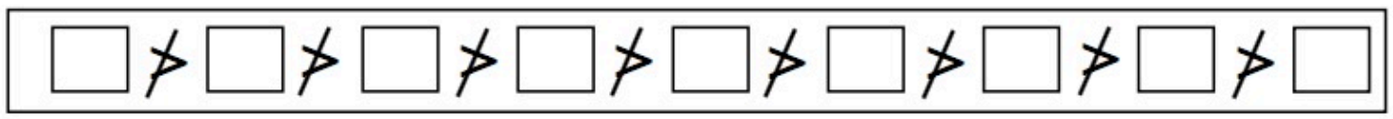
✓ selective

✓ associative



≠ quantitative

≠ order



✓ length

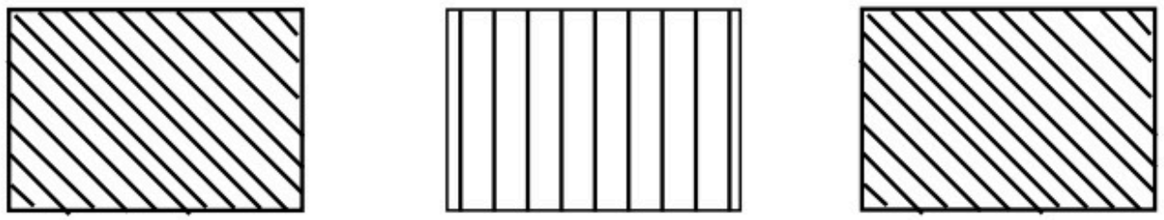
- theoretically infinite but practically limited
- association and selection ~ < 7 and distinction ~ 20

# Effects of Visual Variables (by Sheelagh Carpendale)

## Orientation

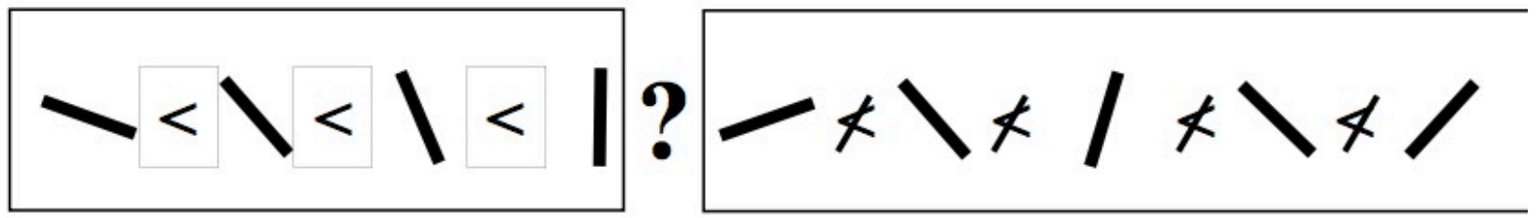
✓selective

✓ associative



≠ quantitative

≠ order



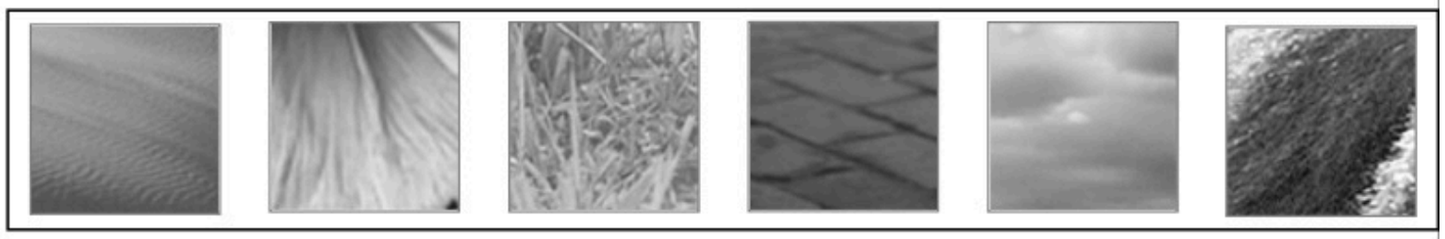

✓ length

- ~5 in 2D; ? in 3D

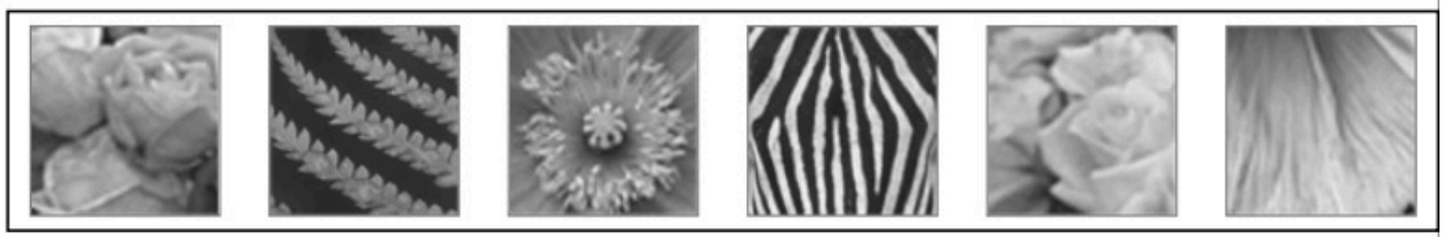
# Effects of Visual Variables (by Sheelagh Carpendale)

## Texture

✓ selective

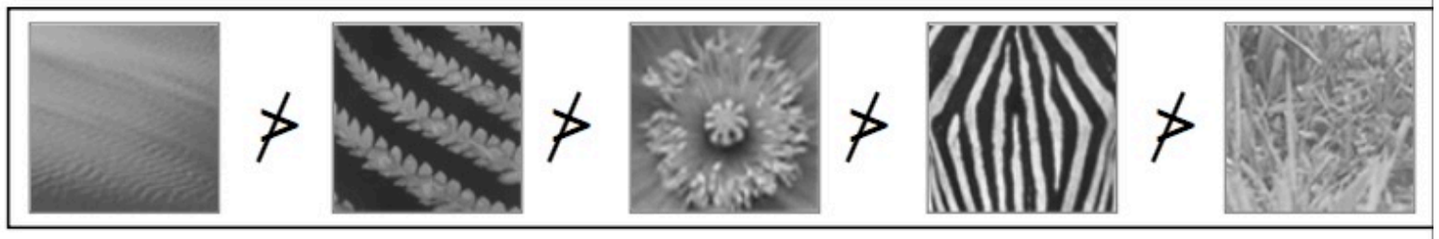


✓ associative



≠ quantitative

≠ order



✓ length

- theoretically infinite

# Effects of Visual Variables (by Sheelagh Carpendale)

## Motion

✓ selective
- motion is one of our most powerful attention grabbers

✓ associative
- moving in unison groups objects effectively

≠ quantitative
- subjective perception

≠ order

? length
- distinguishable types of motion?

# Effects of Visual Variables (by Sheelagh Carpendale)

- **Check the slides by Sheelagh Carpendale, University of Calgary**
  - **https://pages.cpsc.ucalgary.ca/~saul/hci_topics/pdf_files/visual-variables.pdf**
- **For each graphic attribute evaluates its use for each visual variable:**
  - **selective (is a change enough to allow us to select it from a group?)**
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  - **quantitative (is there a numerical reading obtainable from changes in this variable?)**
  - **order (are changes in this variable perceived as ordered?)**
  - **length (across how many changes in this variable are distinctions perceptible?)**

# Marks and Channels by Tamara Munzner

# Channel Rankings

**Channels:** Expressiveness Types and Effectiveness Ranks

➔ **Magnitude Channels: Ordered Attributes**

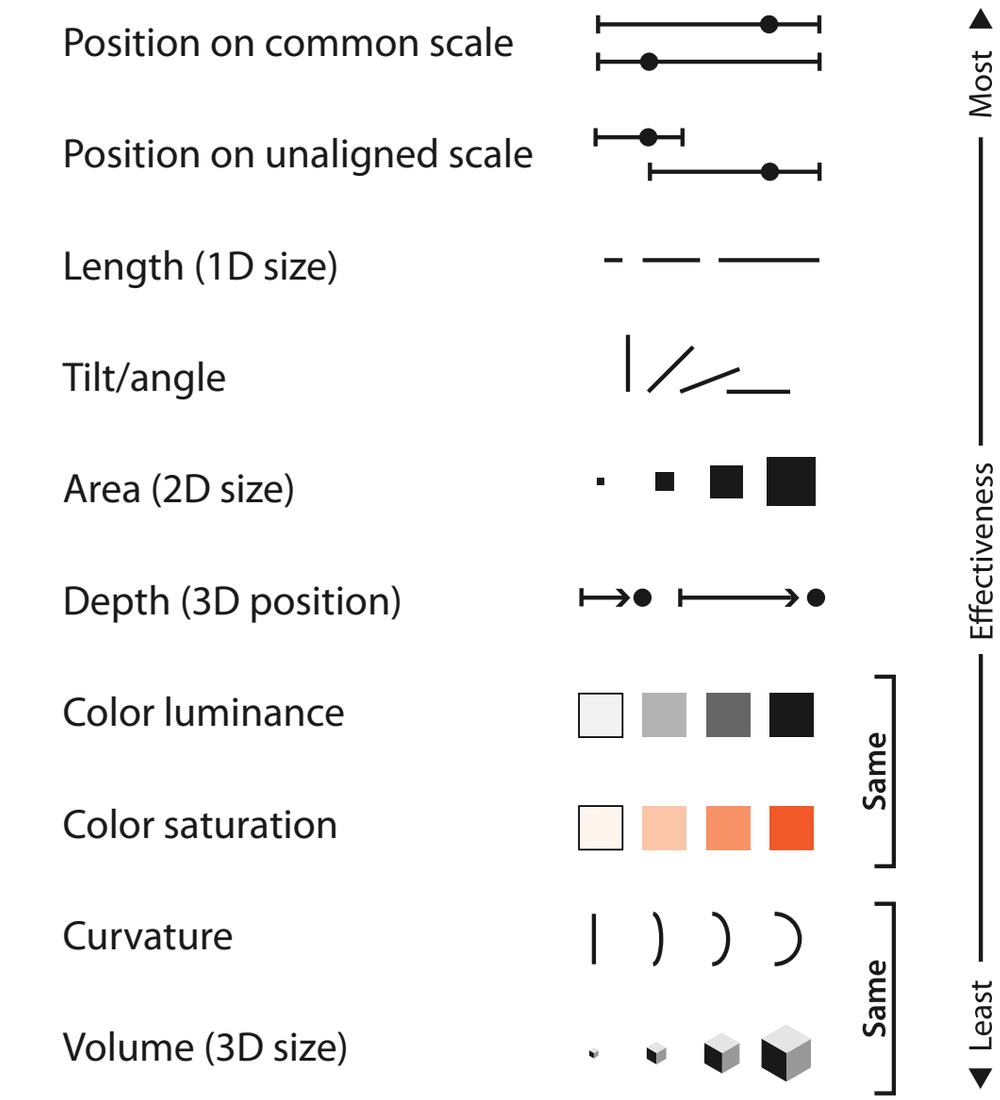



**Figure 5.6.** Channels ranked by effectiveness according to data and channel type. Ordered data should be shown with the magnitude channels, and categorical data with the identity channels.

# Channel Rankings

**Channels:** Expressiveness Types and Effectiveness Ranks

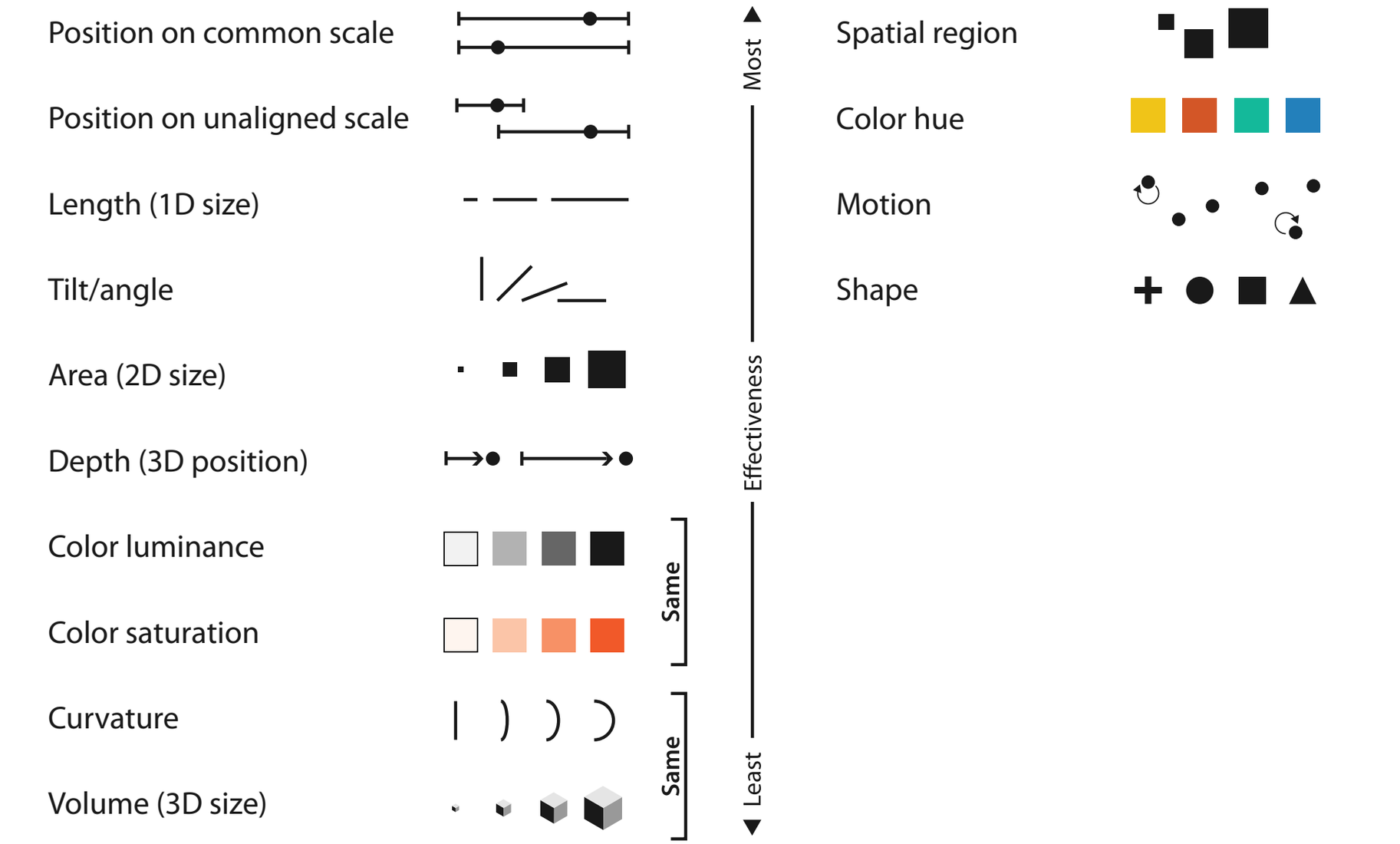



**Figure 5.6.** Channels ranked by effectiveness according to data and channel type. Ordered data should be shown with the magnitude channels, and categorical data with the identity channels.

# Accuracy

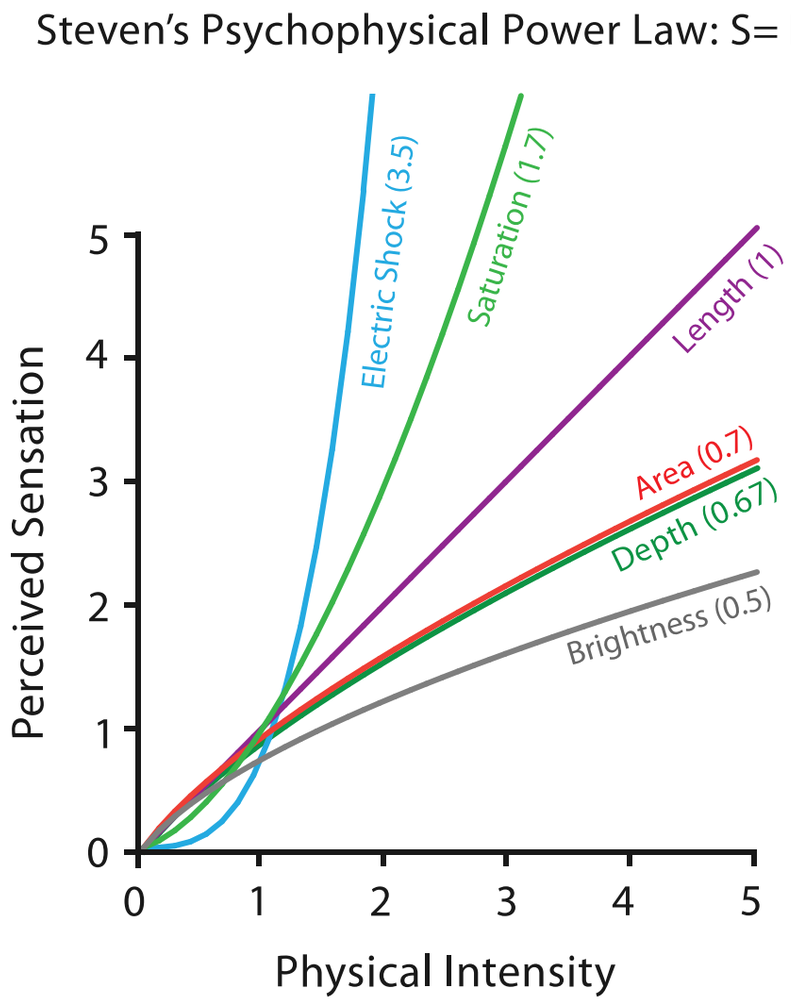
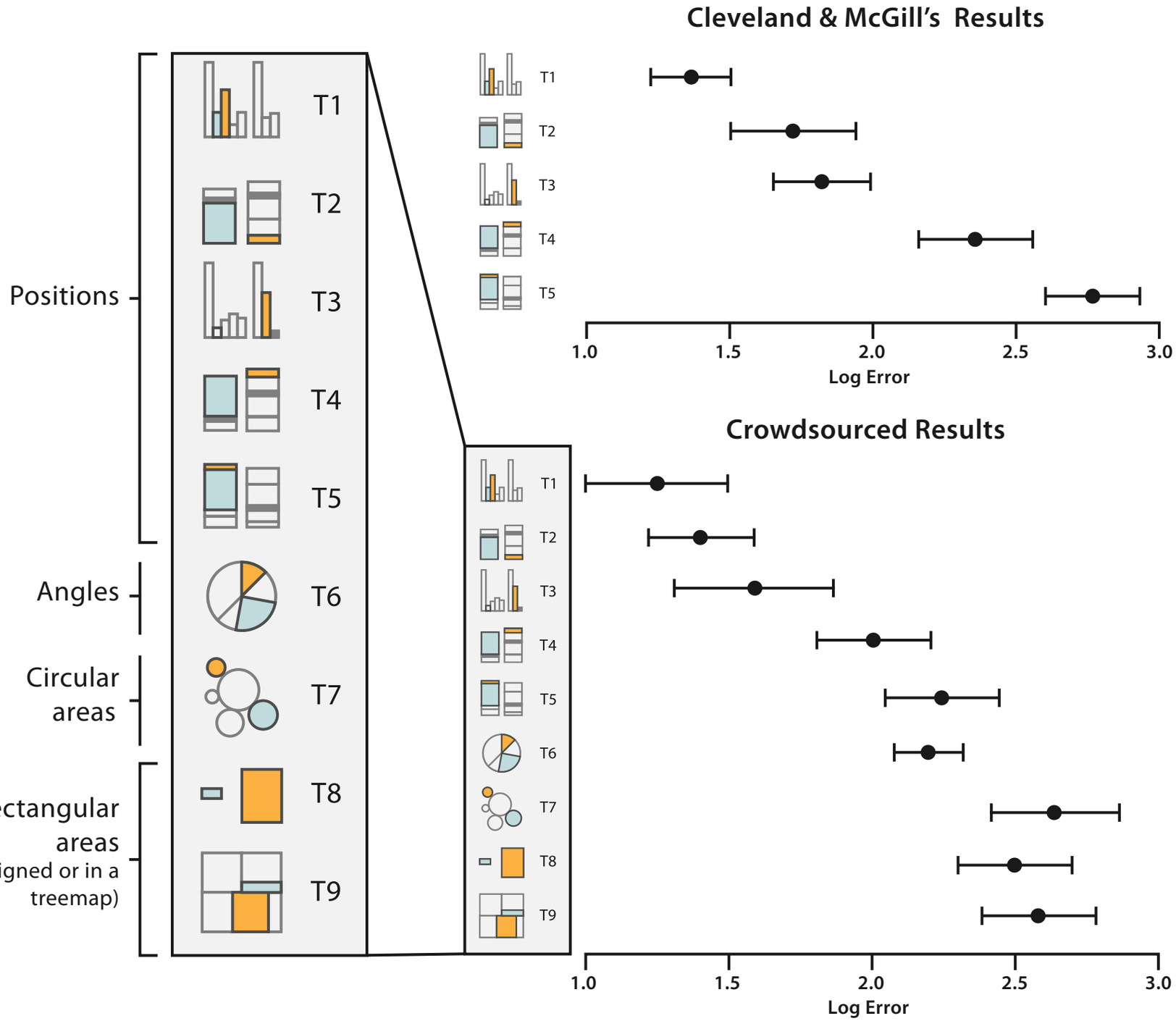



**Figure 5.7.** Stevens showed that the apparent magnitude of all sensory channels follows a power law $S = I^n$, where some sensations are perceptually magnified compared with their objective intensity (when $n > 1$) and some compressed (when $n < 1$). Length perception is completely accurate, whereas area is compressed and saturation is magnified. Data from Stevens [Stevens 75, p. 15].

# Error rates (Cleveland and McGill [Cleveland and McGill 84a]. After [Heer and Bostock])



Positions

T1

T2

T3

T4

T5

Angles

T6

Circular areas

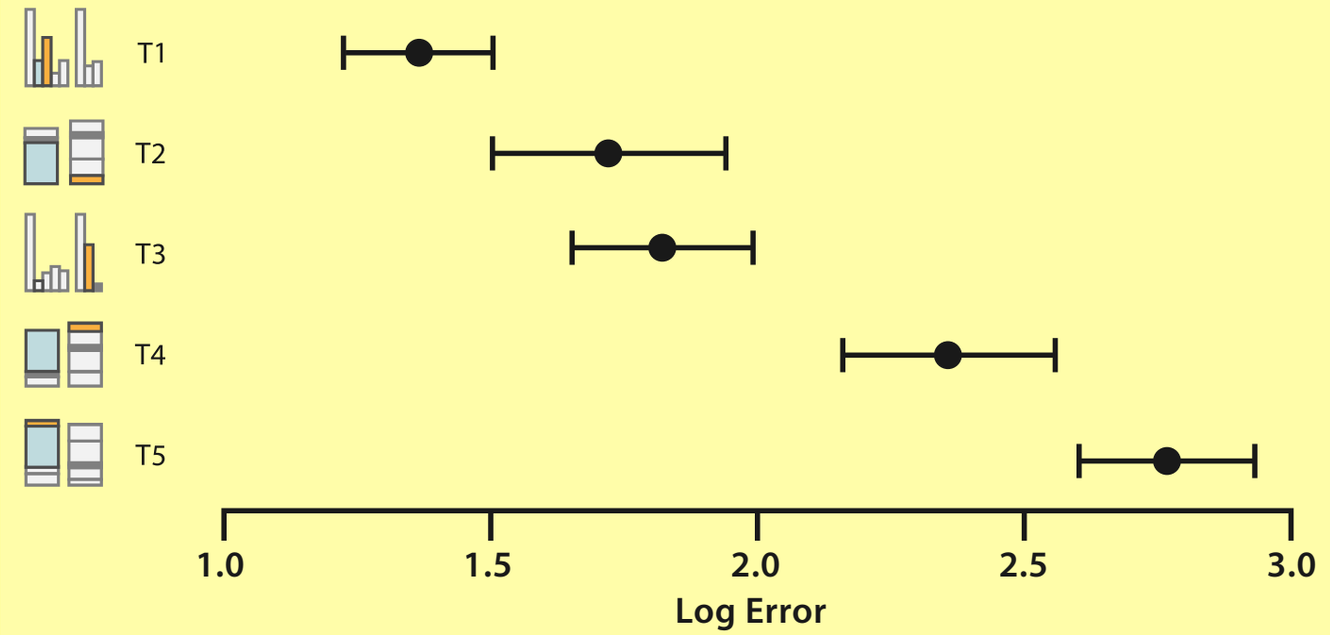
T7

Rectangular areas (aligned or in a treemap)

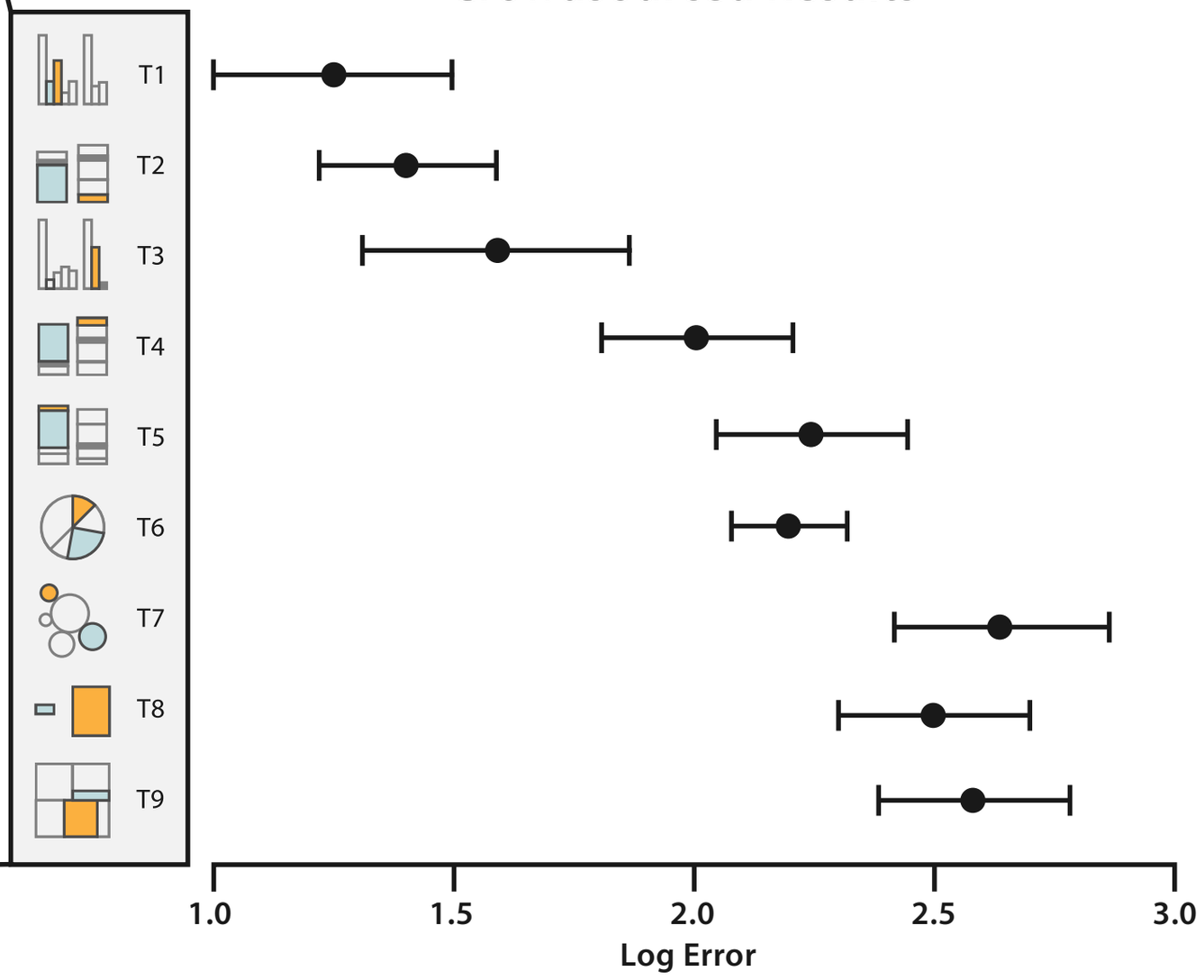
T8

T9

## Cleveland & McGill's Results




## Crowdsourced Results



# Discriminability

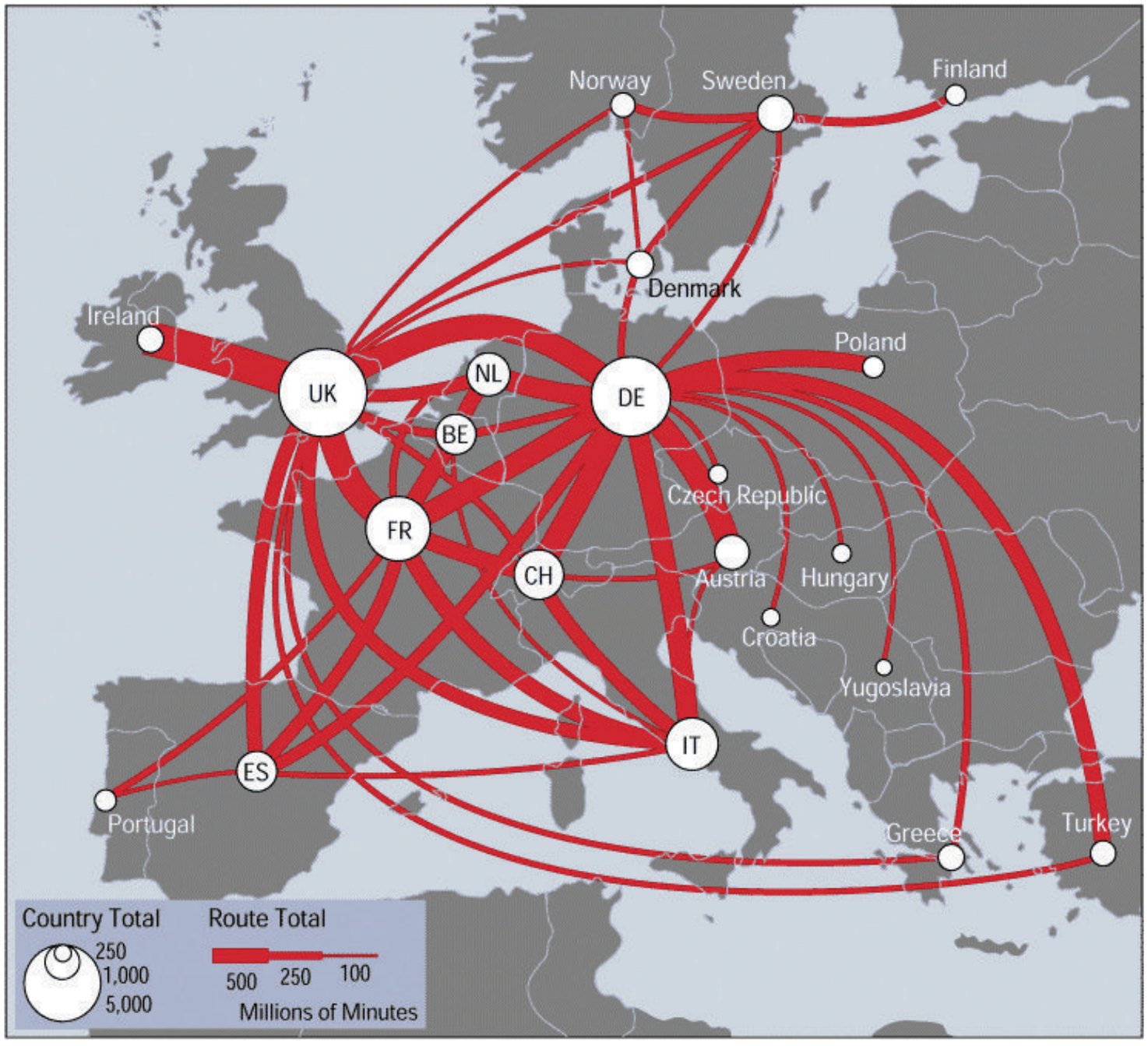



**Figure 5.9.** Linewidth has a limited number of discriminable bins.

# Separability

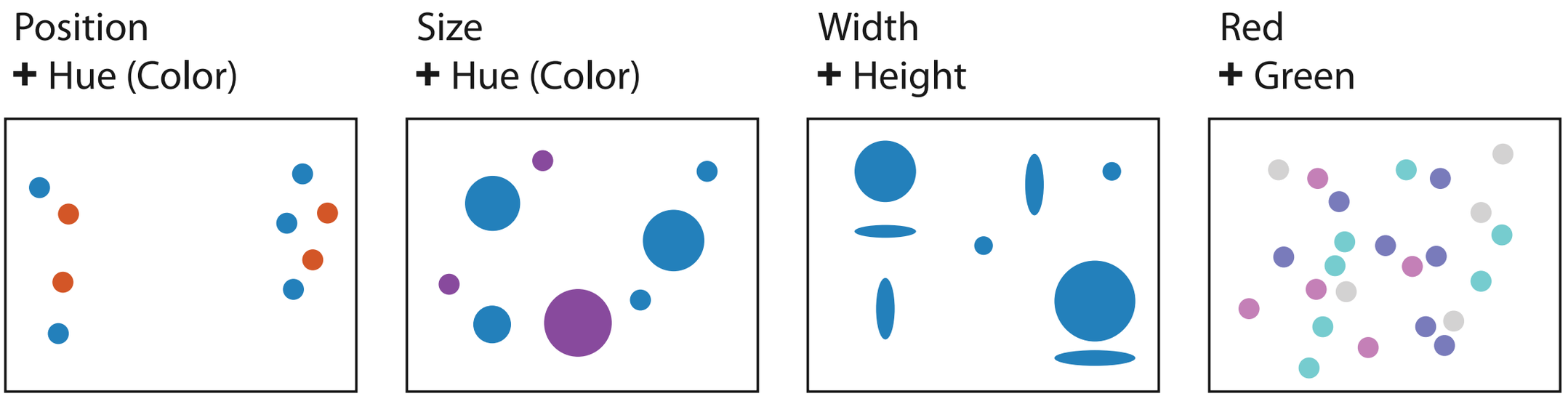



**Figure 5.10.** Pairs of visual channels fall along a continuum from fully separable to intrinsically integral. Color and location are separable channels well suited to encode different data attributes for two different groupings that can be selectively attended to. However, size interacts with hue, which is harder to perceive for small objects. The horizontal size and and vertical size channels are automatically fused into an integrated perception of area, yielding three groups. Attempts to code separate information along the red and green axes of the RGB color space fail, because we simply perceive four different hues. After [Ware 13, Figure 5.23].

# Historical Perspective

# Historical Perspective

- **Bertin (1967) Semiology of Graphics**
- **Mackinlay (1986) APT**
- **Bergeron and Grinstein (1989) Visualization Reference Model**
- **Wehrend and Lewis (1990)**
- **Robertson (1990) Natural Scene Paradigm**
- **Roth (1991) Visage and SAGE**
- **Casner (1991) BOZ**
- **Beshers and Feiner (1992) AutoVisual**

# Historical Perspective

- **Senay and Ignatius (1994) VISTA**
- **Hibbard (1994) Lattice Model**
- **Golovchinsky (1995) AVE**
- **Card, Mackinlay, and Shneiderman (1999) Spatial Substrate**
- **Kamps (1999) EAVE**
- **Wilkinson (1999) Grammar of Graphics**
- **Hoffman (2000) Table Visualizations**

# Historical Perspective

- **In 1967, Jacques Bertin, possibly the most important figure in visualization theory, published his *Sémiologie Graphique.***

| | |
|---|---|
| **Marks** | Points, lines, and areas |
| **Positional** | Two planar dimensions |
| **Retinal** | Size, value, texture, color, orientation, and shape |

Bertin's graphical vocabulary.

# Historical Perspective

- **Mackinlay (1986) introduced a design for an automated graphical presentation designer of relational information, named APT (A Presentation Tool)**
- **Mackinlay went on to describe graphical languages, defining graphical presentations as sentences of these languages. Two graphic design criteria: expressiveness criterion, the effectiveness criterion,**
- **The important aspect of Mackinlay's work pertains to his composition algebra, a collection of primitive graphic languages and composition operators that can form complex presentations.**

# Historical Perspective

| | |
|---|---|
| **Marks** | Points, lines, and areas |
| **Positional** | 1D, 2D, and 3D |
| **Temporal** | Animation |
| **Retinal** | Color, shape, size, saturation, texture, and orientation |

Mackinlay's graphical vocabulary, extended from Bertin.

| **Encoding Technique** | **Primitive Graphical Language** |
|---|---|
| Retinal-list | Color, shape, size, saturation, texture, orientation |
| Single-position | Horizontal axis, vertical axis |
| Apposed-position | Line chart, bar chart, plot chart |
| Map | Road map, topographic map |
| Connection | Tree, acyclic graph, network |
| Misc. (angle, contain, ...) | Pie chart, Venn diagram, ... |

Mackinlay's basis set of primitive graphical languages.

# Keller and Keller (1994) Taxonomy of Visualization Goals

- **Task list**
  - **identify:** establish characteristics by which an object is recognizable
  - **locate:** ascertain the position (absolute or relative);
  - **distinguish:** recognize as distinct or different (identification is not needed);
  - **categorize:** place into divisions or classes;
  - **cluster:** group similar objects
  - **rank:** assign an order or position relative to other objects
  - **compare:** notice similarities and differences;
  - **associate:** link or join in a relationship that may or may not be of the same type;
  - **correlate:** establish a direct connection, such as causal or reciprocal.

# Further Reading and Summary

**Q&A**

# Further Reading

- **Pag 139 - 180 from  Interactive Data Visualization: Foundations, Techniques, and Applications, Matthew O. Ward, Georges Grinstein, Daniel Keim, 2015**

- **Pag 42 - 64 from Visualization Analysis & Design, Tamara Munzner**

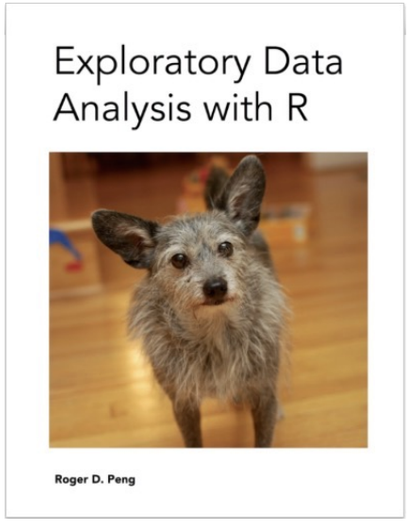
- **Check the slides by Sheelagh Carpendale, University of Calgary**
  - https://pages.cpsc.ucalgary.ca/~saul/hci_topics/pdf_files/visual-variables.pdf

# What you should know

- **The Visualization Process**
- **Expressiveness and Effectiveness**
- **The fundamental ideas of Semiology of Graphical Symbols**
  - data -> (x, y, z*)
- **The eight visual variables(VV)**
  - position, shape - Why they are the most important !
  - the others VVs
- **Effects of Visual Variables**
  - selective, associative, quantitative, order
- **Tasks list(s)**
  - Why it is important to consider a task; Why it is important to consider a taxonomy

# One more thing !

# General Rules for Exploratory Data Analysis




Exploratory Data Analysis with R

Roger D. Peng

# Principles of Analytic Graphics

- **Principle 1: Show comparisons**
  - **Evidence for a hypothesis is always relatives another competing hypothesis**
  - **Always ask "Compared to What?"**

**Testing** whether an **air cleaner installed in a child's home improves their asthma-related symptoms**.

This study was conducted at the Johns Hopkins University School of Medicine and was conducted in homes where a smoker was living for at least 4 days a week.

Each child was assessed at baseline and then 6-months later at a second visit. The aim was to improve a child's symptom-free days over the 6-month period. In this case, a higher number is better, indicating that they had *more* symptom-free days.

Reference: Butz AM, *et al.*, *JAMA Pediatrics*, 2011.

# Principles of Analytic Graphics

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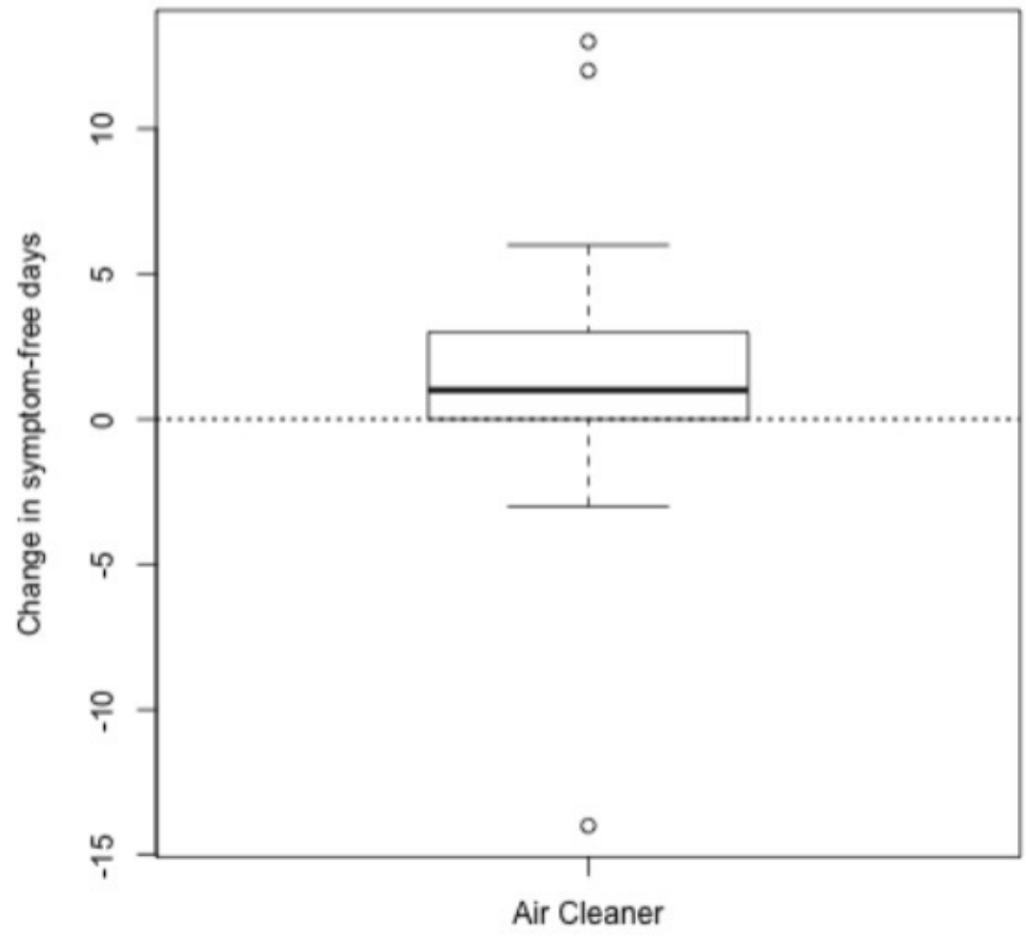


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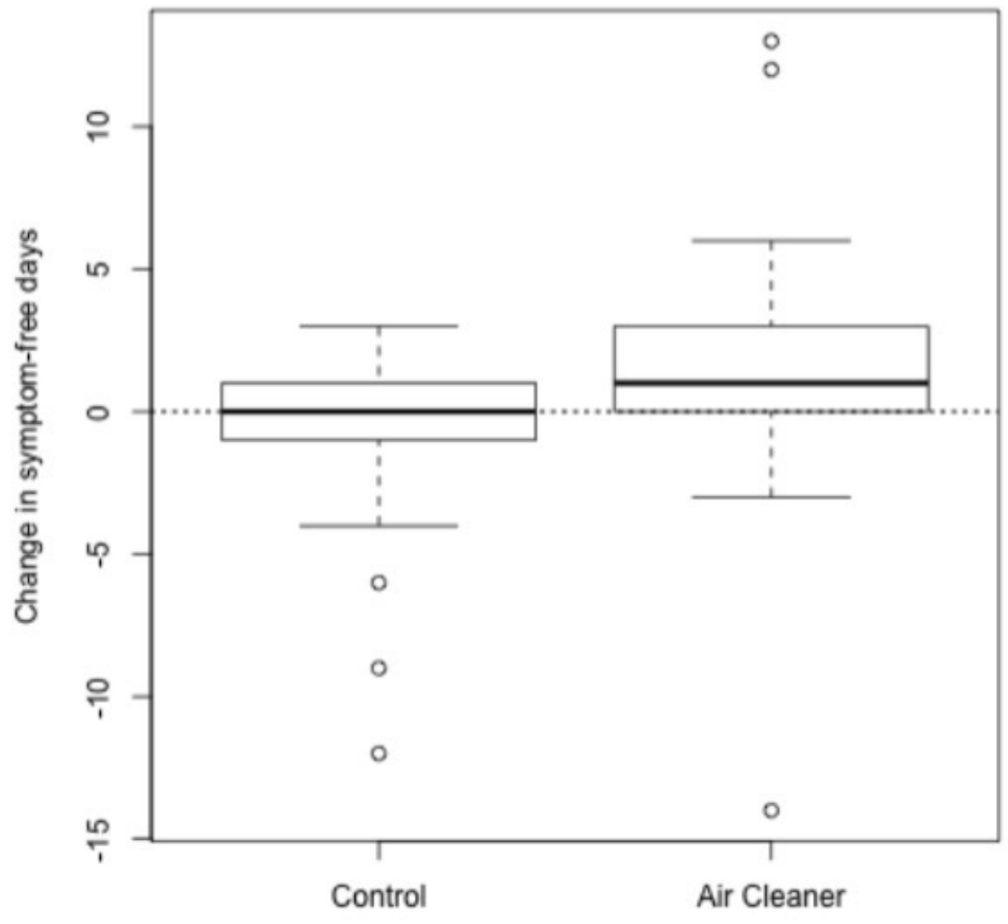



Reference: Butz AM, *et al.*, *JAMA Pediatrics*, 2011.

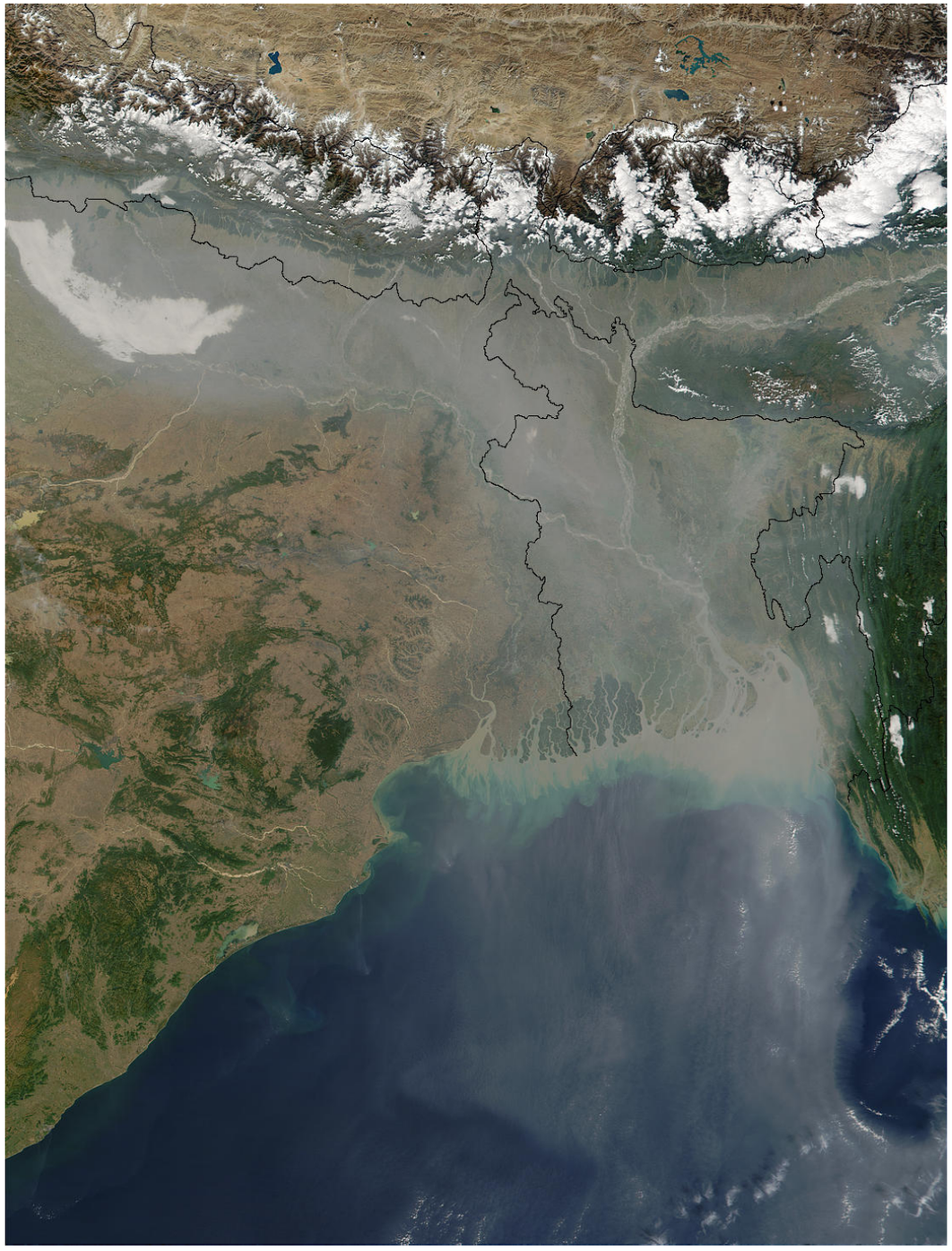
# Principles of Analytic Graphics

- **Principle 1: Show comparisons**
  - **Evidence for a hypothesis is always relatives another competing hypothesis**
  - **Always ask “Compared to What?”**
- **Principle 2: Show causality, mechanism, explanation, systematic structure**
  - **What is your causal framework for thinking about a question?**

# Principles of Analytic Graphics

Air quality standards in the U.S. concerns the long-term average level of fine particle pollution, also referred to as PM2.5

The standard says that the “annual mean, averaged over 3 years” cannot exceed 12 micrograms per cubic meter.



# Principles of Analytic Graphics

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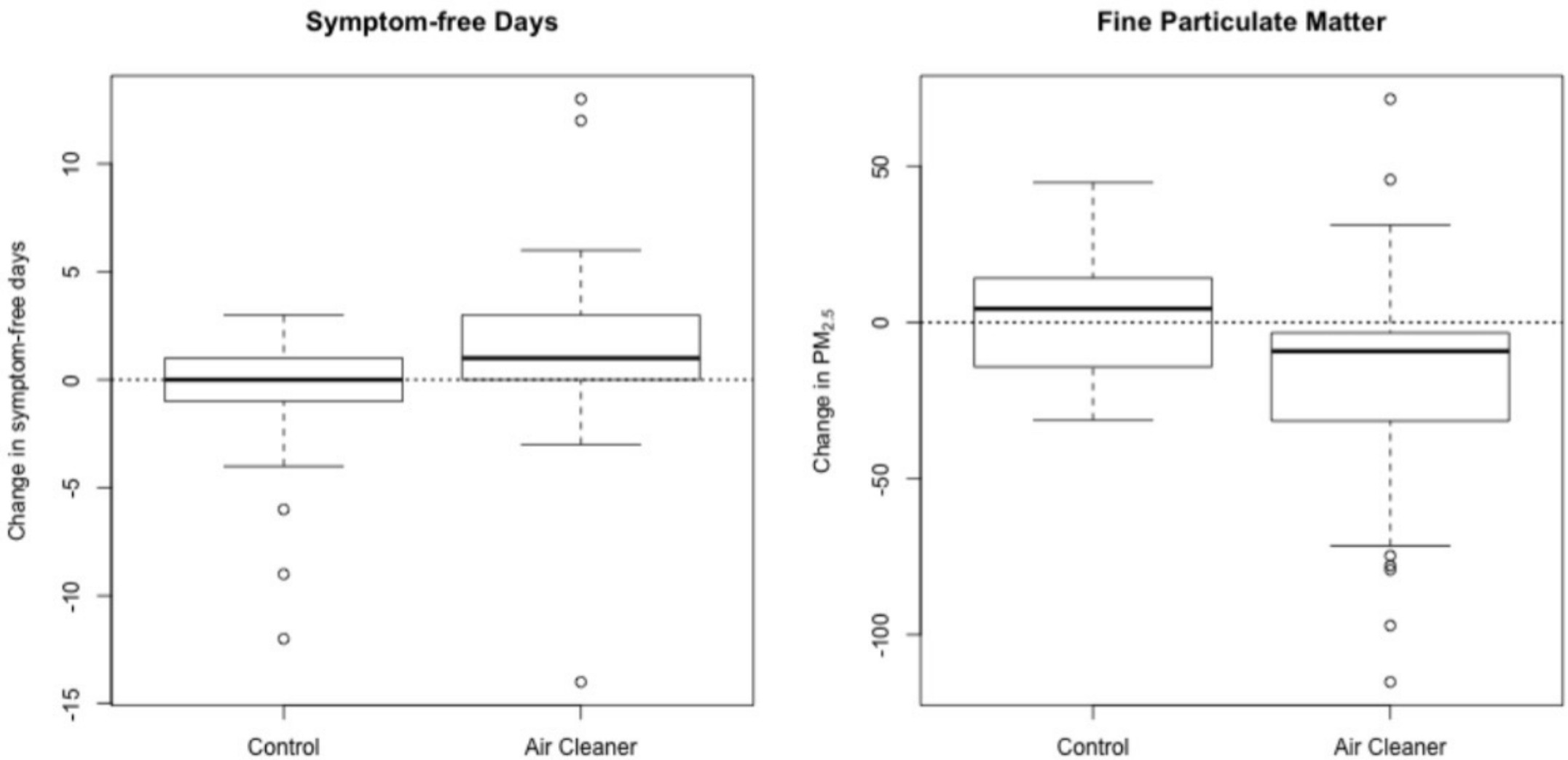


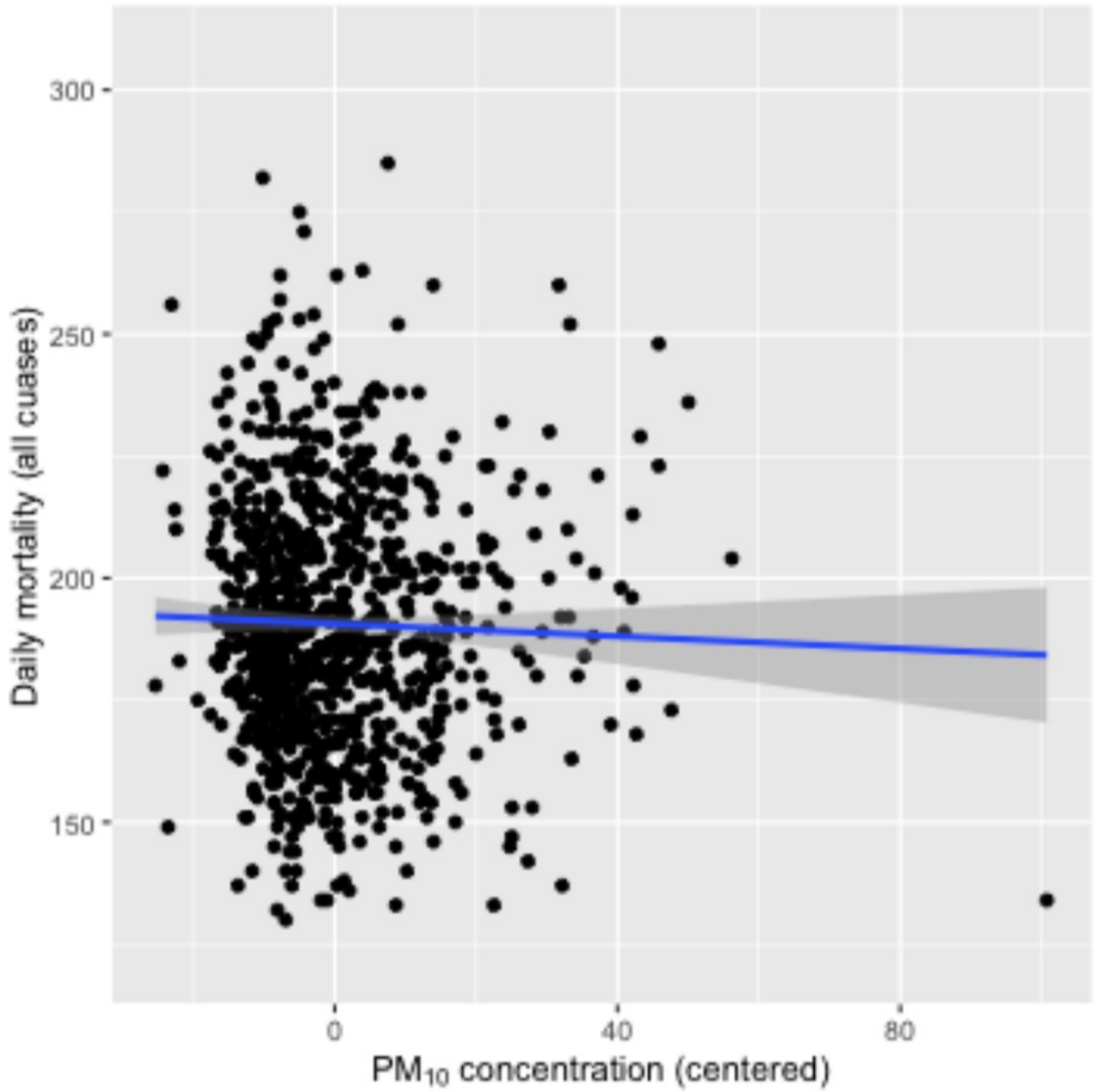

Reference: Butz AM, *et al.*, *JAMA Pediatrics*, 2011.

# Principles of Analytic Graphics

- **Principle 1: Show comparisons**
- **Principle 2: Show causality, mechanism, explanation, systematic structure**
- **Principle 3: Show multivariate data**
  - **Multivariate = more than 2  variables**
  - **The real world is multivariate**
  - **Need to “escape flatland"**

# Principles of Analytic Graphics

- **Principle 3: Show multivariate data**




**PM10 and mortality in New York City**

it **seems** that there is a **slight negative relationship between the two variables**.

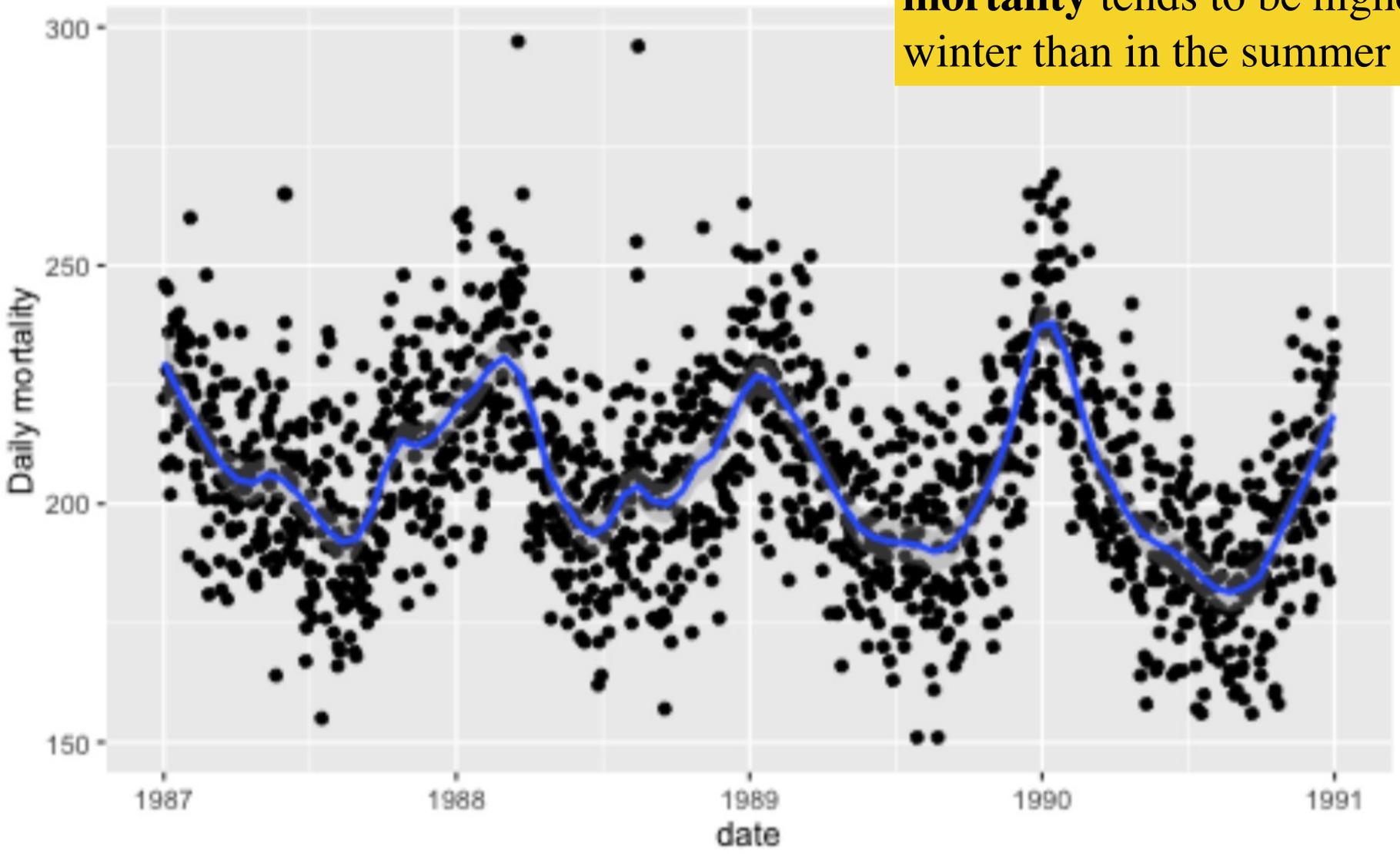
That is, higher daily average levels of PM10 appear to be associated with lower levels of mortality (fewer deaths per day).

Reference: Butz AM, *et al.*, *JAMA Pediatrics*, 2011.

# Principles of Analytic Graphics

- **Principle 3: Show multivariate data**

**mortality** tends to be higher in the winter than in the summer



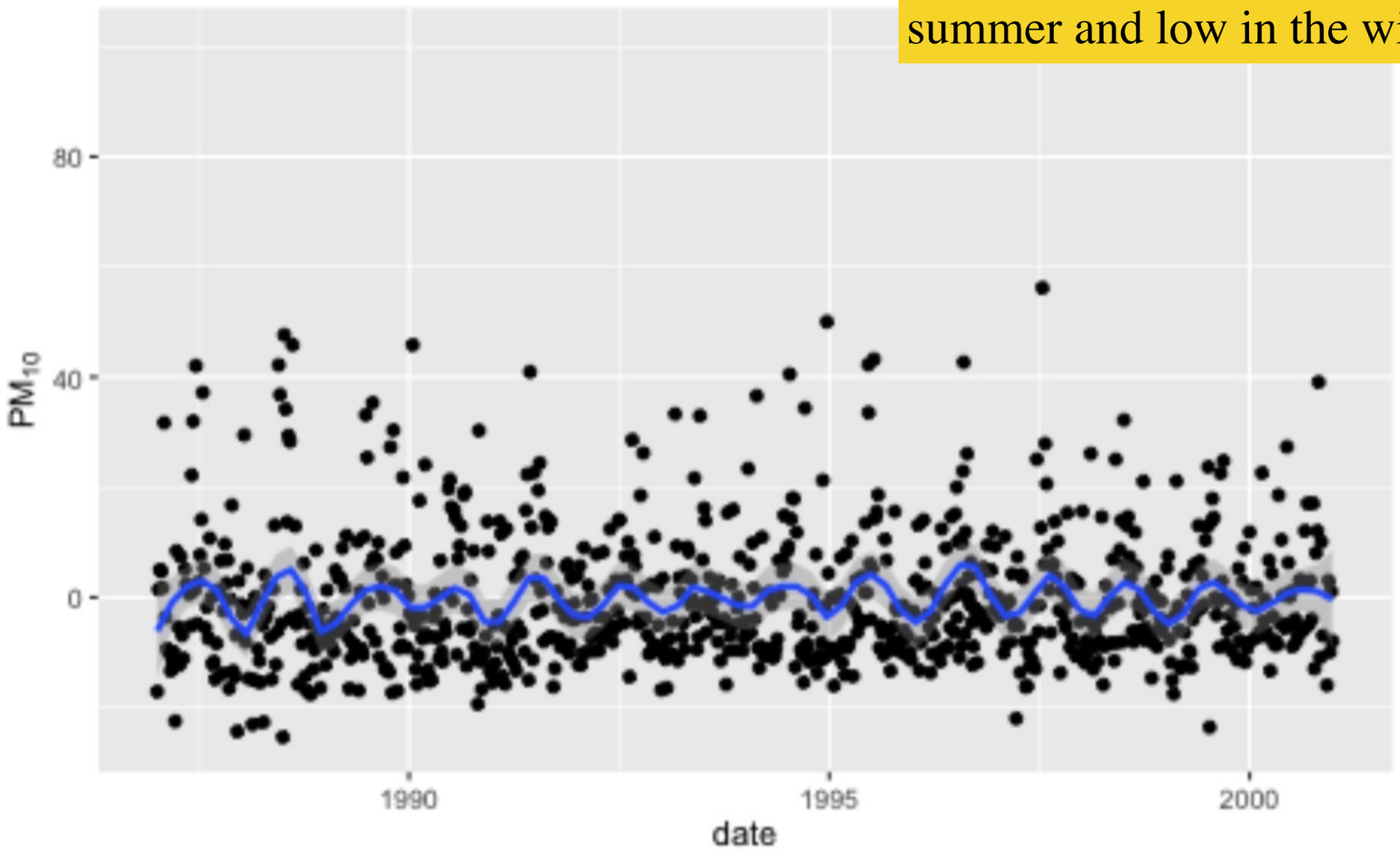

**Daily mortality in New York City**

Reference: Butz AM, *et al.*, *JAMA Pediatrics*, 2011.

# Principles of Analytic Graphics

- **Principle 3: Show multivariate data**

**PM10 levels** tend to be high in the summer and low in the winter.



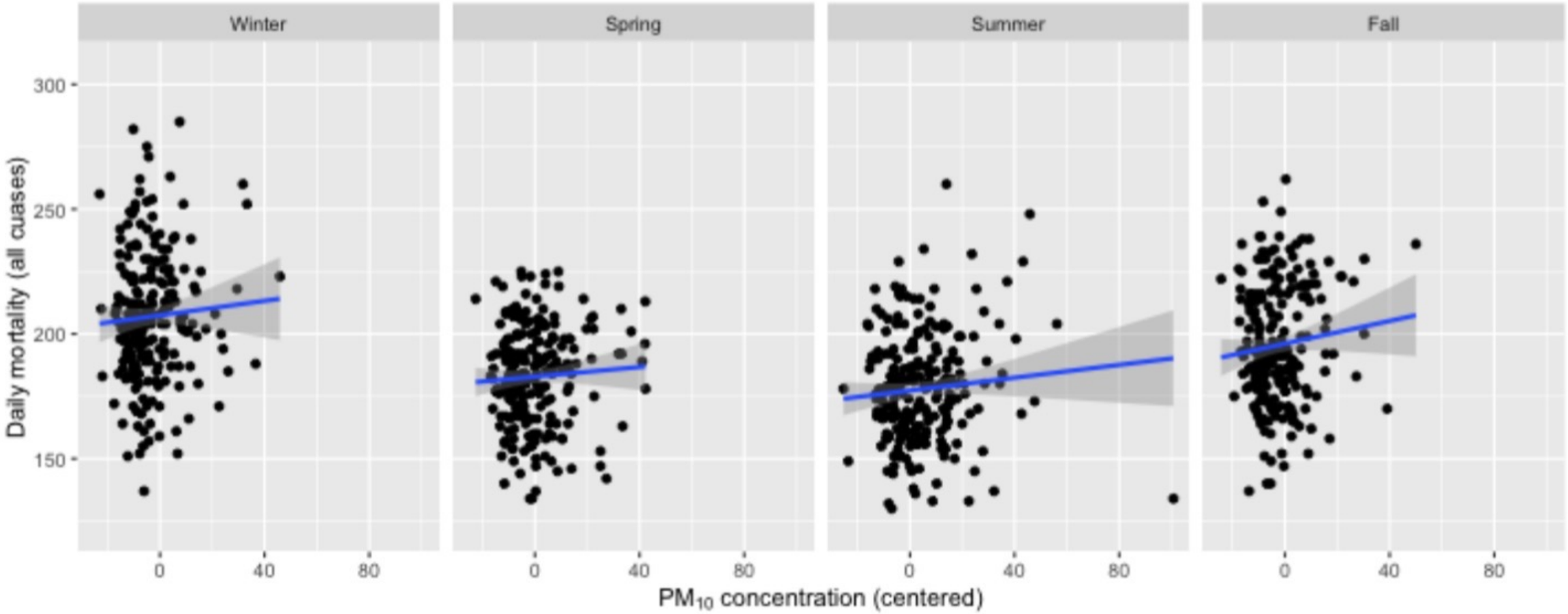

**Daily PM10 in New York City**

Reference: Butz AM, *et al.*, *JAMA Pediatrics*, 2011.

# Principles of Analytic Graphics

- **Principle 3: Show multivariate data**

There is a **slight positive** relationship between the two variables in each season




**PM10 and mortality in New York City by season**

Reference: Butz AM, *et al.*, *JAMA Pediatrics*, 2011.

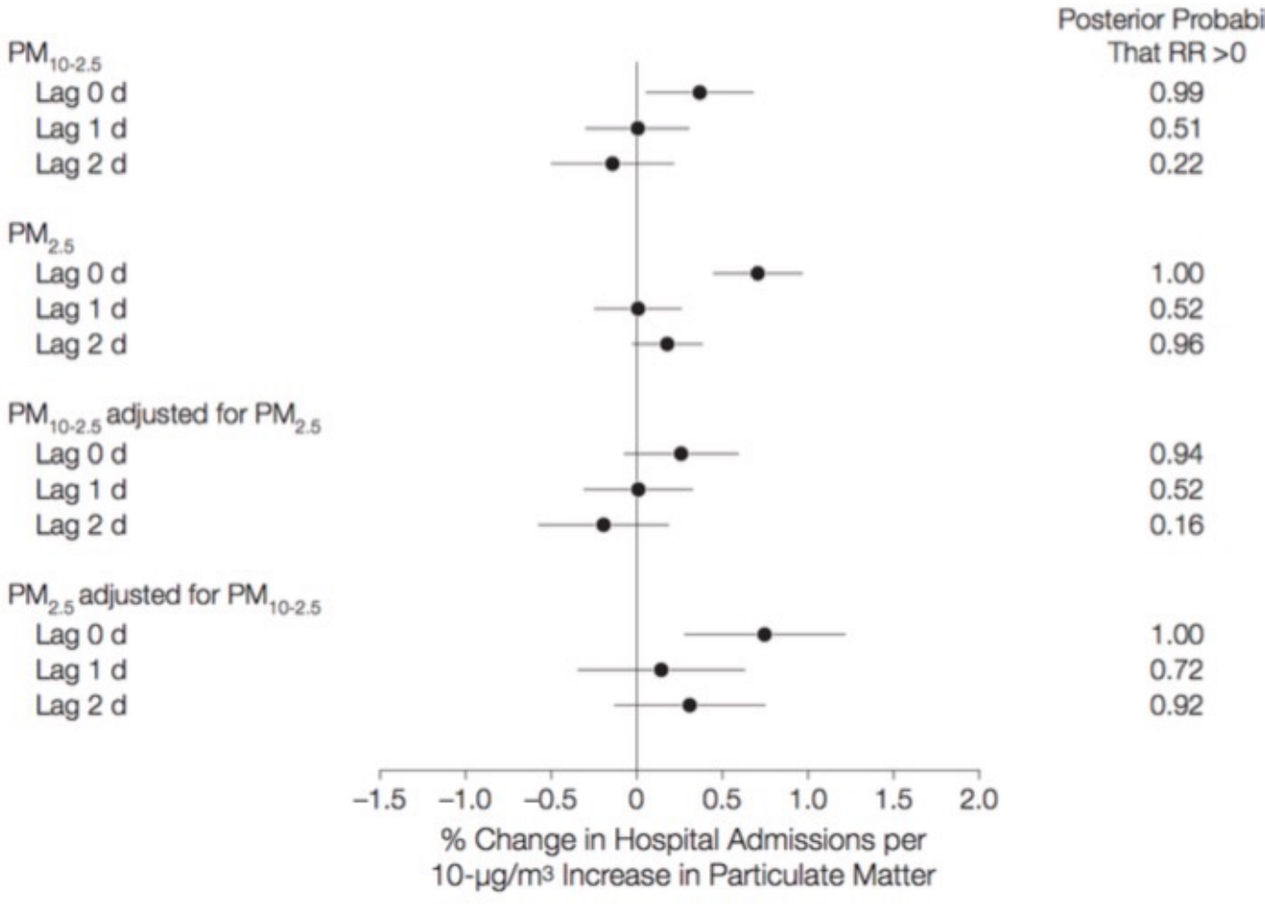
# Principles of Analytic Graphics

- **Principle 1: Show comparisons**
- **Principle 2: Show causality, mechanism, explanation, systematic structure**
- **Principle 3: Show multivariate data**
- **Principle 4: Integration of evidence**
  - **Completely integrate words, numbers, images, diagrams**
  - **Data graphics should make use of many modes of data presentation**
  - **Don’t let the tool drive the analysis**

# Principles of Analytic Graphics

- **Principle 4: Integration of evidence**

**Figure 2.** Percentage Change in Emergency Hospital Admissions Rate for Cardiovascular Diseases per a 10-μg/m³ Increase in Particulate Matter




Estimates are on average across 108 counties. $PM_{2.5}$ indicates particulate matter is 2.5 μm or less in aerodynamic diameter; $PM_{10}$, particulate matter is 10 μm or less in aerodynamic diameter; $PM_{10-2.5}$, particulate matter is greater than 2.5 μm and 10 μm or less in aerodynamic diameter; RR, relative risk. Error bars indicate 95% posterior intervals.

Ideally, a plot would have all of the necessary descriptions attached to it.

You might think that this level of documentation should be reserved for "final" plots as opposed to exploratory ones, but it's good to get in the habit of documenting your evidence sooner rather than later.

Reference: Butz AM, *et al.*, *JAMA Pediatrics*, 2011.

# Principles of Analytic Graphics

- **Principle 1: Show comparisons**
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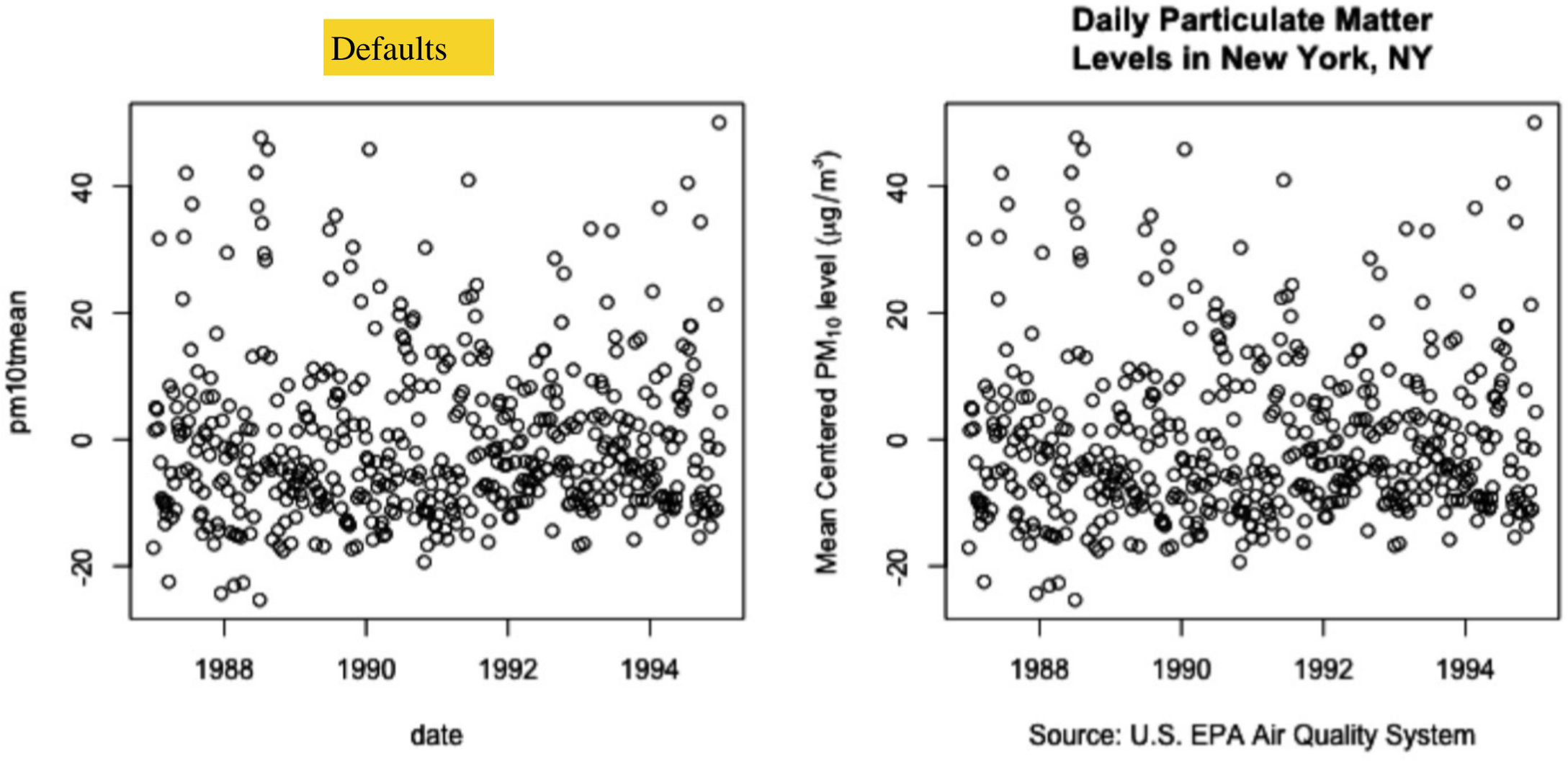
- **Principle 3: Show multivariate data**
- **Principle 4: Integration of evidence**
- **Principle 5: Describe and document the evidence with appropriate labels, scales, sources**

# Principles of Analytic Graphics

- **Principle 5: Describe and document the evidence with appropriate labels, scales, sources**




Reference: Butz AM, *et al.*, *JAMA Pediatrics*, 2011.

# Principles of Analytic Graphics

- **Principle 1: Show comparisons**
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- **Principle 3: Show multivariate data**
- **Principle 4: Integration of evidence**
- **Principle 5: Describe and document the evidence with appropriate labels, scales, sources**
- **Principle 6: Content is King**
  - **Analytical presentations ultimately stand or fall depending on the quality, relevance, and integrity of their content.**

# Principles of Analytic Graphics

- **Principle 1: Show comparisons**
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- **Principle 3: Show multivariate data**
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Edward Tufte (2006). *Beautiful Evidence*, Graphics Press LLC.

www.edwardtufte.com

Reference: Butz AM, *et al.*, *JAMA Pediatrics*, 2011.