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

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The Visualization Process in Detail

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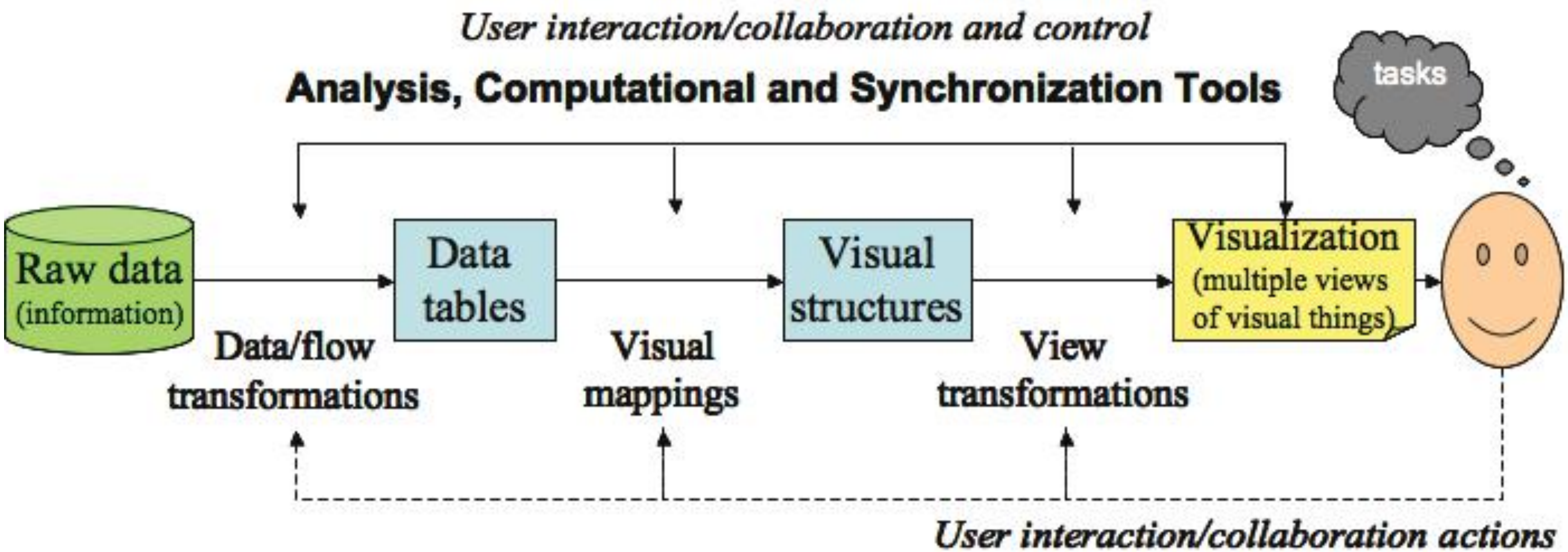

The Visualization Process in Detail

- **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**
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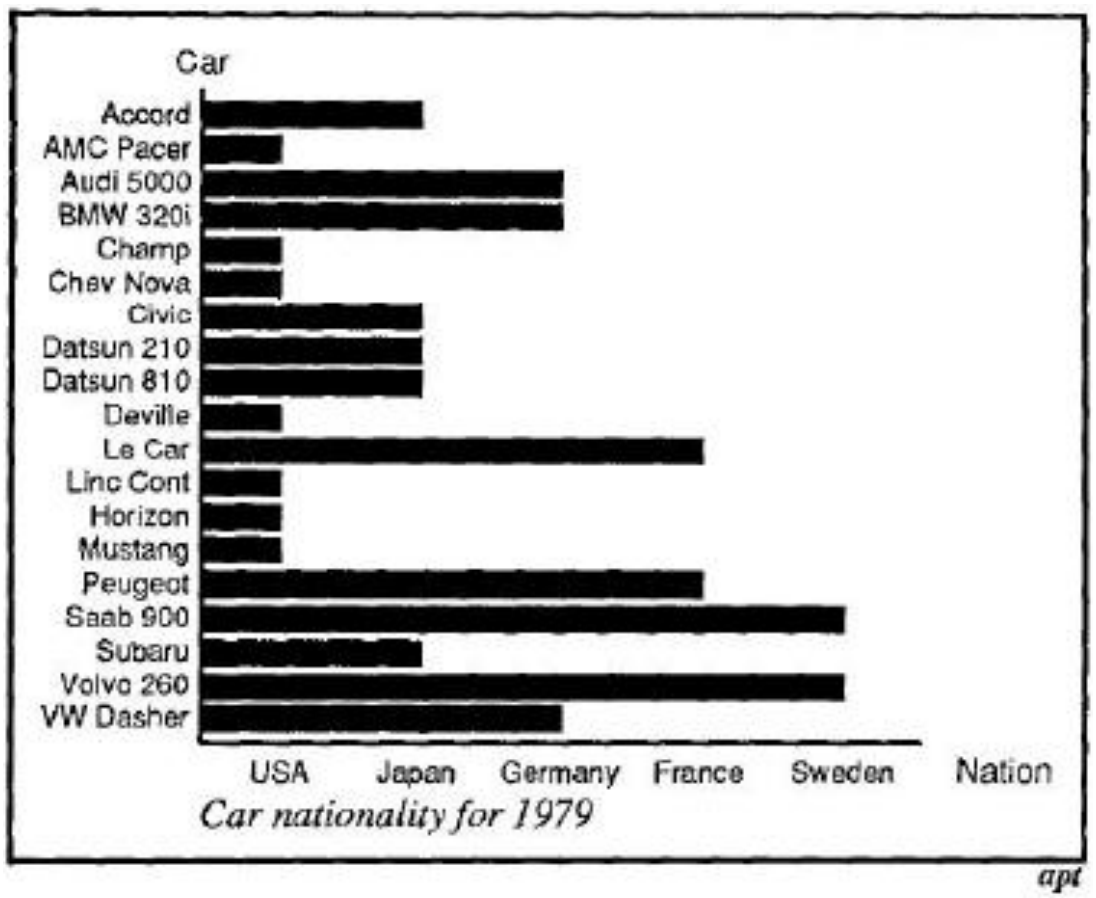
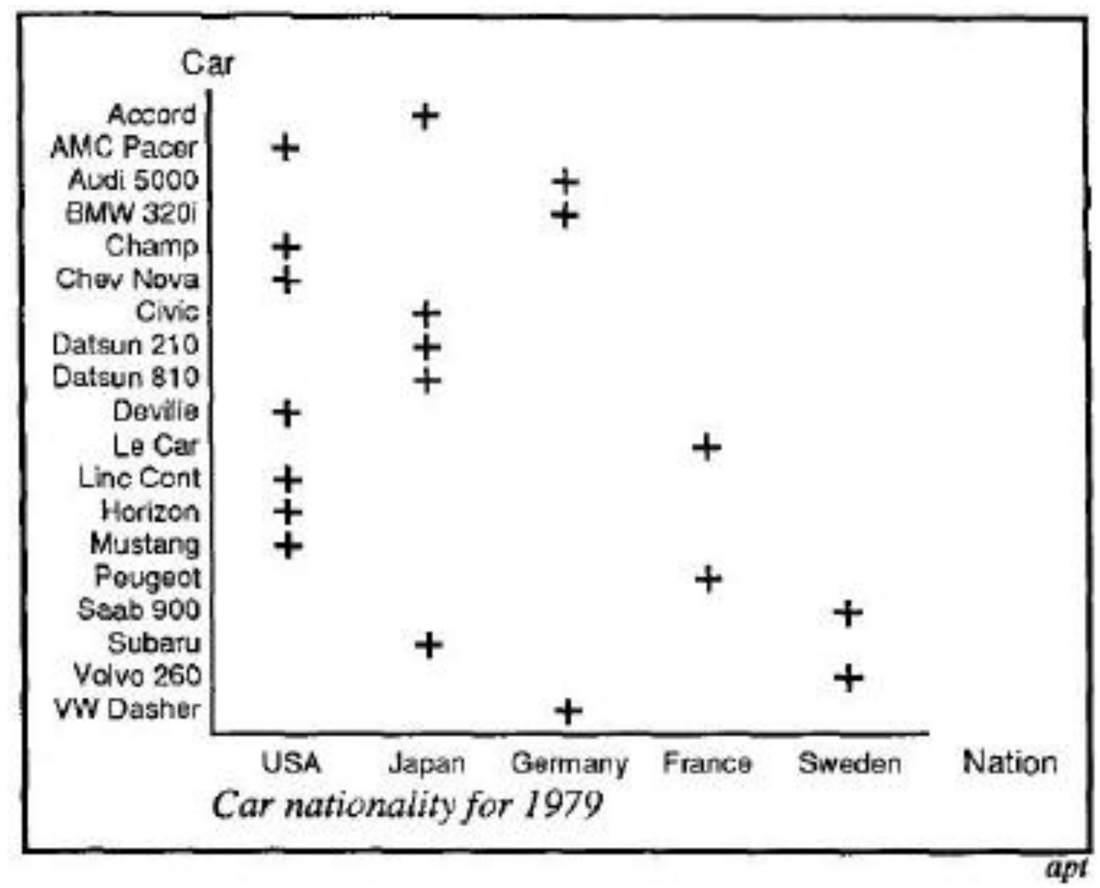


(a)



(b)

Figure 4.2. (a) Poor use of a bar chart. (b) Better use of a scatterplot.

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  - **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.

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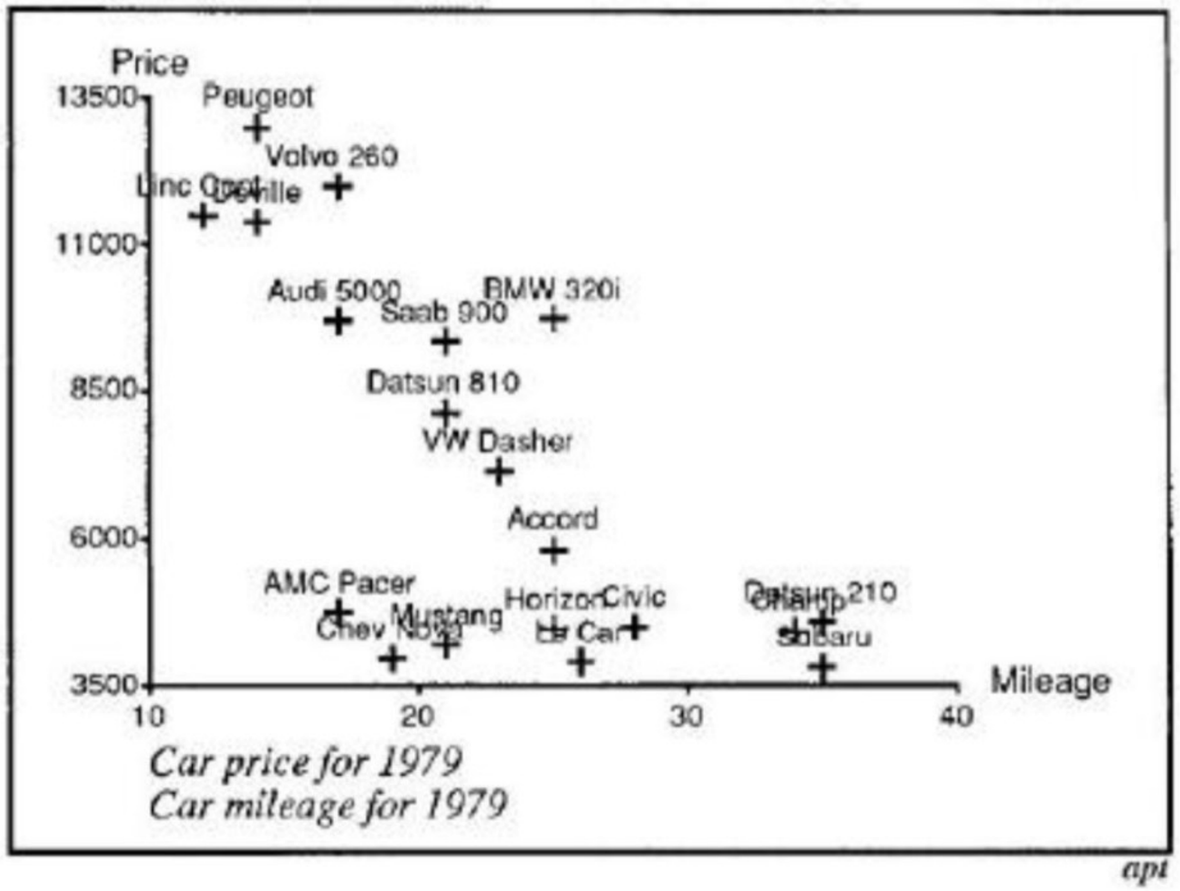
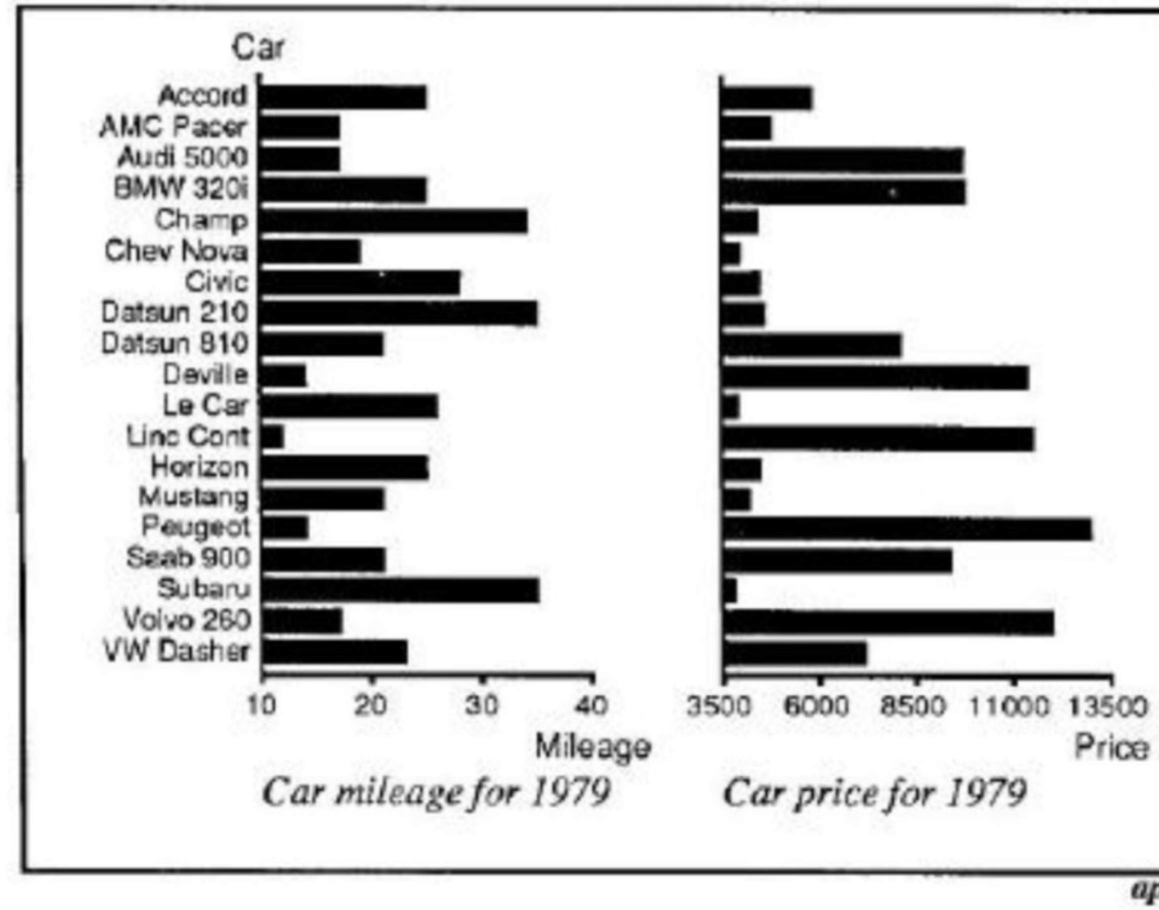
  - **If M_{eff} is large (close to 1), then both the interpretation and the rendering time are very small.**

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

Task: presenting the car prices and mileage for 1979

M_{exp}(a) ≈ M_{exp} (b)

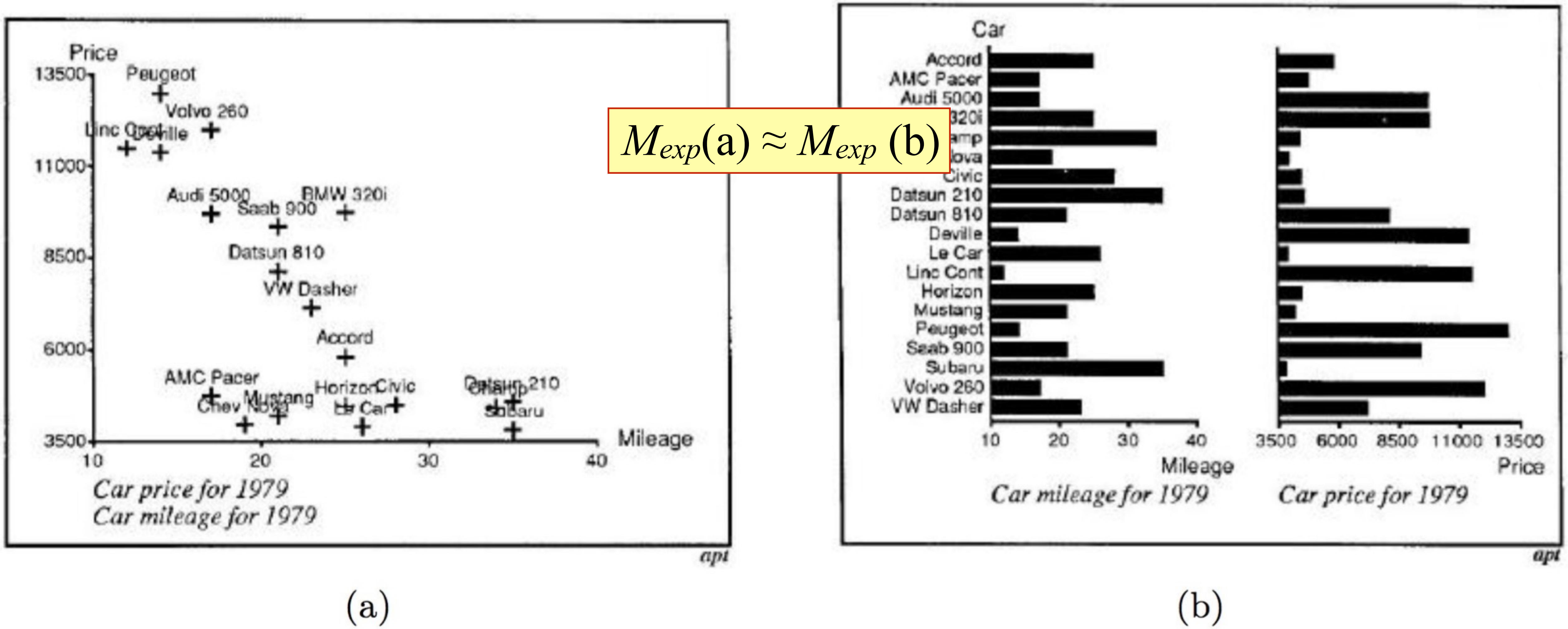


Figure 4.3. (a) Scatterplot using plus as symbol provides good query-answering capabilities, but is slower for simple one-variable queries. (b) Bar charts clearly display cost and mileage, but don't provide as much flexibility in answering some other queries.

Semiology of Graphical Symbols

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- **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.**

Symbols and Visualizations

(a)

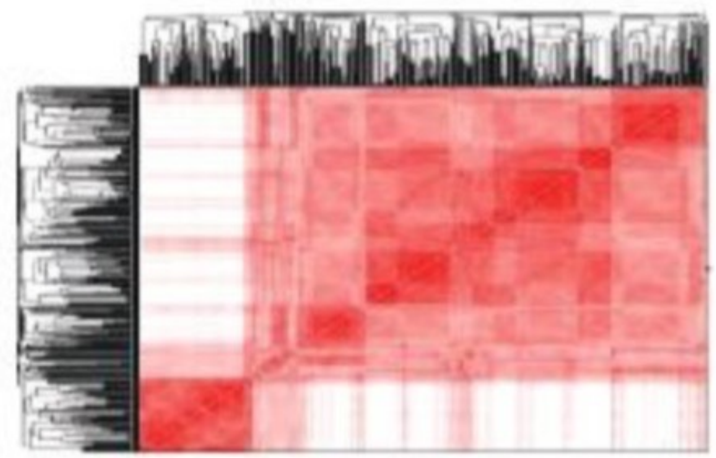
(a) Symbol with obvious meaning.

- **(a) is universally recognizable.**

  Such images become preattentively recognizable with experience.

- **(a) is perceived in one step, and that step is simply an association of its meaning**

Symbols and Visualizations



(b)

(b) Representation with complex meaning.

- (b) requires a great deal of attention to understand;
- the first steps are to recognize patterns within (b) and identify the major elements of the image;

  with the second identifying the various relationships between these.

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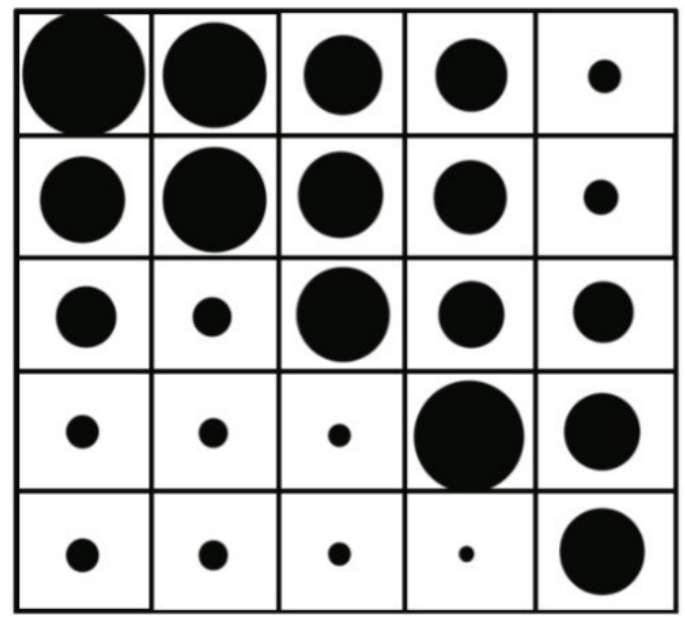
    - **If it does not, then it is an artifact of the selected representation (and is disturbing).**
  - **Similarly, any perceived pattern variation in the graphic or symbol cognitively implies such a similar variation in the data.**
  - **Any perceived order in graphic symbols is directly correlated with 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.**

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- 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

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- 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**.
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- 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

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

It is important to remember that the result will **be an image** that is to be interpreted by the human visual system

Eight visual variables: Position

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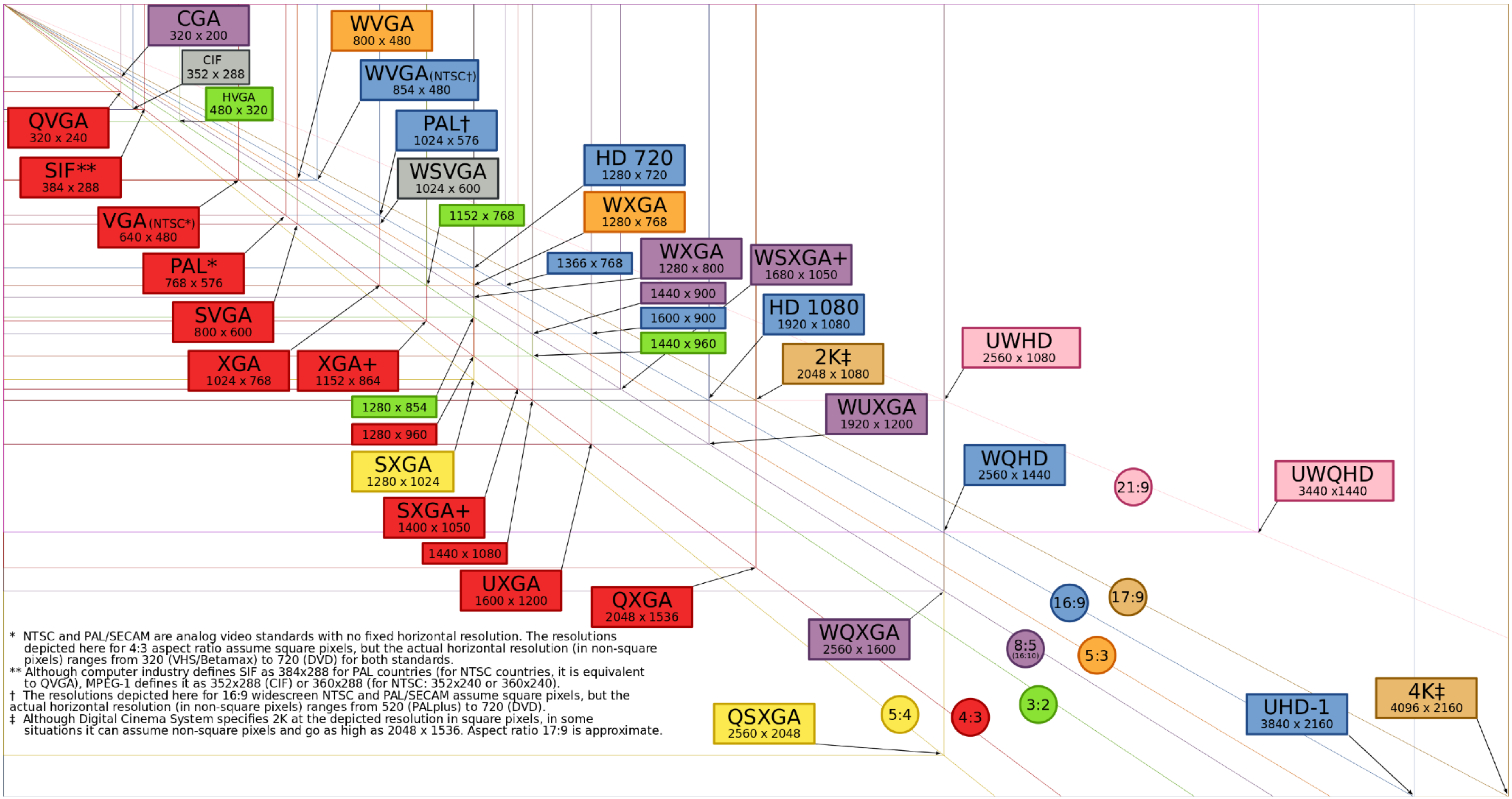
  - **Worst case** positioning scheme maps all graphics to the exact **same position**
  - **Best positioning** scheme maps **each graphic to unique positions**, such that all the graphics can be seen with no overlaps.

Eight visual variables: Screen resolution



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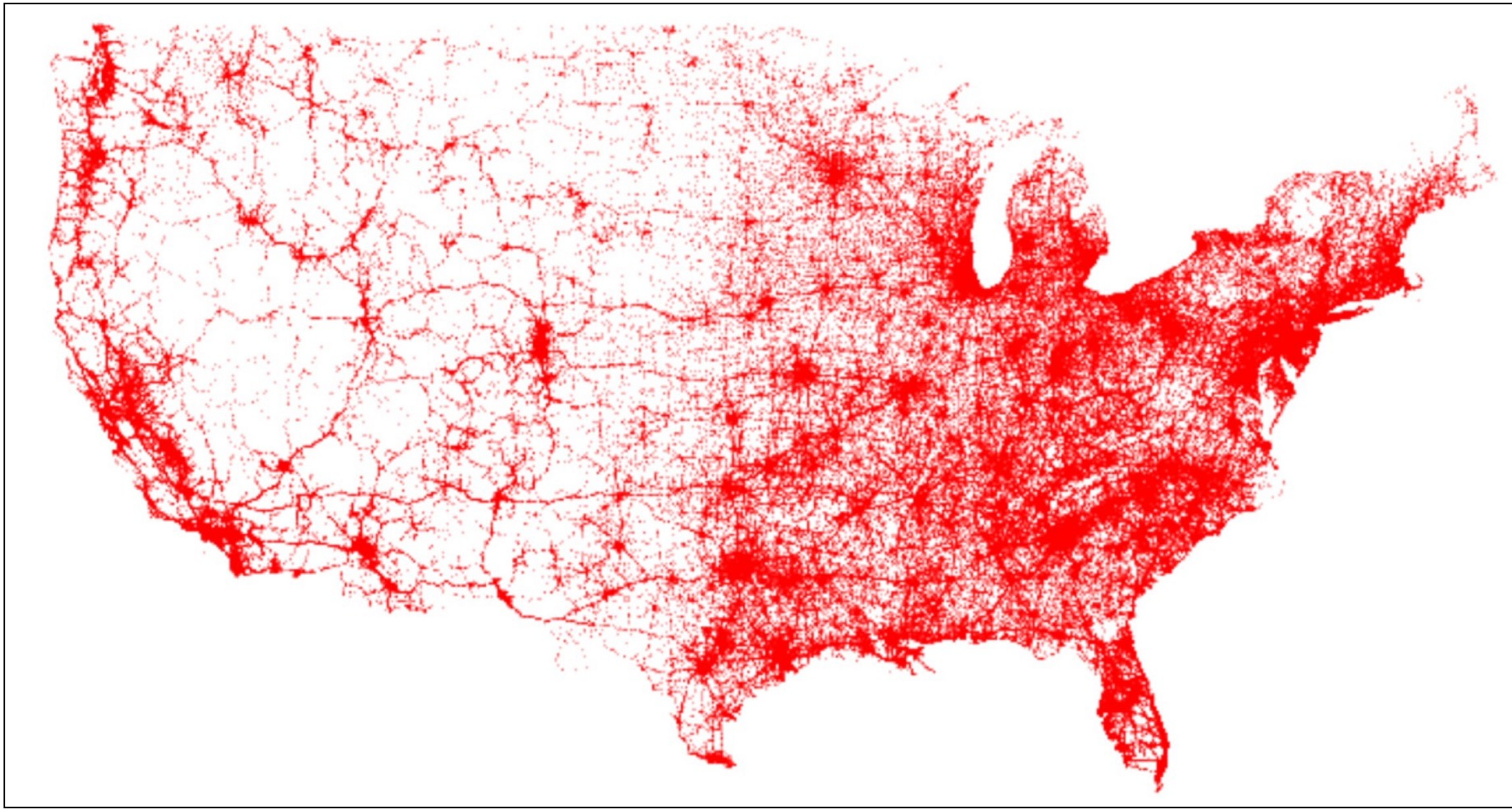
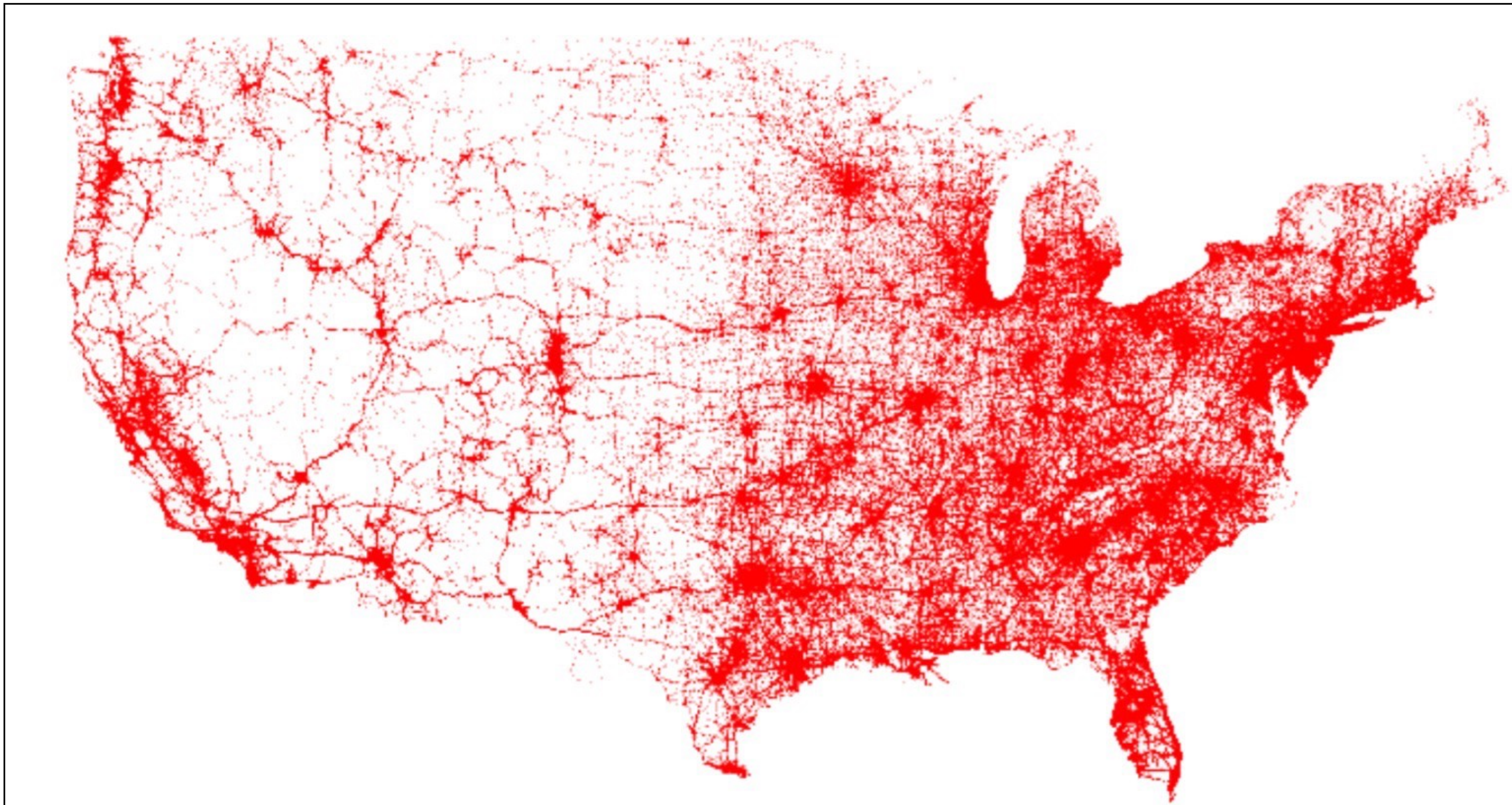
- **450.710 geo-referenced accidents between 2001 and 2013 in US**

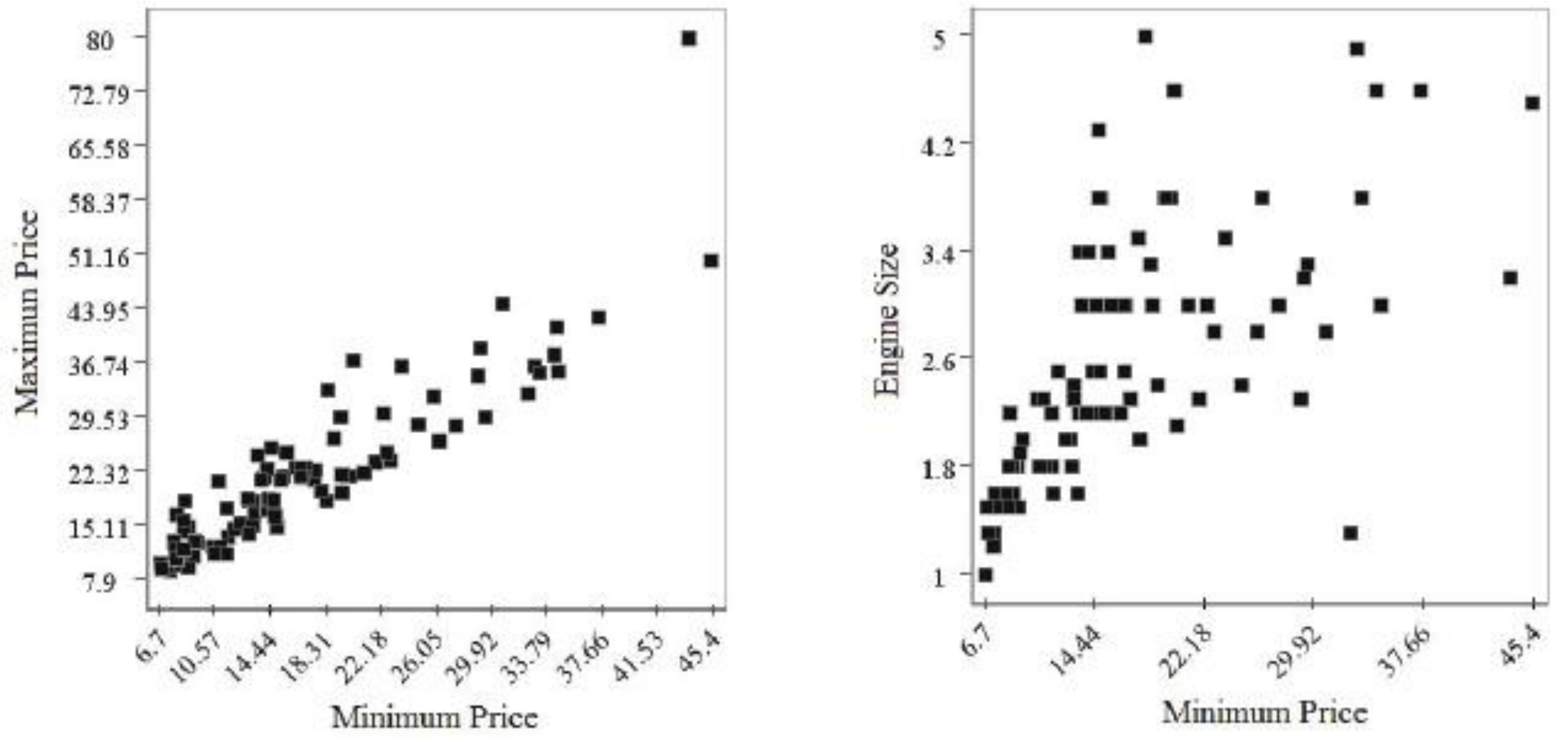


Eight visual variables: Screen resolution

- **Preprocessed data: 53% of items from original data set**



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.

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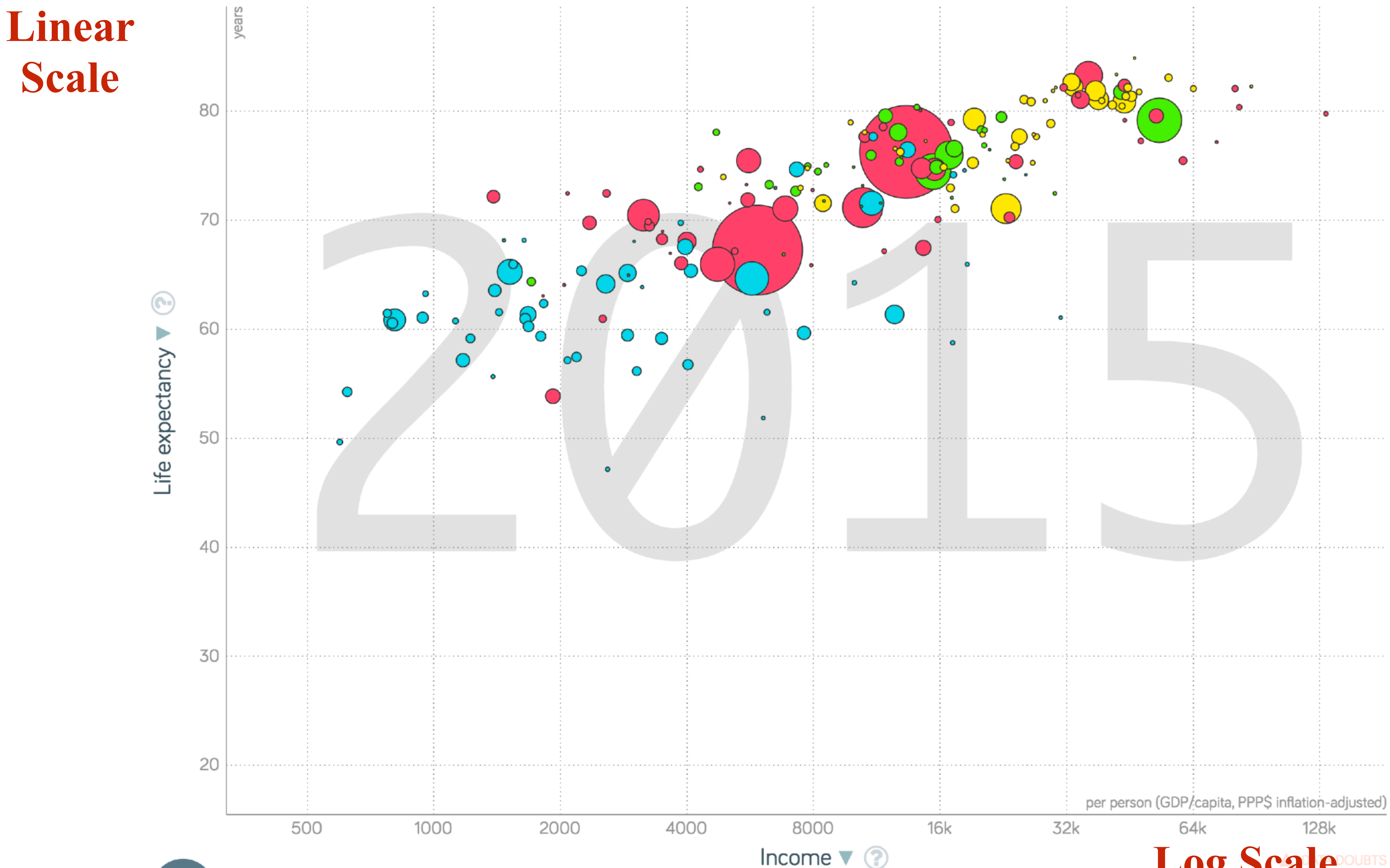

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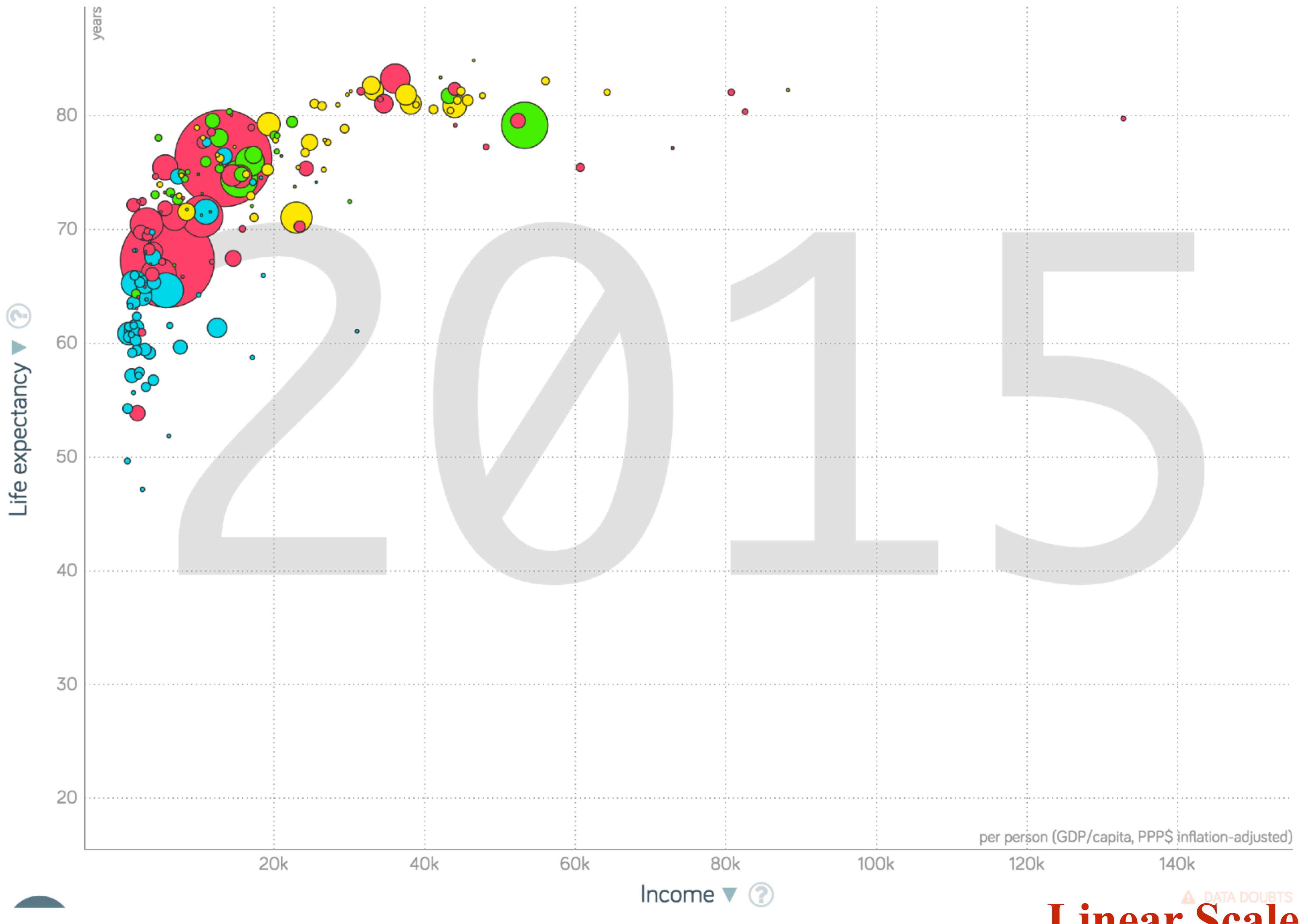
Linear Scale



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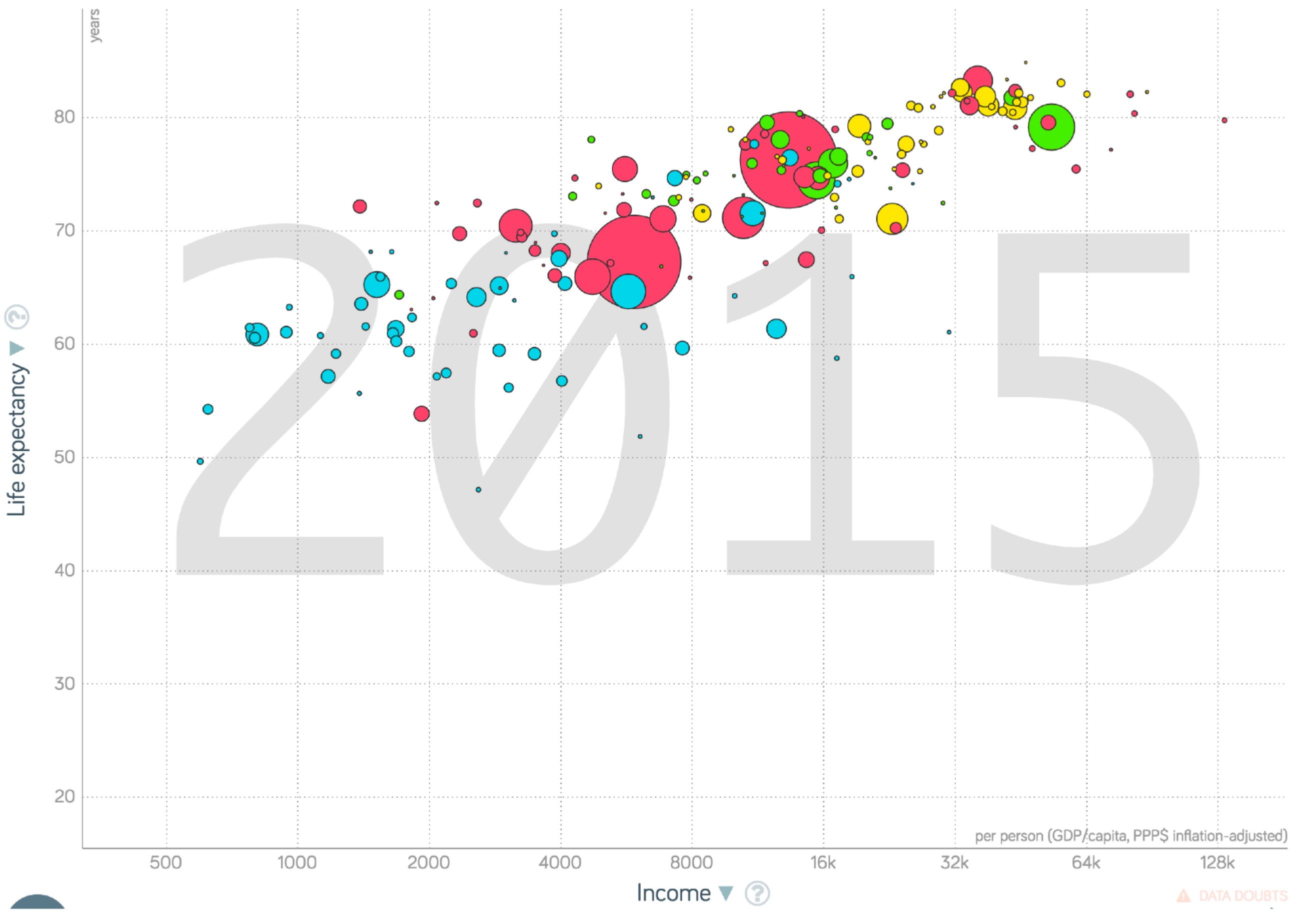
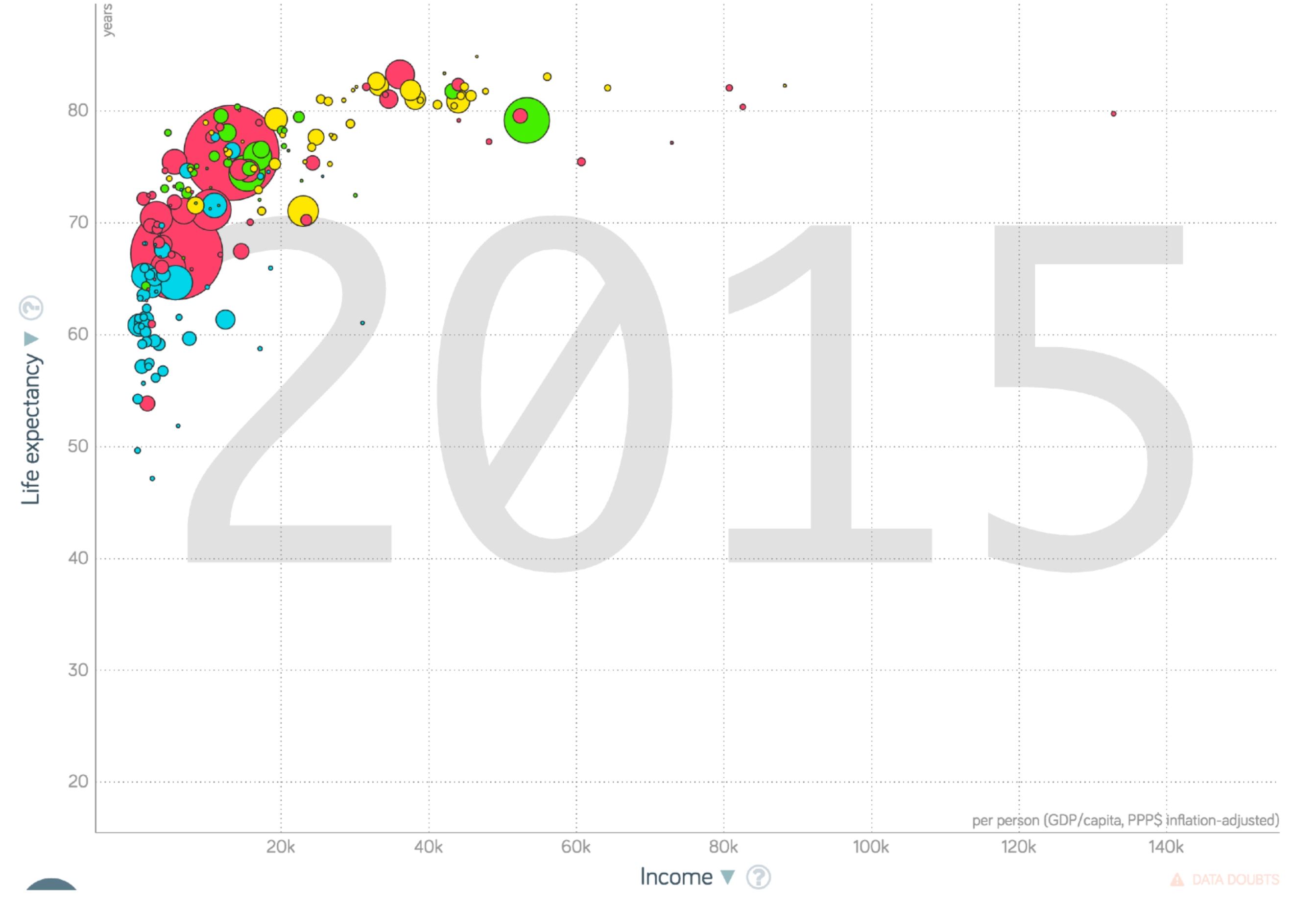


Log Scale



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

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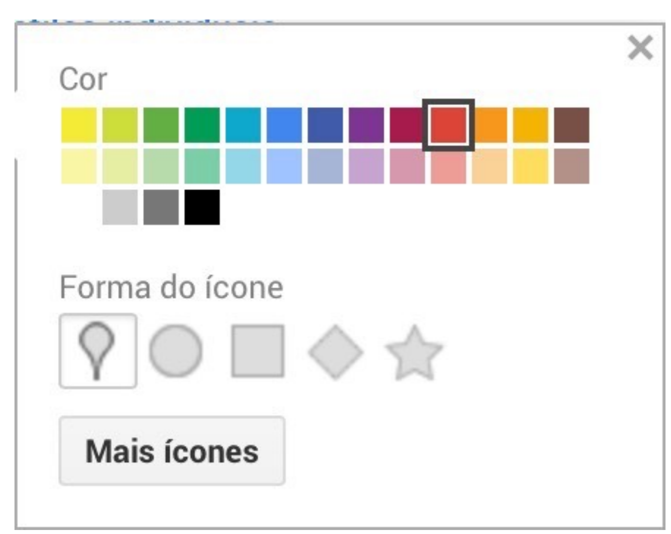
- **Example with google maps**



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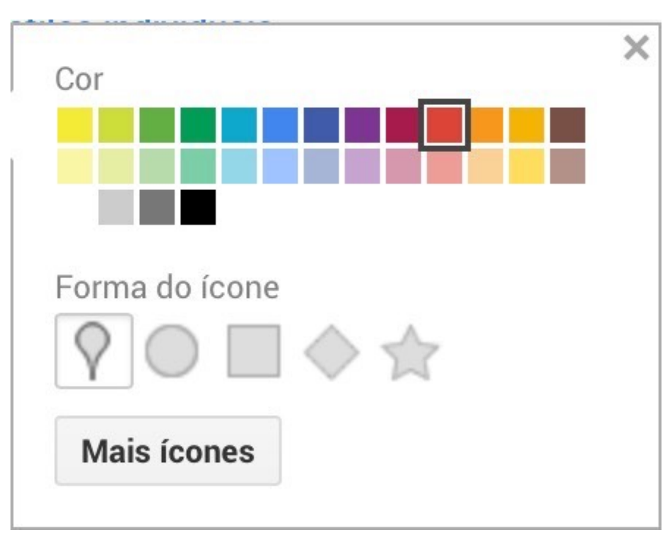
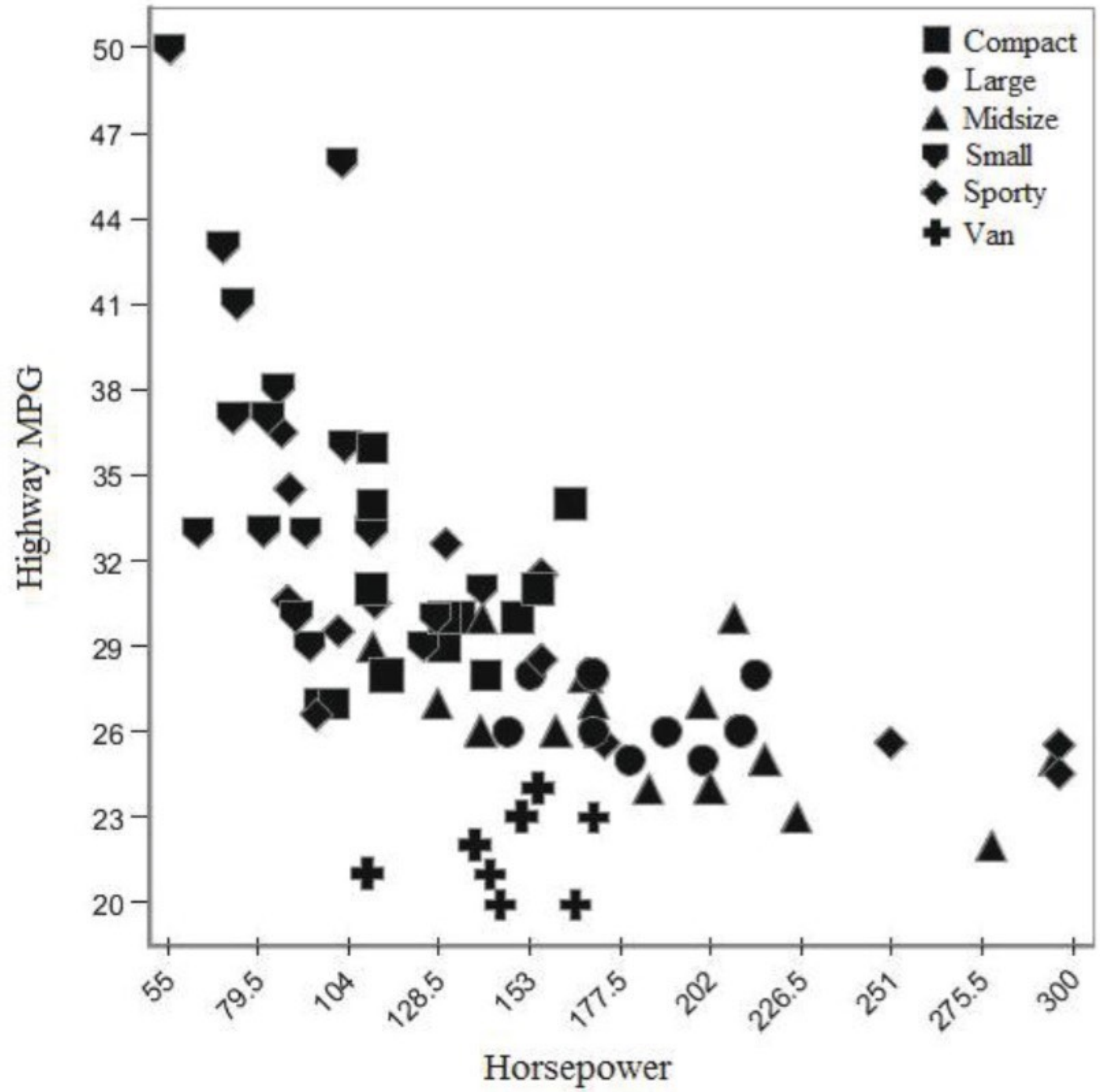


- When using marks, it is important to consider how well one mark can be differentiated from other marks

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.

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

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

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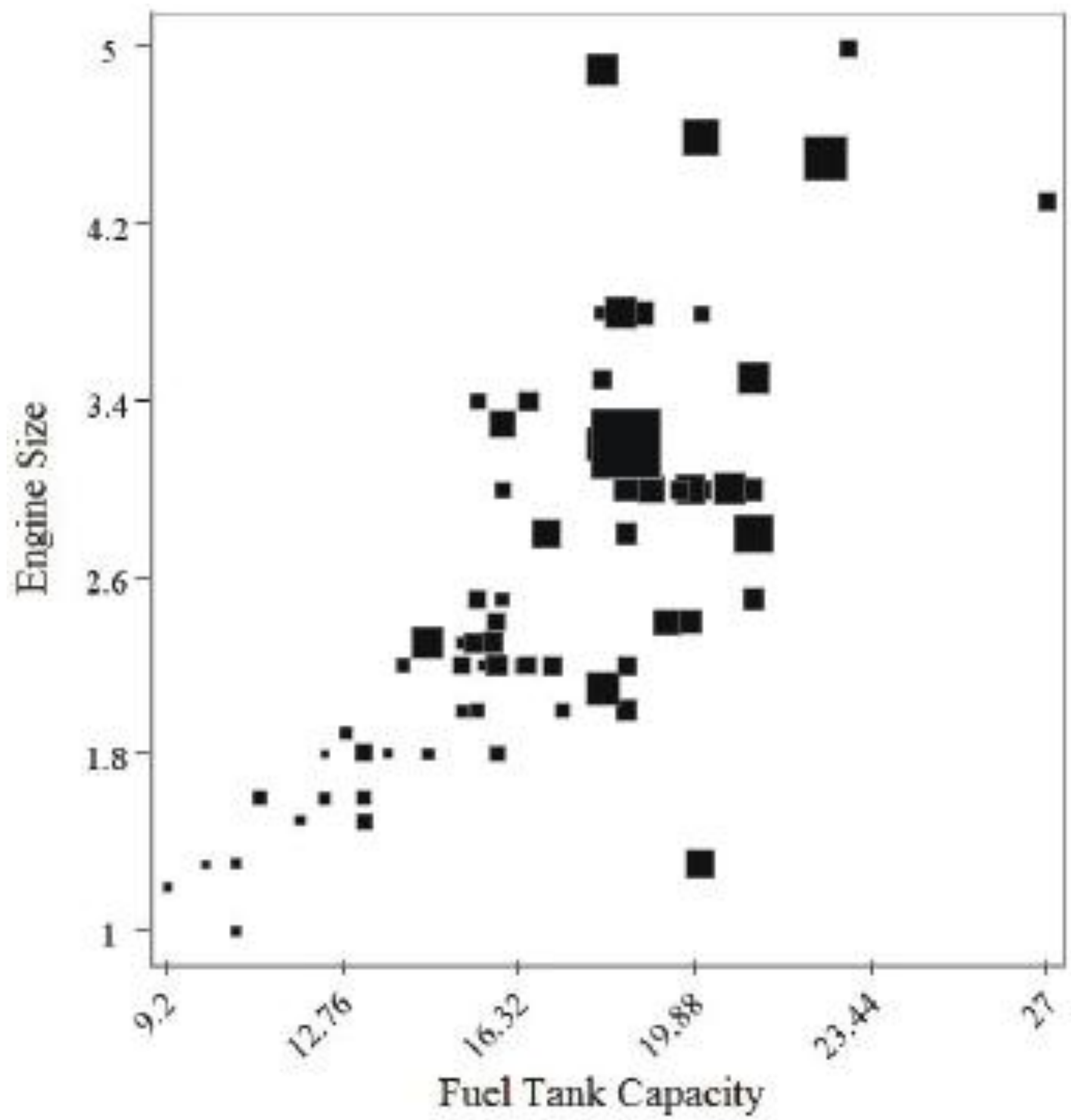
Example sizes to encode data.

- 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.

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.

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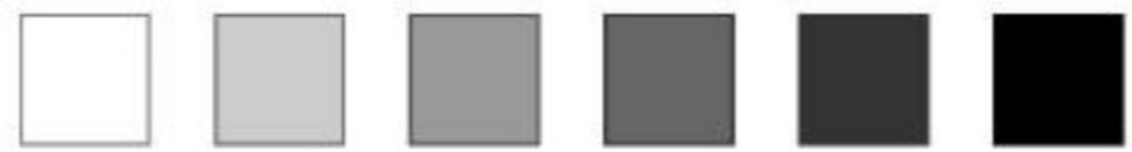
Eight visual variables: Brightness (ou luminance)

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



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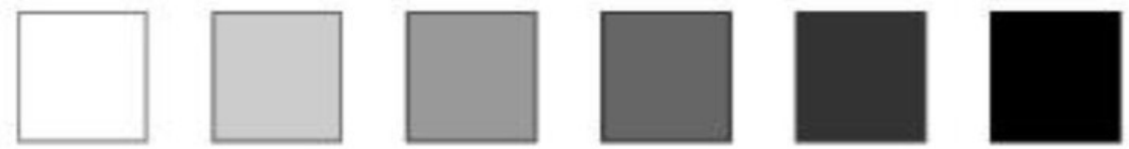

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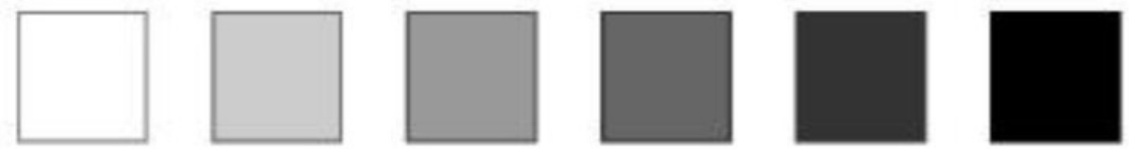

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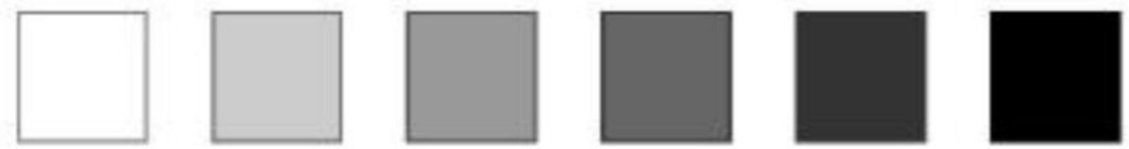

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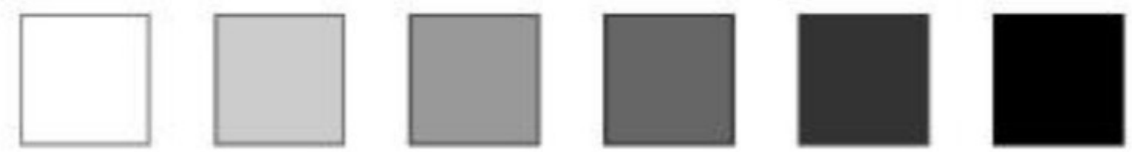
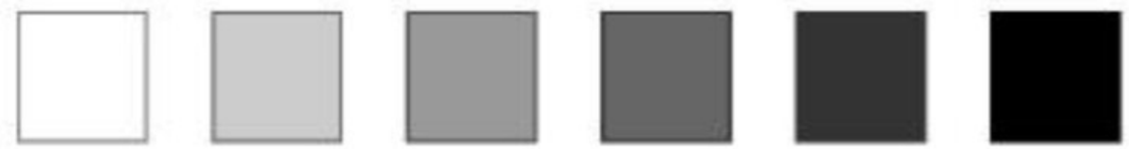


Brightness scale for mapping values to the display.

- **While it is possible to use the complete numerical range of brightness values, human perception cannot distinguish between all pairs of brightness values.**

Eight visual variables: Brightness (ou luminance)

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

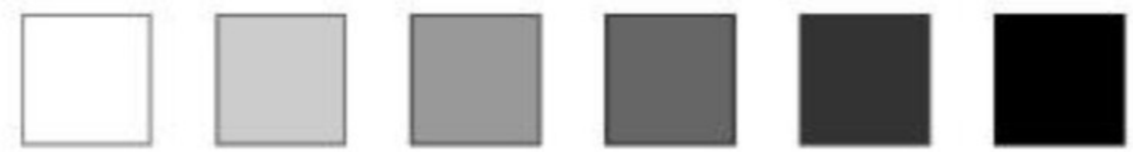


Brightness scale for mapping values to the display.

- **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,**

Eight visual variables: Brightness (ou luminance)

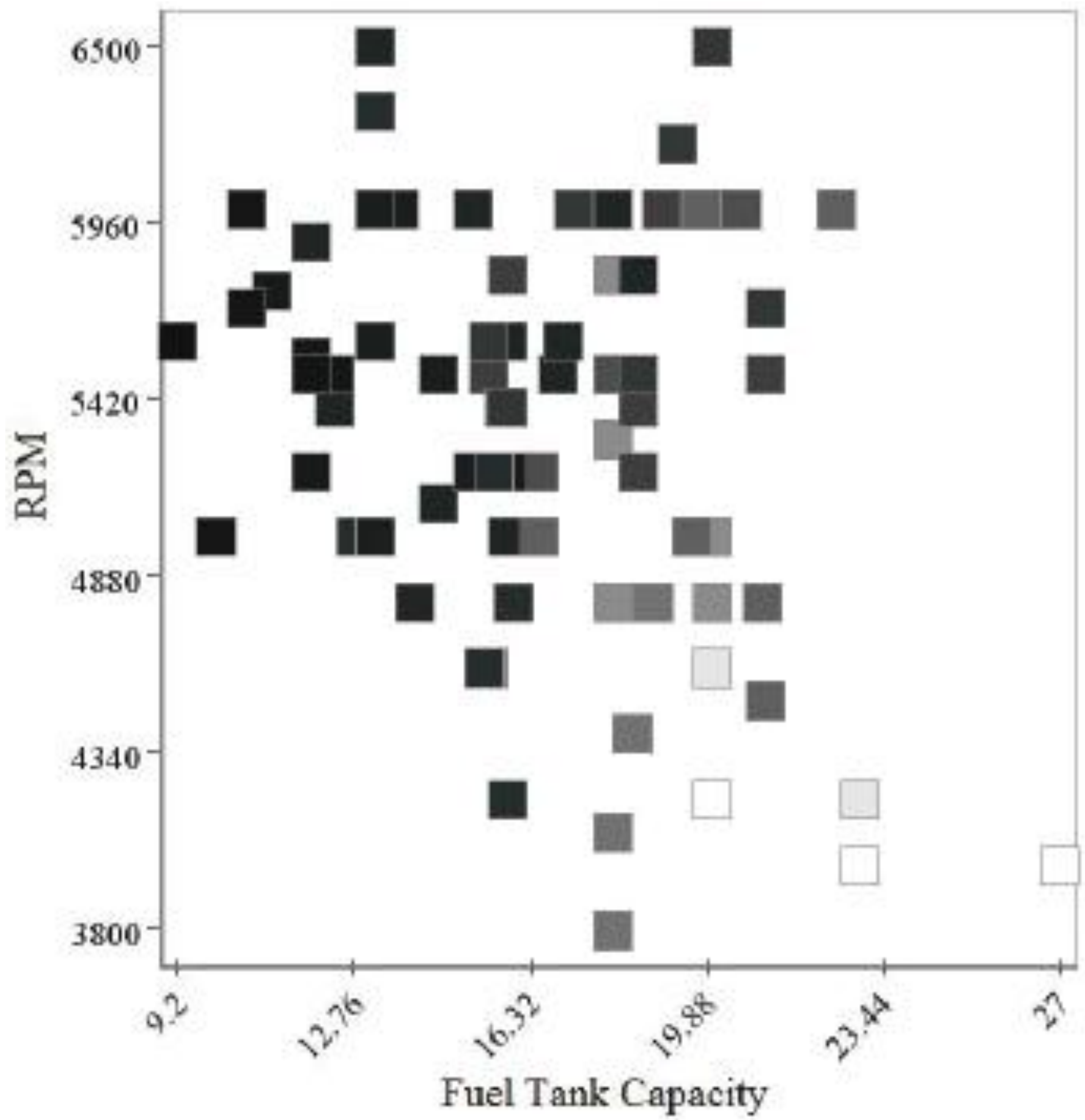
- **Brightness is the second visual variable used to modify marks to encode additional data variables.**



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.**

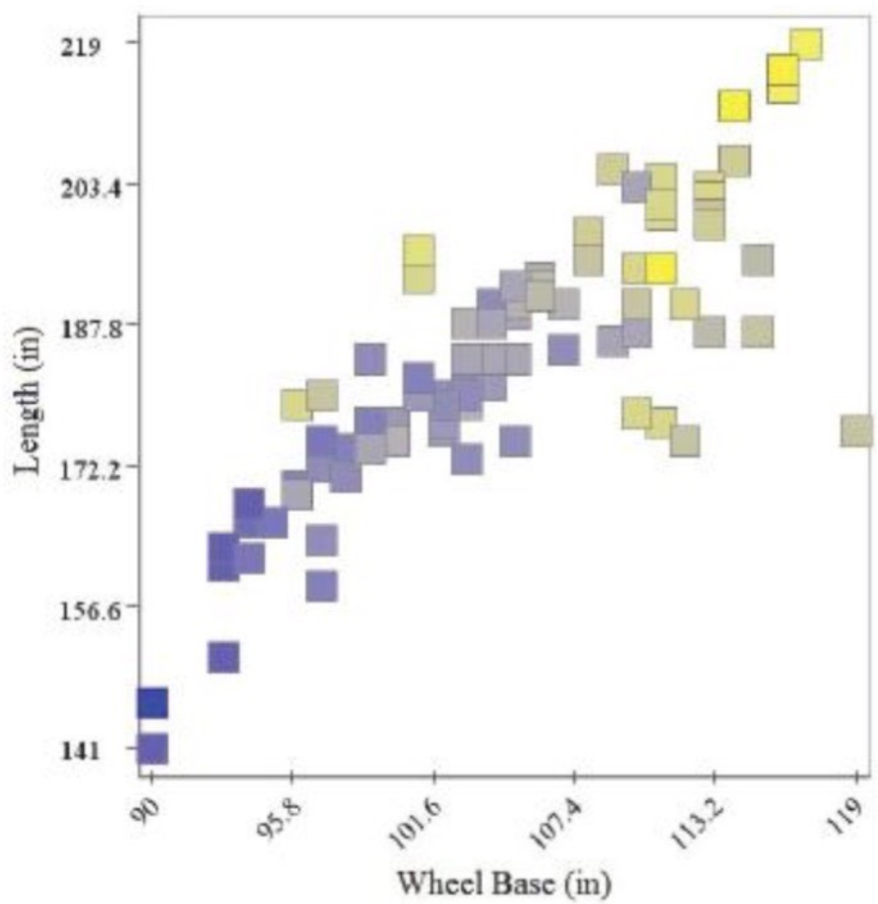
Eight visual variables: Brightness (ou luminance)



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

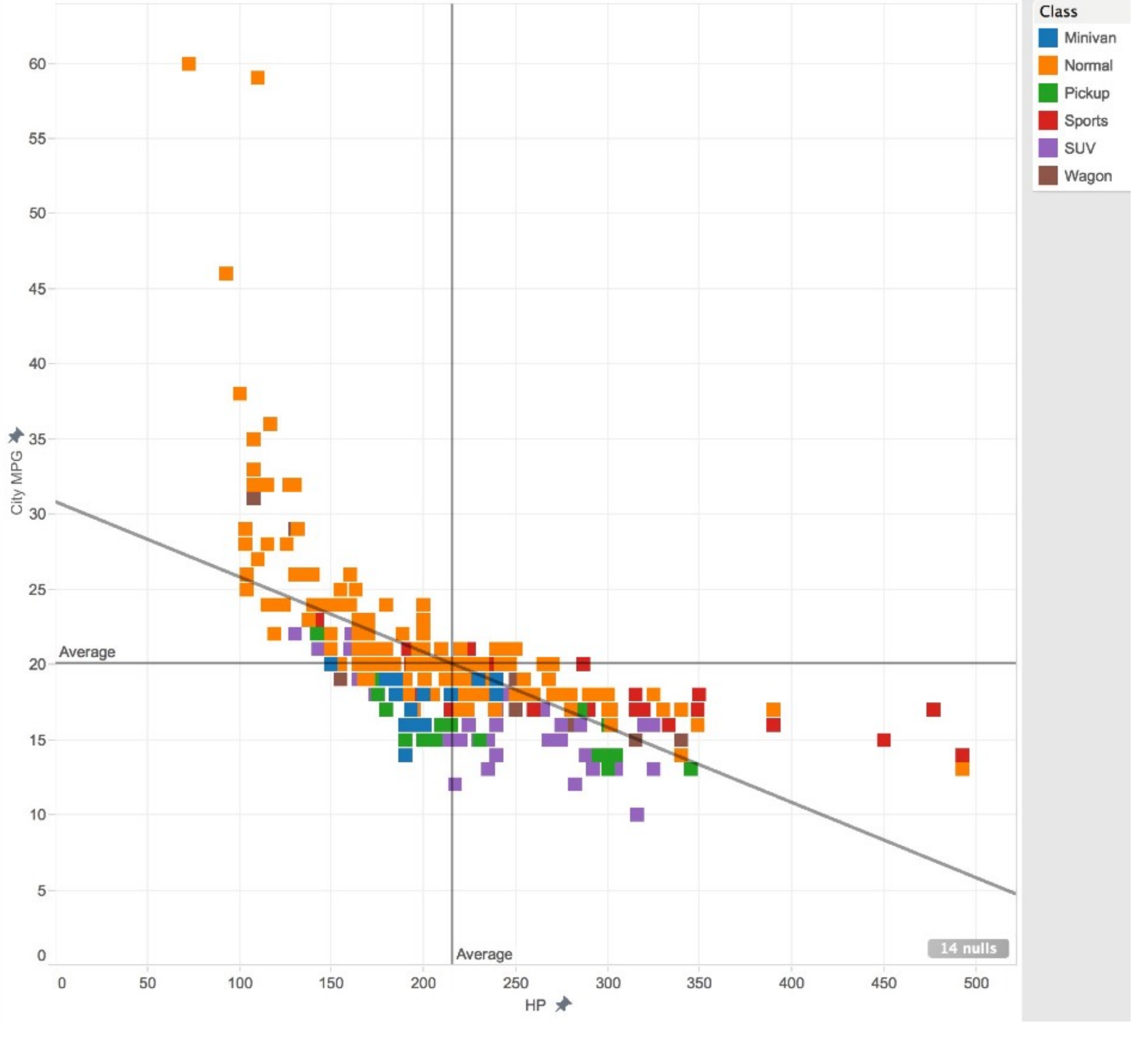
- **Color maps are useful for handling both interval and continuous data variables, since a color map is generally defined as a continuous range of hue and saturation values**



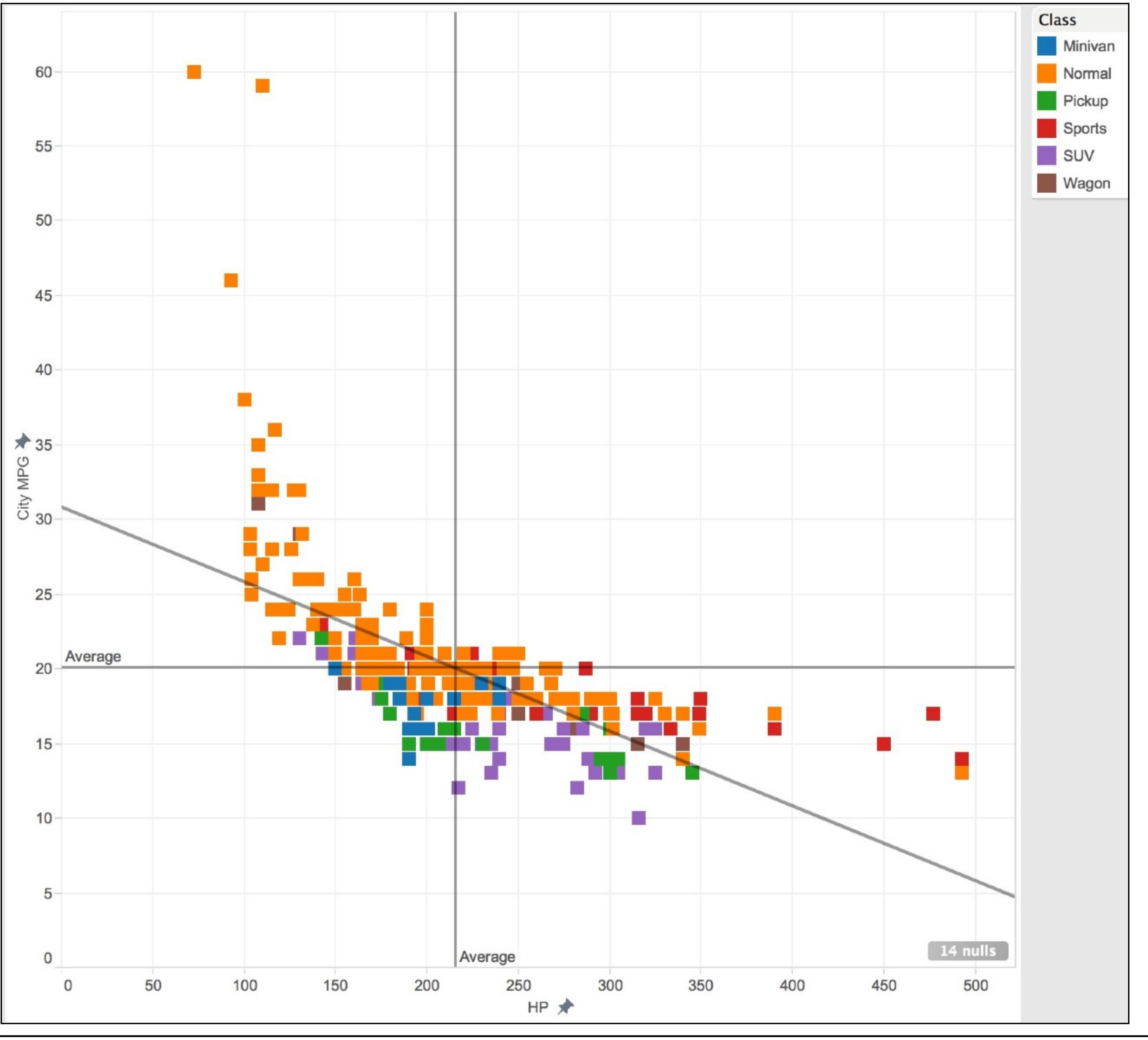
A visualization of the 1993 car models, showing the use of color to display the car's length. Here length is also associated with the y-axis and is plotted against wheelbase. In this figure, blue indicates a shorter length, while yellow indicates a longer length.

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**

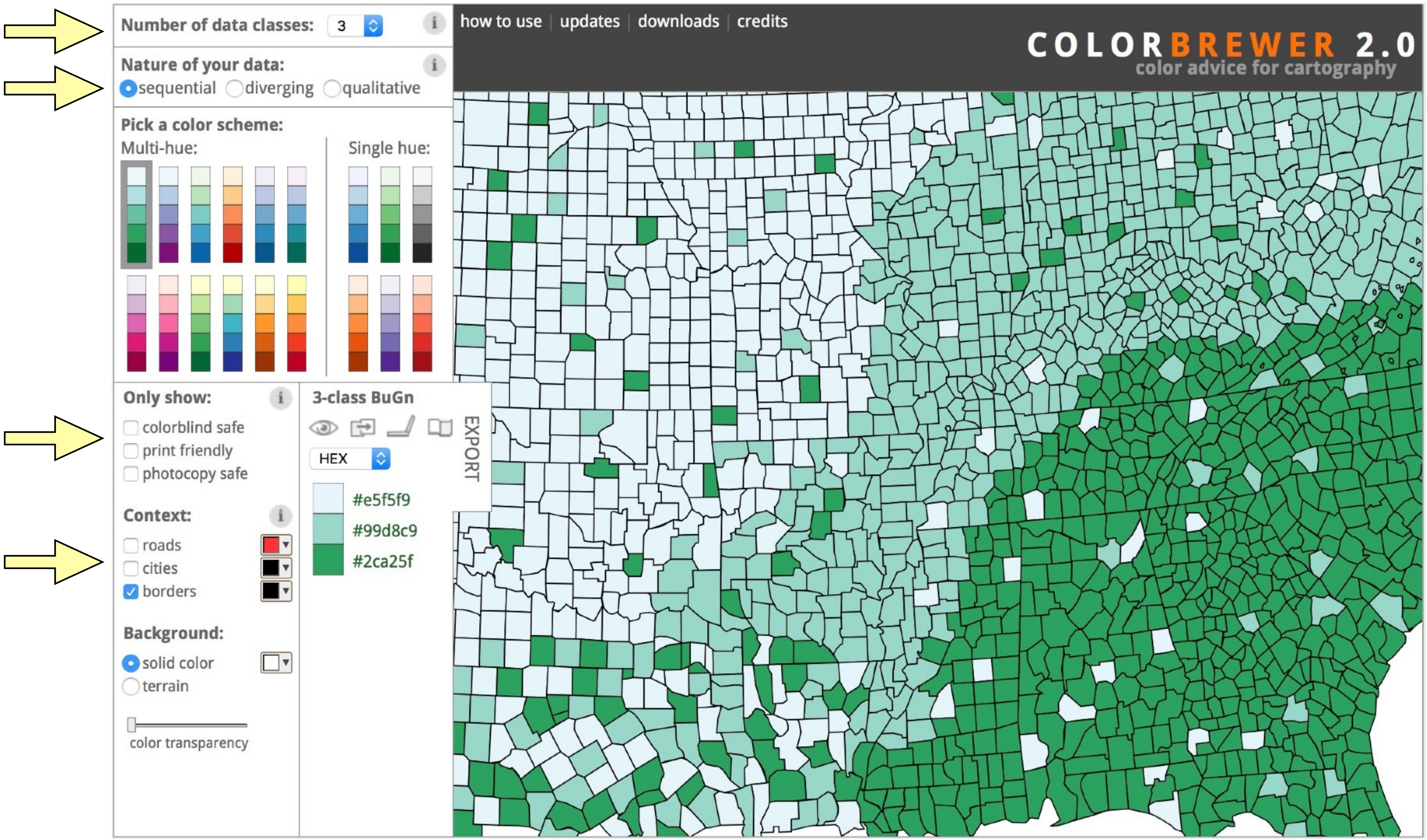


Eight visual variables: Color

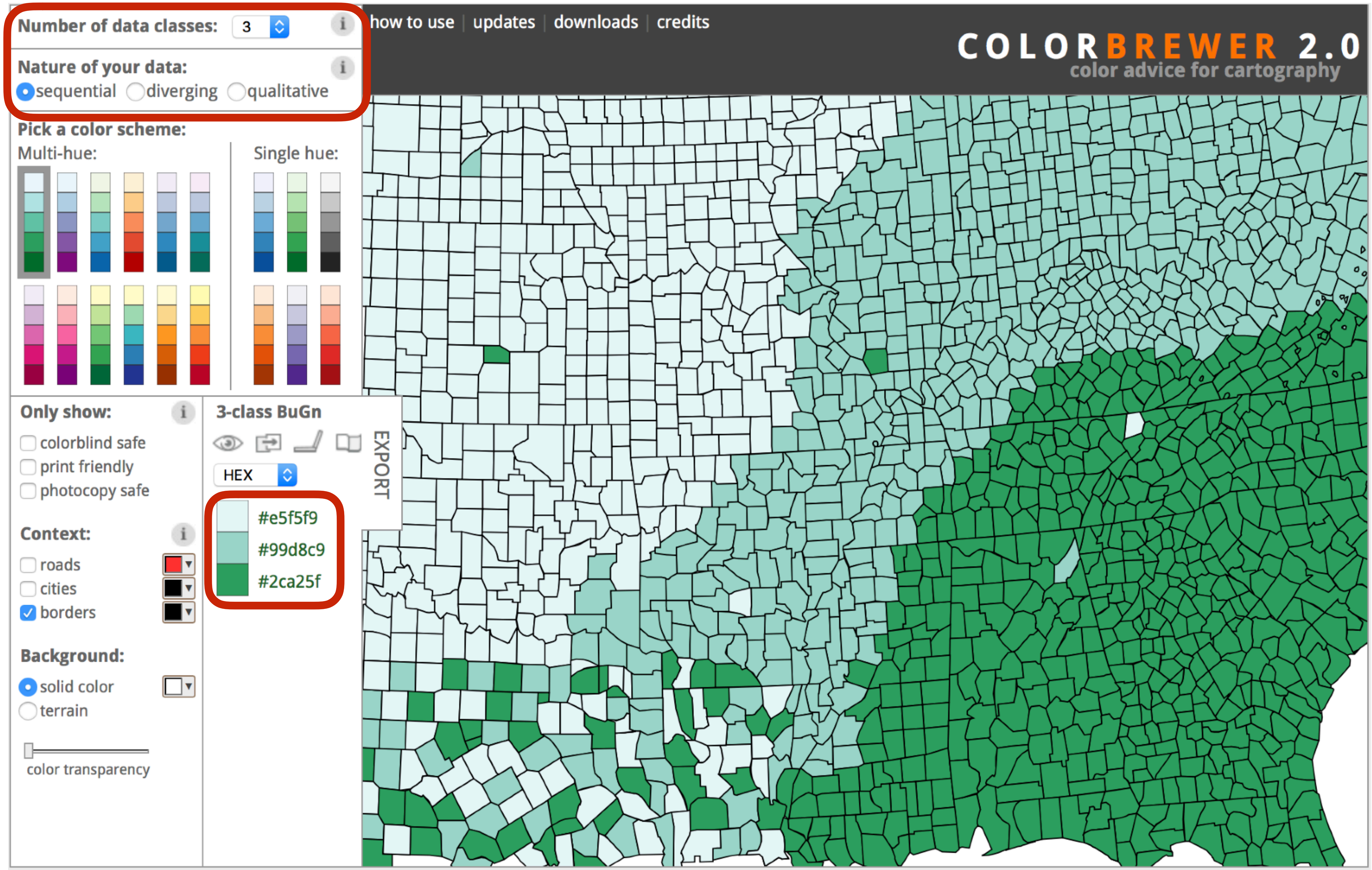


Eight visual variables: Color

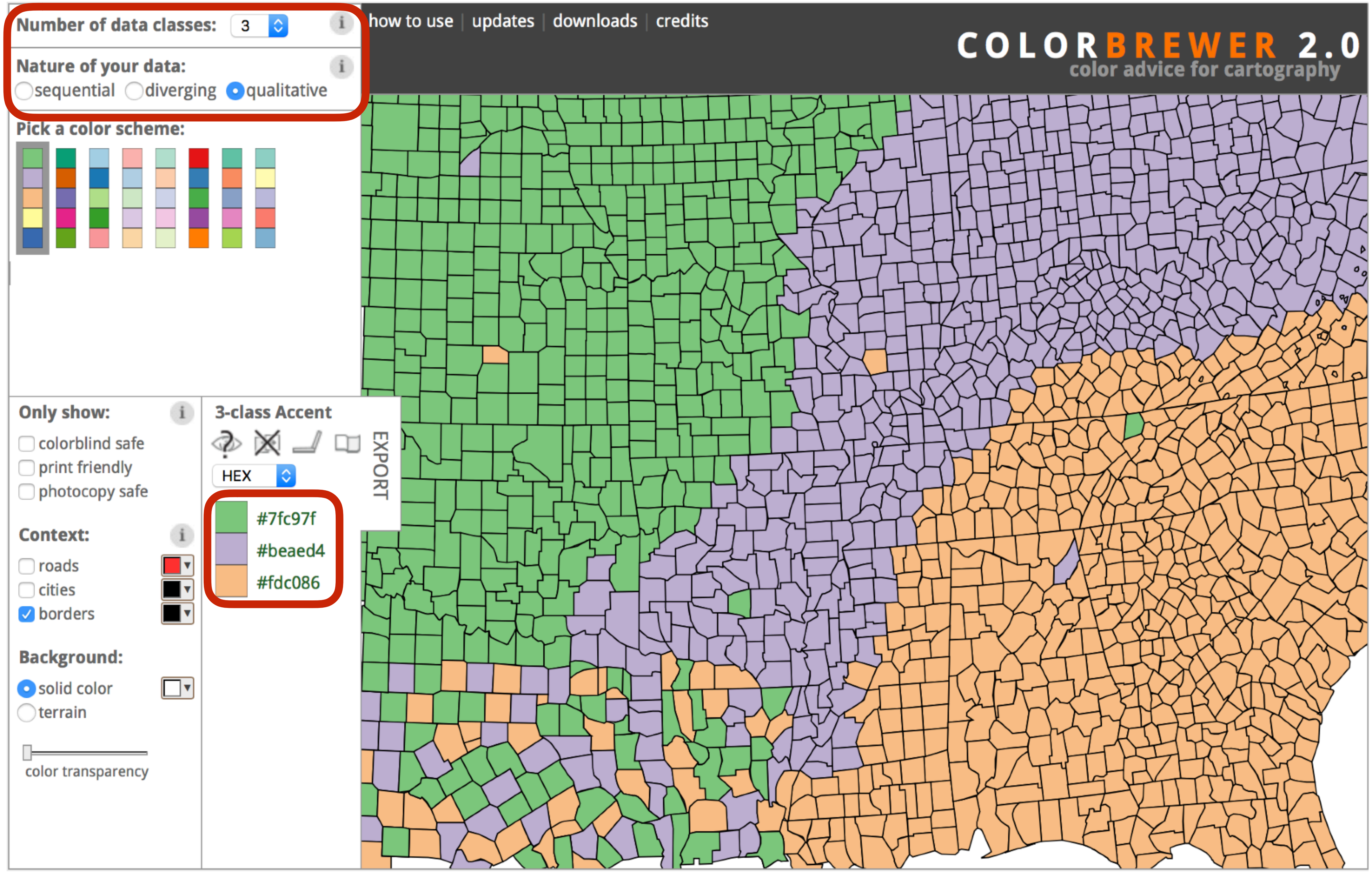
- **Check and try with: www.colorbrewer2.org**



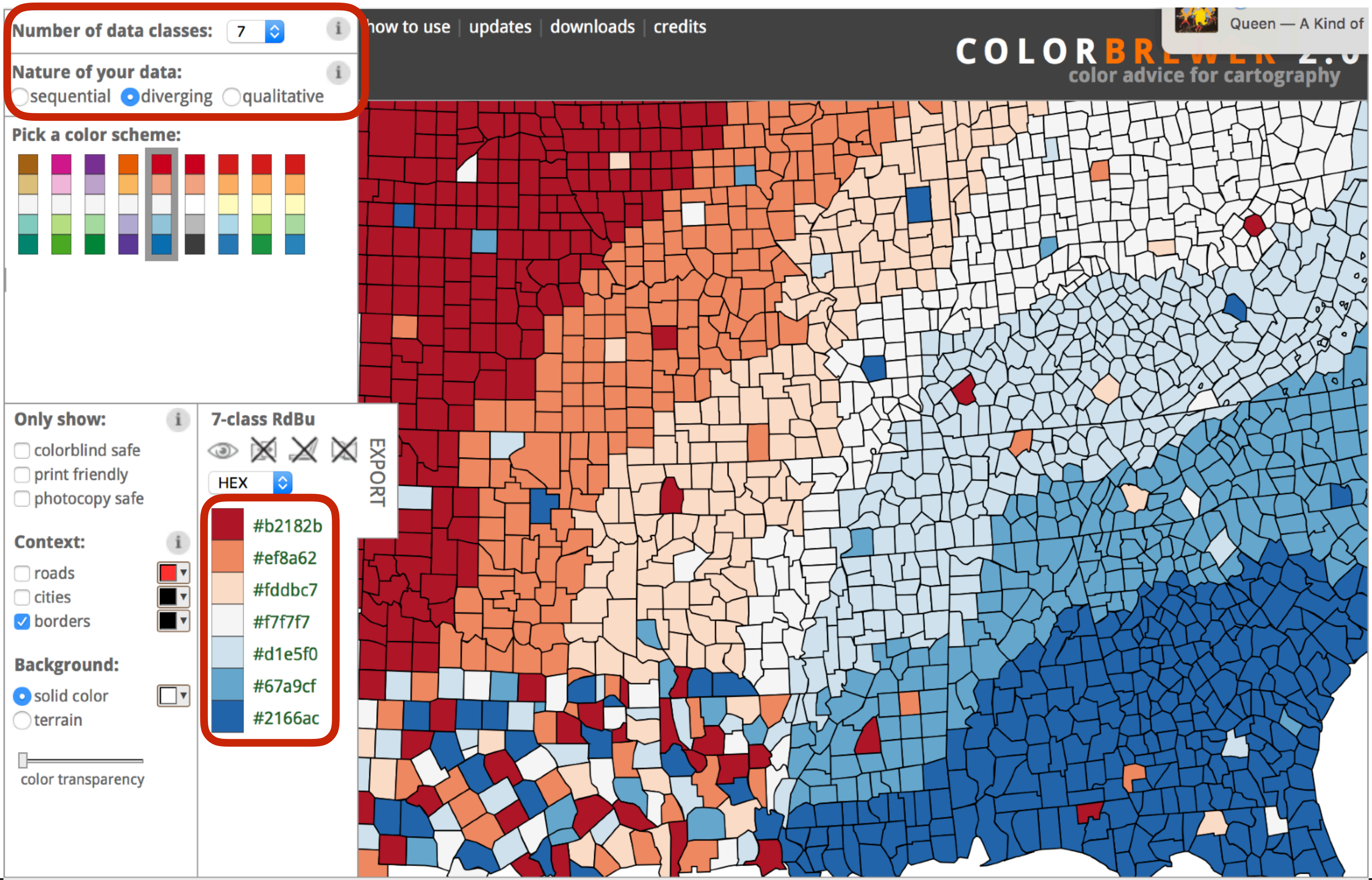
Eight visual variables: Color



Eight visual variables: Color



Eight visual variables: Color



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.

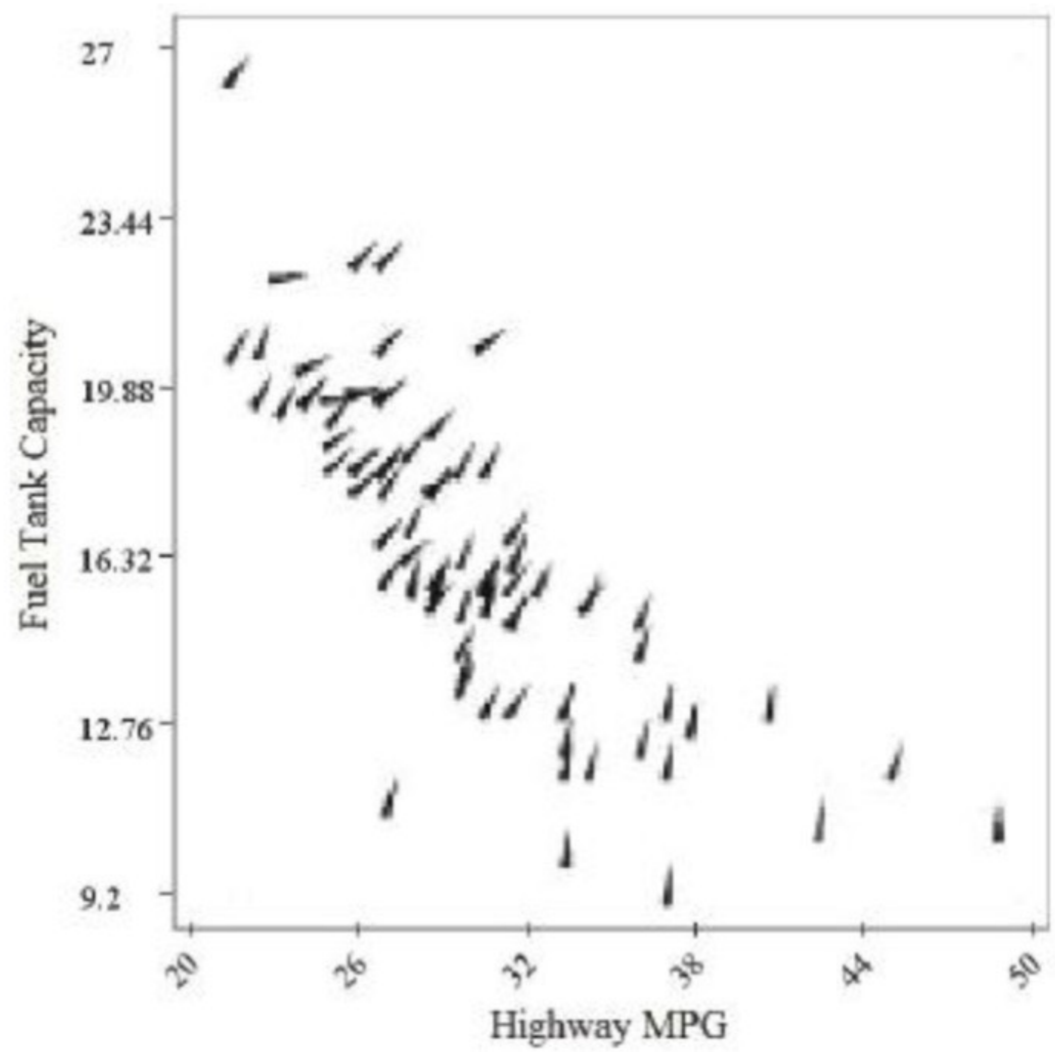
Eight visual variables: Orientation

- **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.**

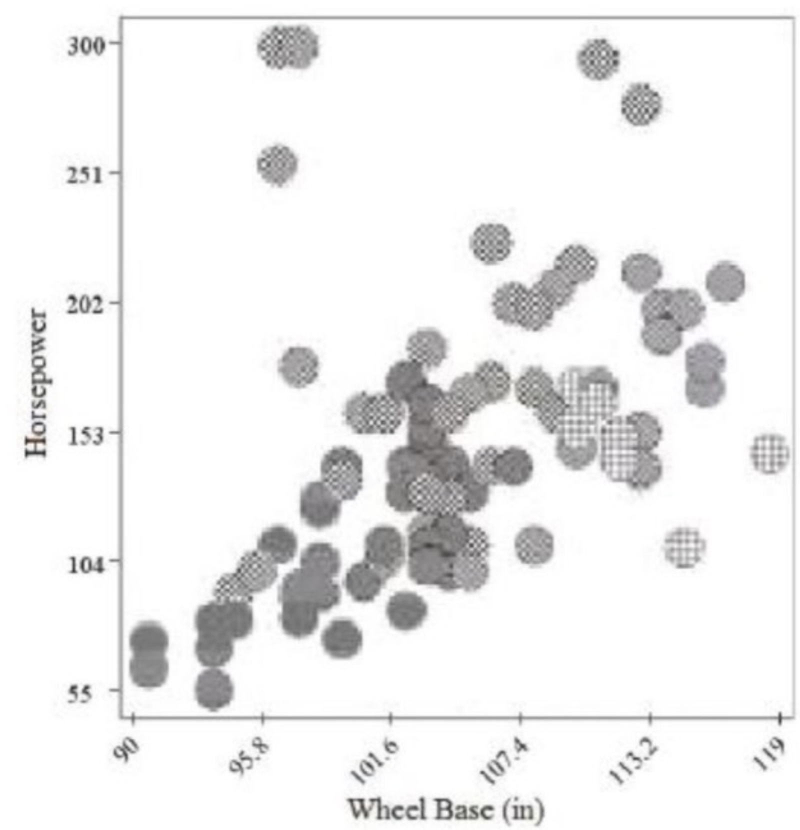
Eight visual variables: Orientation



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: 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

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).**

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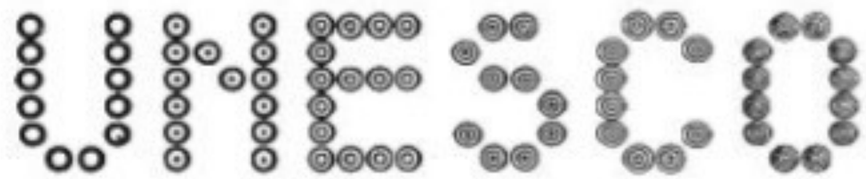
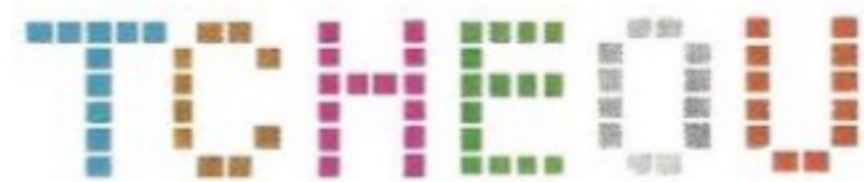
Effects of Visual Variables

- **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).**
    - **Size (length, area/volume);**
    - **Brightness;**
    - **Texture;**
    - **Color (only primary colors): varies with the brightness value;**
    - **Direction / orientation.**

Effects of Visual Variables

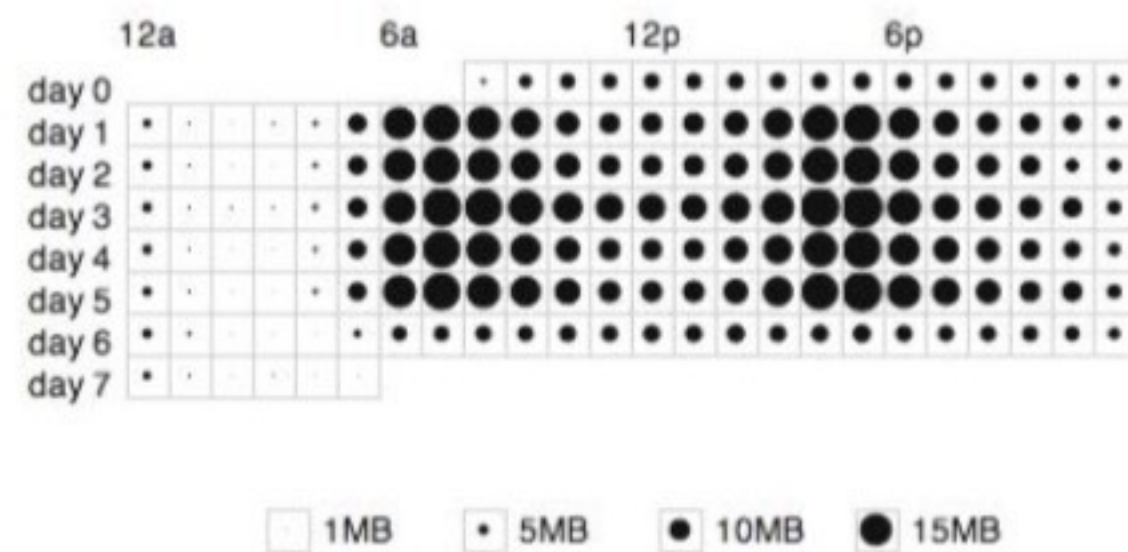
- **Associative visual variables:**
  - **All factors have same visibility (e.g., for visualizing nominal values).**
    - **Texture;**
    - **Color;**
    - **Direction / orientation;**
    - **Shape.**

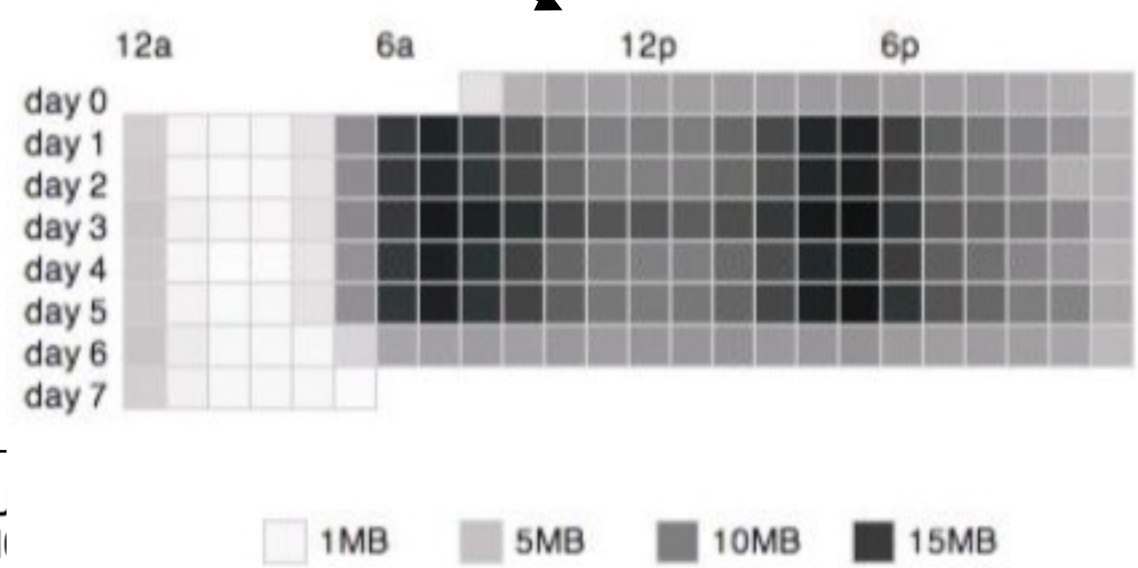




Effects of Visual Variables

- **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).**
    - **Texture;**
    - **Size;**
    - **Brightness.**

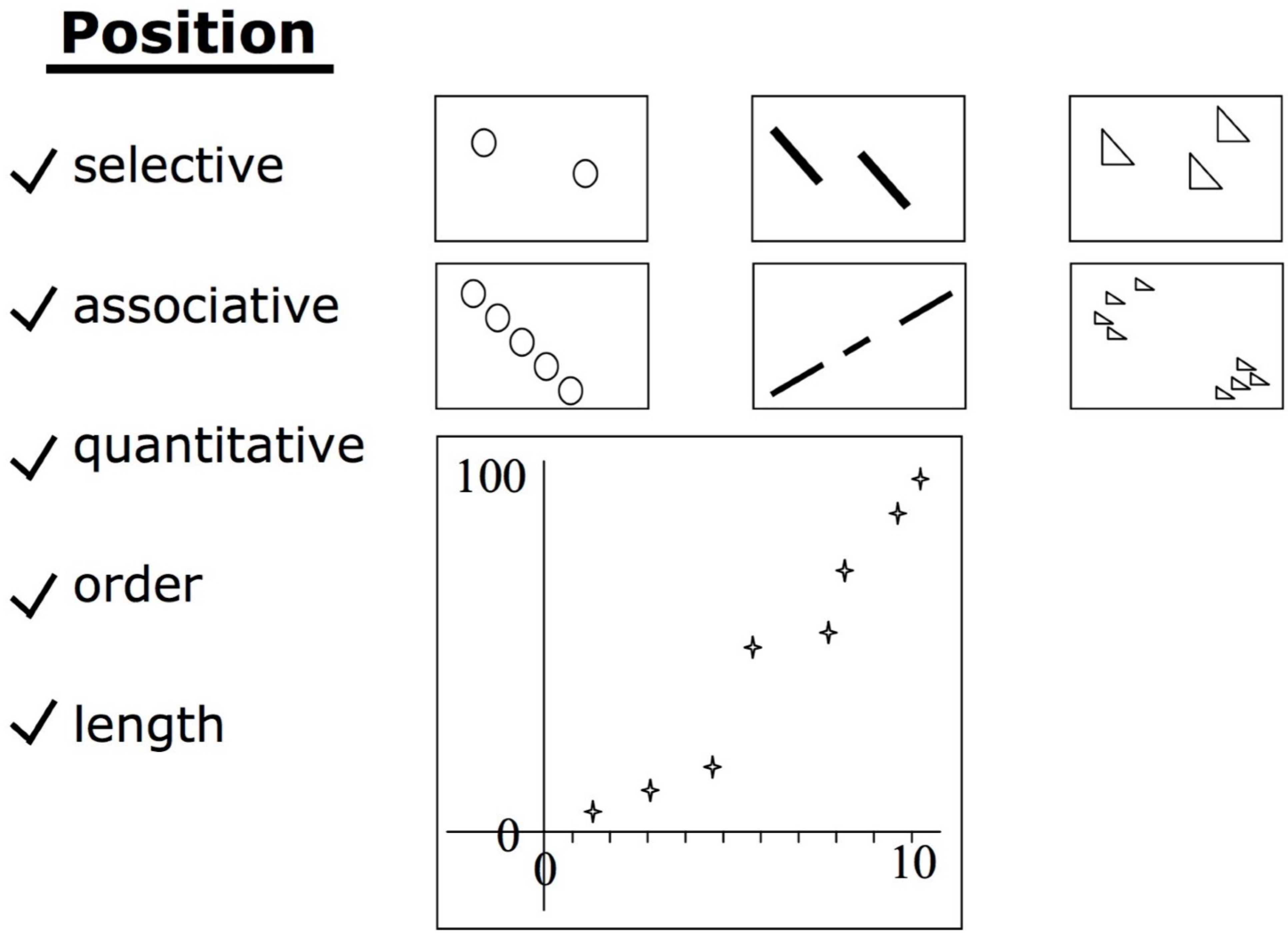




Effects of Visual Variables

- **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?)**

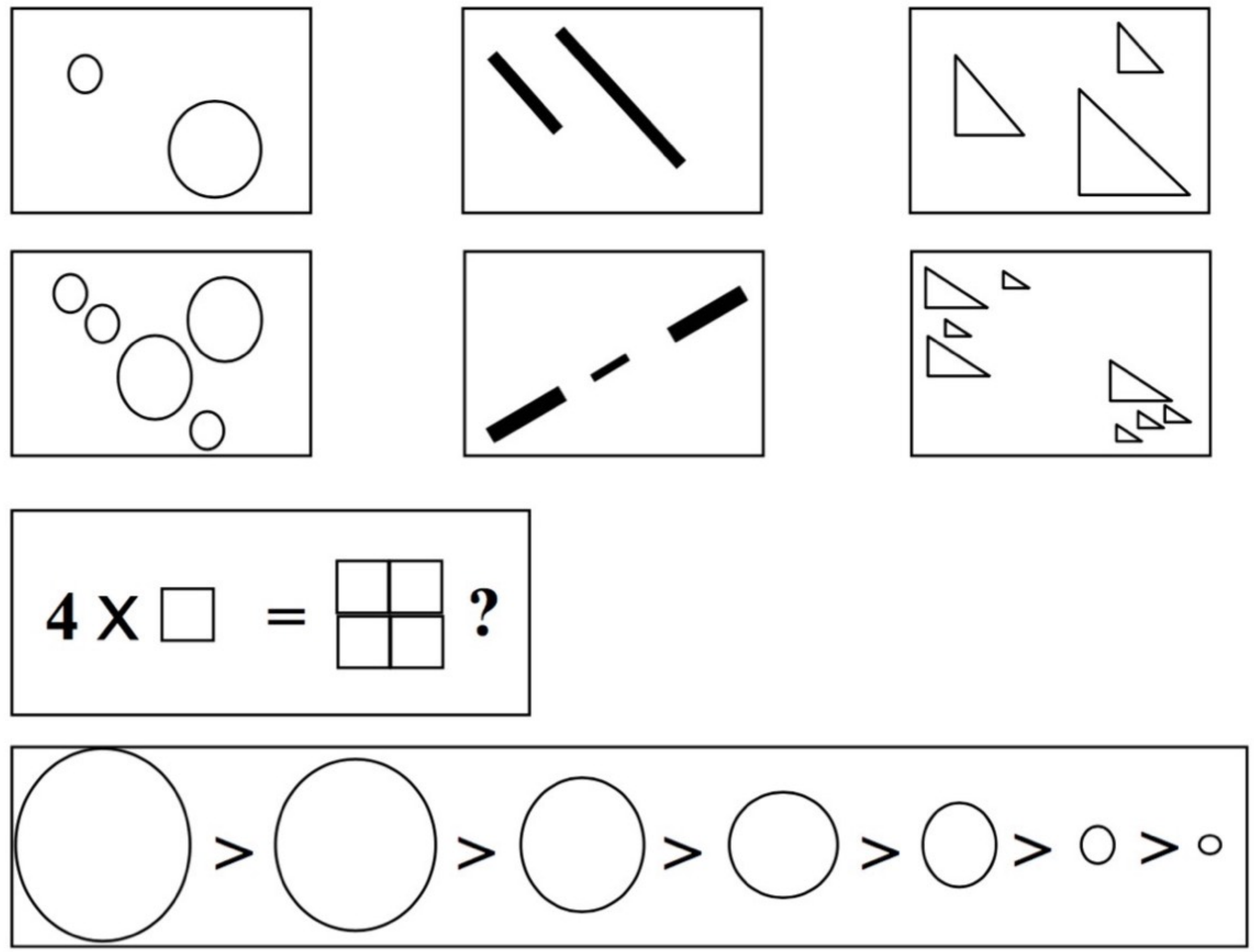
Effects of Visual Variables (by Sheelagh Carpendale)



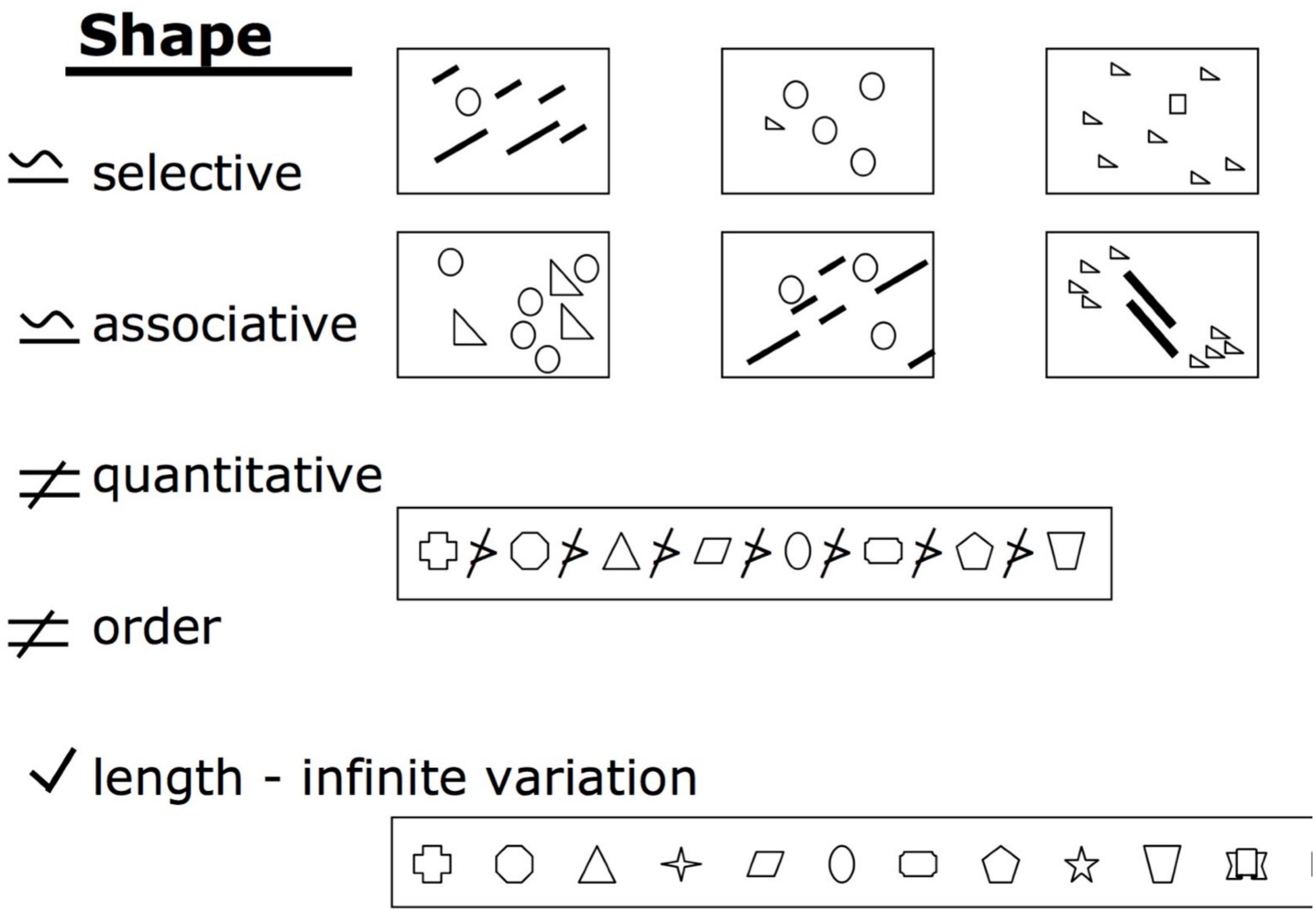
Effects of Visual Variables (by Sheelagh Carpendale)

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)



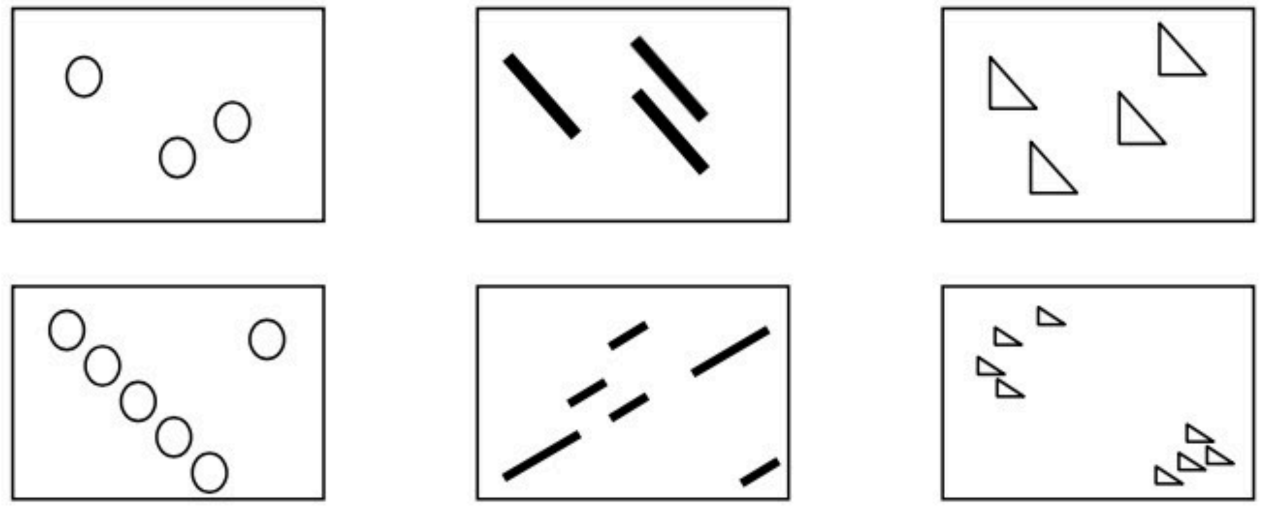
Effects of Visual Variables (by Sheelagh Carpendale)

Value

(Brightness)

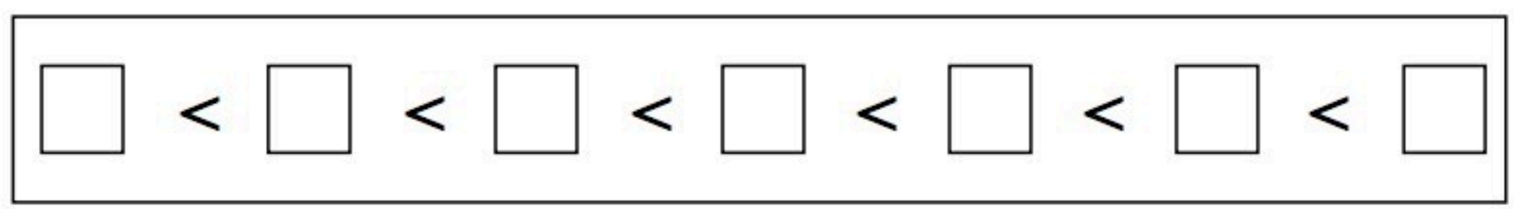
✓ selective

✓ associative



≠ quantitative

✓ order



✓ length

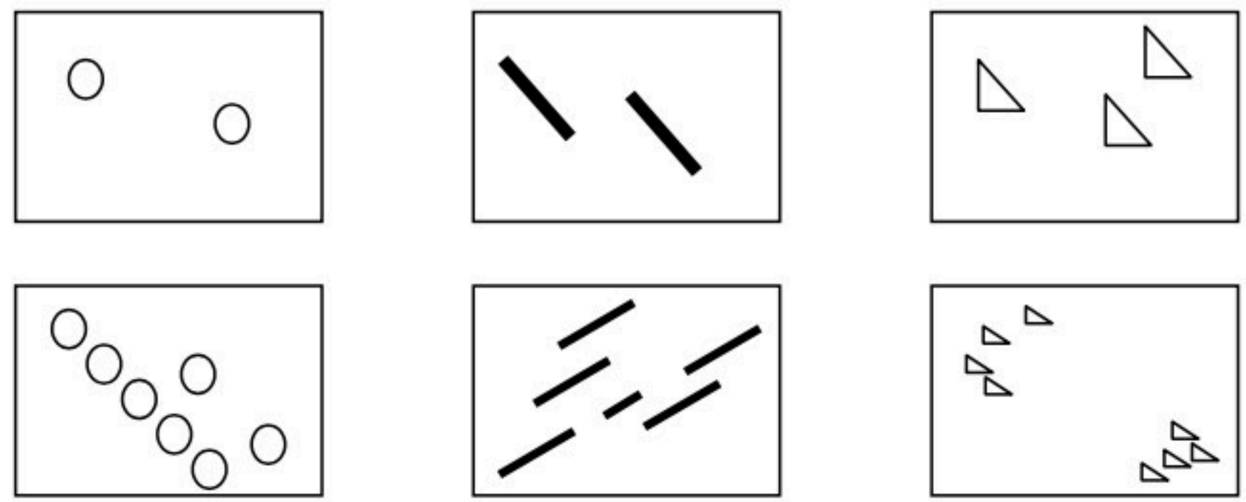
- theoretically infinite but practically limited
- association and selection ~ < 7 and distinction ~ 10

Effects of Visual Variables (by Sheelagh Carpendale)

Color

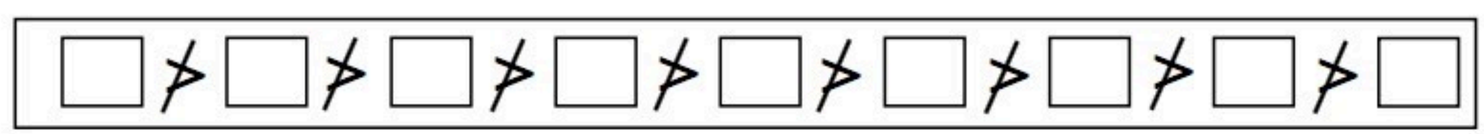
✓ selective

✓ associative



≠ quantitative

≠ order



✓ length

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

Effects of Visual Variables (by Sheelagh Carpendale)

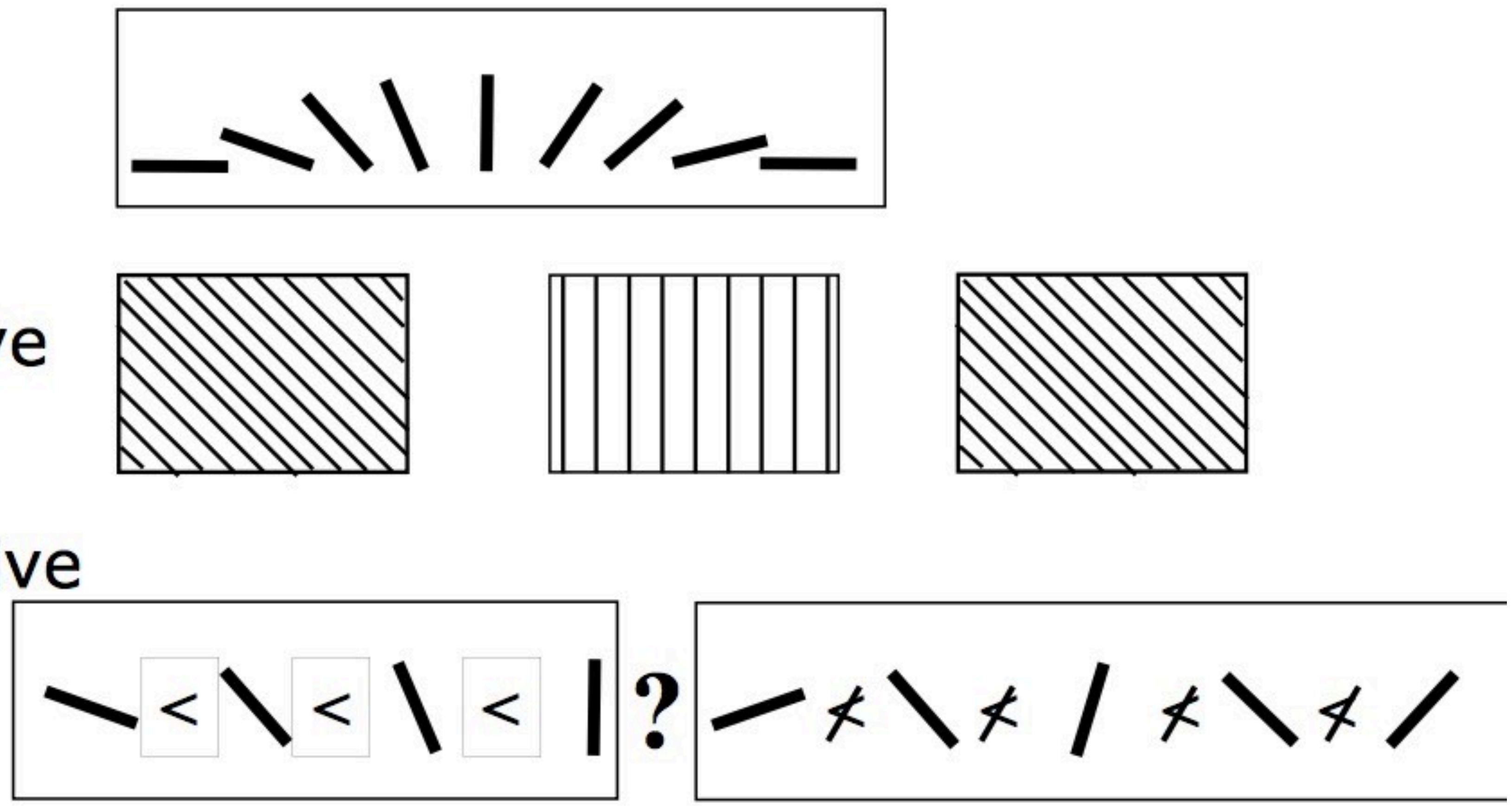
Orientation

✓ selective

✓ associative

≠ quantitative

≠ order



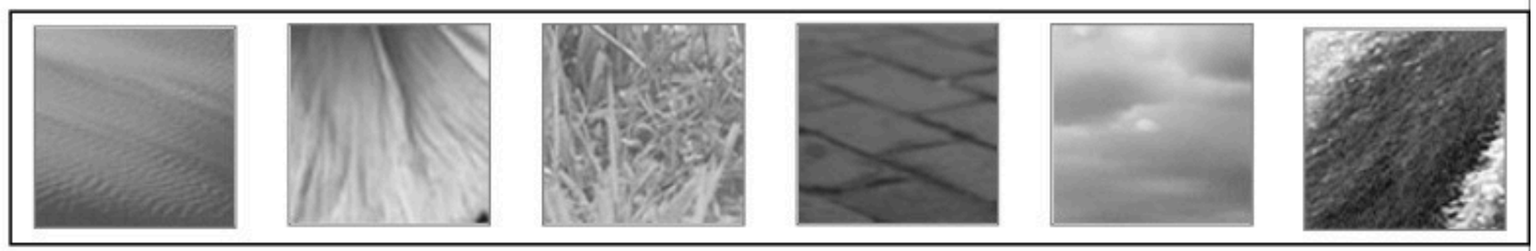
✓ length

– ~5 in 2D; ? in 3D

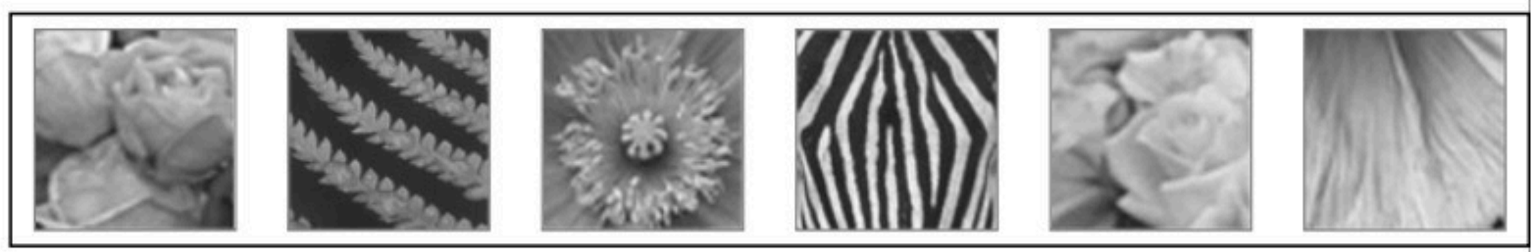
Effects of Visual Variables (by Sheelagh Carpendale)

Texture

✓ selective

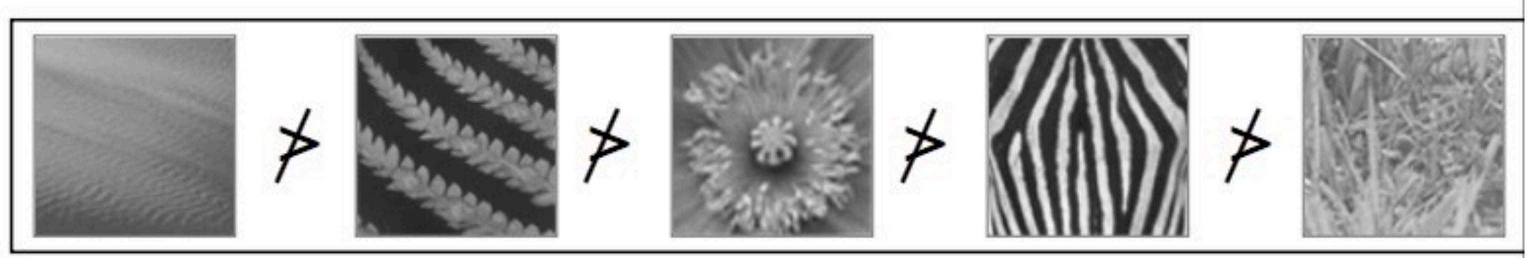


✓ associative



≠ 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)

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  - length (across how many changes in this variable are distinctions perceptible?)

Marks and Channels by Tamara Munzner

Channel Rankings

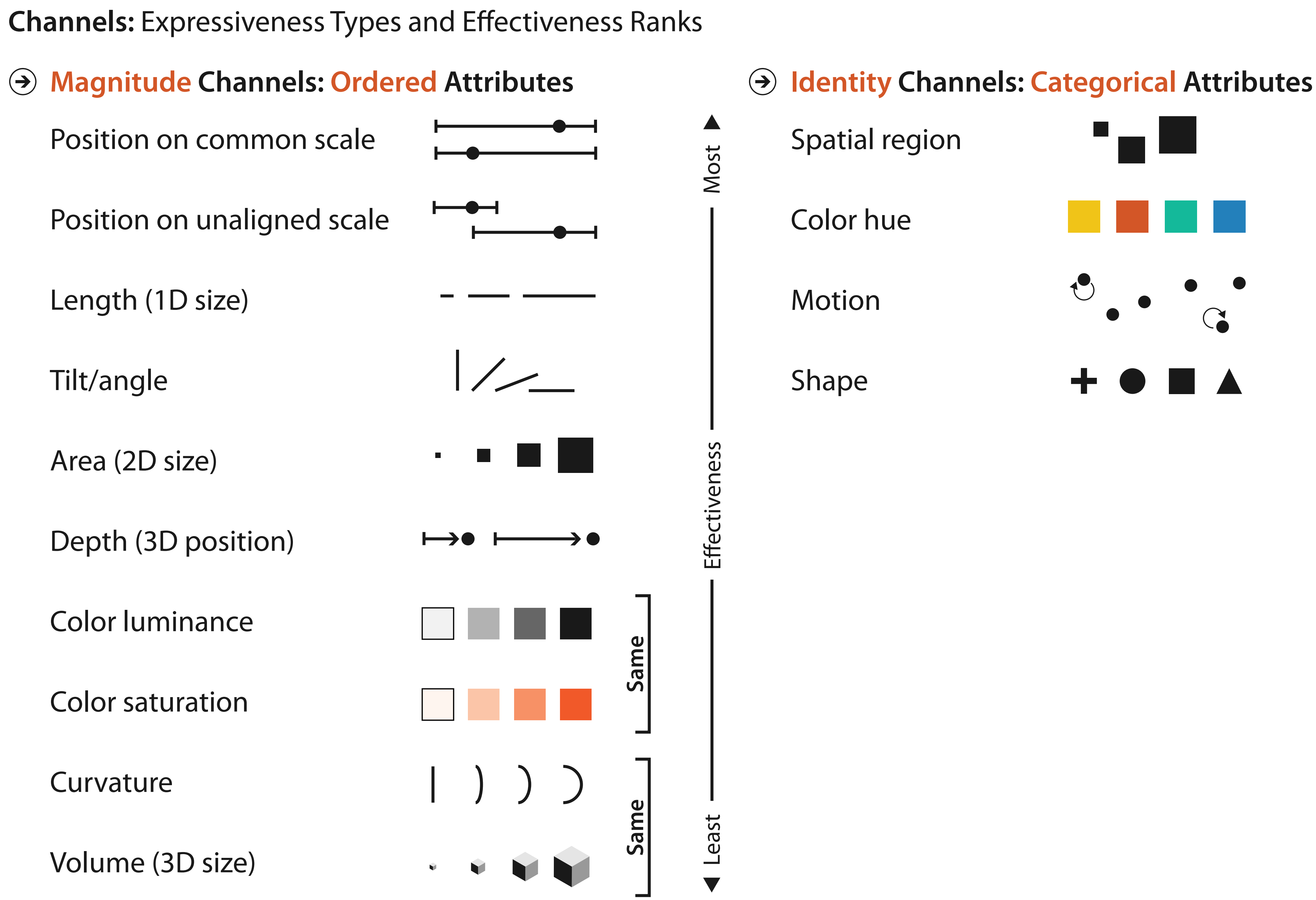


Figure 5.6. Channels ranked by effectiveness according to data and channel type. Ordered data should be shown with the magnitude channels, and categorical data with the identity channels.

Accuracy

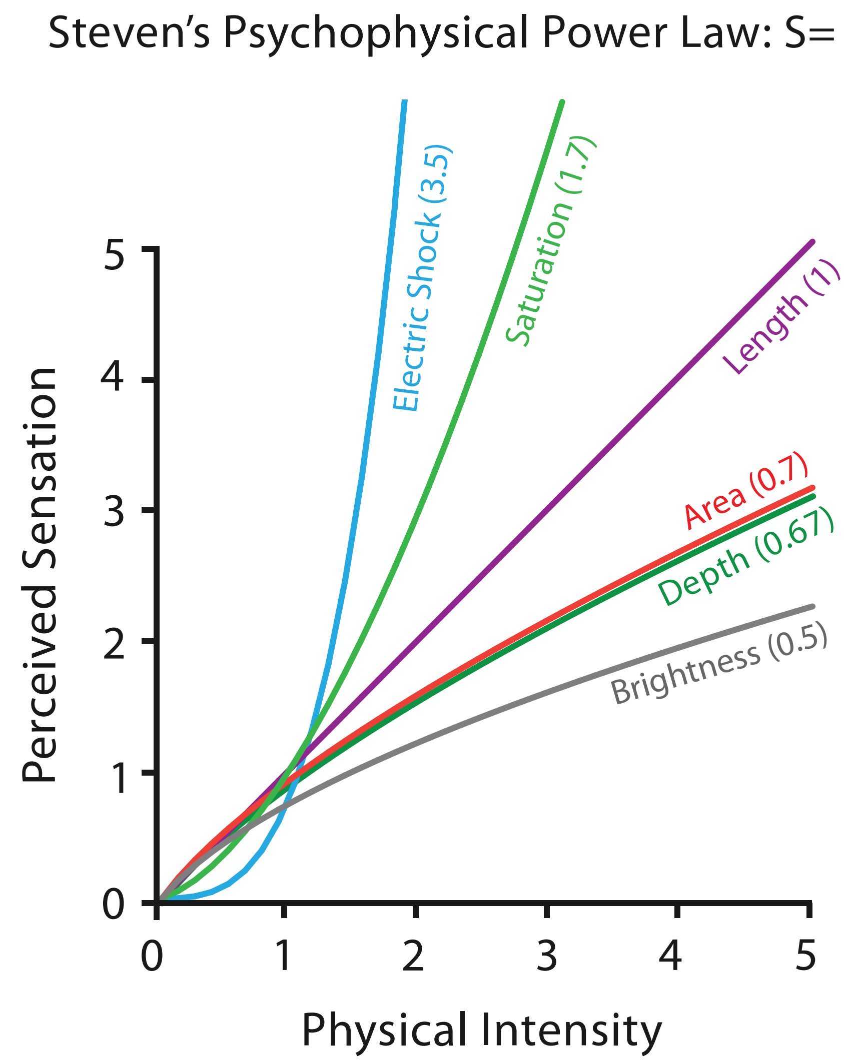
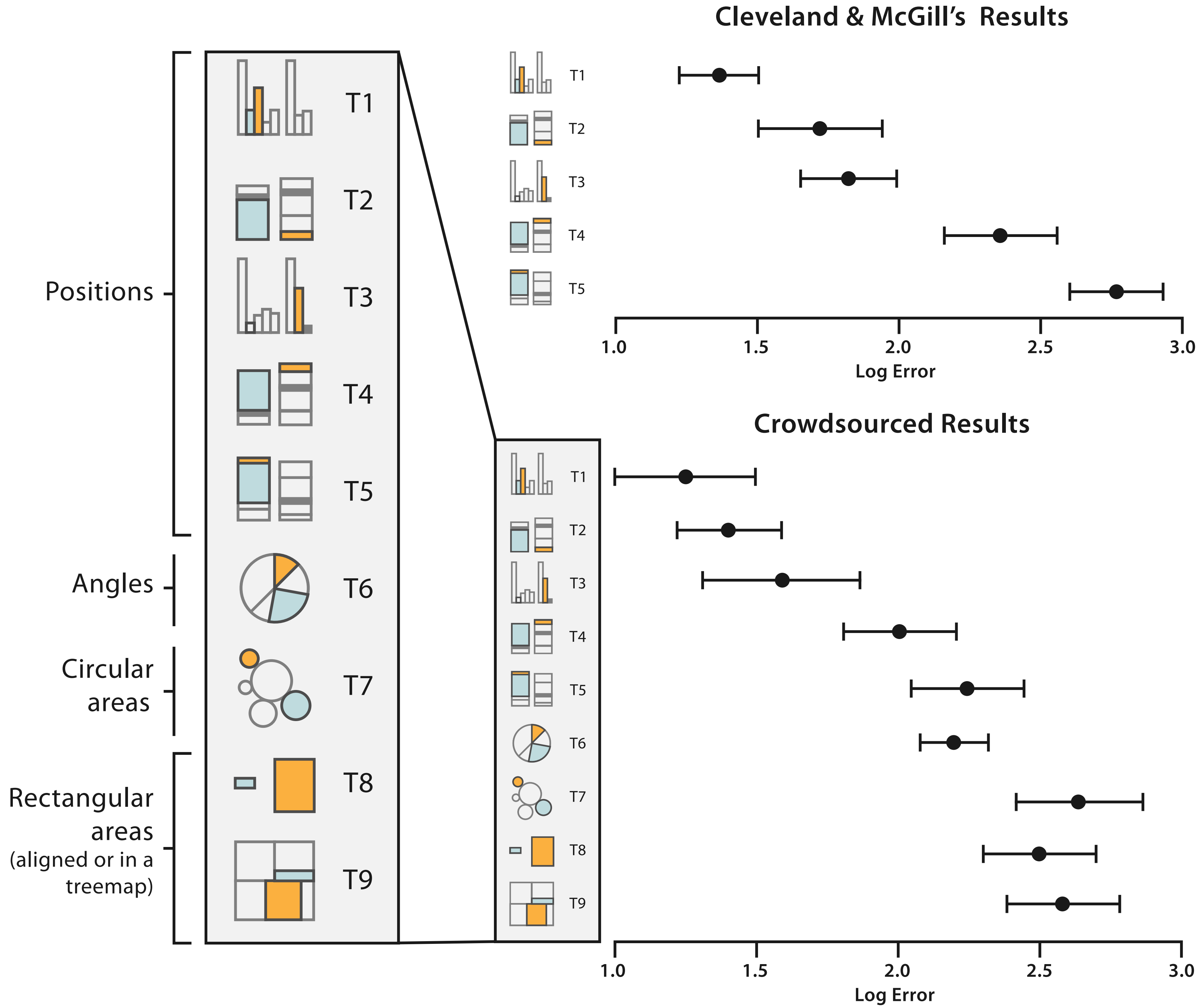
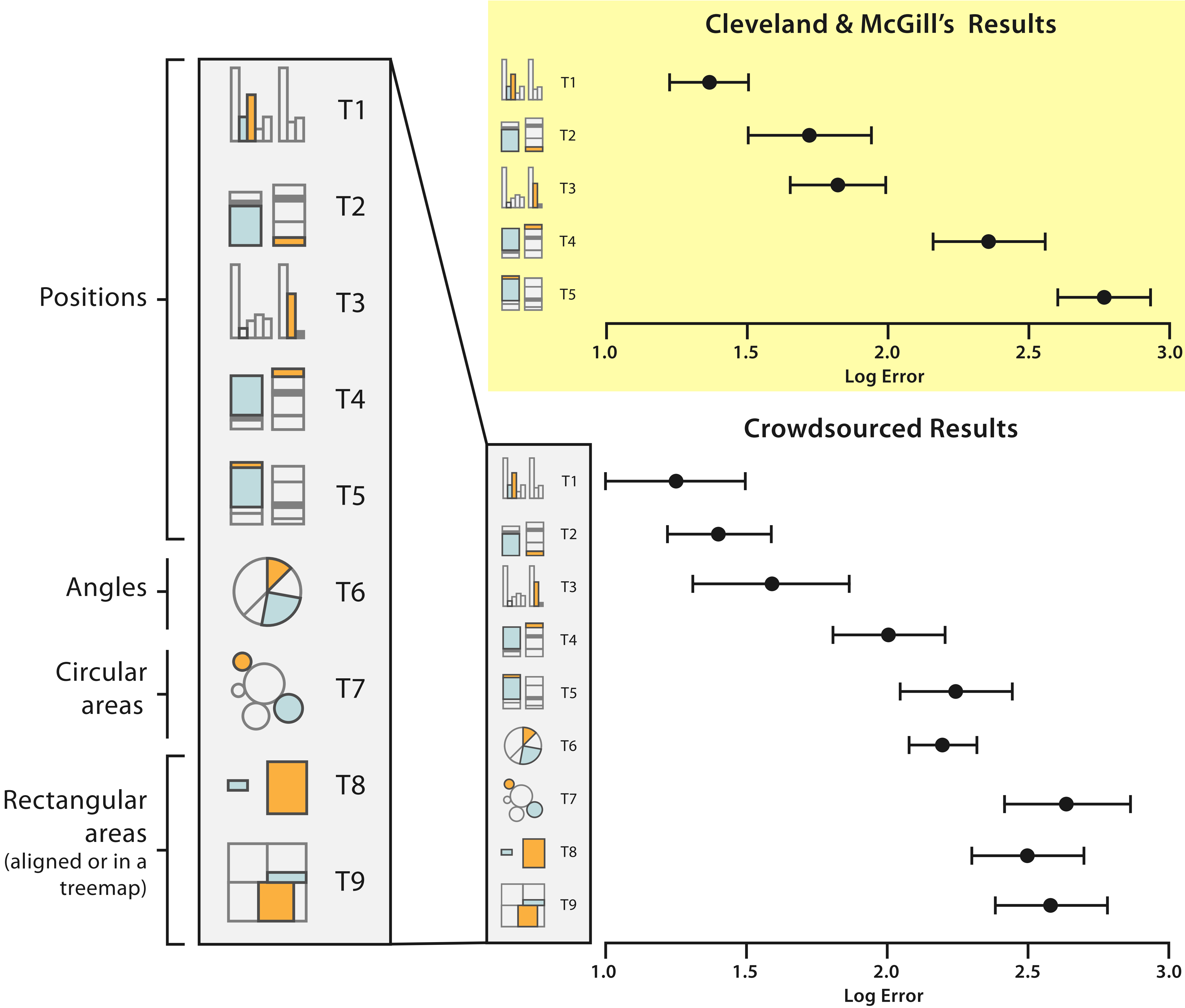


Figure 5.7. Stevens showed that the apparent magnitude of all sensory channels follows a power law $S = I^n$, where some sensations are perceptually magnified compared with their objective intensity (when $n > 1$) and some compressed (when $n < 1$). Length perception is completely accurate, whereas area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





Cleveland & McGill's Results
T1
T2
T3
T4
T5
1.0
1.5
2.0
2.5
3.0
Log Error
Crowdsourced Results
Positions
Angles
Circular areas
Rectangular areas (aligned or in a treemap)
T1
T2
T3
T4
T5
T6
T7
T8
T9
1.0
1.5
2.0
2.5
3.0
Log Error

Discriminability

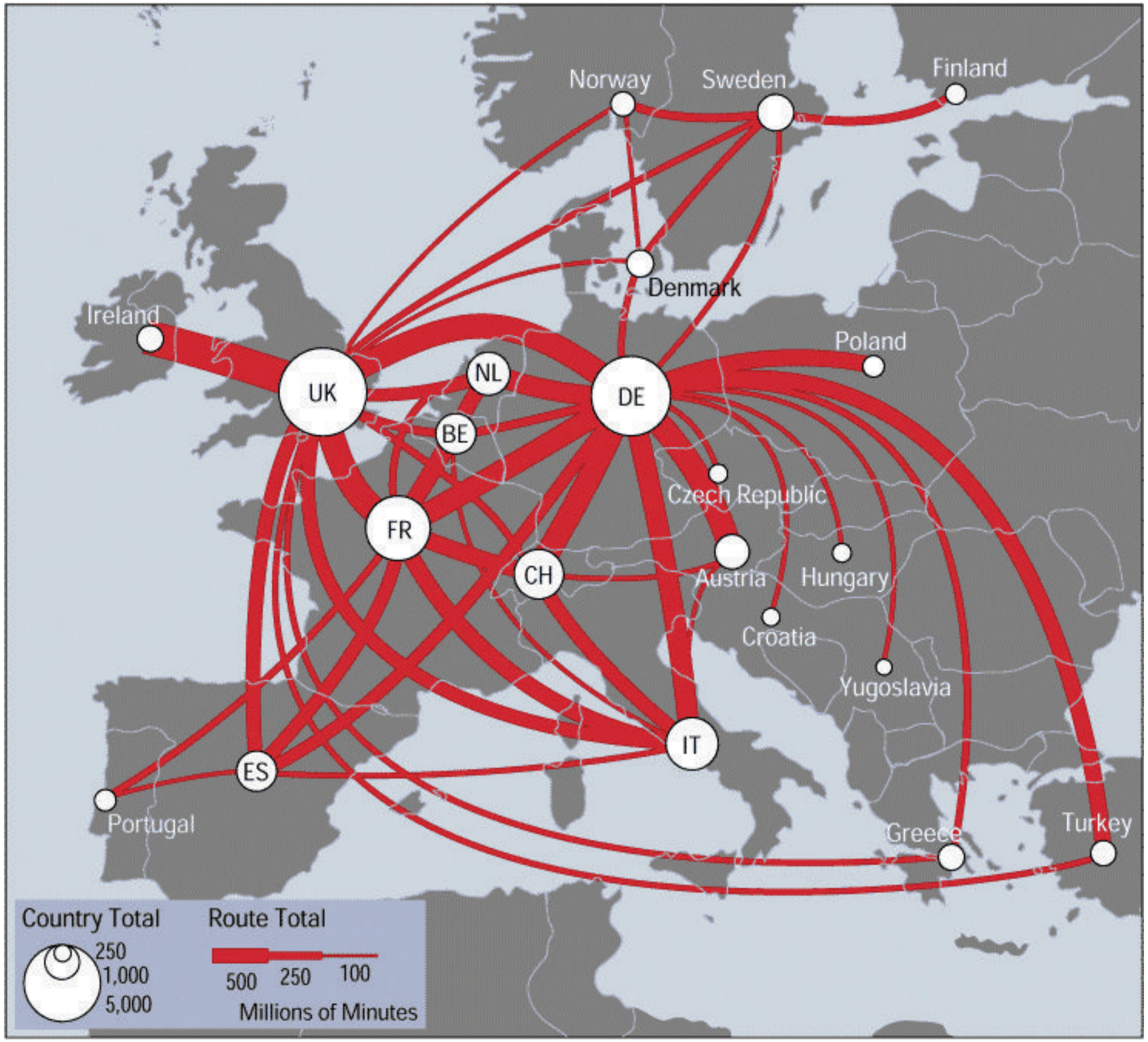


Figure 5.9. Linewidth has a limited number of discriminable bins.

Separability

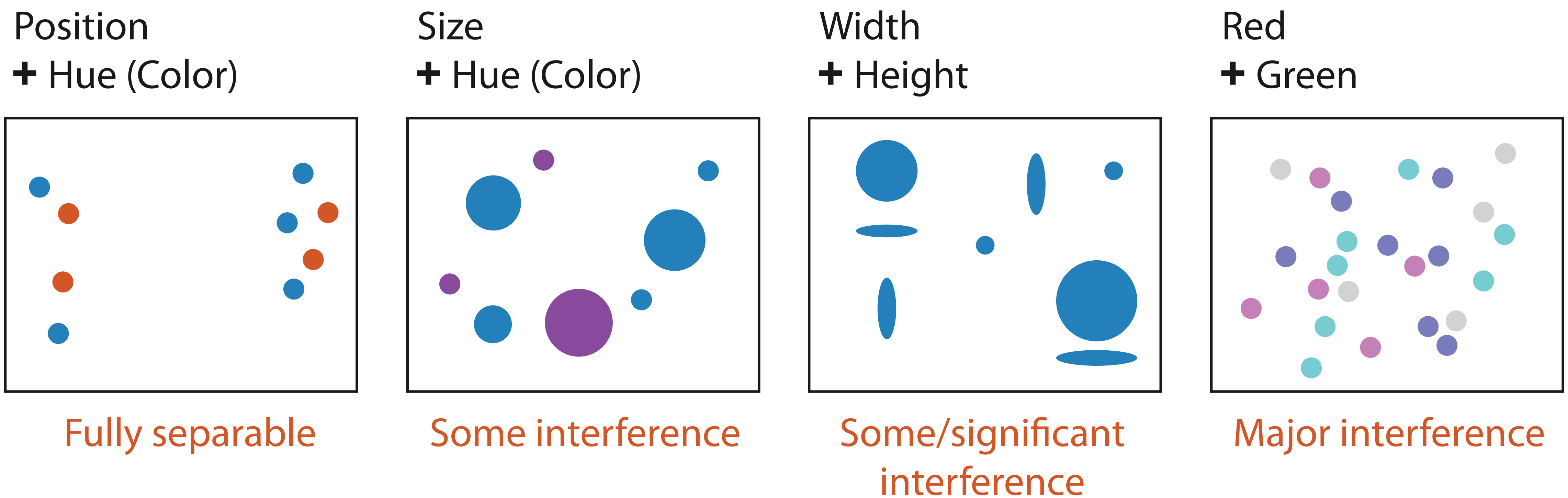


Figure 5.10. Pairs of visual channels fall along a continuum from fully separable to intrinsically integral. Color and location are separable channels well suited to encode different data attributes for two different groupings that can be selectively attended to. However, size interacts with hue, which 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.

Taxonomies

Taxonomies

- A taxonomy is a means to convey a classification
- In visualization, we are interested in many forms of taxonomies:
  - data
  - visualization techniques;
  - tasks;
  - methods for interaction.
- Based on the data types and a list of tasks they propose and classify around 100 techniques.

Keller and Keller (1994) Taxonomy of Visualization Goals

- **Classify visualization techniques based on the type of data being analyzed and the user's task(s).**
- **The data types:**
  - **scalar (or scalar field);**
  - **nominal;**
  - **direction (or direction field);**
  - **shape;**
  - **position;**
  - **spatially extended region or object (SERO).**

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.

Shneiderman (1996) Data Type by Task Taxonomy

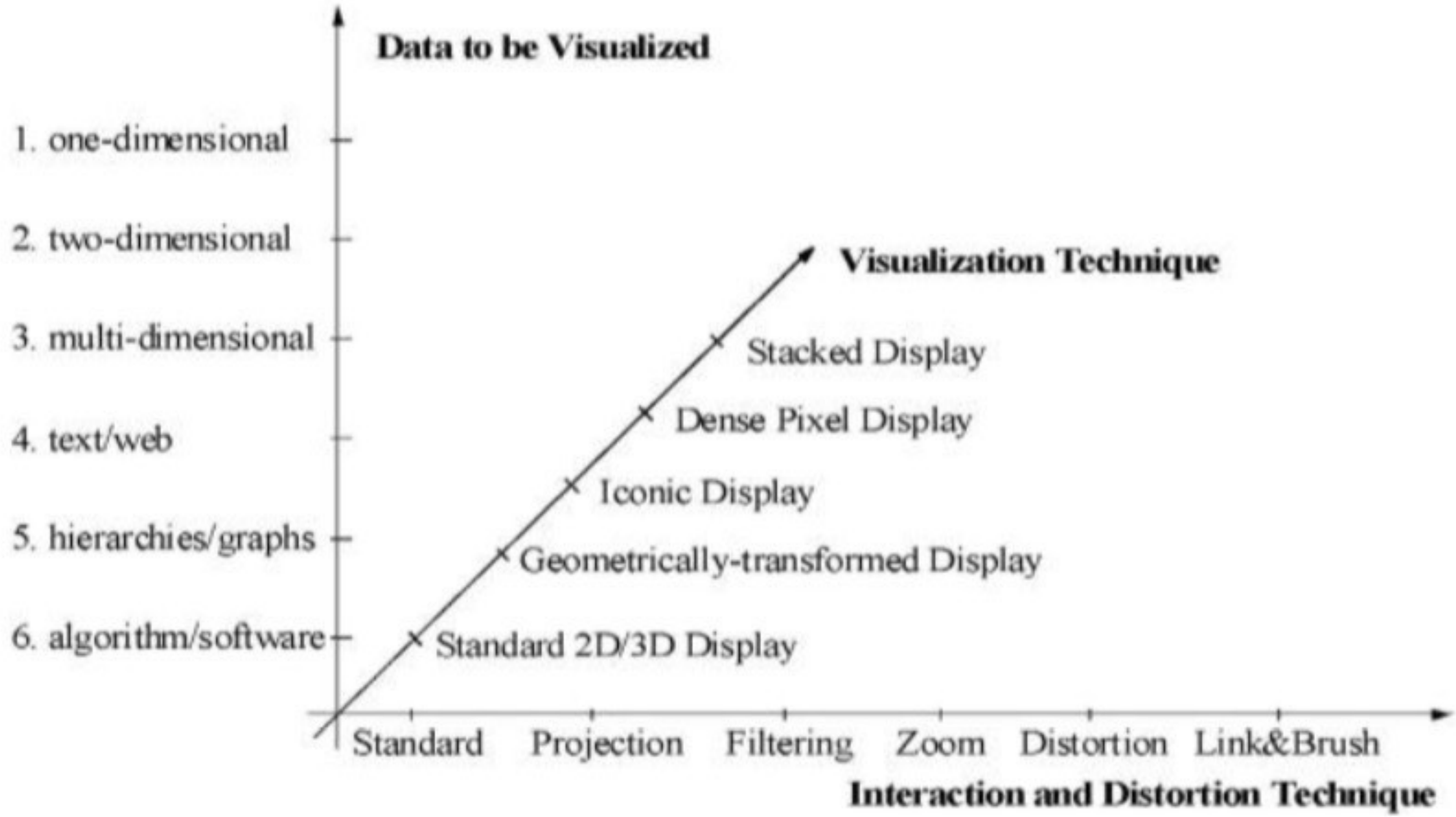
- **The data types:**
  - **one-dimensional linear;**
  - **two-dimensional map;**
  - **three-dimensional world;**
  - **temporal;**
  - **multidimensional;**
  - **tree;**
  - **network.**

Shneiderman (1996) Data Type by Task Taxonomy

- **Shneiderman looked more at the behavior of analysts as they attempt to extract knowledge from the data.**
  - **Overview. Gain an overview of the entire collection.**
  - **Zoom. Zoom in items of interest to gain a more detailed view.**
  - **Filter. Filter out uninteresting items to allow the user to reduce the size of a search**
  - **Details-on-demand. Select an item or group and get details when needed.**
  - **Relate. View relationships among items.**
  - **History. Keep a history to allow undo, replay, and progressive refinement.**
  - **Extract. Extract the items or data in a format that would facilitate other uses.**

Keim (2002) Information Visualization Classification

- **Keim designed a classification scheme for visualization systems based on three dimensions: data types, visualization techniques, and interaction/distortion methods**



Keim (2002) Information Visualization Classification

- **Keim designed a classification scheme for visualization systems based on three dimensions: data types, visualization techniques, and interaction/distortion methods.**
  Classification of Visualization Techniques:
  - **Standard 2D/3D displays: x,y- or x,y,z-plots, bar charts, line graphs;**
  - **Geometrically transformed displays: landscapes, scatterplot matrices, projection pursuit techniques, prosection views, hyper-slice, parallel coordinates;**
  - **Iconic displays: Chernoff faces, needle icons, star icons, stick figure icons, color icons, tilebars;**
  - **Dense pixel displays: recursive pattern, circle segments, graph sketches;**
  - **Stacked displays: dimensional stacking, hierarchical axes, worlds-within-worlds, tree-maps, cone trees.**

Keim (2002) Information Visualization Classification

- **Classification of Interaction and Distortion Techniques:**
  - **Dynamic projection: grand tour system, XGobi, XLispStat, ExplorN;**
  - **Interactive filtering: Magic Lenses, InfoCrystal, dynamic queries, Polaris;**
  - **Interactive zooming: TableLens, PAD++, IVEE/Spotfire, DataSpace, MGV and scalable framework;**
  - **Interactive distortion: hyperbolic and spherical distortions, bifocal displays, perspective wall, graphical fisheye views, hyperbolic visualization, hyperbox;**
  - **Interactive linking and brushing: multiple scatterplots, bar charts, parallel coordinates, pixel displays and maps, Polaris, scalable framework, S-Plus, XGobi, XmdvTool, DataDesk.**

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