

# STAT 1291: Data Science

## Lecture 4 - Data Visualization: Composing/dissecting Data Graphics

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### Where are we?

- *What is Data Science?*
- *How do we learn Data Science?*
- *Data visualization: What is a good graphic?*
- Composing/Dissecting Data Graphics

### A taxonomy for data graphics

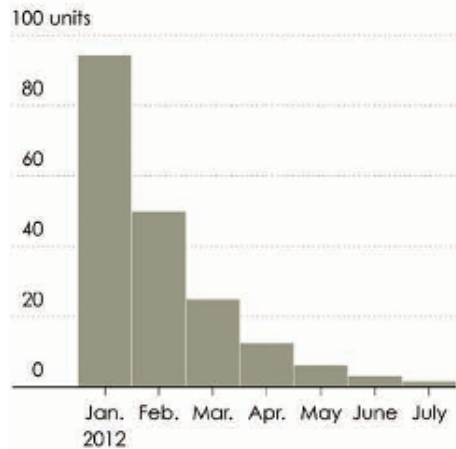
- Nathan Yau (<http://flowingdata.com/>) provides a systematic way of thinking about how data graphics convey specific pieces of information, and how they could be improved.
- A complementary grammar of graphics is implemented by Hadley Wickham in the `ggplot2` graphics package in R
- Data graphics can be understood in terms of four basic elements:
  1. visual cues
  2. coordinate system
  3. scale
  4. context

## Working parts

Several pieces work together to make a graph. Sometimes these are explicitly shown in the visualization and other times they form a visual in the background. They all depend on the data.

### Title of this Graph

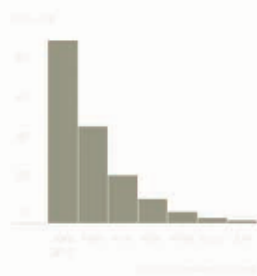
A description of the data or something worth highlighting to set the stage.



Source: Somewhere reputable

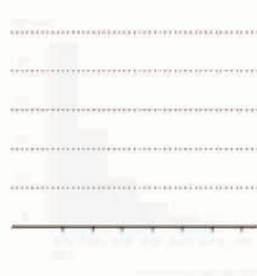
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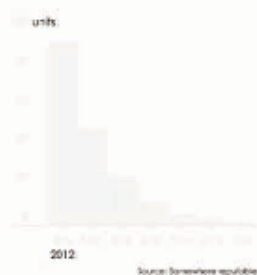
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## Visual Cues

Visualization involves encoding data with shapes, colors, and sizes. Which cues you choose depends on your data and your goals.

## Coordinate System

You map data differently with a scatterplot than you do with a pie chart. It's x- and y-coordinates in one and angles with the other; it's cartesian versus polar.

## Scale

Increments that make sense can increase readability, as well as shift focus.

## Context

If your audience is unfamiliar with the data, it's your job to clarify what values represent and explain how people should read your visualization.

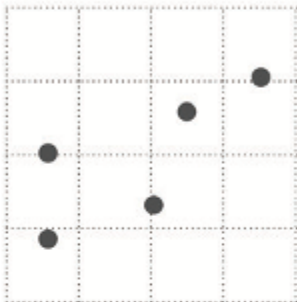
## 1. Visual Cues

### Visual cues

When you visualize data, you encode values to shapes, sizes, and colors.

#### Position

Where in space the data is



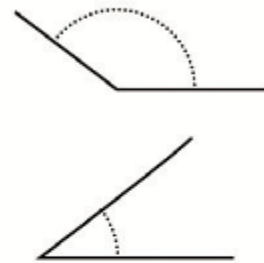
#### Length

How long the shapes are



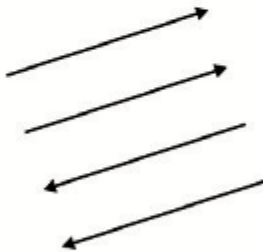
#### Angle

Rotation between vectors



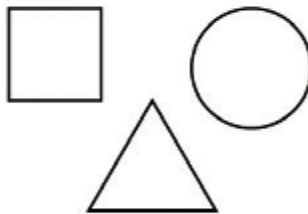
#### Direction

Slope of a vector in space



#### Shapes

Symbols as categories



#### Area

How much 2-D space



#### Volume

How much 3-D space



#### Color saturation

Intensity of a color hue



#### Color hue

Usually referred to as color

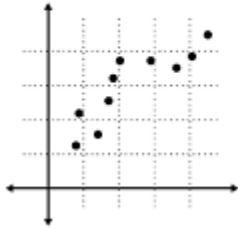


FIGURE 3-3 Visual cues

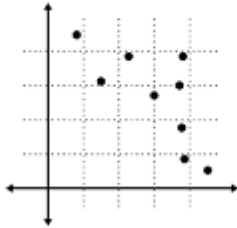
## Visual Cues

1. Position (numerical) where in relation to other things?

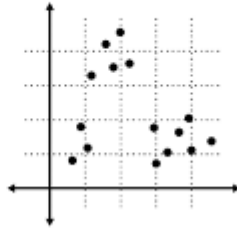
**Upward trend**



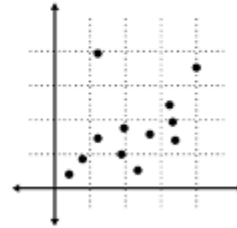
**Downward trend**



**Clustering**

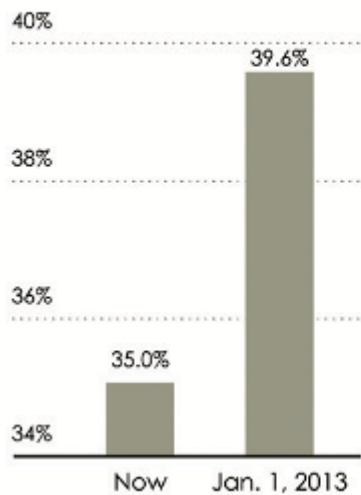


**Outlier**

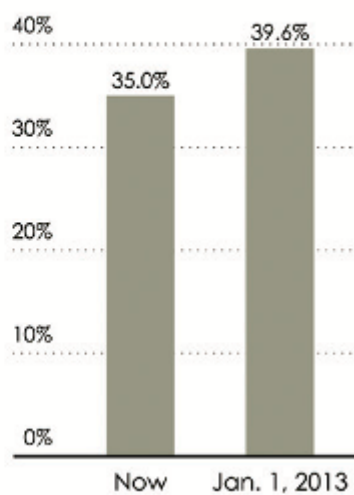


- 
2. Length (numerical) how big (in one dimension)?

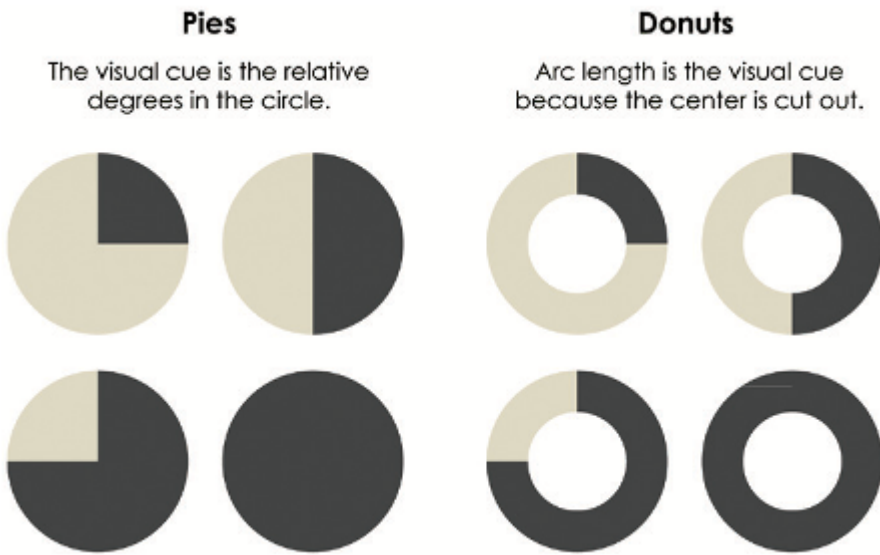
**Axis starting at 34 percent**



**Axis starting at 0 percent**

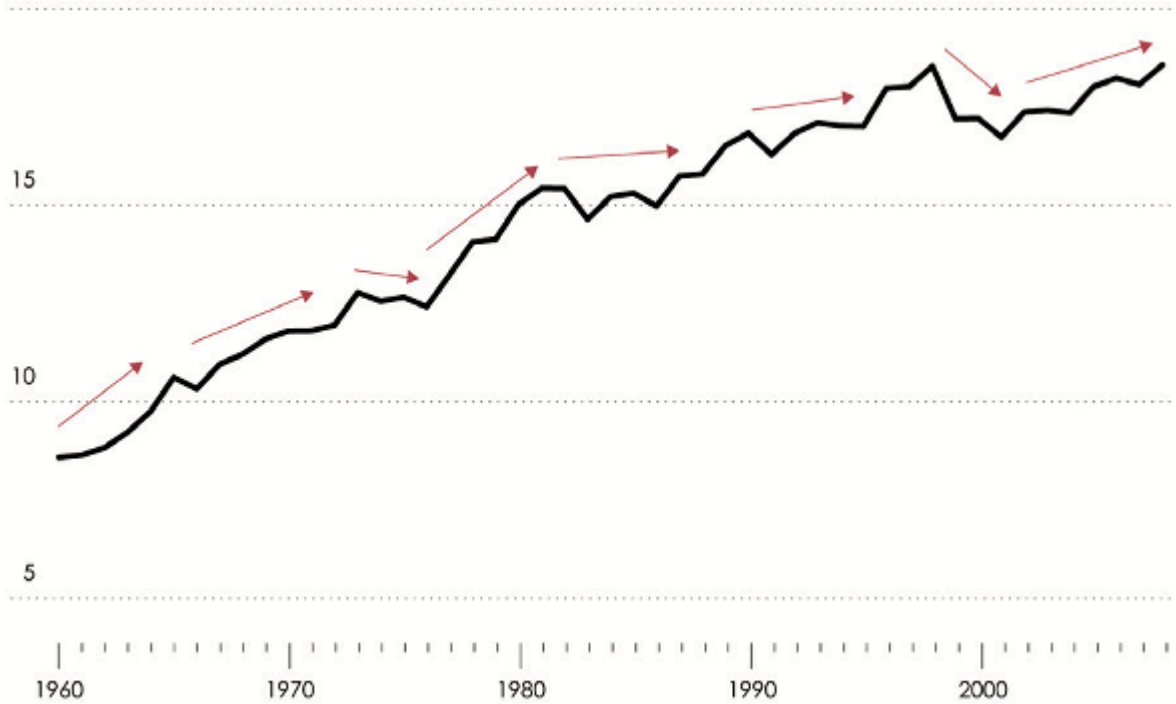


- 
3. Angle (numerical) how wide? parallel to something else?



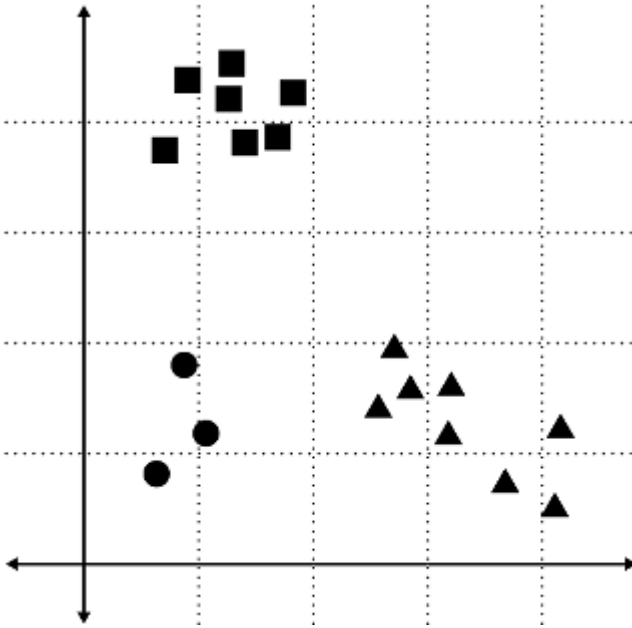
4. Direction (numerical) at what slope? In a time series, going up or down?

20 metric tons of CO<sub>2</sub> per capita in Australia



Source: The World Bank

5. Shape (categorical) belonging to which group?



6. Area (numerical) how big (in two dimensions)?
7. Volume (numerical) how big (in three dimensions)?

#### Sizing by area

This is one unit.



Four units sized by area



4 times the area as unit square

Four units incorrectly sized by side length



16 times the area as unit square

#### Sizing by volume

This is one unit.

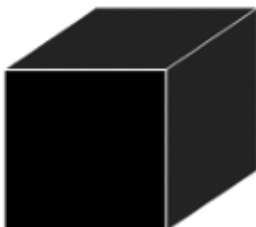


Four units sized by volume



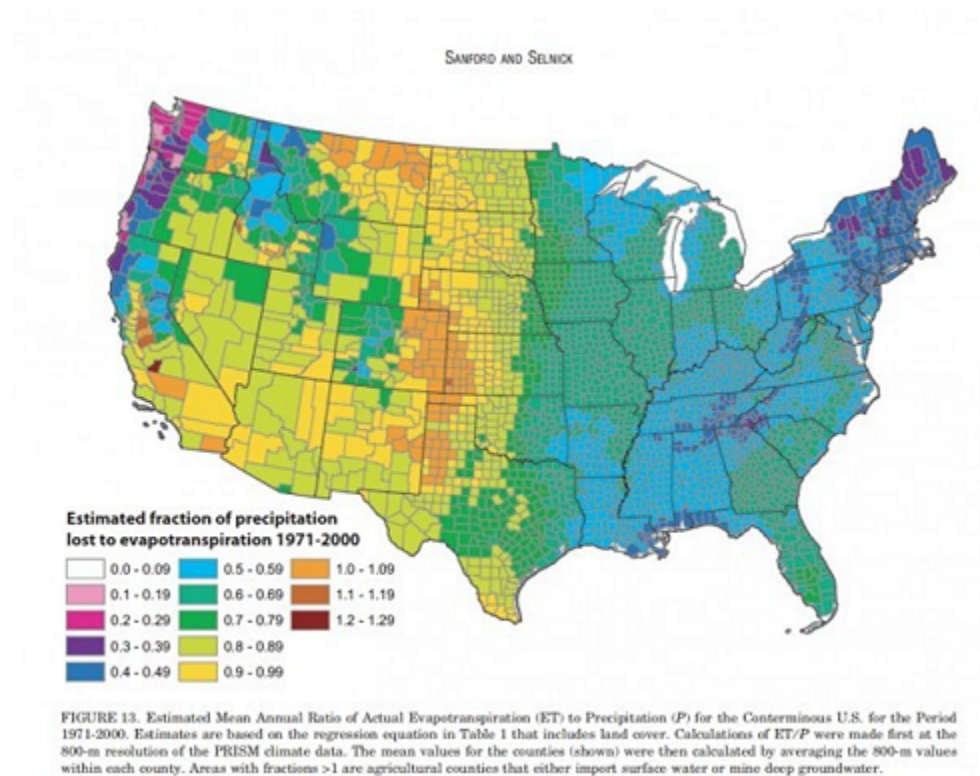
4 times the volume as unit cube

Four units incorrectly sized by edge length



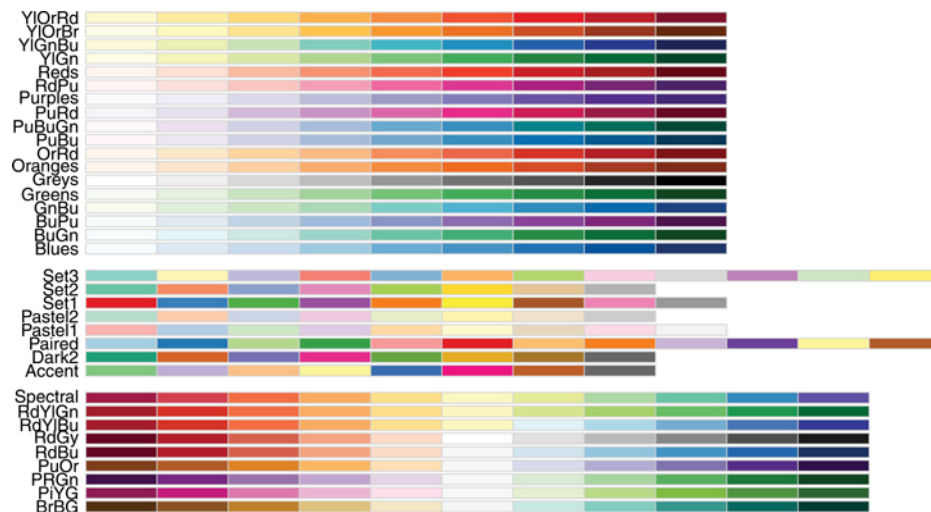
32 times the volume as unit square

8. Shade and color (color saturation and color hue) to what extent? how severely? Beware of red/green color blindness



Note: Colors can represent both quantitative and categorical variables, using the following

- **Sequential** The ordering of the data has only one direction.
- **Diverging** The ordering of the data has two directions.
- **Qualitative** There is no ordering of the data



Which visual cues are more effective?

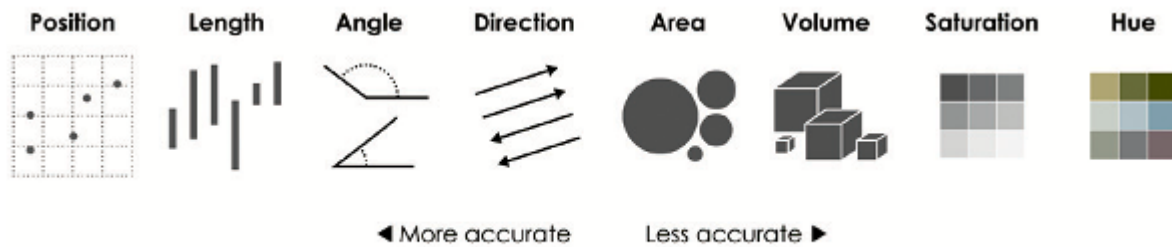
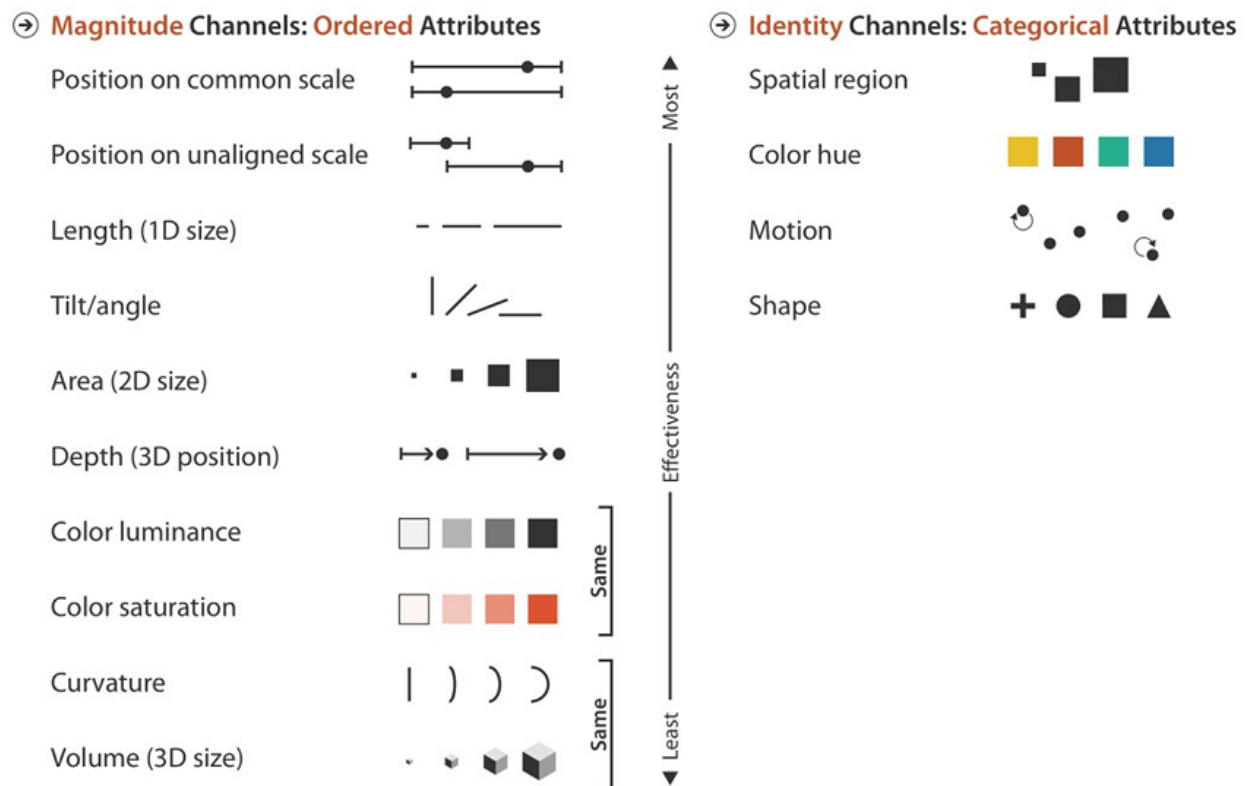


FIGURE 3-12 Visual cues ranked by Cleveland and McGill

Which visual cues are more effective? (2)



T.Munzner: Visualization Analysis and Design, 2014

## 2. Coordinate systems

How are the data points organized? While any number of coordinate systems are possible, three are most common:

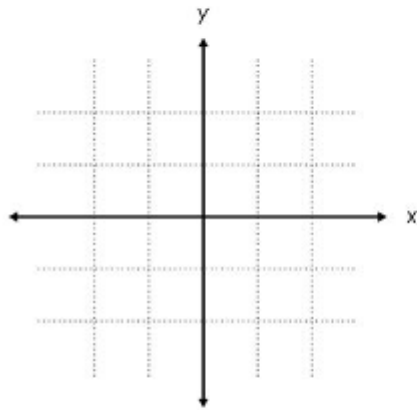


## Coordinate systems

There are a variety of them, from cylindrical to spherical, but these three will cover most of your bases.

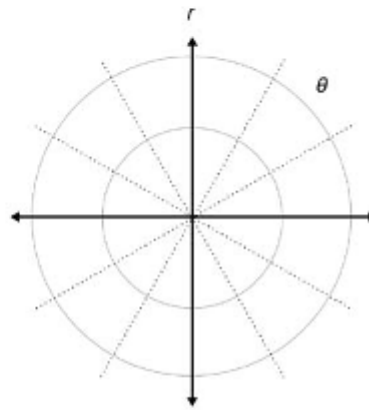
### Cartesian

If you've ever made a graph, the x- and y-coordinate system will look familiar to you.



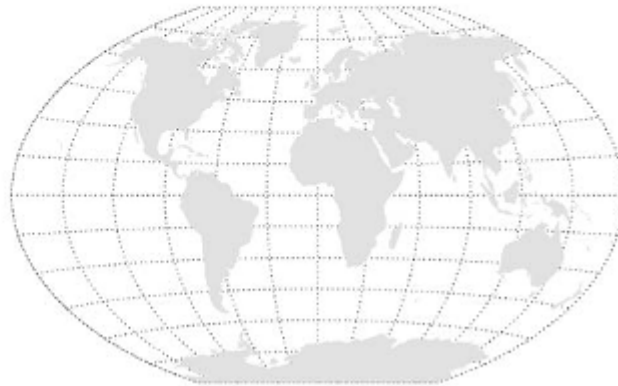
### Polar

Pie charts use this system. Coordinates are placed based on radius  $r$  and angle  $\theta$ .



### Geographic

Latitude and longitude are used to identify locations in the world. Because the planet is round, there are multiple projections to display geographic data in two dimensions. This one is the Winkel tripel.



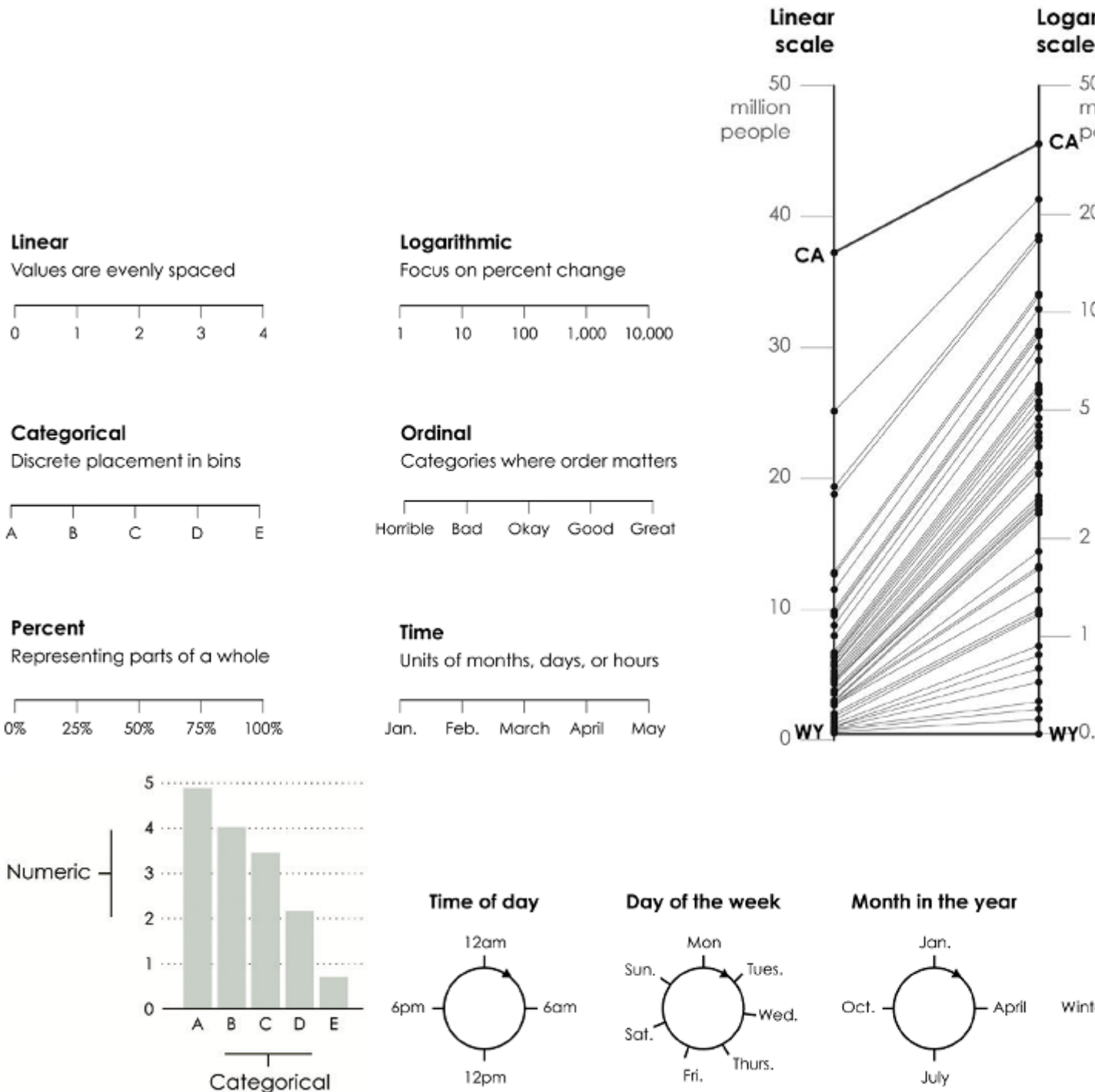
An appropriate choice for a coordinate system is critical in representing one's data accurately, since, for example, displaying spatial data like airline routes on a flat Cartesian plane can lead to gross distortions of reality

## 3. Scale

Scales translate values into visual cues. The choice of scale is often crucial. The central question is how does distance in the data graphic translate into meaningful differences in quantity? Each coordinate axis can have its own scale, for which we have three different choices:

1. **Numeric** A numeric quantity is most commonly set on a linear, logarithmic, or percentage scale.
2. **Categorical** A categorical variable may have no ordering (e.g., Democrat, Republican, or Independent), or it may be ordinal (e.g., never, former, or current smoker).

3. **Time** Time is a numeric quantity that has some special properties. First, because of the calendar, it can be demarcated by a series of different units (e.g., year, month, day, etc.). Second, it can be considered periodically as a wrap-around scale.



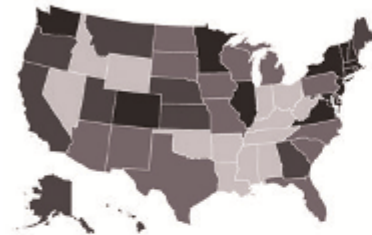
Use data transformation (mutation) to choose the most effective scale

## Varying scales

Choice of scale can shift focus and present a different message. The below maps represent how a single dataset can easily change based on this choice.

### Quartiles

Breaks decided by splitting into four equally-sized groups

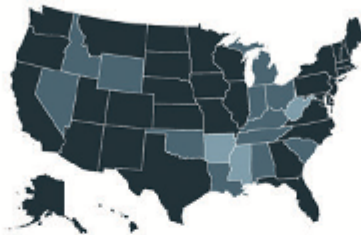


% with at least Bachelor's in 2009

Greater than 30.6%  
26.6% – 30.6%  
24.2% – 26.5%  
Less than 24.2%

### Linear

Scale incremented evenly over range

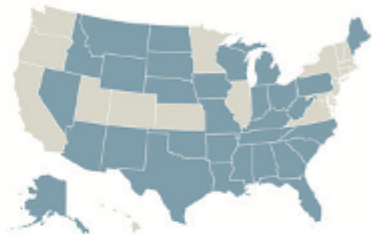


% with at least Bachelor's in 2009

20% >25%  
15% 25%

### Numeric category

Create category based on a metric in data



2009 US Avg. of 27.9%  
Below avg. Above avg.

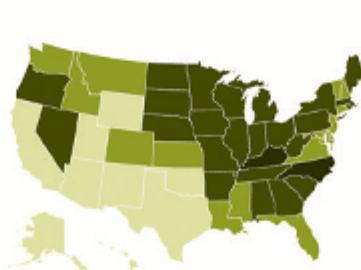
### Categorical

Groups based on metadata, such as region



### Difference

A linear scale, but based on percent change between years



% change from 1990 to 2009

30% 50%  
<30% 40% >50%

### Categorical difference

Simple split based on increase or decrease (Good news: all increase in this example)



Change from 1990 to 2009

Decrease Increase

## 4. Context

The purpose of data graphics is to help the viewer make meaningful comparisons. Context can be added to data graphics in the form of

- titles or subtitles
- axis labels
- reference points or lines

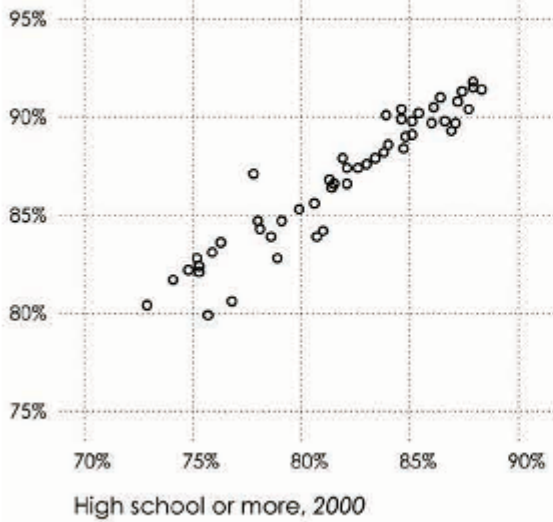
## For multivariate data

Challenging to condense multivariate information into a two-dimensional image. Use

- Small multiples Also known as *facets*
- Layers
- Animation

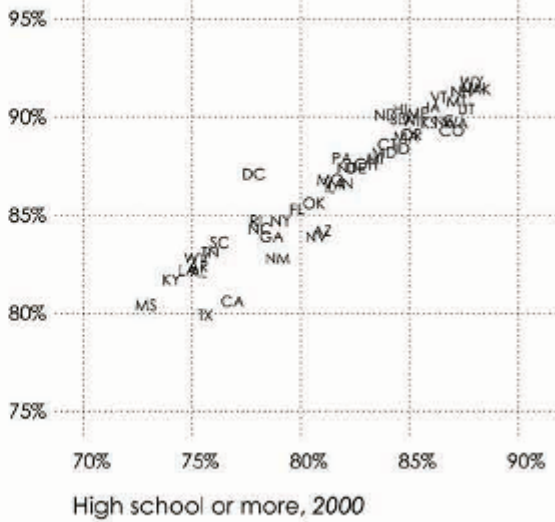
### Position

High school  
or more,  
in 2009



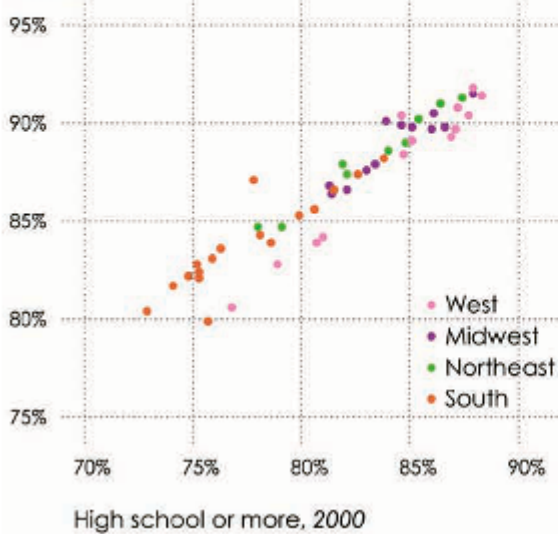
### Position + Symbols

High school  
or more,  
in 2009



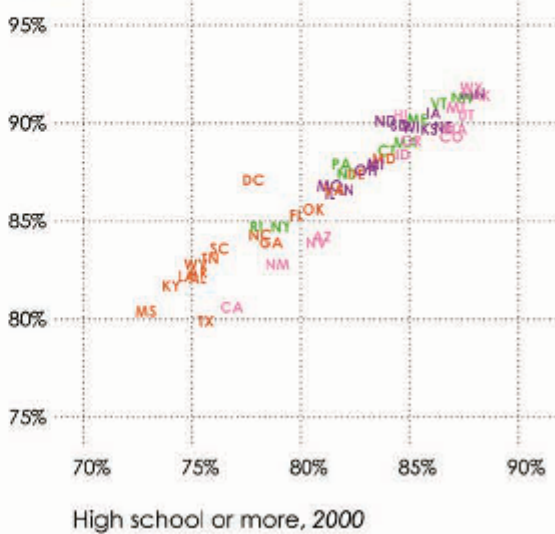
### Position + Color

High school  
or more,  
in 2009









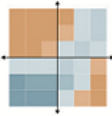
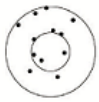













### Position + Symbols + Color

High school  
or more,  
in 2009



(We will revisit facets and layers while learning *A Layered Grammar of Graphics*, implemented in `ggplot2`)

## Putting it all together

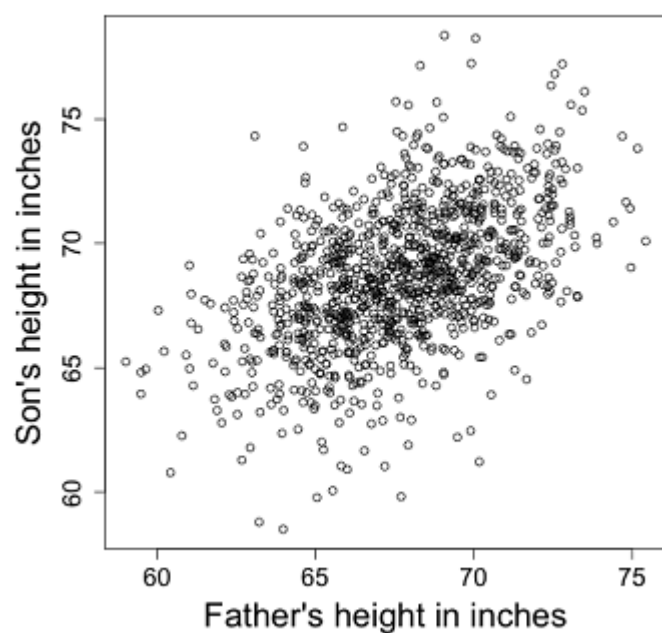
Visual cues							
	Position	Length	Angle	Direction	Shapes	Area or Volume	Color
Coordinate systems							
Cartesian							
Polar							
Geographic							

## Exercises

For each of data graphics, answer the following:

1. Which variables are used, and what are the types of variables?
2. Which visual cue is used?
3. On which coordinate system, and on which scale?
4. How context is provided?

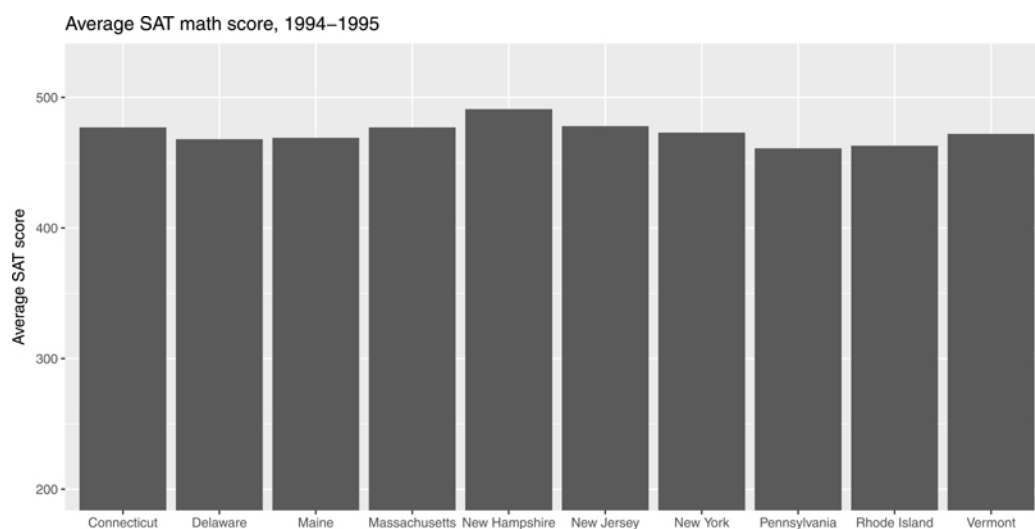
### Exercise 1.



1. *Two quantitative variables* (Son's height and father's height) are used
2. using the visual cue of *position*,
3. in the *Cartesian* plane with *linear* scales
4. Context is provided by the axis labels (to show the positive association).

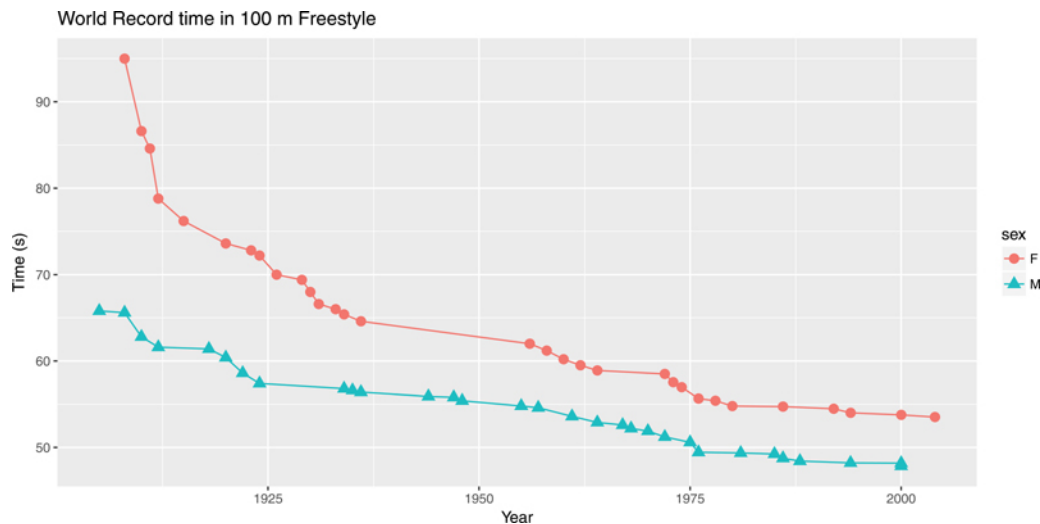
### Exercise 2.

The bar graph displays the average score on the math portion of the 1994–1995 SAT (with possible scores ranging from 200 to 800) among states for whom at least two-thirds of the students took the SAT.



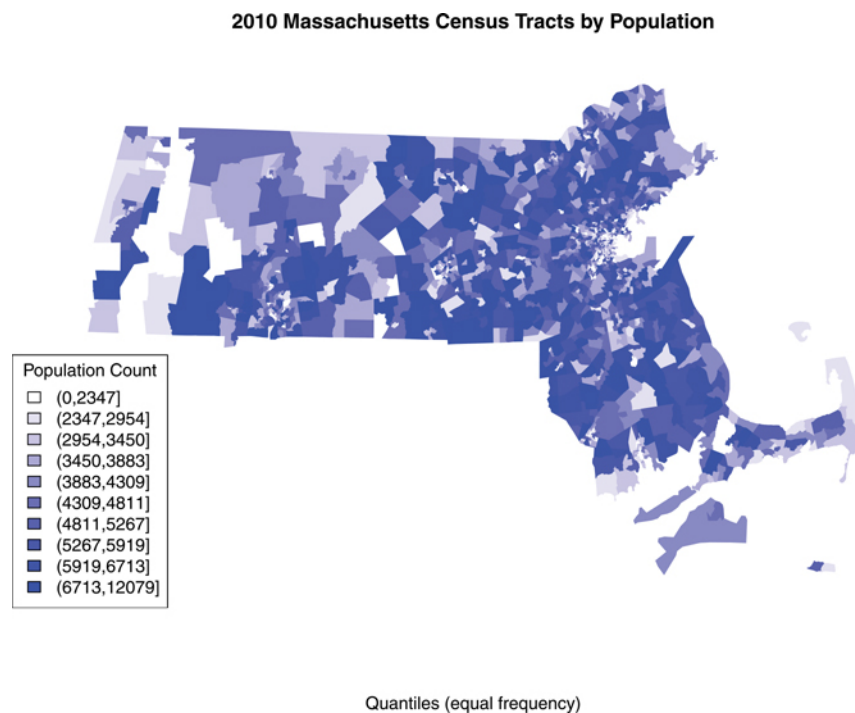
### Exercise 3.

A time series shows the progression of the world record times in the 100-meter freestyle swimming event for men and women. The time series plot displays the times as a function of the year in which the new record was set.



### Exercise 4.

A choropleth map showing the population of Massachusetts by the 2010 Census tracts



### Homework

1. Read the excerpt of “The Visual Display of Quantitative Information” by Edward Tufte



2. Dissecting data graphics. Textbook exercises.
3. Find a data graphic *in the wild*, and criticize it. For this you will need to utilize the best of both worlds (of Tufte's and Yau's).

Find the detailed instruction on the course webpage.