

# INTRODUCTION TO DATA SCIENCE

Lecture based on:

M. Cetinkays-Rundel, „Data Analysis and Statistical Inference”, Univ. of Duke

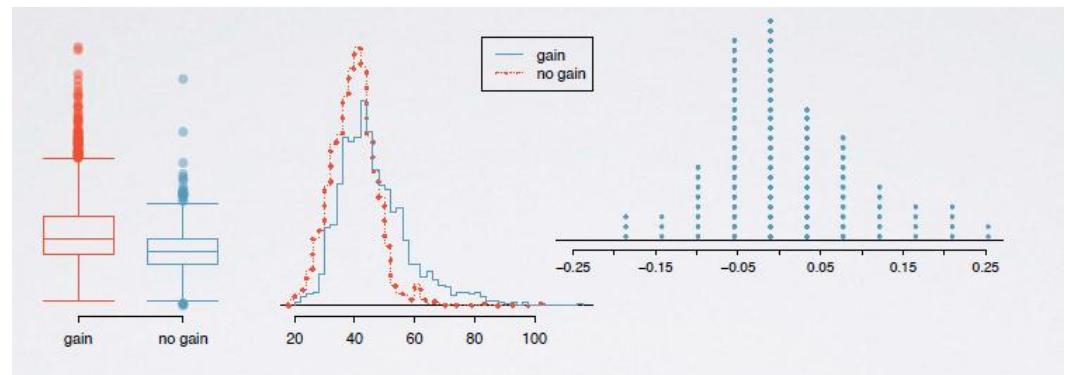
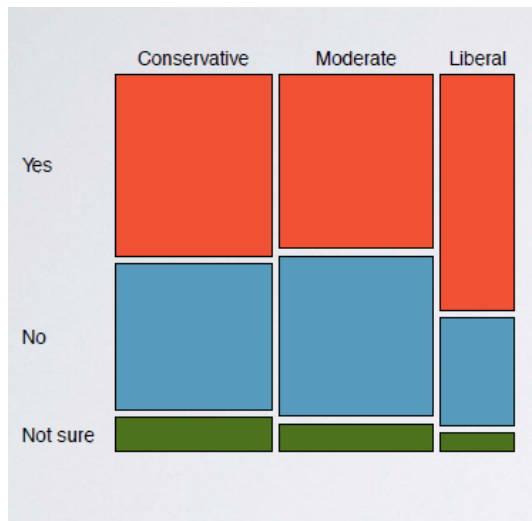
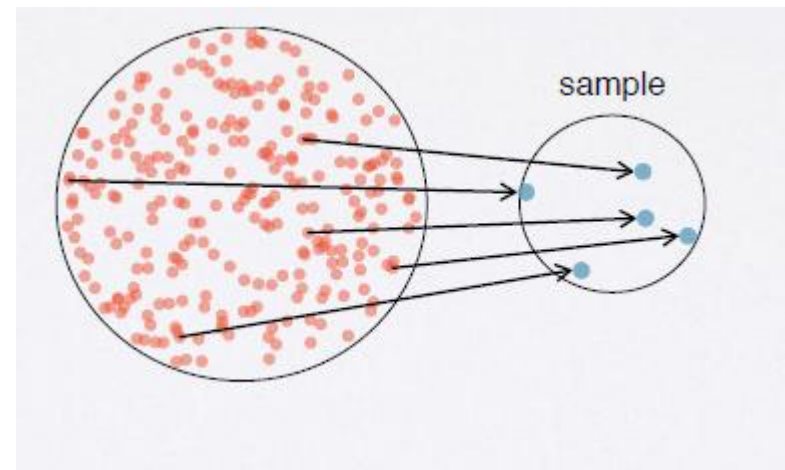
8/10/2019

WFAiS UJ, Fizyka, II stopień studiów

# Exploratory data analysis

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How to collect, visualise and interpret the data.



early  
smoking  
research

anecdotal  
evidence

*“My uncle smokes  
three packs a day  
and he’s in perfectly  
good health”*

*“smoking is a complex  
human behavior, by its  
nature difficult to study,  
confounded by human  
variability”*

Source: Brandt, The Cigarette Century (2009)

populations  
and  
samples

research  
question

population

sample

generalize  
to

Are consumers  
of certain  
alcohol brands  
more likely to  
end up in the  
emergency  
room with  
injuries?

Everyone

ER patients  
at the Johns  
Hopkins  
Hospital  
in Baltimore  
in the US

Residents  
of  
Baltimore

Source: Jernigan, David H.,  
et al. "Alcohol brand use  
and injury in the  
emergency department: A  
pilot study." Substance  
use & misuse (2013).

Image credit: Jon Sullivan

<http://www.public-domain-image.com/food-and-drink-public-domain-images-pictures/wine-public-domain-images-pictures/champagne-flutes-glasses-bubbles.jpg.html>

# Exploratory data analysis

5

population

sample

design

scope

exploratory  
data  
analysis

inference

# Data: basics

6

- Observations, variables, data matrices
- Type of variables
- Relationship between variables

# Example: data matrix

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**Requests send to Google to remove links from the search engine database.**

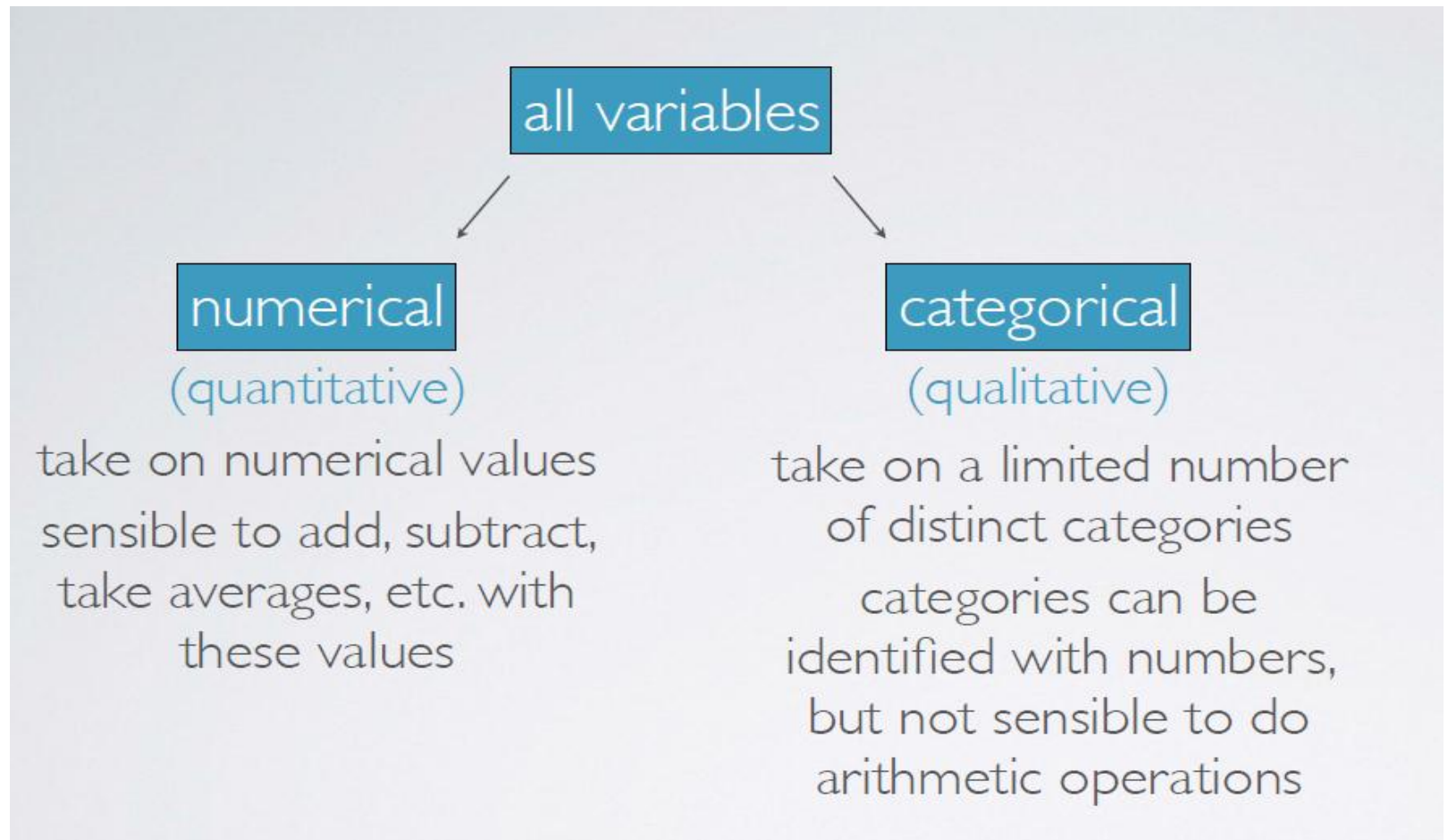
country	cr_req	cr_comply	ud_req	ud_comply	...	hemisphere	hdi
Argentina	21	100	134	32	...	southern	very high
Australia	10	40	361	73	...	southern	very high
Belgium	<10	100	90	67	...	northern	very high
Brazil	224	67	703	82	...	southern	high
...	...	...	...	...	...	...	...
United States	92	63	5950	93	...	northern	very high

observation  
(case)

variable

# Type of variables

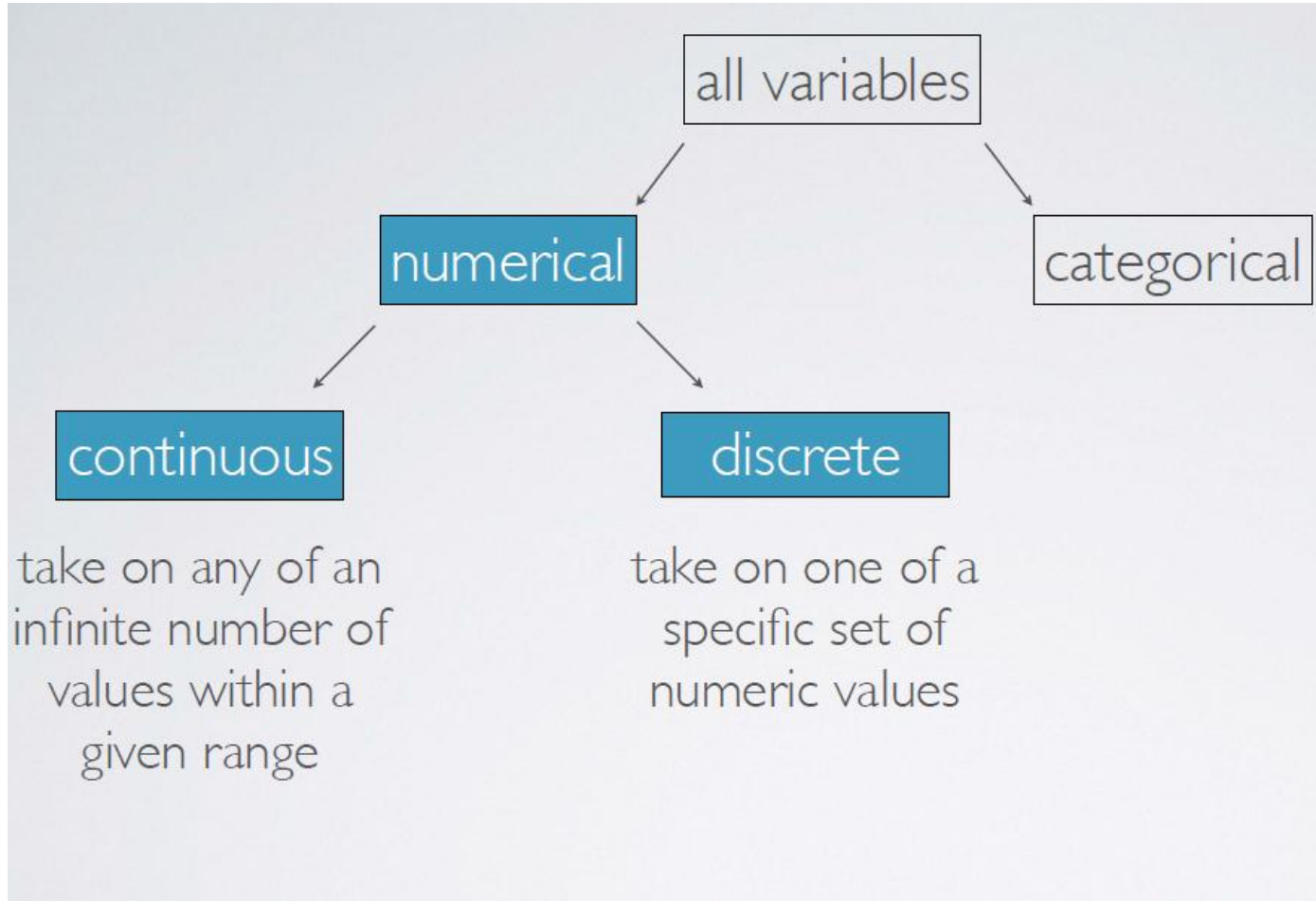
8





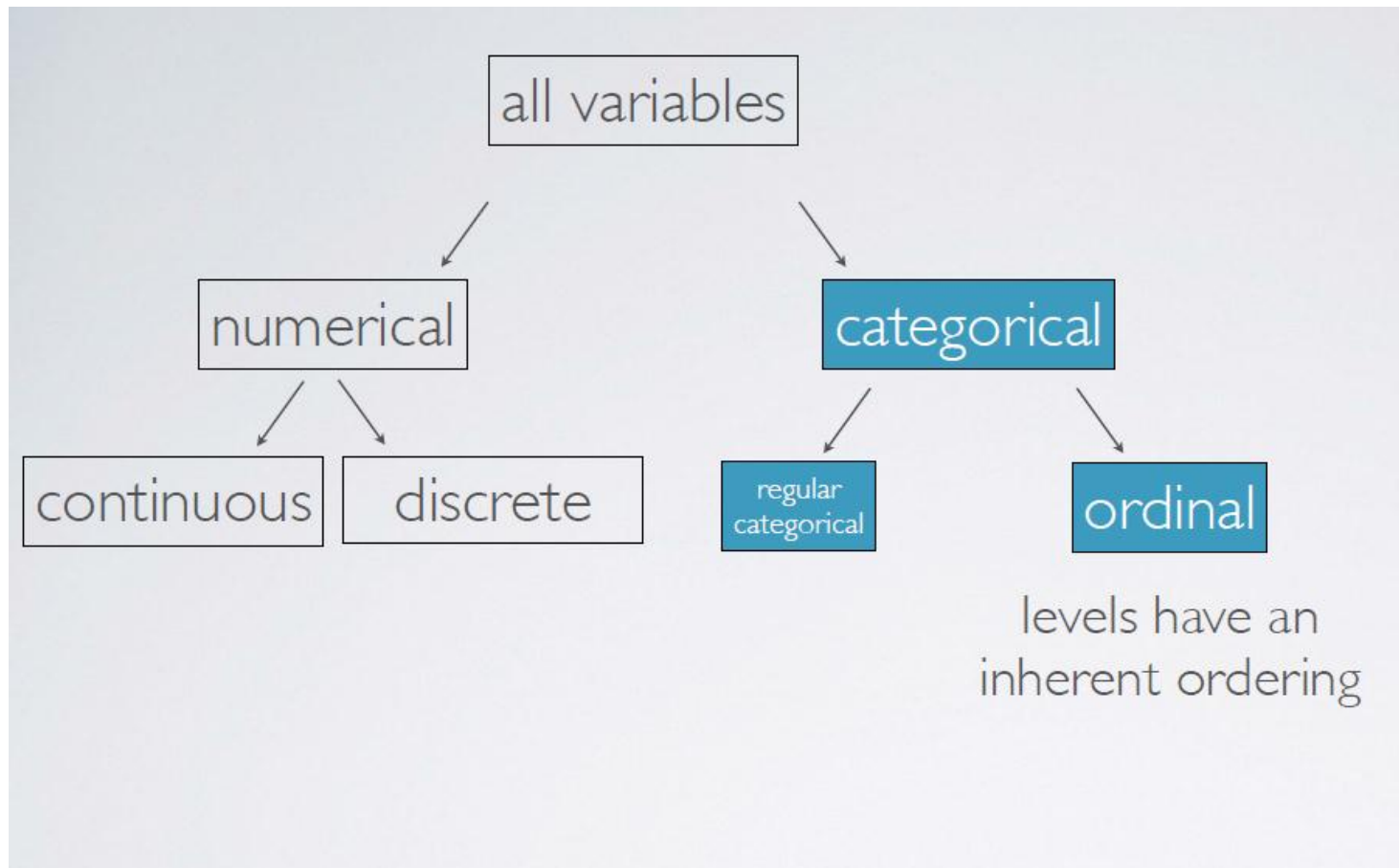
# Numerical variables

9



# Categorical variables

10



# Data matrix

11

country	cr_req	cr_comply	ud_req	ud_comply	...	hemisphere	hdi
Argentina	21	100	134	32	...	southern	very high
Australia	10	40	361	73	...	southern	very high
Belgium	<10	100	90	67	...	northern	very high
Brazil	224	67	703	82	...	southern	high
...	...	...	...	...	...	...	...
United States	92	63	5950	93	...	northern	very high



country: Name of the country

# Data matrix

12

country	cr_req	cr_comply	ud_req	ud_comply	...	hemisphere	hdi
Argentina	21	100	134	32	...	southern	very high
Australia	10	40	361	73	...	southern	very high
Belgium	<10	100	90	67	...	northern	very high
Brazil	224	67	703	82	...	southern	high
...	...	...	...	...	...	...	...
United States	92	63	5950	93	...	northern	very high



cr\_req: Number of content removal requests made to Google

discrete  
numerical

# Data matrix

13

country	cr_req	cr_comply	ud_req	ud_comply	...	hemisphere	hdi
Argentina	21	100	134	32	...	southern	very high
Australia	10	40	361	73	...	southern	very high
Belgium	<10	100	90	67	...	northern	very high
Brazil	224	67	703	82	...	southern	high
...	...	...	...	...	...	...	...
United States	92	63	5950	93	...	northern	very high



`cr_comply`: Percentage of content removal requests Google complied with

continuous  
numerical

# Data matrix

14

country	cr_req	cr_comply	ud_req	ud_comply	...	hemisphere	hdi
Argentina	21	100	134	32	...	southern	very high
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Belgium	<10	100	90	67	...	northern	very high
Brazil	224	67	703	82	...	southern	high
...	...	...	...	...	...	...	...
United States	92	63	5950	93	...	northern	very high



ud\_req: Number of user data requests as part of a criminal investigation

# Data matrix

15

country	cr_req	cr_comply	ud_req	ud_comply	...	hemisphere	hdi
Argentina	21	100	134	32	...	southern	very high
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Belgium	<10	100	90	67	...	northern	very high
Brazil	224	67	703	82	...	southern	high
...	...	...	...	...	...	...	...
United States	92	63	5950	93	...	northern	very high



ud\_comply: Percentage of user data requests Google complied with

**continuous  
numerical**

# Data matrix

16

country	cr_req	cr_comply	ud_req	ud_comply	...	hemisphere	hdi
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Belgium	<10	100	90	67	...	northern	very high
Brazil	224	67	703	82	...	southern	high
...	...	...	...	...	...	...	...
United States	92	63	5950	93	...	northern	very high

**categorical**

hemisphere: Hemisphere that the country is located in  
(southern, northern)



# Data matrix

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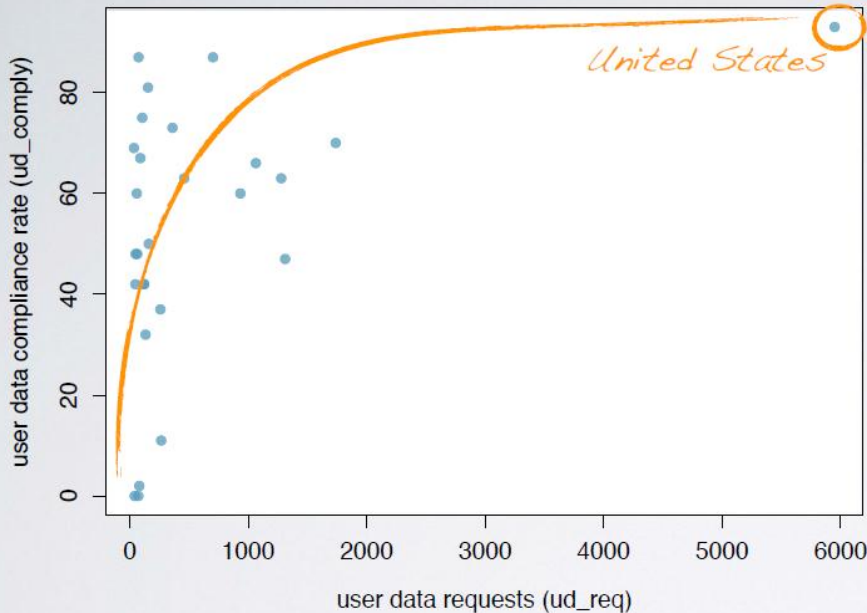
country	cr_req	cr_comply	ud_req	ud_comply	...	hemisphere	hdi
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Brazil	224	67	703	82	...	southern	high
...	...	...	...	...	...	...	...
United States	92	63	5950	93	...	northern	very high

↓  
hdi: Human Development Index  
(very high, high, medium, low)

# Relationships between variables

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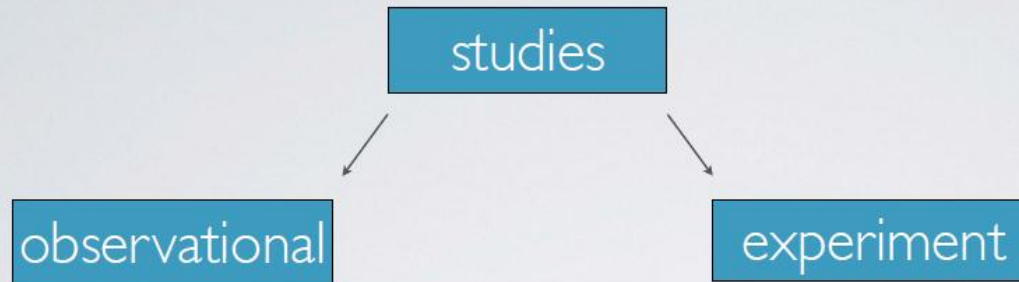
## relationships between variables



- ▶ Two variables that show some connection with one another are called **associated (dependent)**
- ▶ Association can be further described as **positive** or **negative**
- ▶ If two variables are not associated, they are said to be **independent**

# Observational studies & experiments

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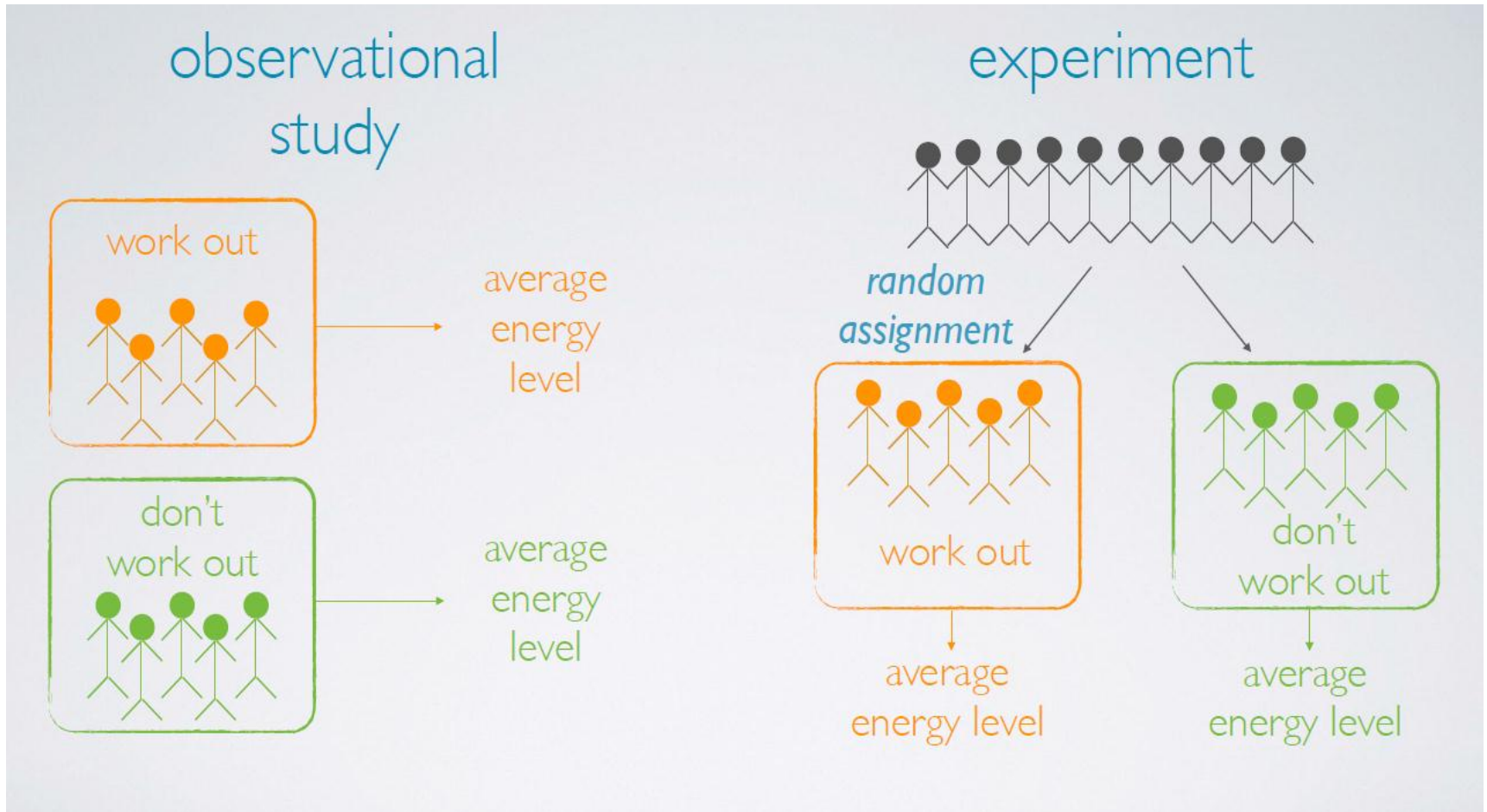


- ▶ collect data in a way that does not directly interfere with how the data arise (“observe”)
- ▶ only establish an association
- ▶ **retrospective**: uses past data
- ▶ **prospective**: data are collected throughout the study

- ▶ randomly assign subjects to treatments
- ▶ establish causal connections

# Observational studies & experiments

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# Correlation & Causation

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## □ Case study

---

### Study: Breakfast cereal keeps girls slim

USA TODAY

Sept 8, 2005

[...]

Girls who ate breakfast of any type had a lower average body mass index, a common obesity gauge, than those who said they didn't. The index was even lower for girls who said they ate cereal for breakfast, according to findings of the study conducted by the Maryland Medical Research Institute with funding from the National Institutes of Health (NIH) and cereal-maker General Mills.

[...]

The results were gleaned from a larger NIH survey of 2,379 girls in California, Ohio, and Maryland who were tracked between the ages of 9 and 19.

[...]

As part of the survey, the girls were asked once a year what they had eaten during the previous three days.

[...]

---

# Possible explanations

22

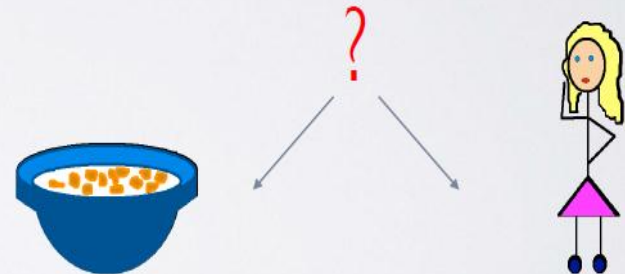
1. eating breakfast causes girls to be slimmer



2. being slim causes girls to eat breakfast



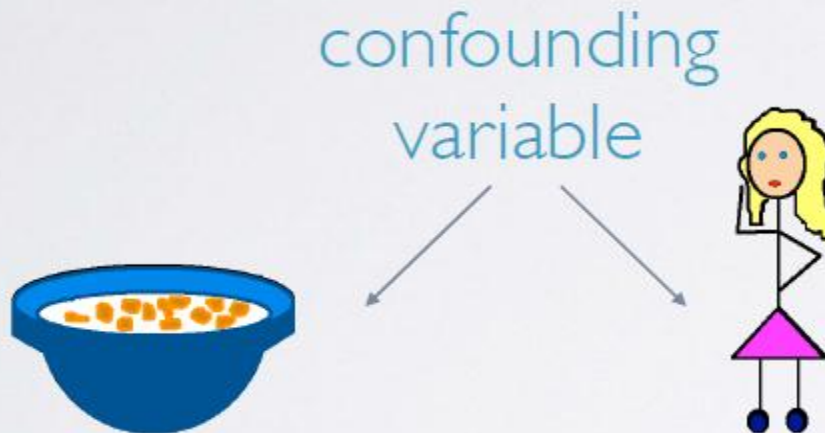
3. a third variable is responsible for both



# Confounding variables

23

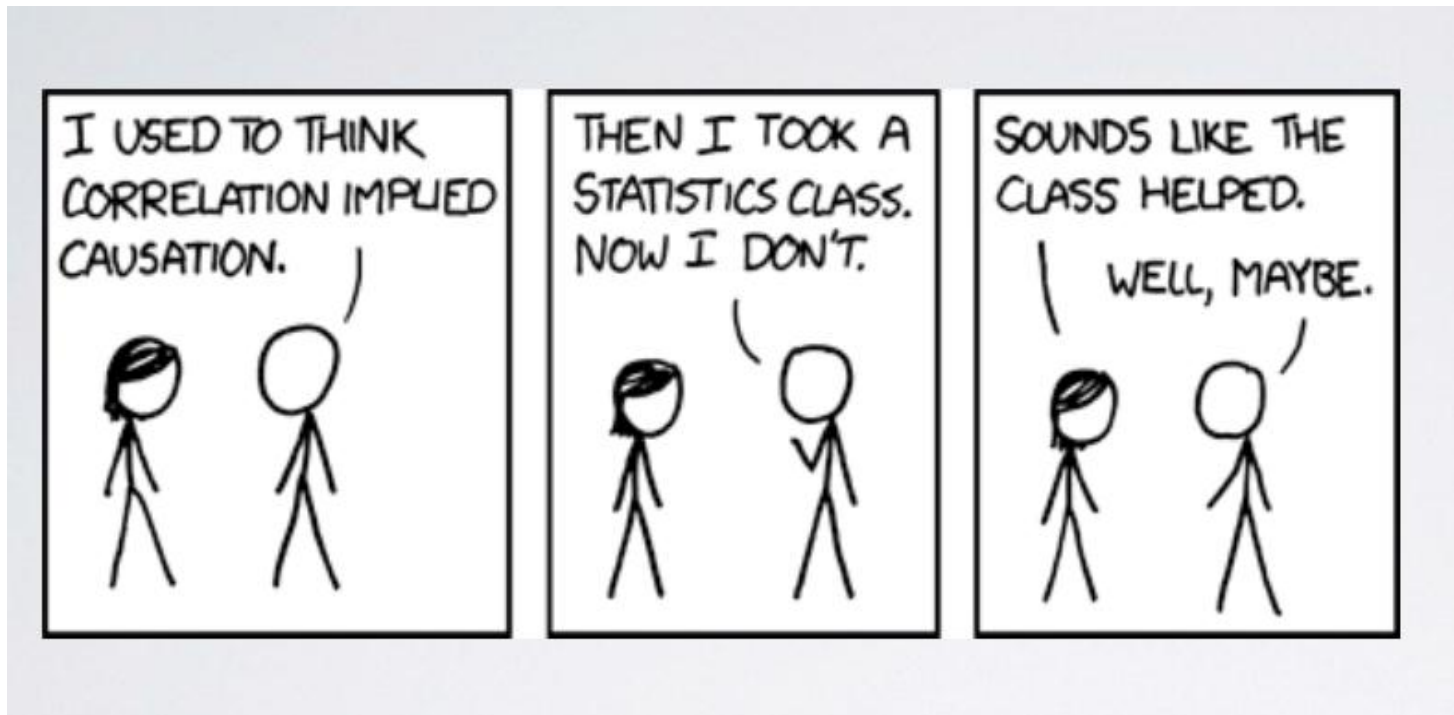
extraneous variables that affect both the explanatory and the response variable, and that make it seem like there is a relationship between them



# Correlation & Causation

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- Correlation does not imply causation





# Sampling & sources bias

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- Census vs sample
- Source o bias
- Sampling methods

# Census

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Wouldn't it be better to just include everyone and "sample" the entire population, i.e. conduct a [census](#)?

- ▶ Some individuals are hard to locate or measure, and these people be different from the rest of the population.
- ▶ Populations rarely stand still.

## Illegal Immigrants Reluctant To Fill Out Census Form

by PETER O'DOWD

March 31, 2010 4:00 AM



There is an effort underway to make sure Hispanics are accurately counted in the 2010 Census. Phoenix has some of the country's "hardest-to-count" districts. Some Latinos, especially illegal residents, fear that participating in the count will expose them to immigration raids or government harassment.

8/10/2019

# A few sources of sampling bias

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- ▶ **Convenience sample:** Individuals who are easily accessible are more likely to be included in the sample
- ▶ **Non-response:** If only a (non-random) fraction of the randomly sampled people respond to a survey such that the sample is no longer representative of the population
- ▶ **Voluntary response:** Occurs when the sample consists of people who volunteer to respond because they have strong opinions on the issue

**QUICK VOTE**

Should the West intervene in Syria?

Yes  No

**VOTE** or view results

---

**QUICK VOTE**

Should the West intervene in Syria?

Yes 34% 534

No 66% 1038

Total Votes: 1572

This is not a scientific poll

# A few sources of sampling bias

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1936

**Landon vs. FDR**  
(Republican) (Democrat)

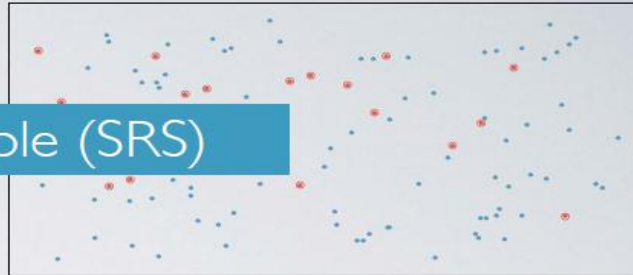
**The Literary Digest**  
Election results

Lose with 43% of the votes  
Win with 62% of the votes

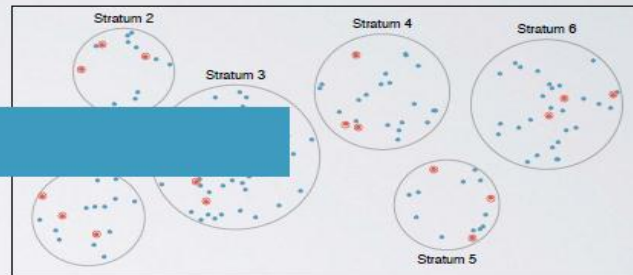
# Sampling methods

29

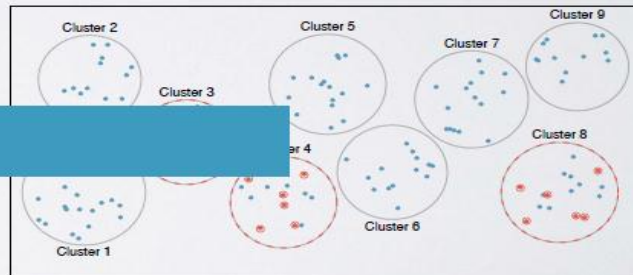
simple random sample (SRS)



stratified sample



cluster sample



# Sampling methods: random sampling

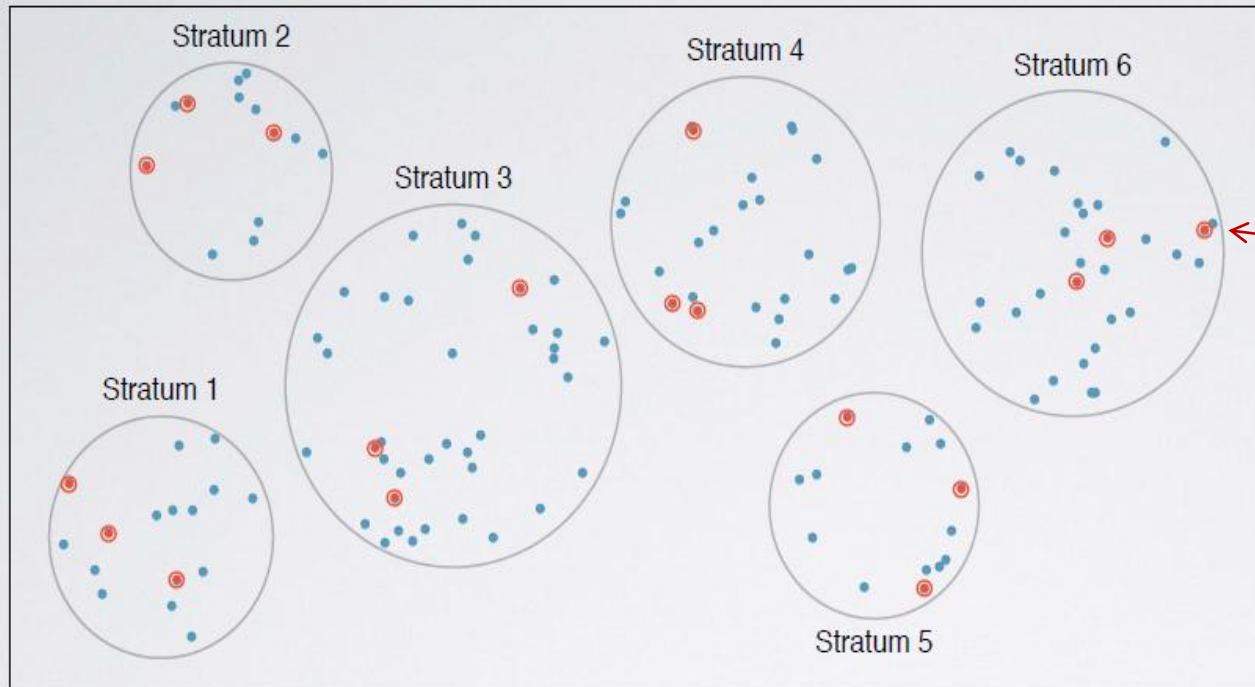
30



each case is equally likely to be selected

# Sampling methods: stratified sample

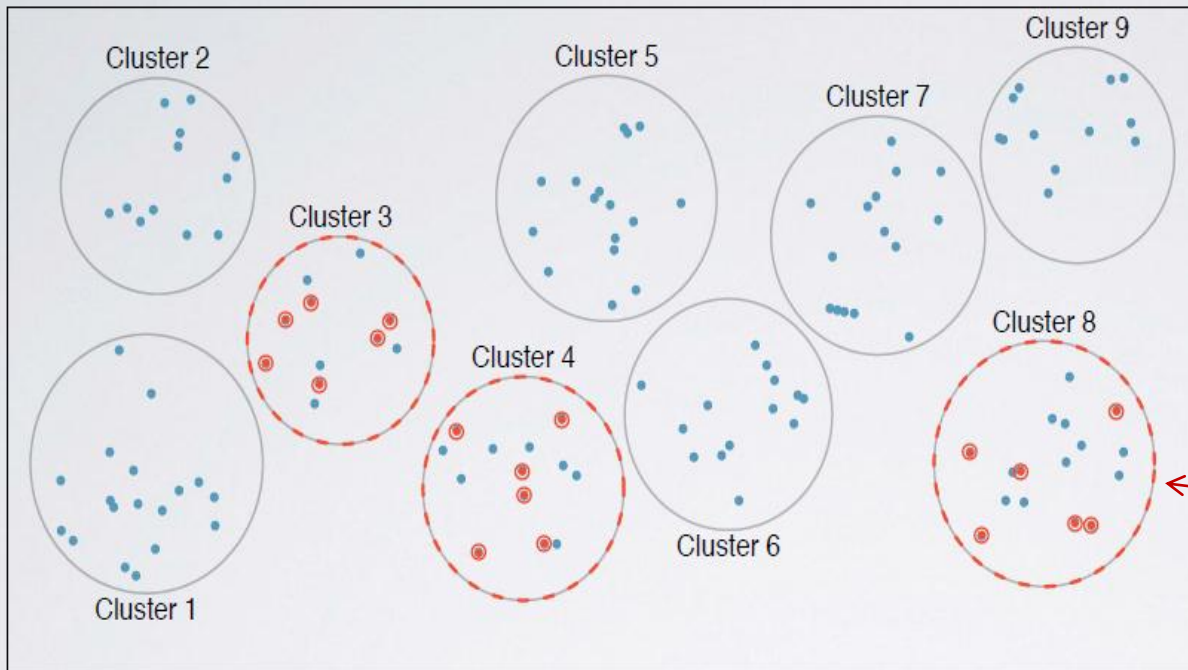
31



divide the population into homogenous *strata*, then randomly sample from within each stratum

# Sampling methods: cluster

32



selected

divide the population **clusters**, randomly sample a few clusters, then randomly sample from within these clusters



# Vizualizing numerical data

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- Scatter plots for paired data
- Other visualizations for describing distributions of numerical variables

# Data matrix

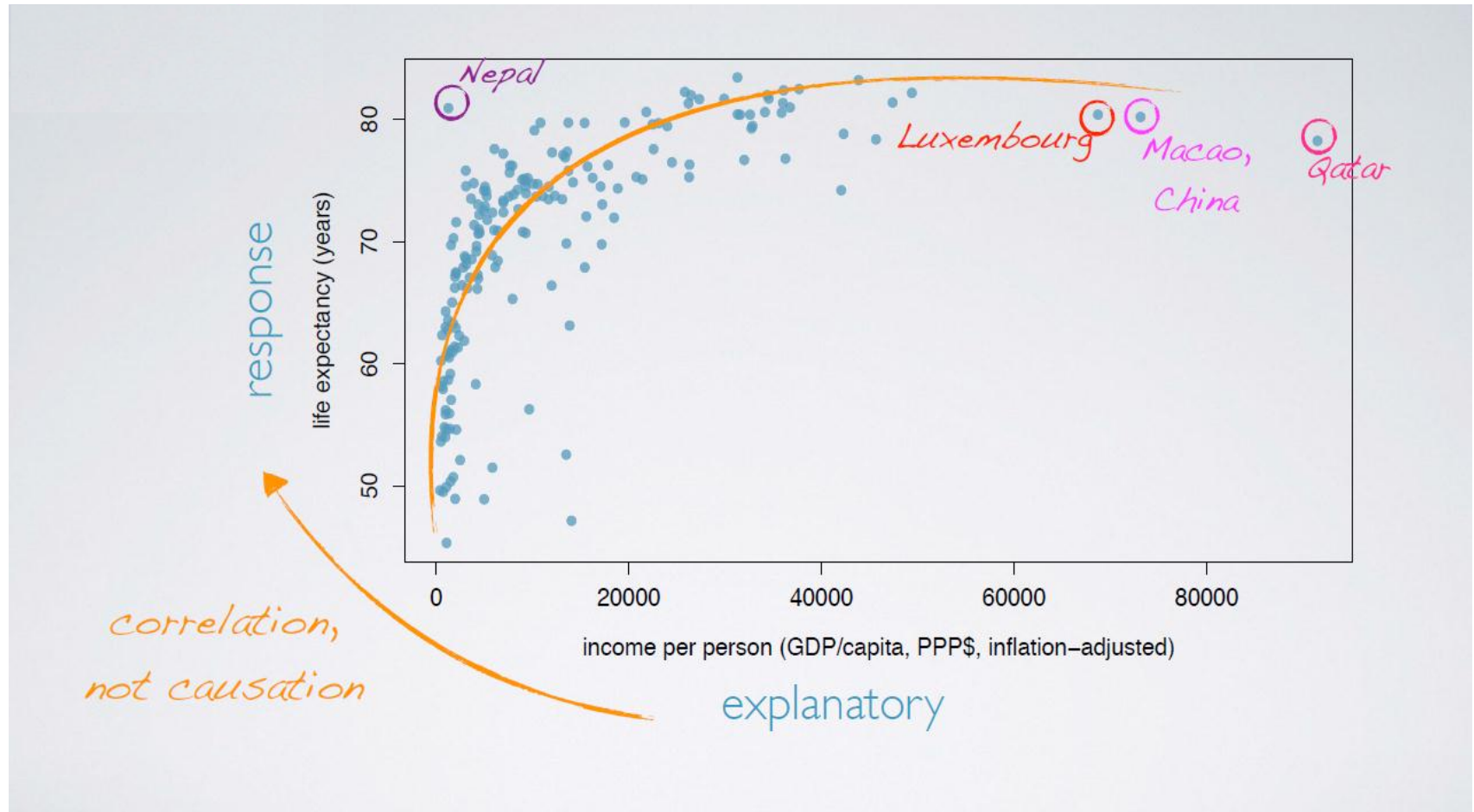
34

data	income per person (\$, 2012)	life expectancy (years, 2012)
Afghanistan	1359.7	60.254
Albania	6969.3	77.185
Algeria	6419.1	70.874
...	...	...
Zimbabwe	545.3	58.142

Source: [gapminder.com](http://gapminder.com)

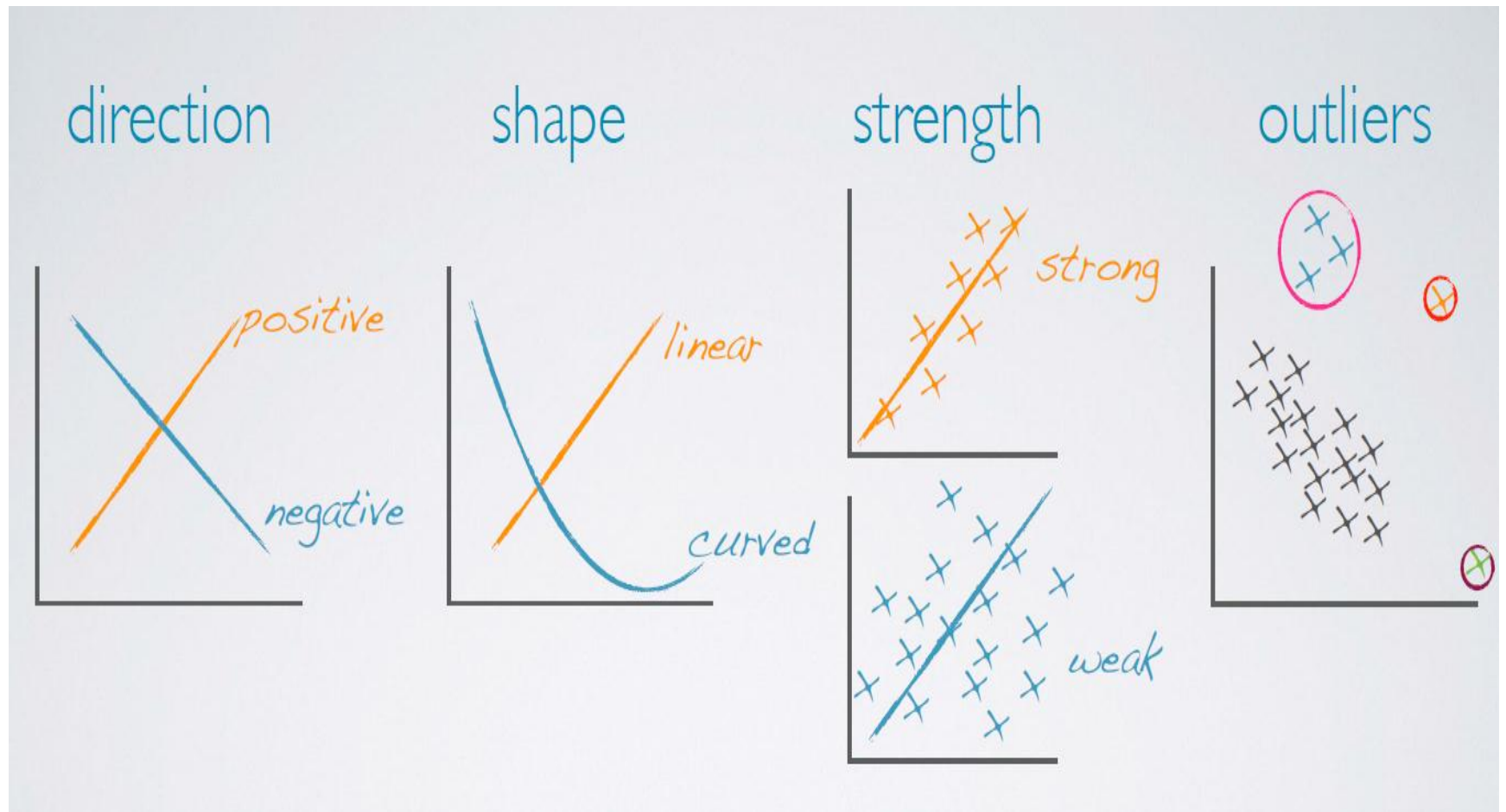
# Scatterplots

35



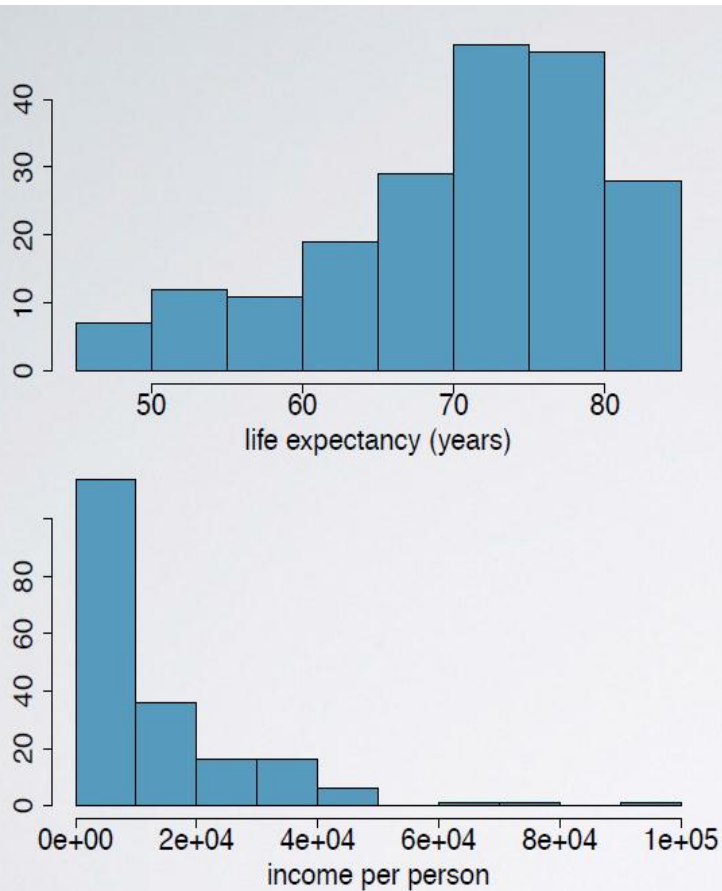
# Evaluating their relationship

36



# Histogram

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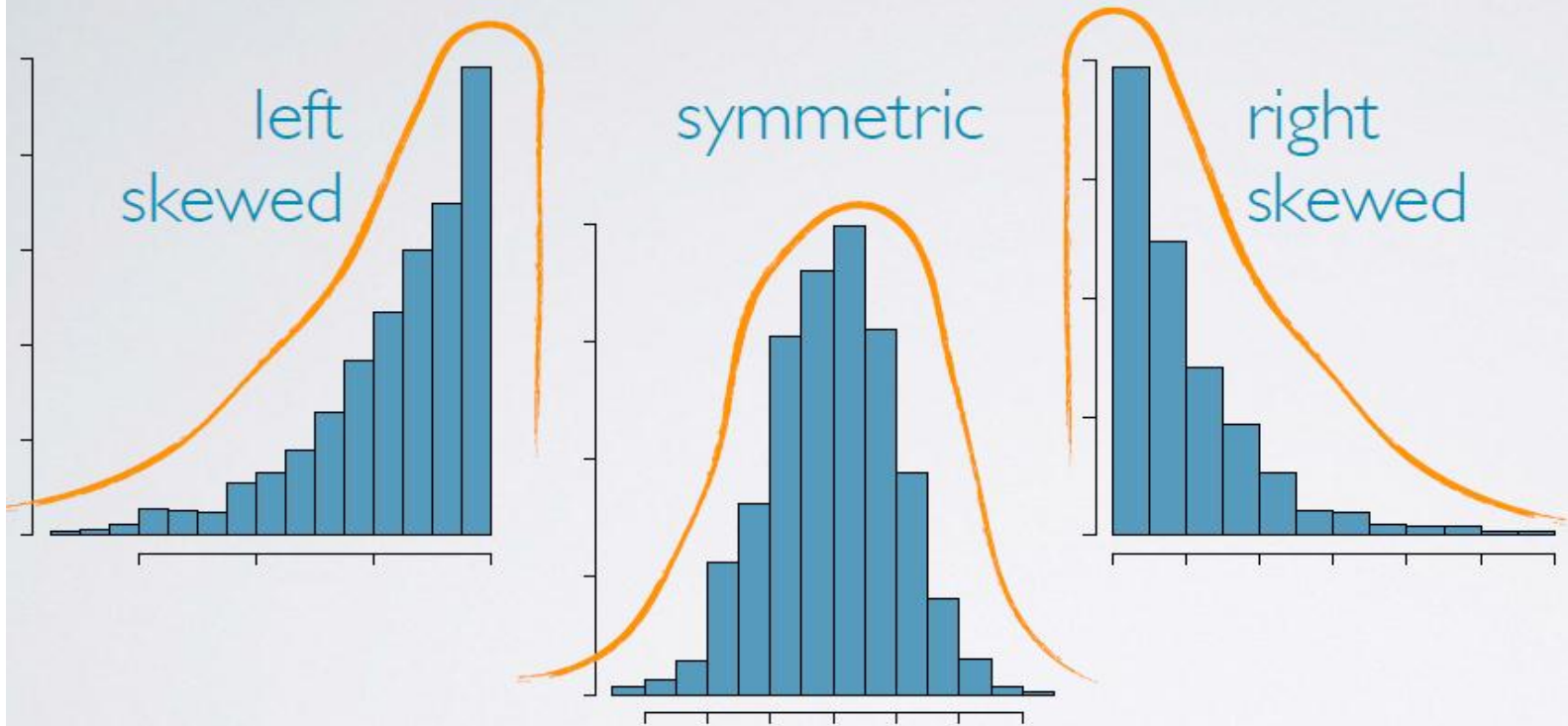
## histogram

- ▶ provides a view of the [data density](#)
- ▶ especially useful for describing the shape of the distribution

# Histogram

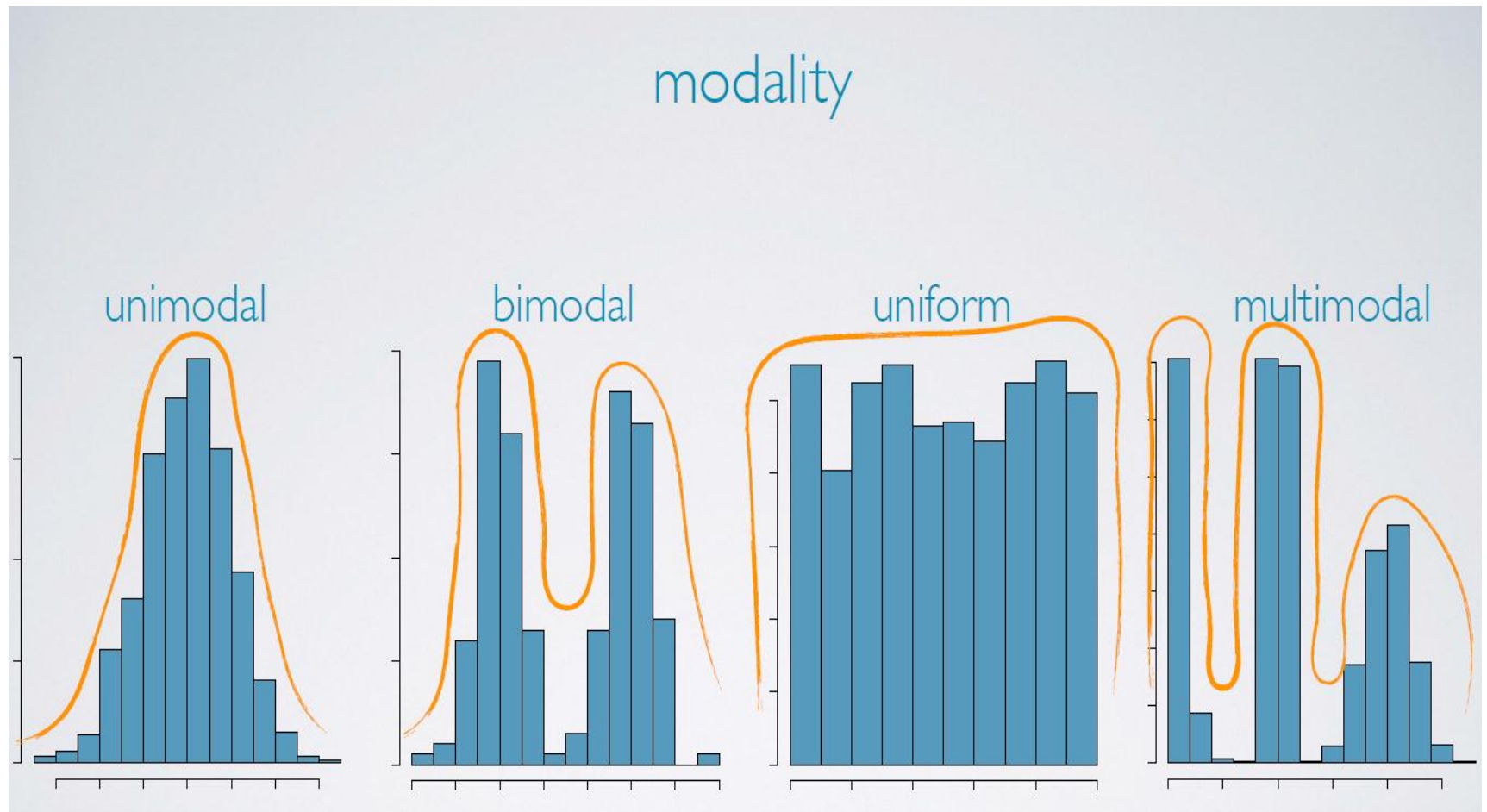
38

distributions are skewed to the side of the long tail



# Histogram

39



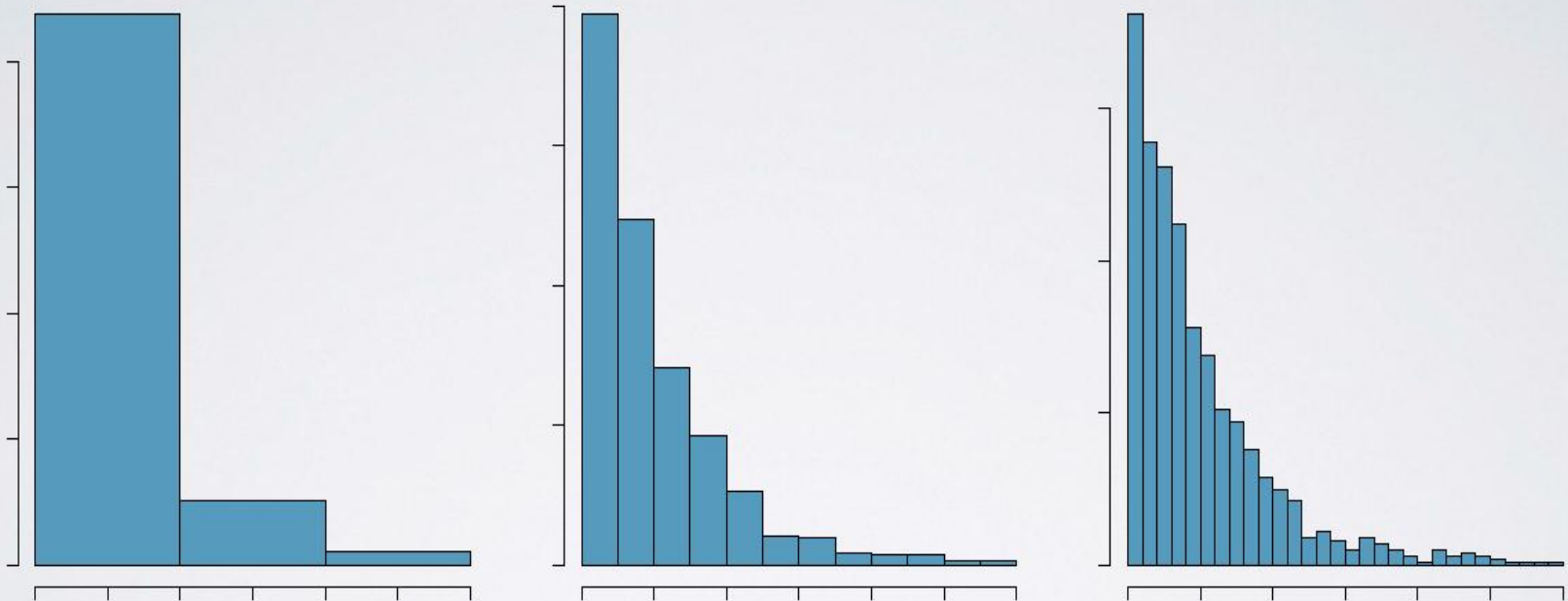
8/10/2019

# Histogram

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## histogram & bin width

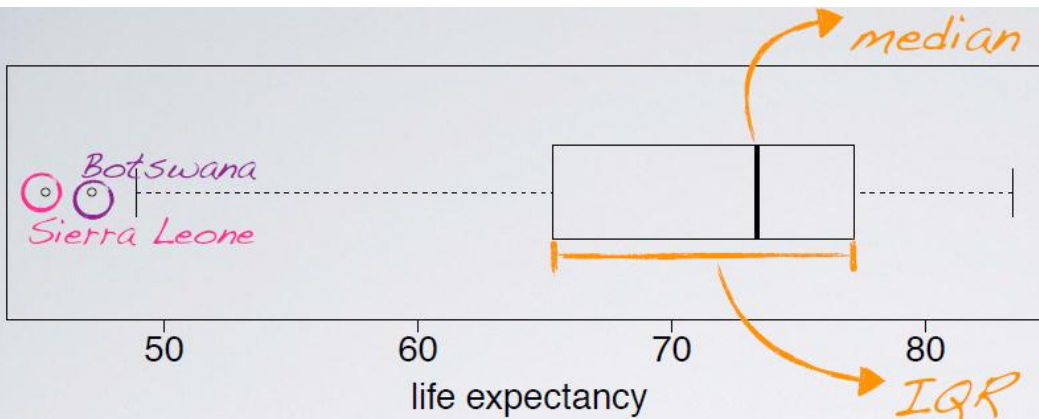
The chosen **bin width** can alter the story the histogram is telling.





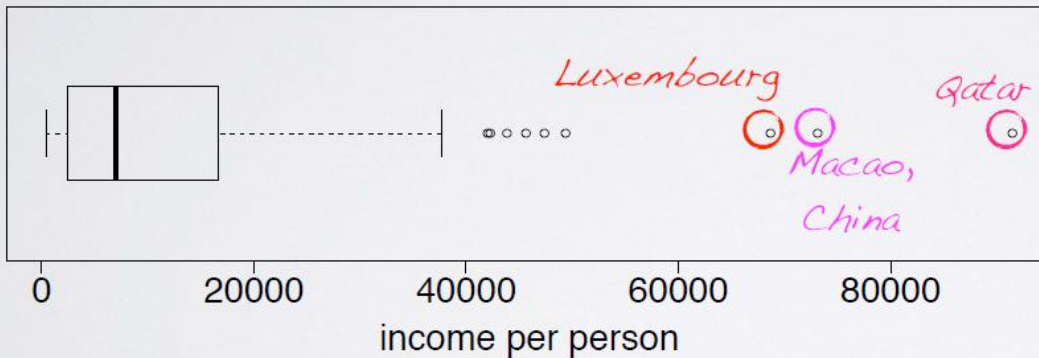
# Box plot

41



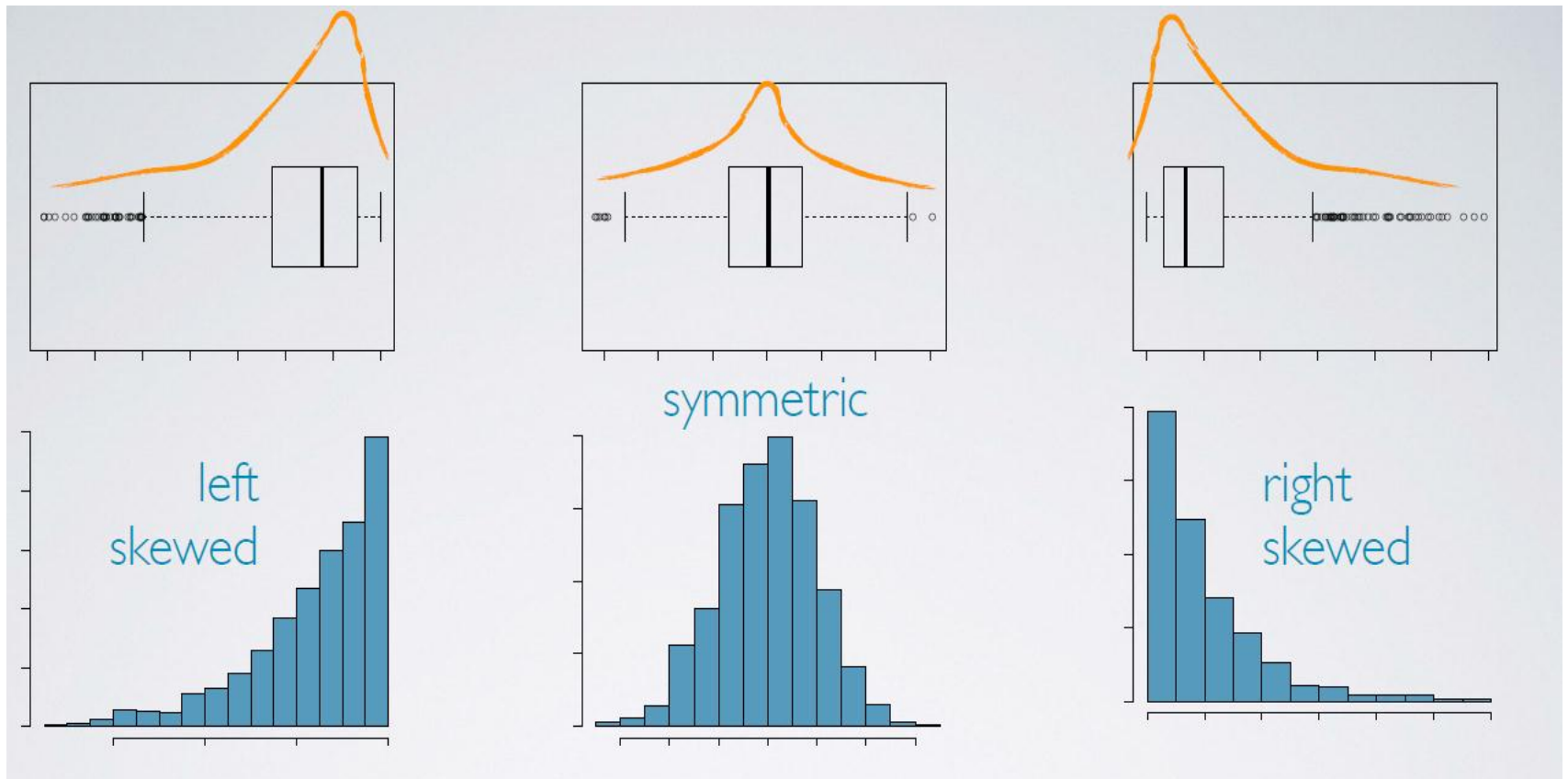
box plot

useful for highlighting outliers, median, IQR



# Box plot

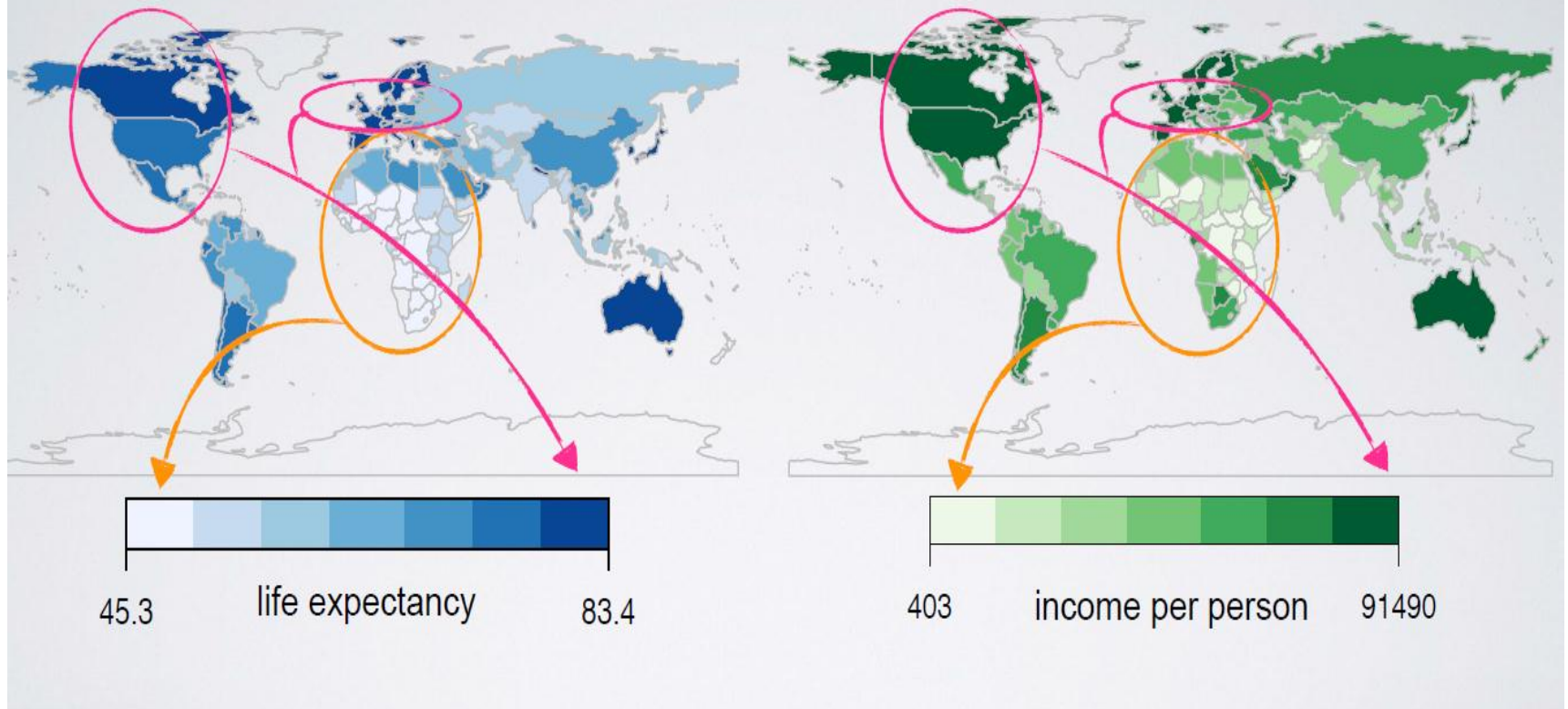
42



# Intensity map

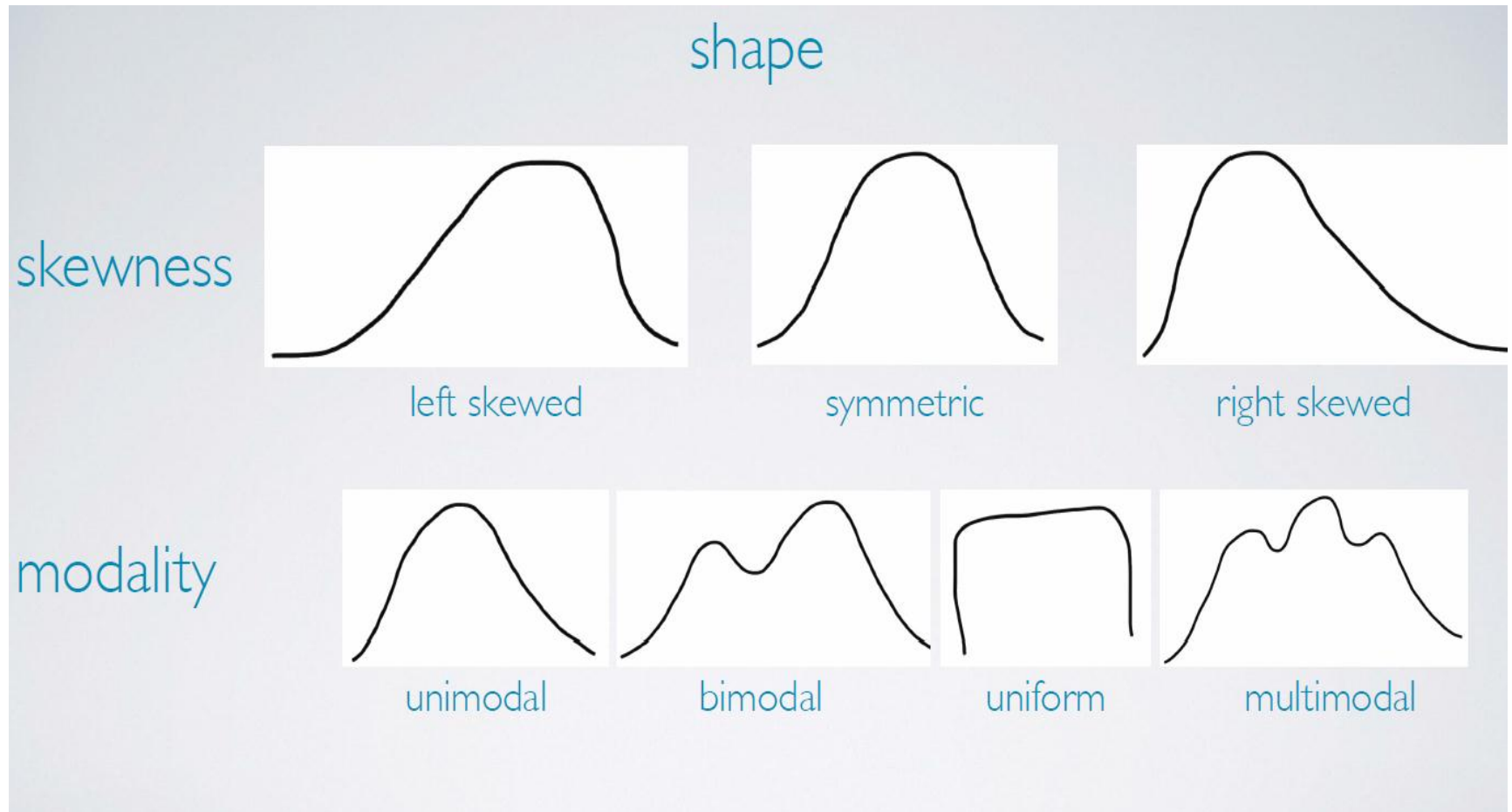
43

► Useful for highlighting the spatial distribution.



# Measures of center

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# Measures of center

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## mean

arithmetic average

$\bar{x}$  sample mean

$\mu$  population mean

## median

midpoint of the  
distribution  
(50th percentile)

## mode

most frequent  
observation

sample statistic

point estimate

population parameter

# Measures of center

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*example*

9 students' exam scores:

75, 69, 88, 93, 95, 54, 87, 88, 27

mean:  $\frac{75+69+88+93+95+54+87+88+27}{9} = 75.11$

mode: 88

median: 27, 54, 69, 75, 87, 88, 88, 93, 95

# Data matrix

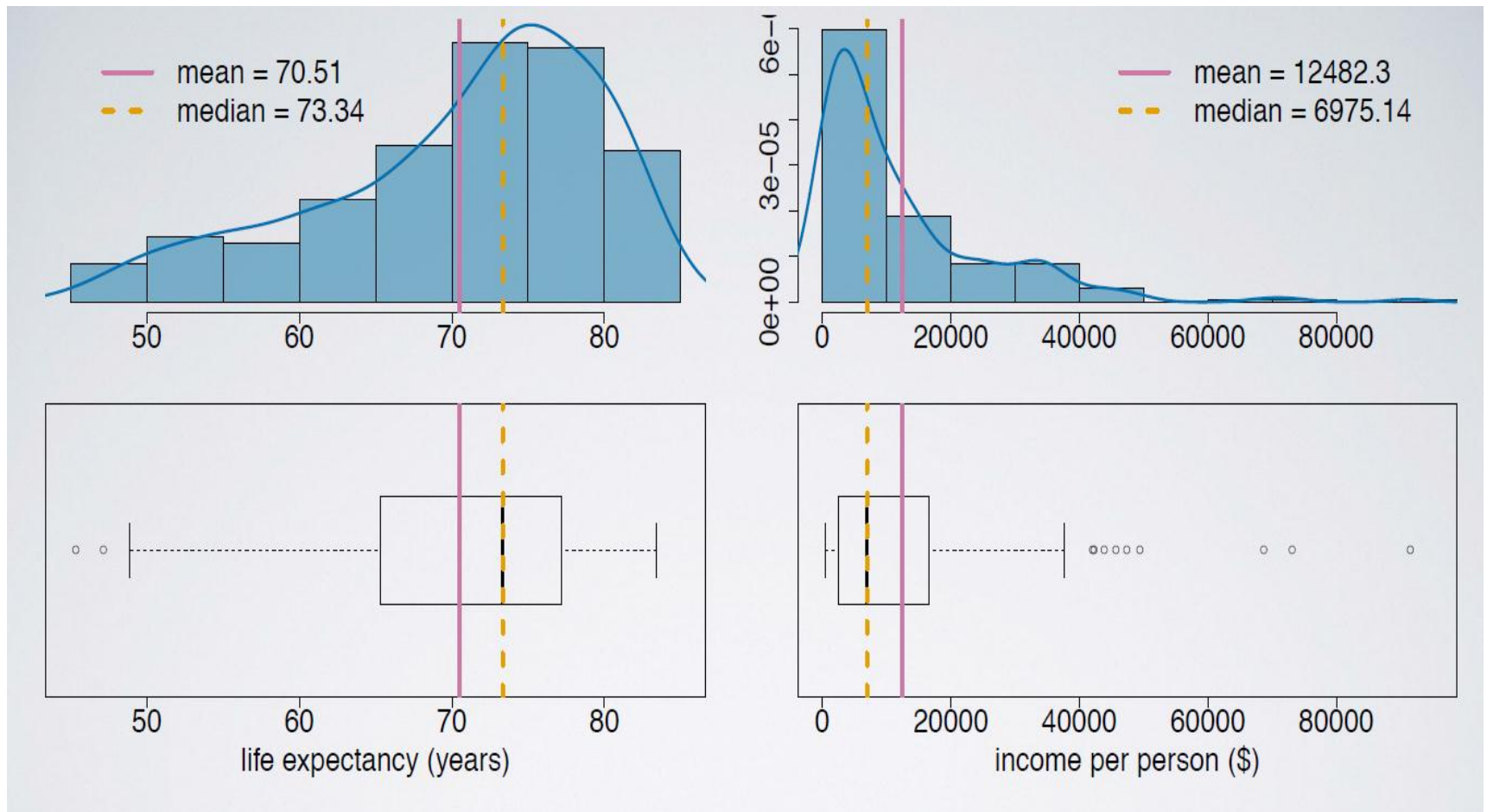
47

data	income per person (\$, 2012)	life expectancy (years, 2012)
Afghanistan	1359.7	60.254
Albania	6969.3	77.185
Algeria	6419.1	70.874
...	...	...
Zimbabwe	545.3	58.142

Source: [gapminder.com](http://gapminder.com)

# Measures of center

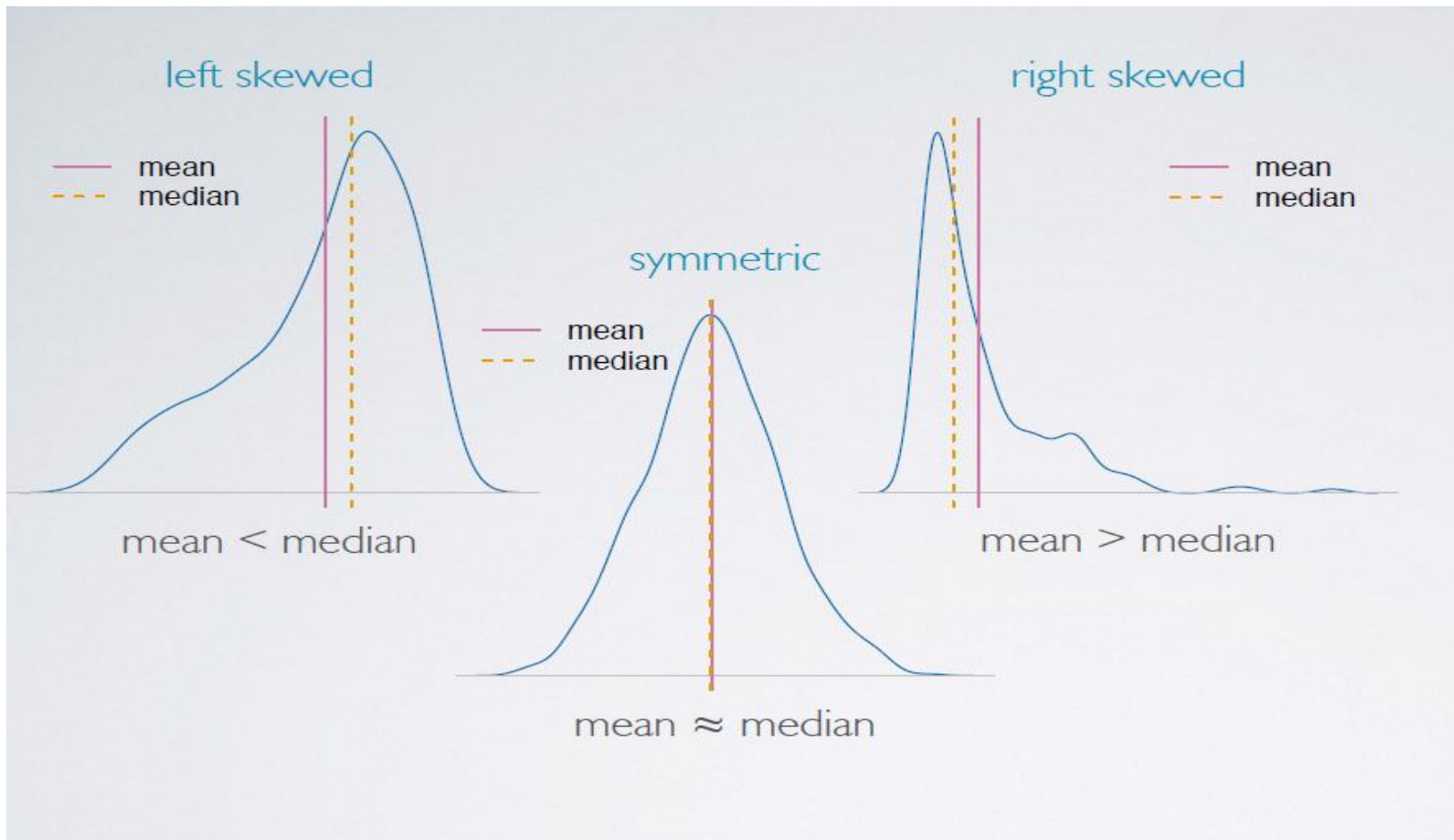
48





# Skewness vs. measures of center

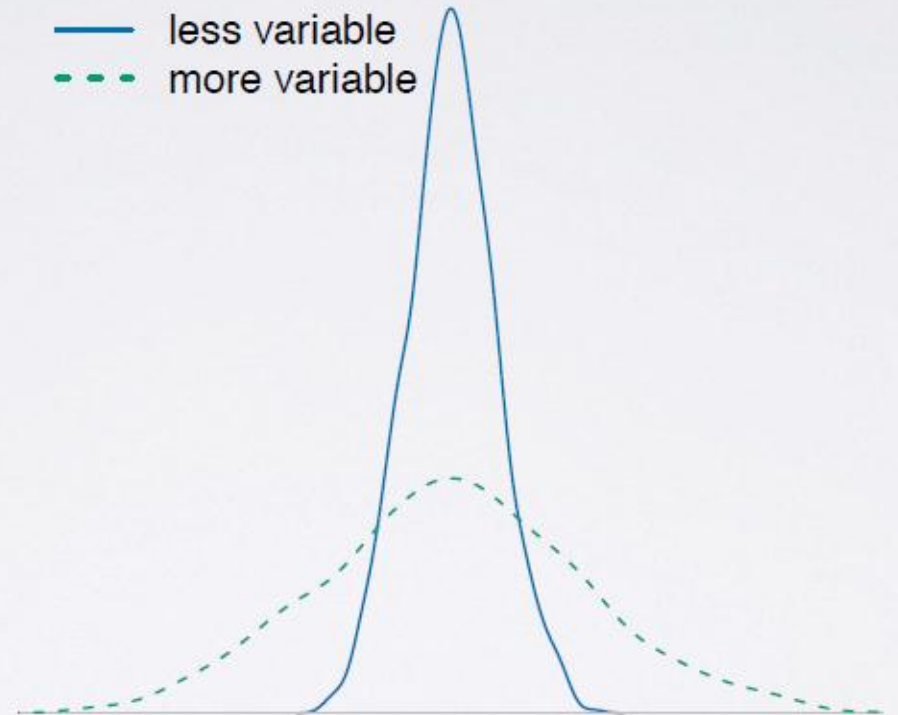
49



# Measures of spread

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- ▶ range: ( $max - min$ )
- ▶ variance
- ▶ standard deviation
- ▶ inter-quartile range



# Measures of spread

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## variance

sample  
variance  
 $s^2$   
population  
variance  
 $\sigma^2$

roughly the average squared deviation from the mean

$$s^2 = \frac{\sum_{i=1}^{n-1} (x_i - \bar{x})^2}{n - 1}$$

*example*

Given that the average life expectancy is 70.5, and there are 201 countries in the dataset:

$$s^2 = \frac{(60.3 - 70.5)^2 + (77.2 - 70.5)^2 + \dots + (58.1 - 70.5)^2}{201 - 1}$$
$$= 83.06 \text{ years}^2$$

	country	life exp
1	Afghanistan	60.3
2	Albania	77.2
3	Algeria	70.9
	...	...
201	Zimbabwe	58.1

# Measures of spread

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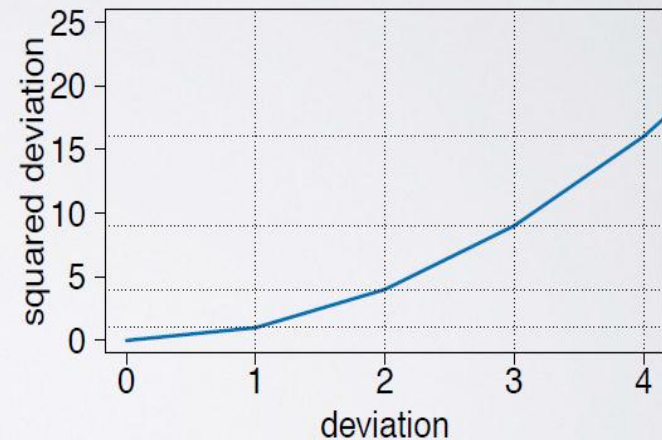
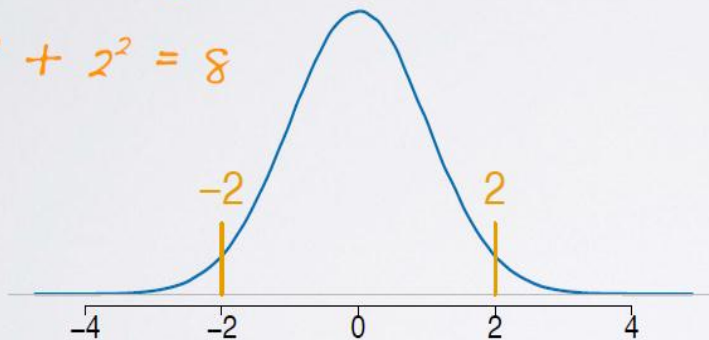
Why do we square the differences?

$$s^2 = \frac{\sum_{i=1}^{n-1} (x_i - \bar{x})^2}{n - 1}$$

- ▶ get rid of negatives so that negatives and positives don't cancel each other when added together
- ▶ increase larger deviations more than smaller ones so that they are weighed more heavily

$$(-2) + 2 = 0$$

$$(-2)^2 + 2^2 = 8$$



# Measures of spread

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## standard deviation

sample sd  
 $s$   
population sd  
 $\sigma$

roughly the average deviation around the mean, and has the same units as the data.

$$s = \sqrt{s^2} = \sqrt{\frac{\sum_{i=1}^{n-1} (x_i - \bar{x})^2}{n - 1}}$$

*square root of  
the variance*

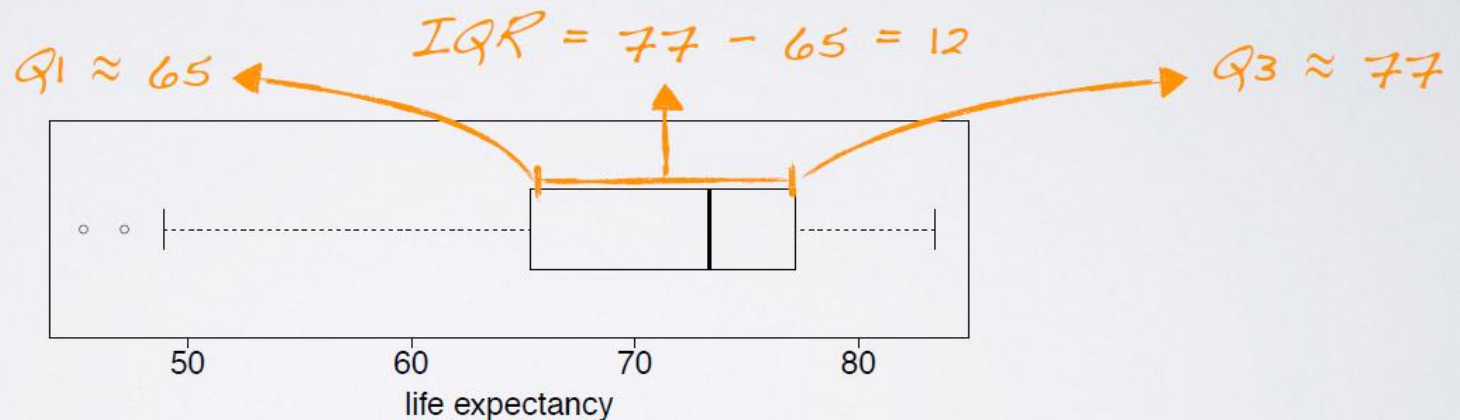
# Measures of spread

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## interquartile range

range of the middle 50% of the data, distance between the first quartile (25th percentile) and third quartile (75th percentile)

$$IQR = Q3 - Q1$$



# Robust statistics

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we define **robust statistics** as measures on which extreme observations have little effect

*example*

data	mean	median
1, 2, 3, 4, 5, 6	3.5	3.5
1, 2, 3, 4, 5, 1000	169	3.5

# Robust statistics

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	robust	non-robust
center	median	mean
spread	IQR	SD, range

*skewed,  
with extreme  
observations*

*symmetric*



# Transforming data

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- ▶ a **transformation** is a rescaling of the data using a function
- ▶ when data are very strongly skewed, we sometimes transform them so they are easier to model

## goals of transformations

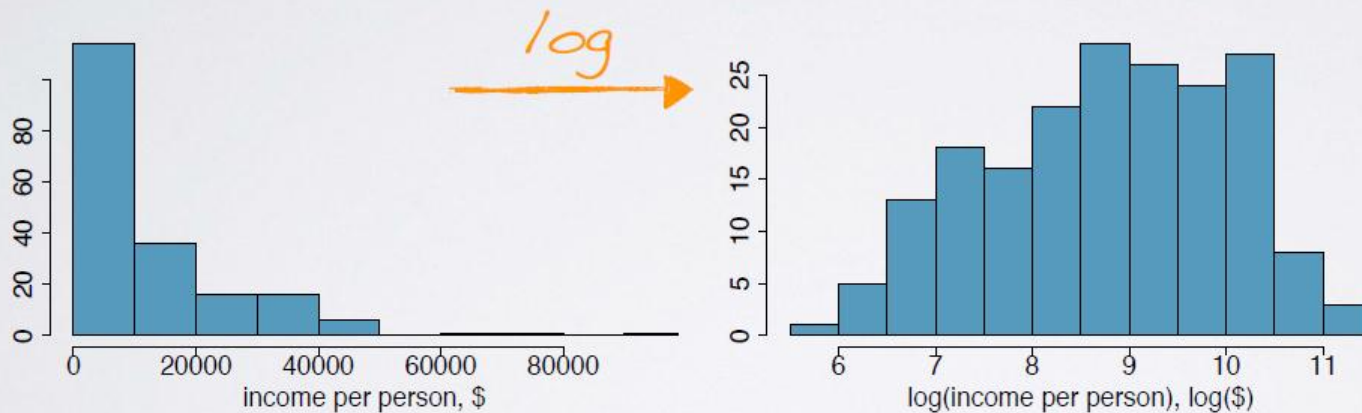
- ▶ to see the data structure differently
- ▶ to reduce skew assist in modeling
- ▶ to straighten a nonlinear relationship in a scatterplot

# Transforming data

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## (natural) log transformation

often applied when much of the data cluster near zero (relative to the larger values in the data set) and all observations are positive

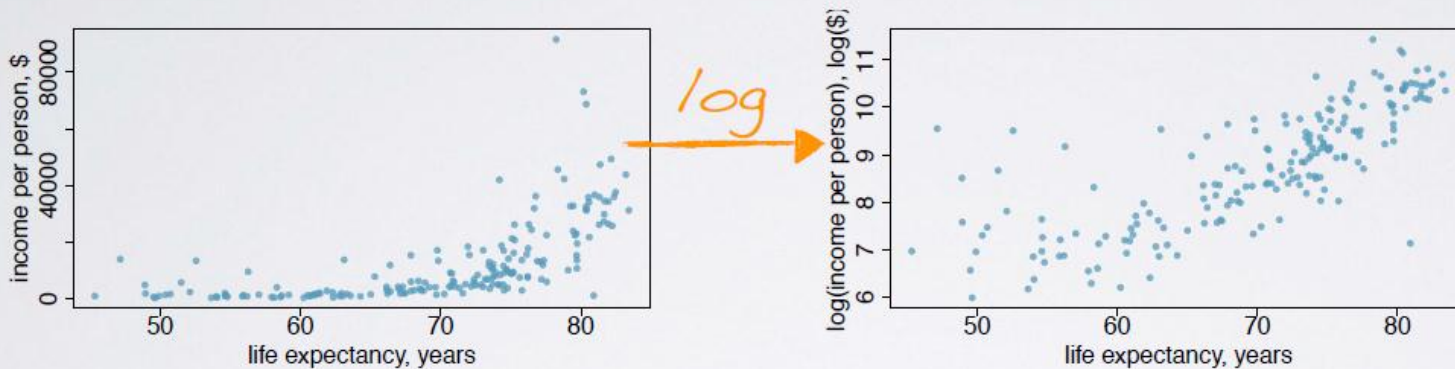


# Transforming data

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## log transformation

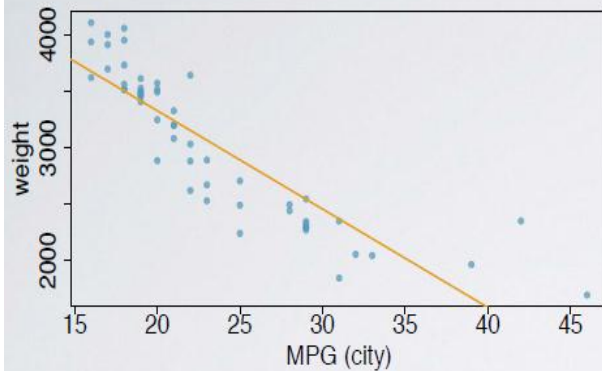
to make the relationship between the variables more linear, and hence easier to model with simple methods



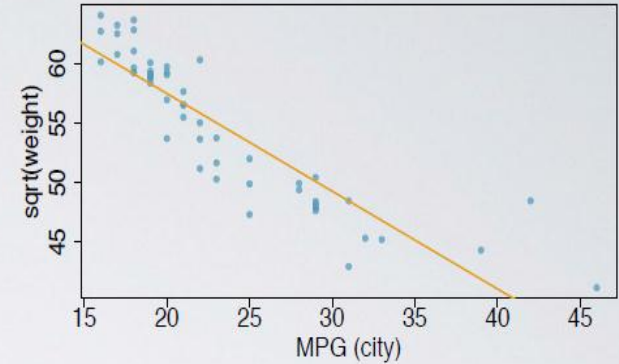
# Transforming data

60

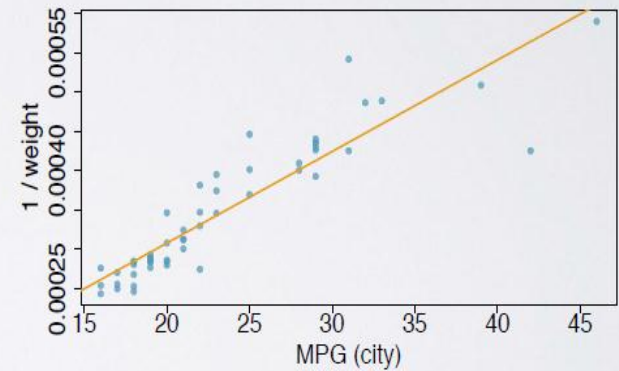
other transformations



*square root*



*inverse*



# Exploring categorical variables

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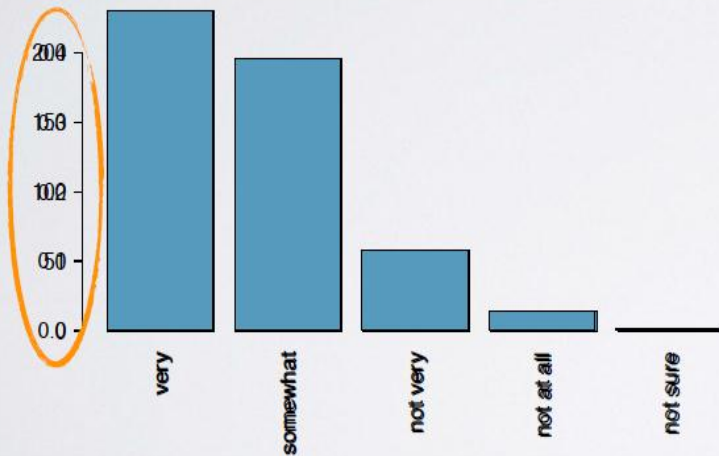
- ▶ describe distribution of a single categorical variable
- ▶ evaluate relationship between two categorical variables
- ▶ evaluate relationship between a categorical and a numerical variable

# Exploring categorical variables

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Difficulty saving money	Counts	Frequencies
Very	231	46%
Somewhat	196	39%
Not very	58	12%
Not at all	14	3%
Not sure	1	~0%
Total	500	100%

frequency table & bar plot

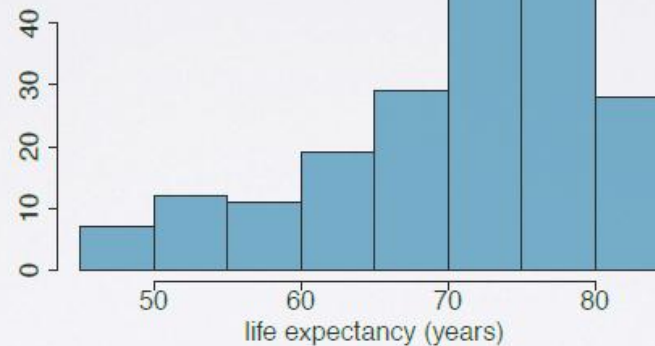
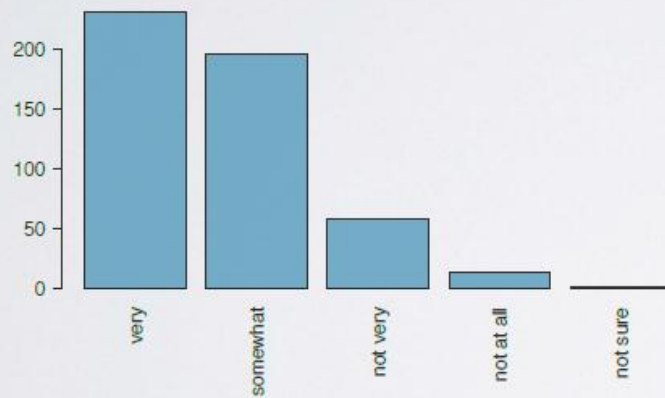


# Exploring categorical variables

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How are bar plots different than histograms?

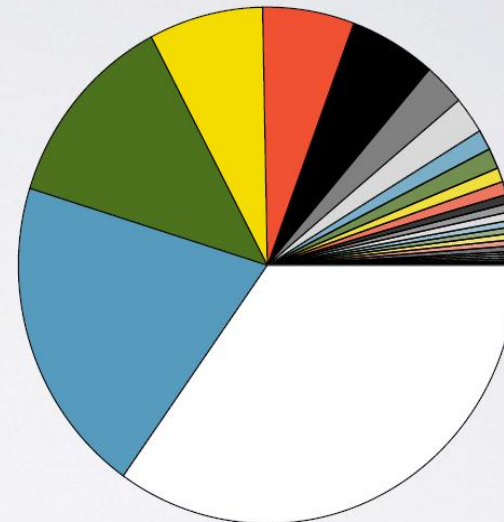
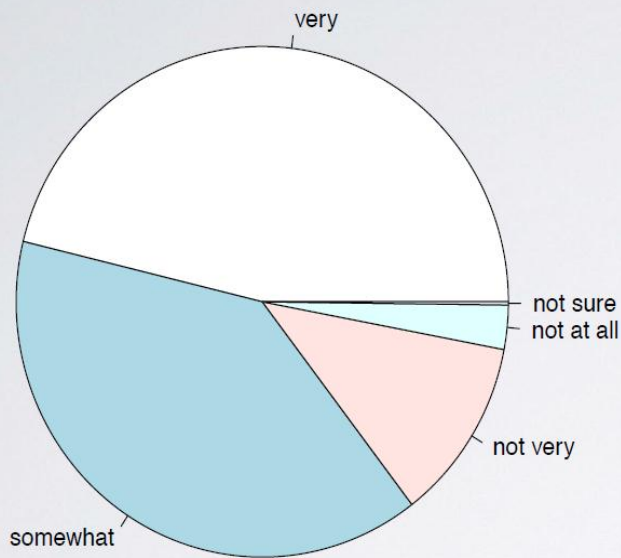
- ▶ barplots for categorical variables, histograms for numerical variables
- ▶ x-axis on a histogram is a number line, and the ordering of the bars are not interchangeable



# Exploring categorical variables

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~~pie chart?~~ no!



- RODENTIA
- CHIROPTERA
- CARNIVORA
- ARTIODACTYLA
- PRIMATES
- SORICOMORPHA
- LAGOMORPHA
- DIPROTODONTIA
- DIDELPHIMORPHA
- CETACEA
- DASYUROMORPHA
- AFROSORICIDA
- ERINACEOMORPHA
- SCANDENTIA
- PERISSODACTYLA
- HYRACOIDEA
- PERAMELEMORPHA
- CINGULATA
- PILOSA
- MACROSCELIDEA
- TUBULIDENTATA
- PHOLIDOTA
- MONOTREMATA
- PAUCITUBERCULATA
- SIRENIA
- PROBOSCIDEA
- DERMOPTERA
- NOTORYCTEMORPHA
- MICROBIOTHERIA



# Exploring categorical variables

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## contingency table

		Income				
		< \$40K	\$40-80K	> \$80K	Refused	Total
Difficulty saving	Very	128	63	31	9	231
	Somewhat	54	71	61	10	196
	Not very	17	7	27	7	58
	Not at all	3	6	5	0	14
	Not sure	0	1	0	0	1
Total		202	148	124	26	500

# Exploring categorical variables

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## □ Relative frequencies

		Income				
		< \$40K	\$40K - \$80K	> \$80K	Refused	Total
Difficulty saving	Very	128	63	31	9	231
	Somewhat	54	71	61	10	196
	Not very	17	7	27	7	58
	Not at all	3	6	5	0	14
	Not sure	0	1	0	0	1
Total		202	148	124	26	500

$\text{< } \$40\text{K: } 128 / 202 = 63\%$  find it very difficult to save

$\text{\$40K-}\text{\$80K: } 63 / 148 = 43\%$

$\text{>}\text{\$80K: } 31 / 124 = 25\%$

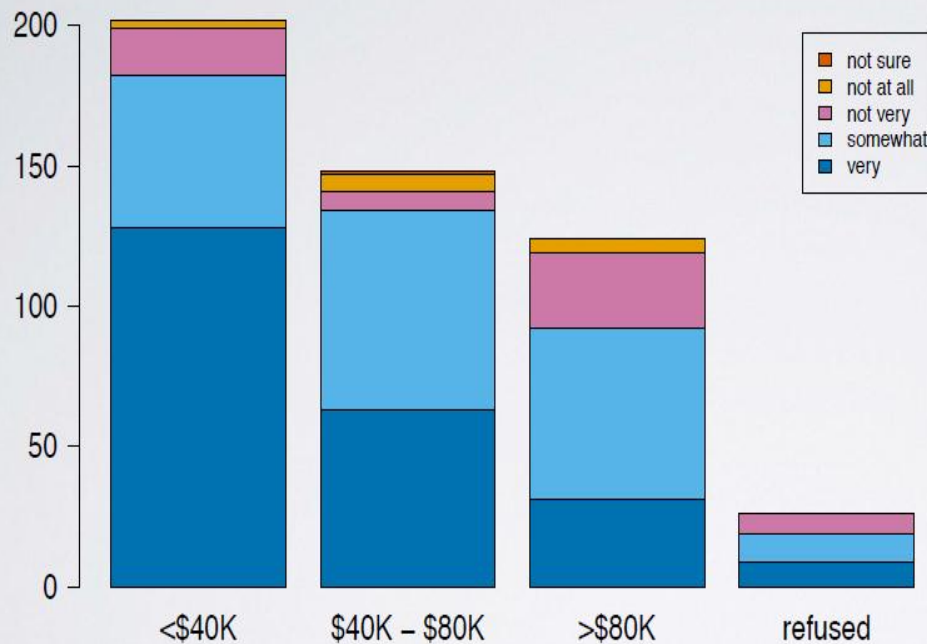
$\text{Refused: } 9 / 26 = 35\%$

feelings about difficulty of saving money and income are associated (dependent)

# Exploring categorical variables

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## segmented bar plot

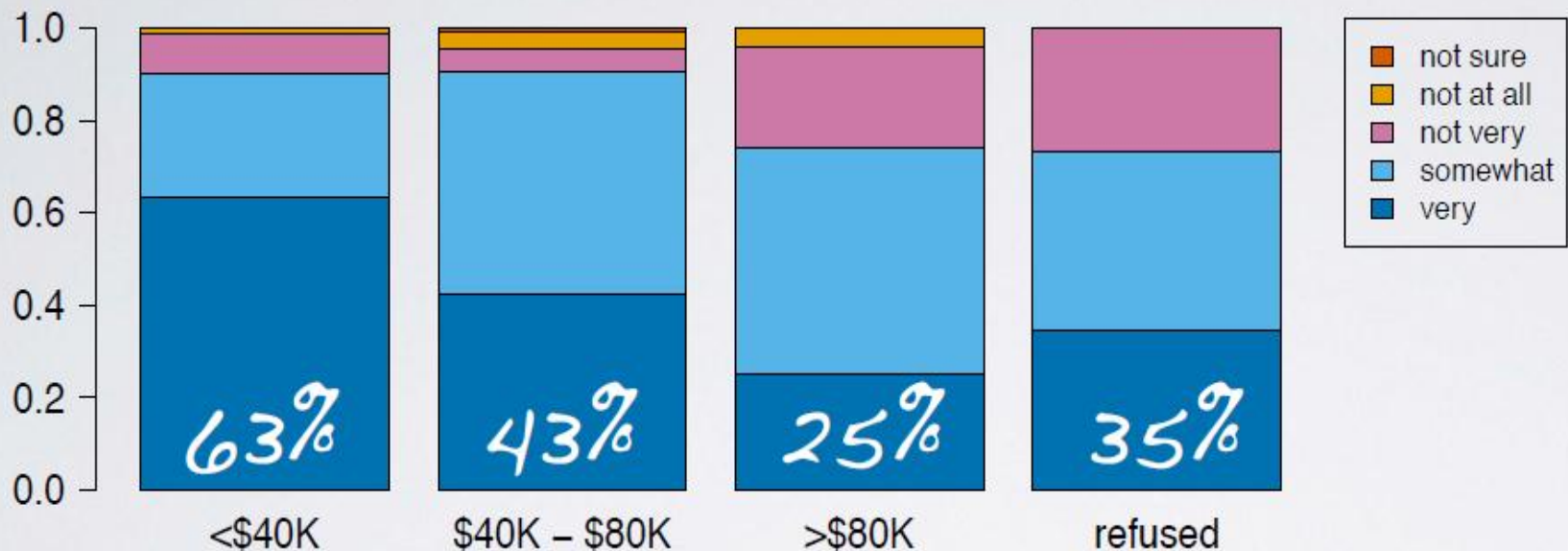


- ▶ useful for visualizing conditional frequency distributions
- ▶ compare relative frequencies to explore the relationship between the variables

# Exploring categorical variables

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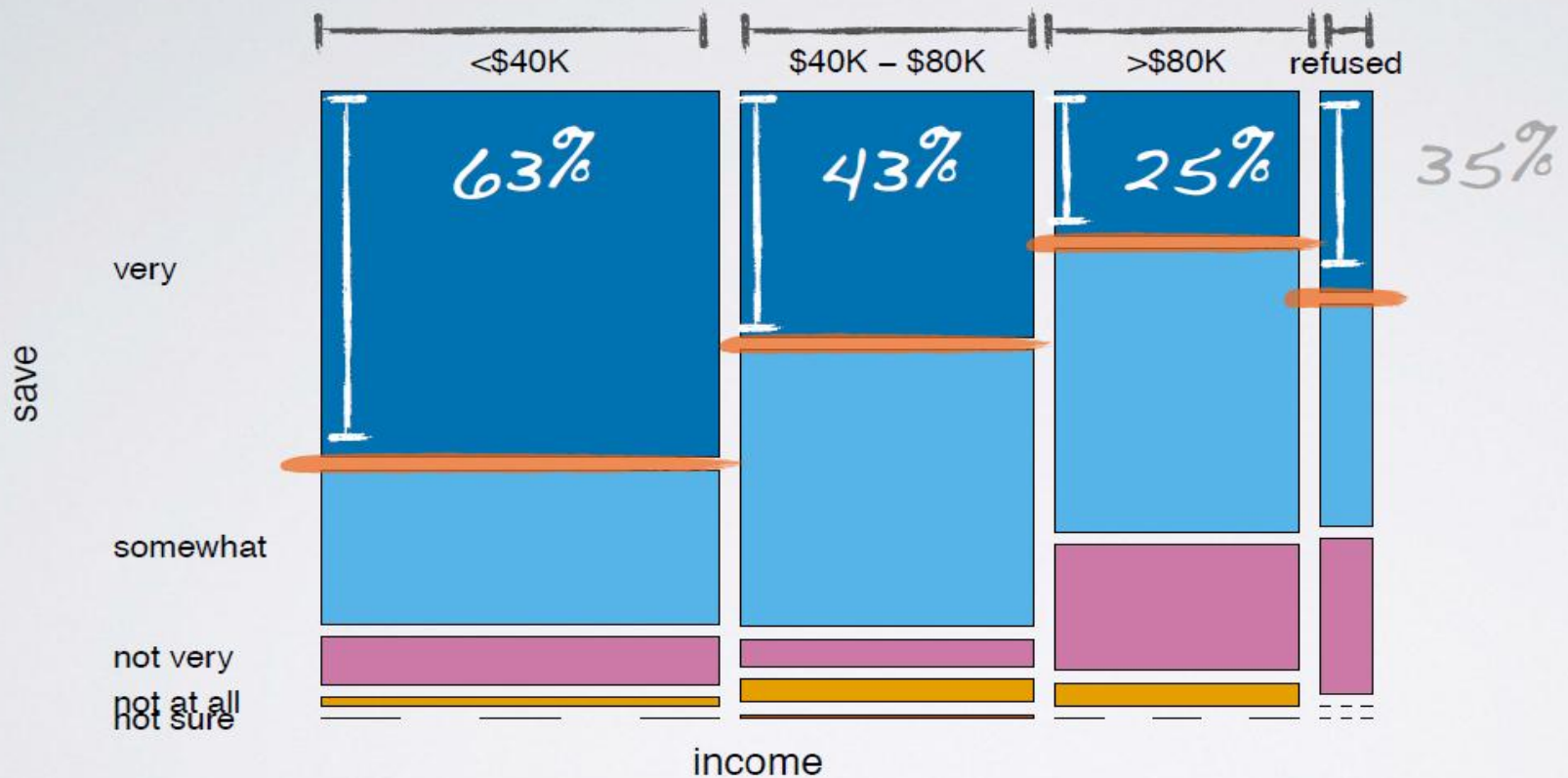
relative frequency segmented bar plot



# Exploring categorical variables

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mosaicplot



# Exploring categorical variables

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side-by-side box plots

