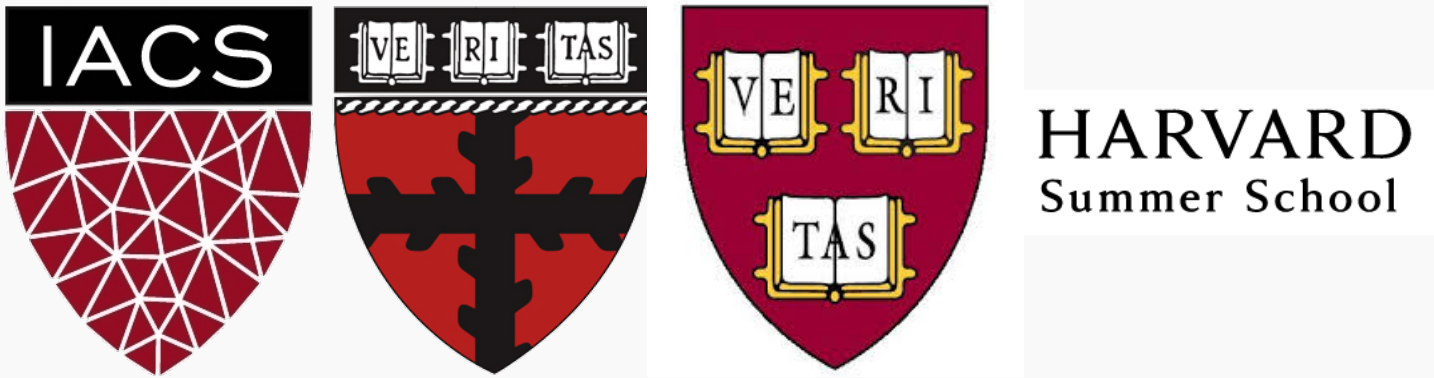
# **Section 1** Introduction to CS-S109A

Sol Girouard

# CS-S109A: Introduction to Data Science

Kevin Rader



# Homework(s)

**There will be 5 homework (not including Homework 0):**

- Homework 0 (due Thursday)
- Homework 1: Web scraping, Beautiful Soup
- Homework 2: Regression kNN and Linear Regression
- Homework 3: Logistic Regression, Model selection, and Prediction Accuracy
- Homework 4: PCA, Unsupervised Classification
- Homework 5: Decision Trees, Random Forests, and Ensemble Methods

# Final Exam

There will be an individual final exam due on Monday, August 3 (11:59pm).

The exam will be cumulative, and will be roughly the same length of a HW assignment.

Open-book and open-notes.  Not open friend :(

# Help

# Help

The process to get help is:

1. Post the question in Ed and hopefully your peers will answer. We monitor the posts and we will respond within 12 hours from the posting time (allows for peer discussion/ comments).
2. Go to Office Hours, this is the best way to get help.
3. For private matters send an email to the Helpline: cs109a2021summer@gmail.com. The Helpline is monitored by all the instructors and TFs.
4. For personal matters send an email Kevin.

**Sundays will be slow days, so please be patient!**

# What is data science?

# The Data Science Process

Ask an interesting question

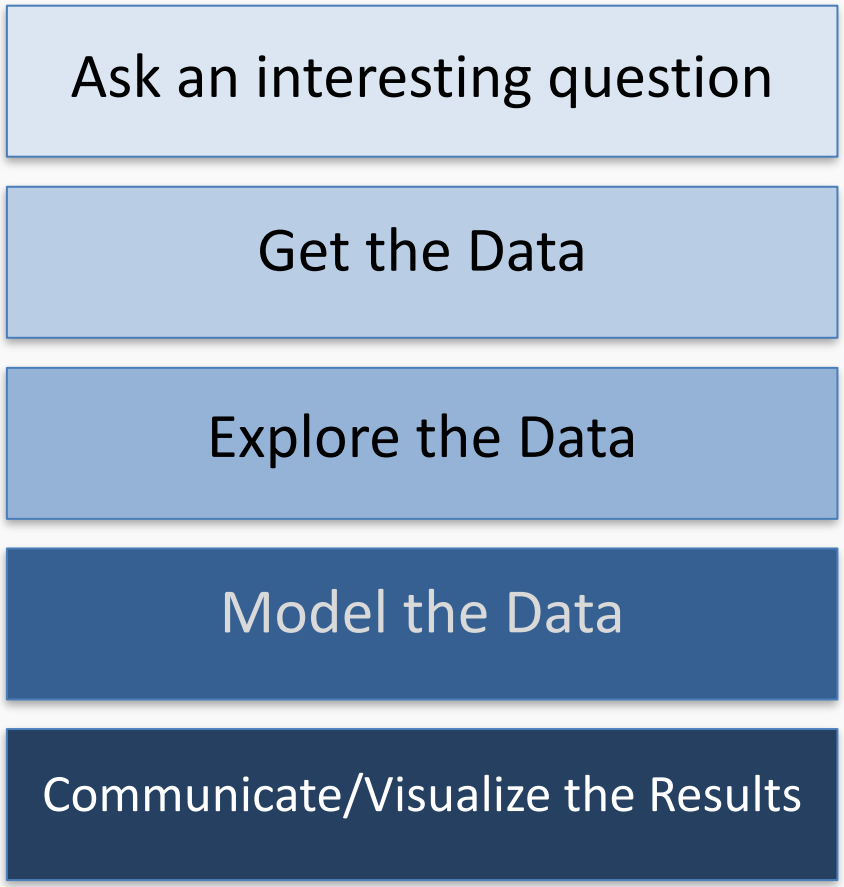
Get the Data

Explore the Data

Model the Data

Communicate/Visualize the Results

# The Data Science Process




What is the scientific goal?

What would you do if you had **all** of the data?

What do you want to predict or estimate?

# The Data Science Process

Ask an interesting question

Get the Data

Explore the Data

Model the Data

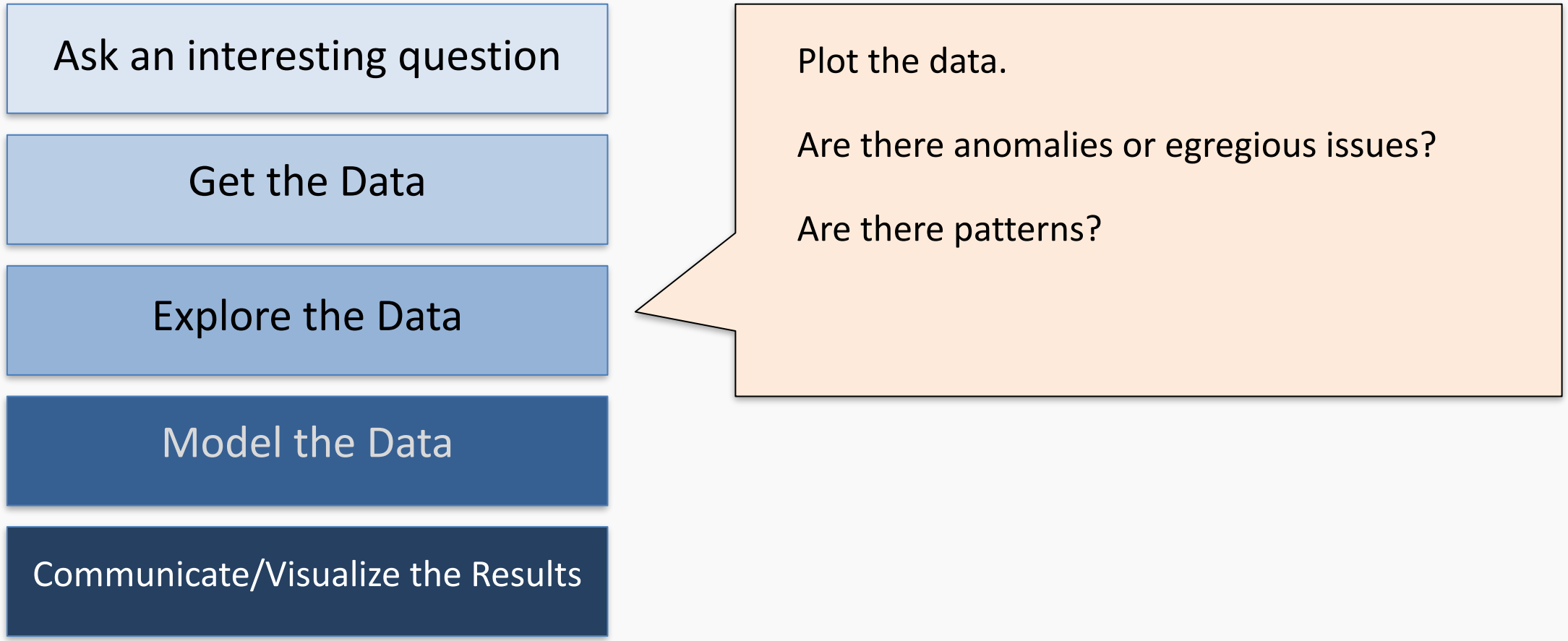
Communicate/Visualize the Results

How were the data sampled?

Which data are relevant?

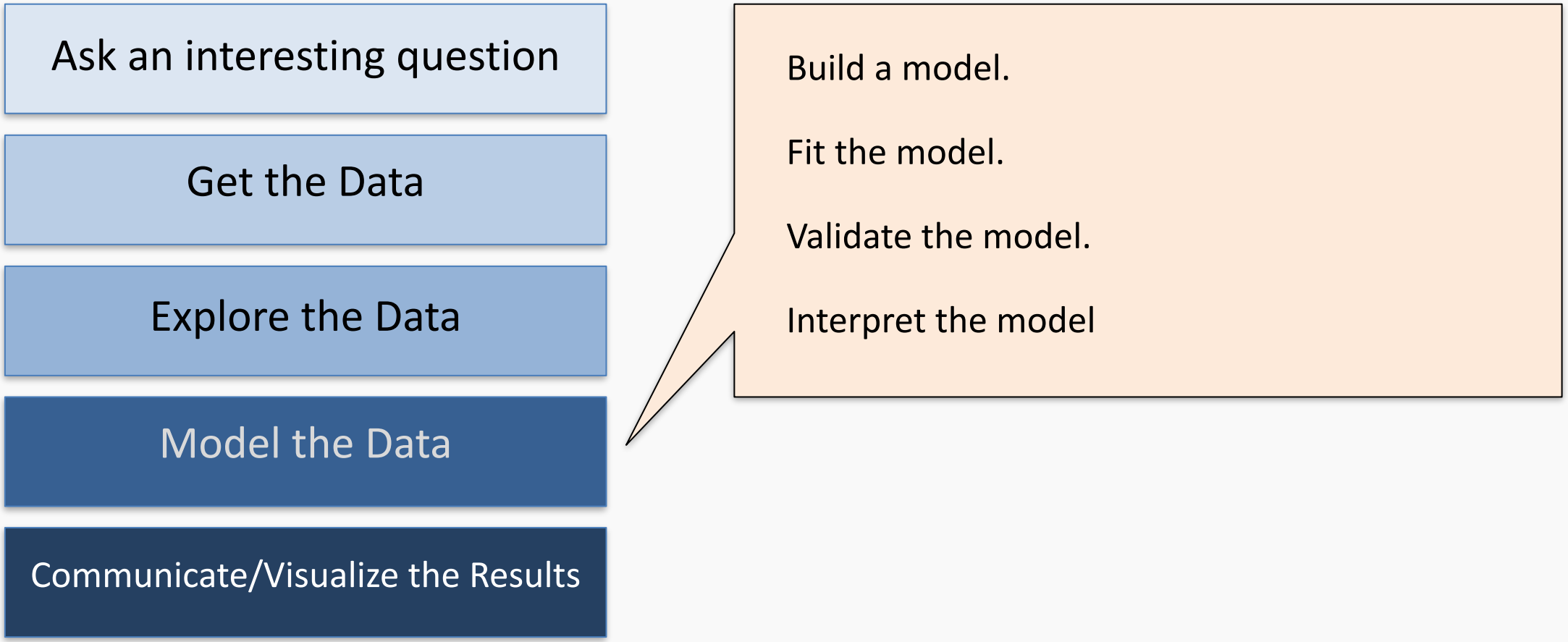
Are there privacy issues?

# The Data Science Process



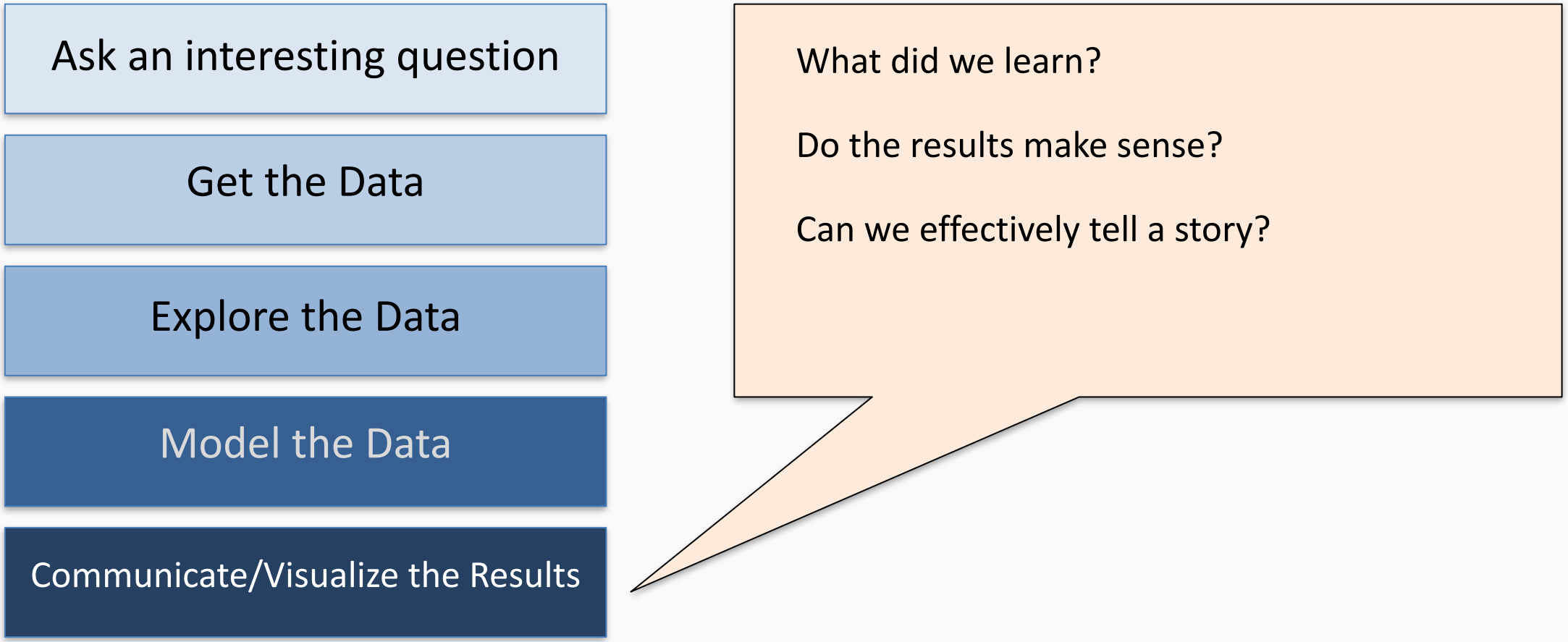
# What?

## The Data Science Process

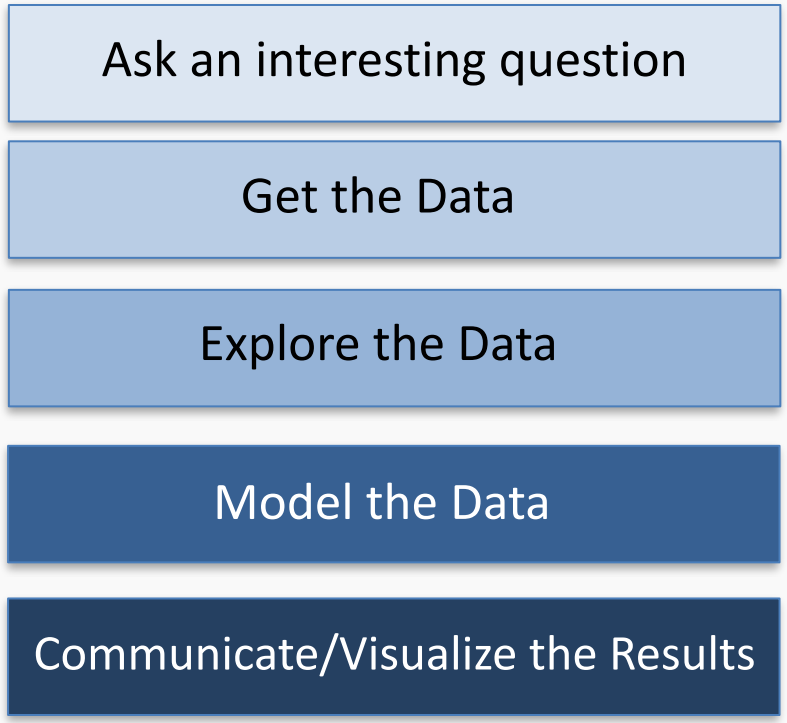


# What?

## The Data Science Process



# The Data Science Process




Today we will begin introducing the data collection and data exploration steps.

# What are data?

"A datum is a single measurement of something on a scale that is understandable to both the recorder and the reader. Data are multiple such measurements."

**Claim:** ***everything is (can be) data!***

# Where do data come from?

- **Internal sources:** already collected by or is part of the overall data collection of you organization.
  For example: business-centric data that is available in the organization data base to record day to day operations; scientific or experimental data.
- **Existing External Sources:** available in ready to read format from an outside source for free or for a fee.
  For example: public government databases, stock market data, Yelp reviews, [your favorite sport]-reference.
- **External Sources Requiring Collection Efforts**: available from external source but acquisition requires special processing.
  For example: data appearing only in print form, or data on websites.

# Ways to gather online data

How to get data generated, published or hosted online:

- **API (Application Programming Interface):** using a prebuilt set of functions developed by a company to access their services. Often pay to use. For example: Google Map API, Facebook API, Twitter API
- **RSS (Rich Site Summary):** summarizes frequently updated online content in standard format. Free to read if the site has one. For example: news-related sites, blogs
- **Web scraping:** using software, scripts or by-hand extracting data from what is displayed on a page or what is contained in the HTML file (often in tables).

# Web scraping

- **Why do it?** Older government or smaller news sites might not have APIs for accessing data, or publish RSS feeds or have databases for download. Or, you don't want to pay to use the API or the database.

- **How do you do it?** See HW1 (beautifulsoup)

- **Should you do it?** ***Ethics; Data Privacy & Data Ethics; Legal Jurisdiction & Legal Risk***
  - You just want to explore: Are you violating their terms of service? Privacy concerns for website and their clients?
  - You want to publish your analysis or product: Do they have an API or fee that you are bypassing? Are they willing to share this data? Are you violating their terms of service? Are there privacy concerns?

# Data types

What kind of values are in your data (**data types**)?

*Simple* or *atomic*:

- **Numeric:** integers, floats
- **Boolean:** binary or true false values
- **Strings:** sequence of symbols

# Data types

What kind of values are in your data (**data types**)?

*Compound*, composed of a bunch of atomic types:

- **Date and time:** compound value with a specific structure
- **Lists:** a list is a sequence of values
- **Dictionaries:** A dictionary is a collection of key-value pairs, a pair of values *x* : *y* where *x* is usually a string called the key representing the "name" of the entry, and *y* is a value of any type.

Example: Student record: what are *x* and *y*?

- First: Kevin
- Last: Rader
- Classes: [CS-109A, STAT139]

# Data storage

How is your data represented and stored (**data format**)?

- **Tabular Data:** a dataset that is a two-dimensional table, where each row typically represents a single data record, and each column represents one type of measurement (csv, dat, xlsx, etc.).

- **Structured Data:** each data record is presented in a form of a [possibly complex and multi-tiered] dictionary (json, xml, etc.)

- **Semistructured Data:** not all records are represented by the same set of keys or some data records are not represented using the key-value pair structure.

# Tabular Data

In tabular data, we expect each **record** or **observations** to represent a set of measurements of a single object or event, e.g. our table contains observations of rides/checkouts).

**First Look At The Data**

```
In [27]: hubway_data = pd.read_csv('hubway_trips.csv', low_memory=False)
         hubway_data.head()
```

Out[27]:

| | seq_id | hubway_id | status | duration | start_date | strt_statn | end_date | end_statn | bike_nr | subsc_type | zip_code | birth_da |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 8 | Closed | 9 | 7/28/2011 10:12:00 | 23.0 | 7/28/2011 10:12:00 | 23.0 | B00468 | Registered | '97217 | 1976.0 |
| 1 | 2 | 9 | Closed | 220 | 7/28/2011 10:21:00 | 23.0 | 7/28/2011 10:25:00 | 23.0 | B00554 | Registered | '02215 | 1966.0 |
| 2 | 3 | 10 | Closed | 56 | 7/28/2011 10:33:00 | 23.0 | 7/28/2011 10:34:00 | 23.0 | B00456 | Registered | '02108 | 1943.0 |
| 3 | 4 | 11 | Closed | 64 | 7/28/2011 10:35:00 | 23.0 | 7/28/2011 10:36:00 | 23.0 | B00554 | Registered | '02116 | 1981.0 |
| 4 | 5 | 12 | Closed | 12 | 7/28/2011 10:37:00 | 23.0 | 7/28/2011 10:37:00 | 23.0 | B00554 | Registered | '97214 | 1983.0 |

Each type of measurement is called a **variable** or an **attribute** of the data (e.g. `seq_id`, `status` and `duration` are variables or attributes). The number of attributes is called the **dimension**. These are often called **features**.

# Types of Data

We'll see later that it's important to distinguish between classes of variables or attributes based on the type of values they can take on.

- **Quantitative variable:** is numerical and can be either:
  - **discrete -** a finite number of values are possible in any bounded interval. For example: "Number of siblings" is a discrete variable
  - **continuous -** an infinite number of values are possible in any bounded interval. For example: "Height" is a continuous variable
- **Categorical variable:** no inherent order among the values For example: "What kind of pet you have" is a categorical variable

# Common Issues

Common issues with data:

- **Missing** values: how do we fill in?
- **Wrong** values: how can we detect and correct?
- **Messy** format
- **Not usable**: the data cannot answer the question posed

# Messy Data

We're measuring individual deliveries; the variables are Time, Day, Number of Produce.

| | Friday | Saturday | Sunday |
|---|---|---|---|
| Morning | 15 | 158 | 10 |
| Afternoon | 2 | 90 | 20 |
| Evening | 55 | 12 | 45 |

Problem: each column header represents a single value rather than a variable. Row headers are "hiding" the Day variable. The values of the variable, "Number of Produce", is not recorded in a single column.

# Fixing Messy Data

We need to reorganize the information to make explicit the event we're observing and the variables associated to this event.

| ID | Time | Day | Number |
|---|---|---|---|
| 1 | Morning | Friday | 15 |
| 2 | Morning | Saturday | 158 |
| 3 | Morning | Sunday | 10 |
| 4 | Afternoon | Friday | 2 |
| 5 | Afternoon | Saturday | 9 |
| 6 | Afternoon | Sunday | 20 |
| 7 | Evening | Friday | 55 |
| 8 | Evening | Saturday | 12 |
| 9 | Evening | Sunday | 45 |

# Tabular = Happy Kevin ☺

Common causes of messiness are:

- Column headers are values, not variable names
- Variables are stored in both rows and columns
- Multiple variables are stored in one column/entry
- Multiple types of experimental units stored in same table

In general, we want each file to correspond to a dataset, each column to represent a single variable and each row to represent a single observation.

We want to **tabularize** the data. This makes Python happy.

# Data Exploration **Descriptive Statistics**

# Basics of Sampling

Population versus sample:

- A **population** is the entire set of objects or events under study. Population can be hypothetical "all students" or all students in this class.
- A **sample** is a "representative" subset of the objects or events under study. Needed because it's impossible or intractable to obtain or compute with population data.

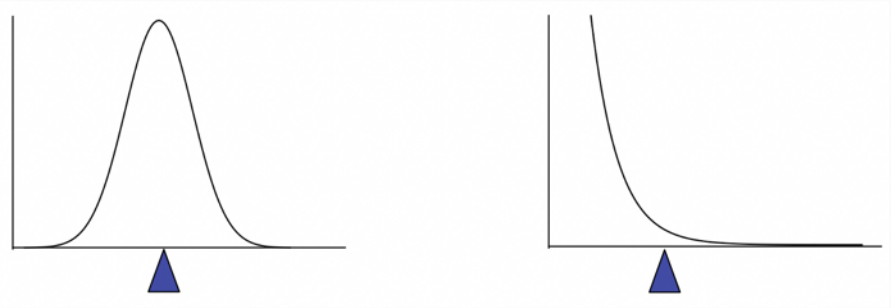
**Biases** in samples: ***Ethics; Data Privacy & Data Ethics; Legal Jurisdiction & Legal Risk***

- **Selection bias**: some subjects or records are more likely to be selected
- Volunteer/**nonresponse bias**: subjects or records who are not easily available are not represented

# Sample mean

The **mean** of a set of *n* observations of a variable is denoted $\bar{x}$ and is defined as:

$$\bar{x} = \frac{x_1 + x_2 + \ldots + x_n}{n} = \frac{1}{n}\sum_{i=1}^{n} x_i$$



The mean describes what a "typical" sample value looks like, or where is the "center" of the distribution of the data.

**Key theme**: there is always uncertainty involved when calculating a sample mean to estimate a population mean.

# Sample median

The **median** of a set of n number of observations in a sample, ordered by value, of a variable is is defined by

$$\text{Median} = \begin{cases} x_{(n+1)/2} & \text{if } n \text{ is odd} \\ \frac{x_{n/2} + x_{(n+1)/2}}{2} & \text{if } n \text{ is even} \end{cases}$$

Example (already in order):

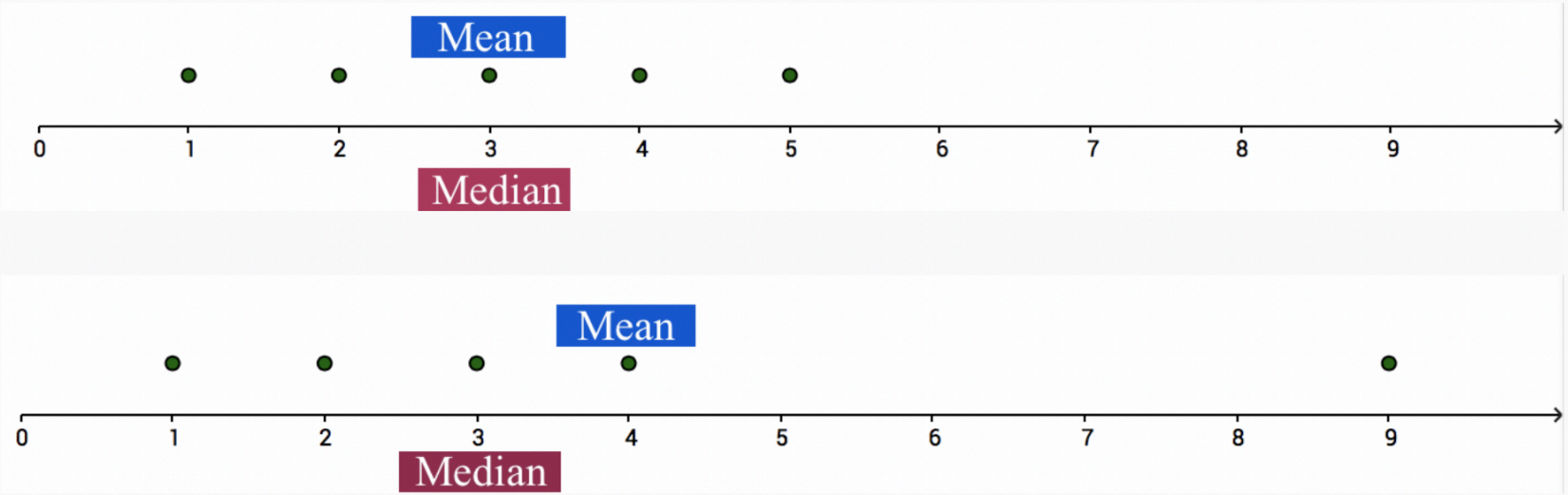
Ages: 17, 19, 21, 22, 23, 23, 23, 38

Median = (22+23)/2 = 22.5

The median also describes what a typical observation looks like, or where is the center of the distribution of the sample of observations.

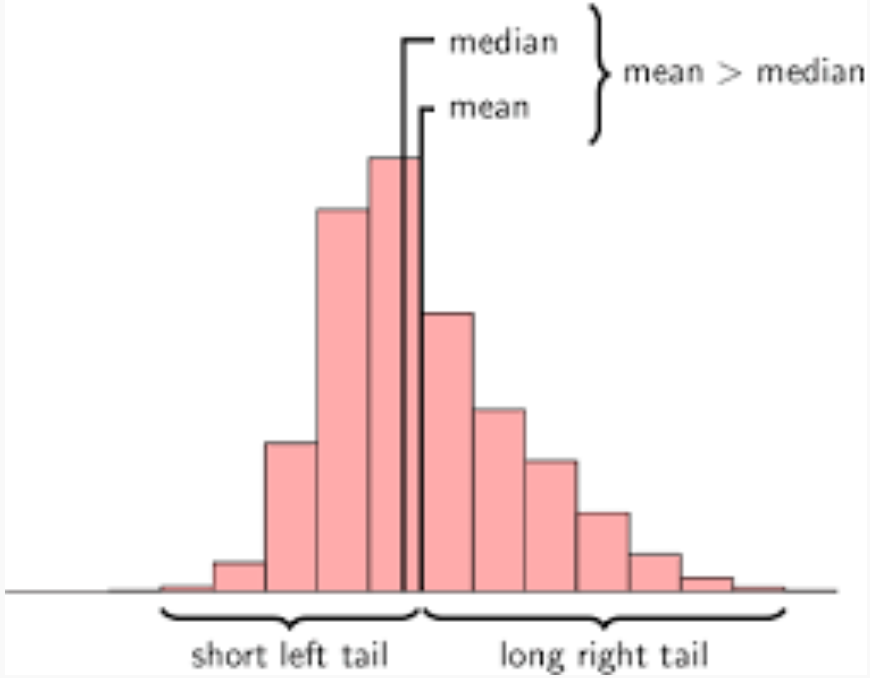
# Mean vs. Median

The mean is sensitive to extreme values (**outliers**)



# Mean, median, and skewness

The mean is sensitive to outliers:




The above distribution is called **right-skewed** since the mean is greater than the median. Note: **skewness** often "follows the longer tail".

# Computational time

How hard (in terms of algorithmic complexity) is it to calculate:

- the mean?

  at most $O(n)$ or $O(n \log n)$?

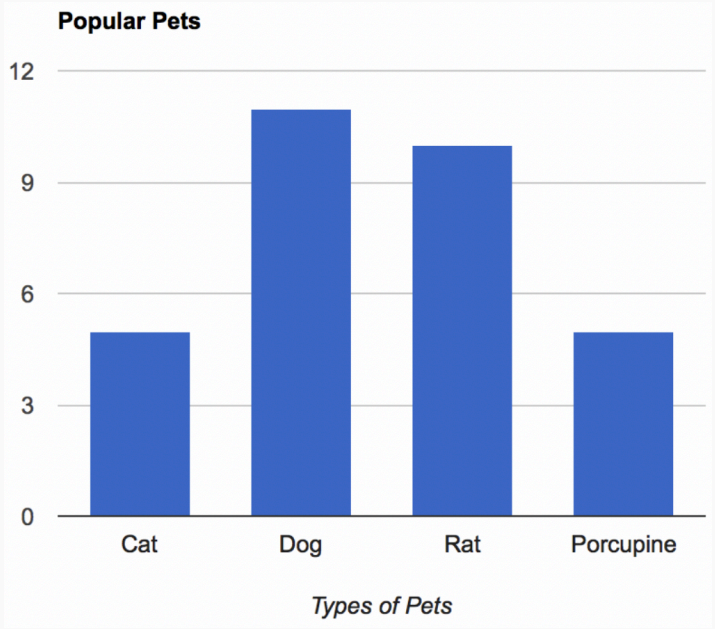
- the median?

  at most $O(n)$ or $O(n \log n)$?

**Note**: **Practicality of implementation should be considered!**

# Regarding Categorical Variables...

For categorical variables, neither mean or median make sense. Why?




The mode might be a better way to find the most “representative” value.

# Measures of Spread: **Range**

The spread of a sample of observations measures how well the mean or median describes the sample.

One way to measure spread of a sample of observations is via the **range**.

Range = Maximum Value - Minimum Value

# Measures of Spread: **Variance**

The (sample) **variance**, denoted $s^2$, measures how much on average the sample values deviate from the mean:

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

**Note**: the term $|x_i - \bar{x}|$ measures the amount by which each $x_i$ deviates from the mean $\bar{x}$. **Squaring these deviations means that $s^2$ is sensitive to extreme values** (outliers).

**Note**: $s^2$ doesn't have the same units as the $x_i$ :(

What does a variance of 1,008 mean? Or 0.0001?

# Measures of Spread: Standard Deviation

The (sample) **standard deviation**, denoted *s*, is the square root of

the variance

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

**Note**: *s* does have the same units as the $x_i$. Phew!

# Data Exploration **Visualizations**

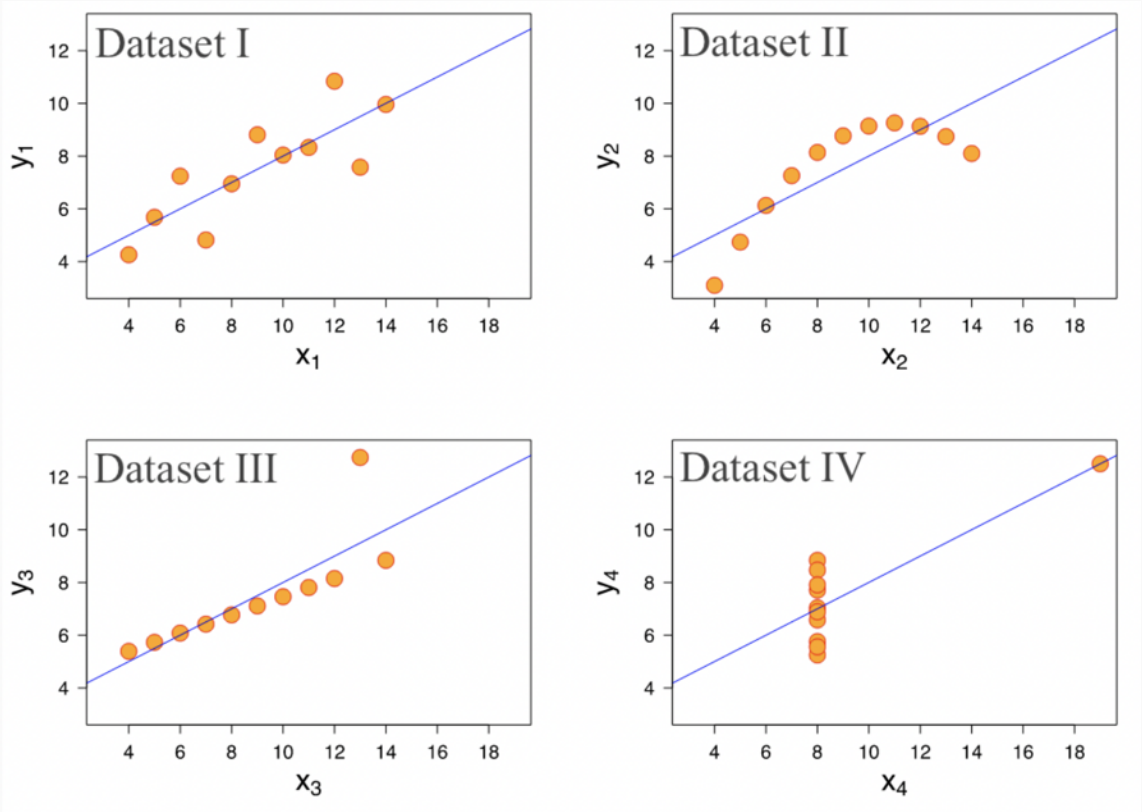
# Anscombe's Data

The following four data sets comprise the Anscombe's Quartet; all four sets of data have identical simple summary statistics.

| | Dataset I | | Dataset II | | Dataset III | | Dataset IV | |
|---|---|---|---|---|---|---|---|---|
| | x | y | x | y | x | y | x | y |
| | 10 | 8.04 | 10 | 9.14 | 10 | 7.46 | 8 | 6.58 |
| | 8 | 6.95 | 8 | 8.14 | 8 | 6.77 | 8 | 5.76 |
| | 13 | 7.58 | 13 | 8.74 | 13 | 12.74 | 8 | 7.71 |
| | 9 | 8.81 | 9 | 8.77 | 9 | 7.11 | 8 | 8.84 |
| | 11 | 8.33 | 11 | 9.26 | 11 | 7.81 | 8 | 8.47 |
| | 14 | 9.96 | 14 | 8.1 | 14 | 8.84 | 8 | 7.04 |
| | 6 | 7.24 | 6 | 6.13 | 6 | 6.08 | 8 | 5.25 |
| | 4 | 4.26 | 4 | 3.1 | 4 | 5.39 | 19 | 12.5 |
| | 12 | 10.84 | 12 | 9.13 | 12 | 8.15 | 8 | 5.56 |
| | 7 | 4.82 | 7 | 7.26 | 7 | 6.42 | 8 | 7.91 |
| | 5 | 5.68 | 5 | 4.74 | 5 | 5.73 | 8 | 6.89 |
| **Sum:** | 99.00 | 82.51 | 99.00 | 82.51 | 99.00 | 82.51 | 99.00 | 82.51 |
| **Avg:** | 9.00 | 7.50 | 9.00 | 7.50 | 9.00 | 7.50 | 9.00 | 7.50 |
| **Std:** | 3.32 | 2.03 | 3.32 | 2.03 | 3.32 | 2.03 | 3.32 | 2.03 |

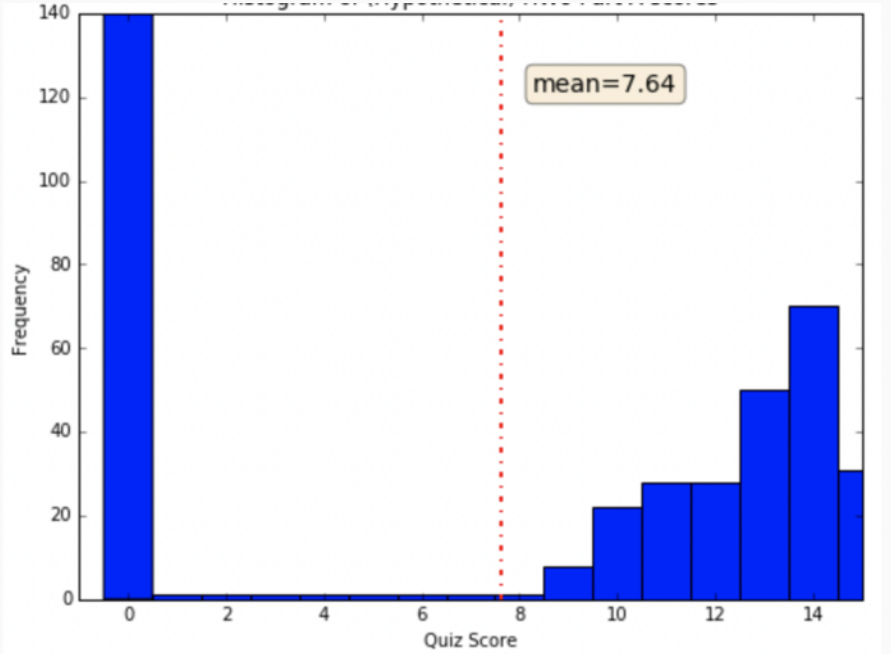
# Anscombe's Data (cont.)

Summary statistics clearly don't tell the story of how they differ.
But a picture can be worth a thousand words:



# More Visualization Motivation

If I tell you that the average score for Homework 0 was: 7.64/15 = 50.9% last year, what does that suggest?




And what does the graph suggest?

# More Visualization Motivation

Visualizations help us to analyze and explore the data. They help to:

- Identify hidden patterns and trends
- Formulate/test hypotheses
- Communicate any modeling results
  - Present information and ideas succinctly
  - Provide evidence and support
  - Influence and persuade
- Determine the next step in analysis/modeling

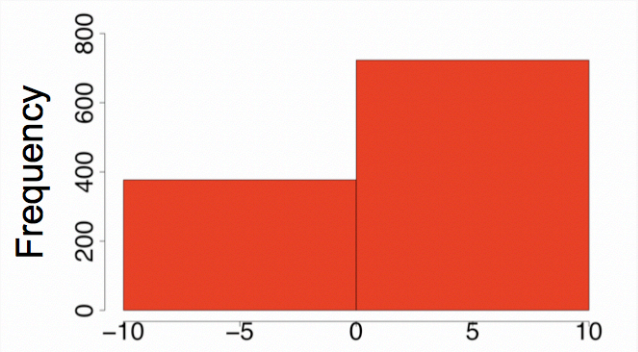
# Types of Visualizations

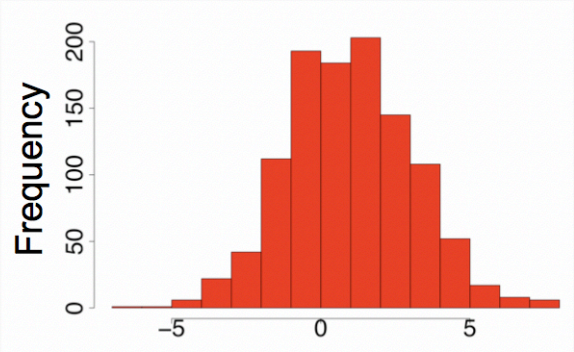
What do you want your visualization to show about your data?

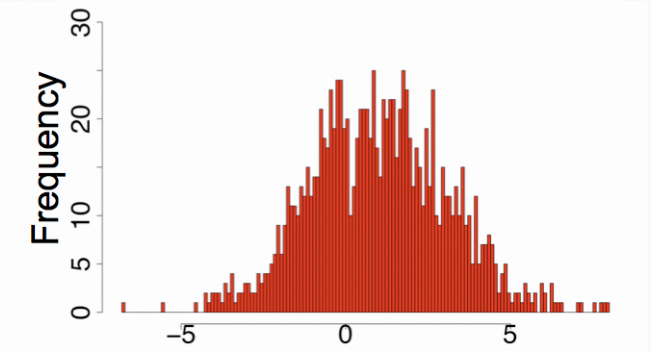
- **Distribution:** how a variable or variables in the dataset distribute over a range of possible values.
- **Relationship:** how the values of multiple variables in the dataset relate .
- **Composition:** how the dataset breaks down into subgroups.
- **Comparison:** how trends in multiple variables or datasets compare.

# Histograms to visualize distribution

A **histogram** is a way to visualize how 1-dimensional data is distributed across certain values.



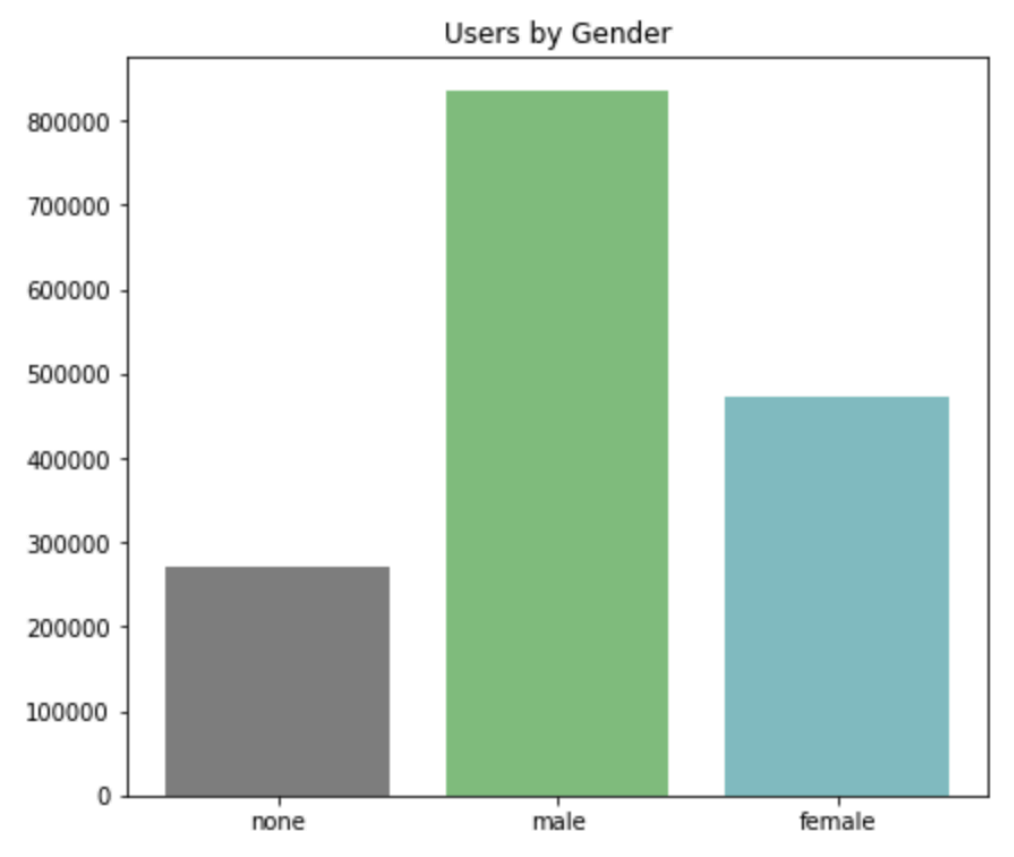




**Note**: Trends in histograms are sensitive to number of bins.

# Pie chart for a categorical variable?

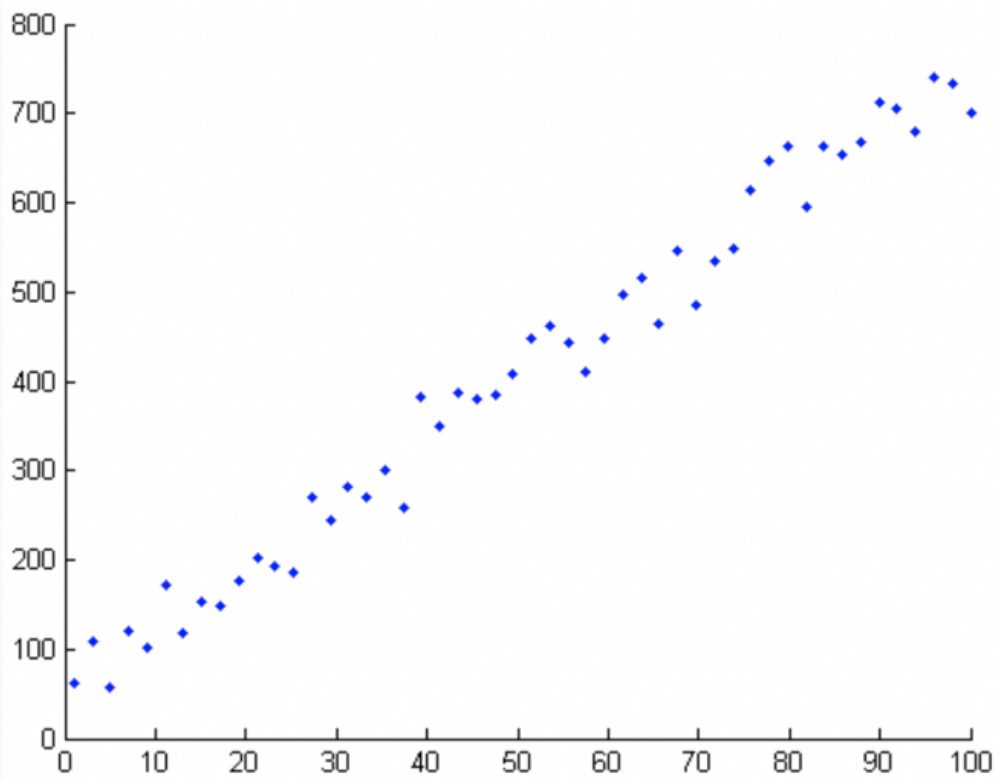
A **bar chart** is a way to visualize the static composition (aka, distribution) of a categorical variable




**Pie charts are an alternative but often frowned upon. Why?**

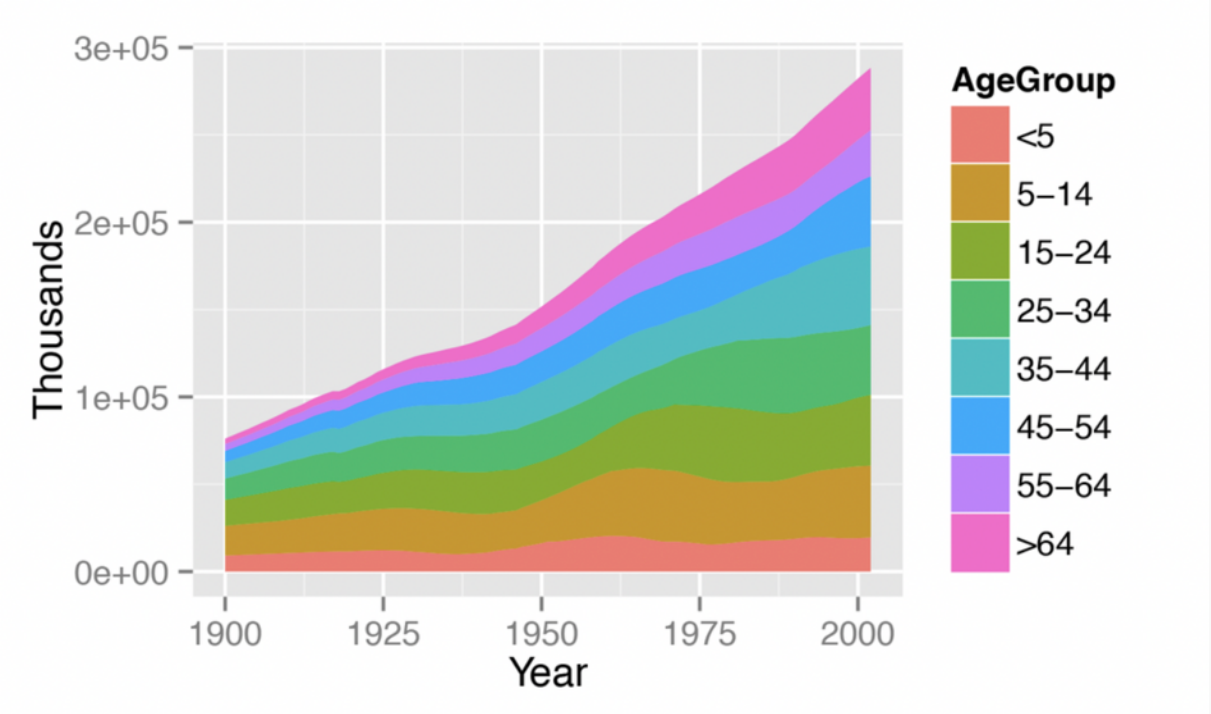
# Scatter plots to visualize relationships

A **scatter plot** is a way to visualize the relationship between two different attributes of multi-dimensional data.



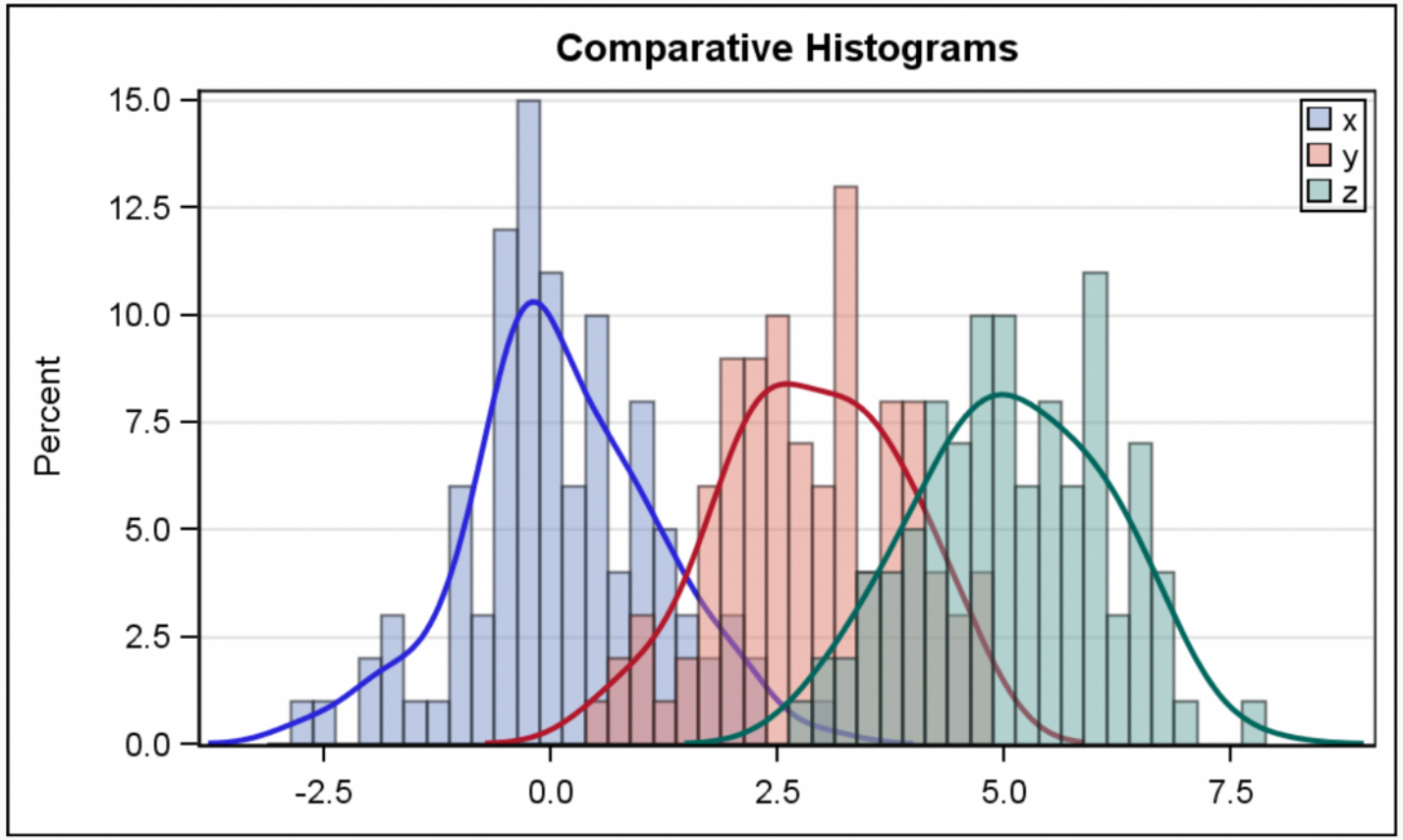
# Stacked area graph to show trend over time

A **stacked area graph** is a way to visualize the composition of a group as it changes over time (or some other quantitative variable). This shows the relationship of a categorical variable (AgeGroup) to a quantitative variable (year).



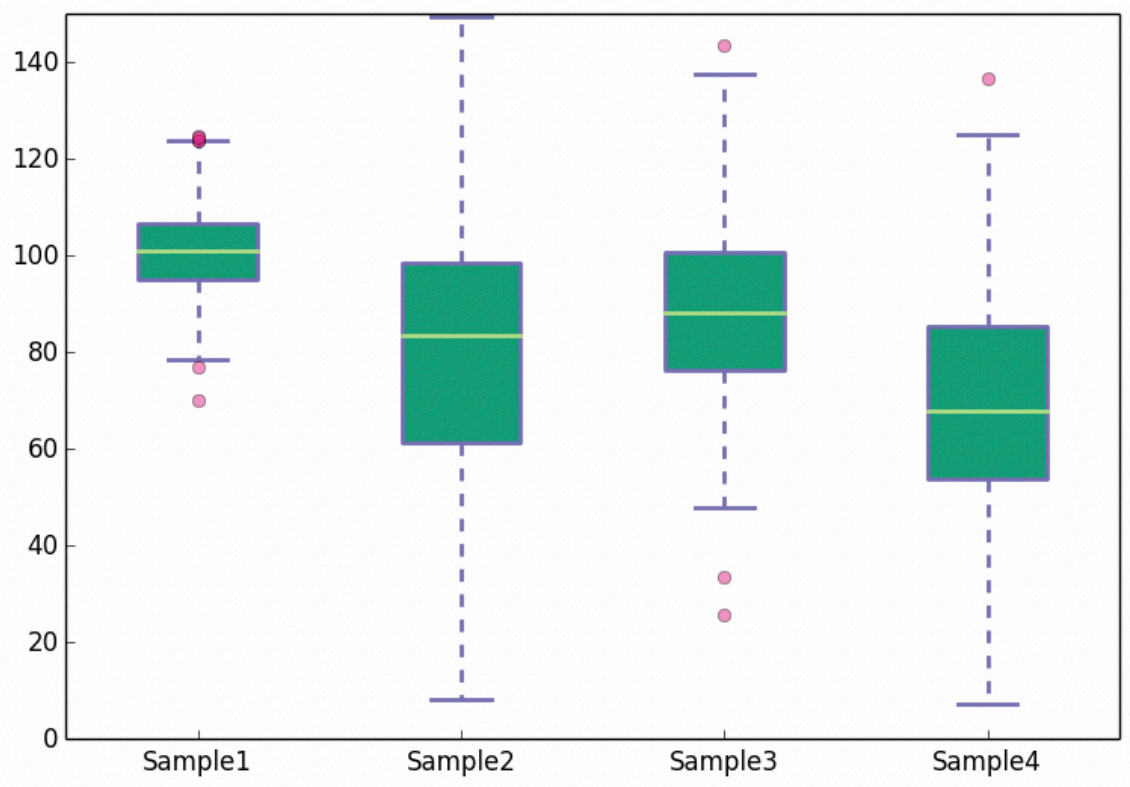
# Multiple histograms

Plotting **multiple histograms (**and **kernel density estimates** of the distribution, here) on the same axes is a way to visualize how different variables compare (or how a variable differs over specific groups).



# Boxplots

A **boxplot** is a simplified visualization to compare a quantitative variable across groups. It highlights the range, quartiles, median and any outliers present in a data set.



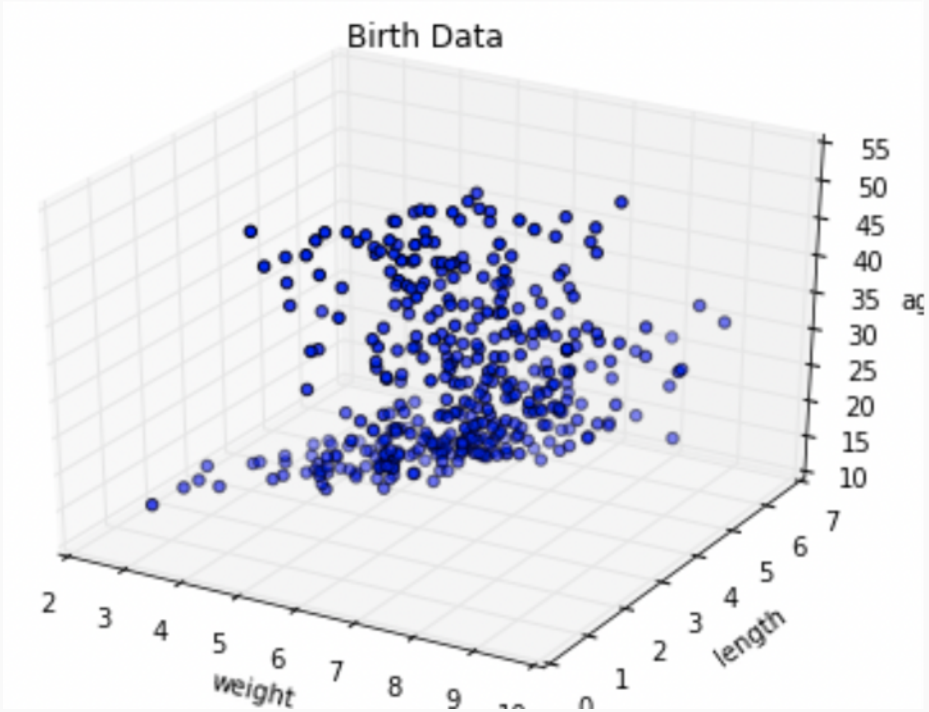
# [Not] Anything is possible!

Often your dataset seem too complex to visualize:

- Data is too high dimensional (how do you plot 100 variables on the same set of axes?)
- Some variables are mix of categorical and quantitative (how do you plot missing values?)

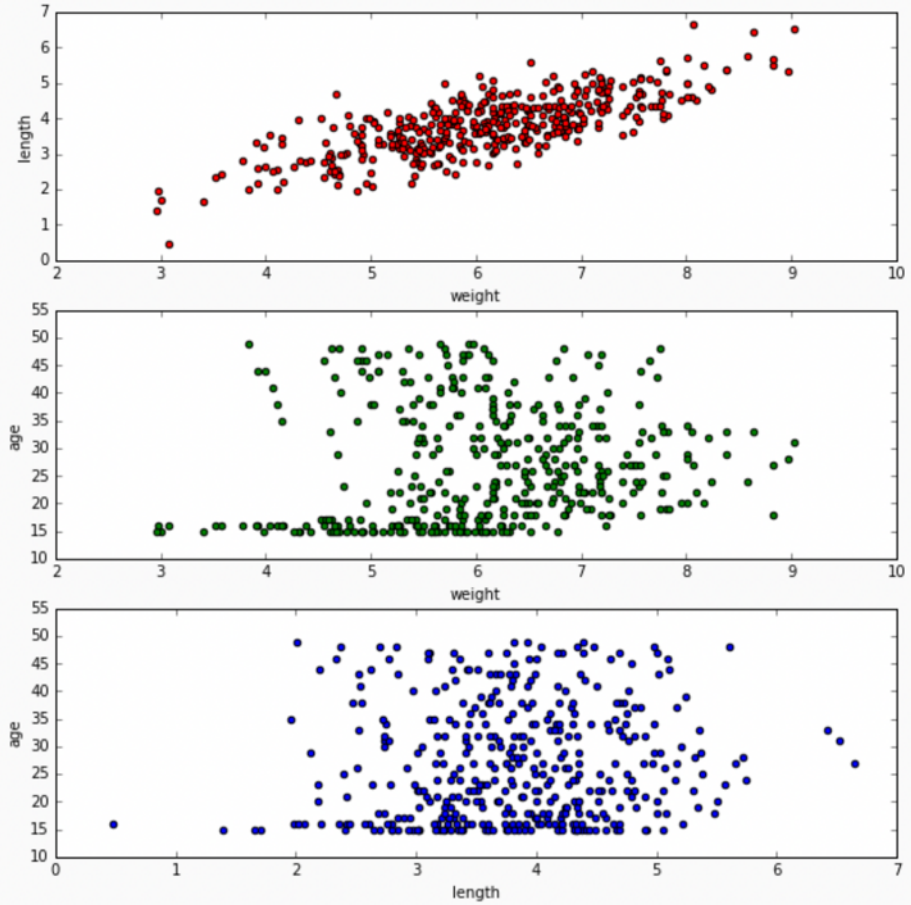
# More dimensions not always better

When the data is high dimensional, a scatter plot of all data attributes can be impossible or unhelpful



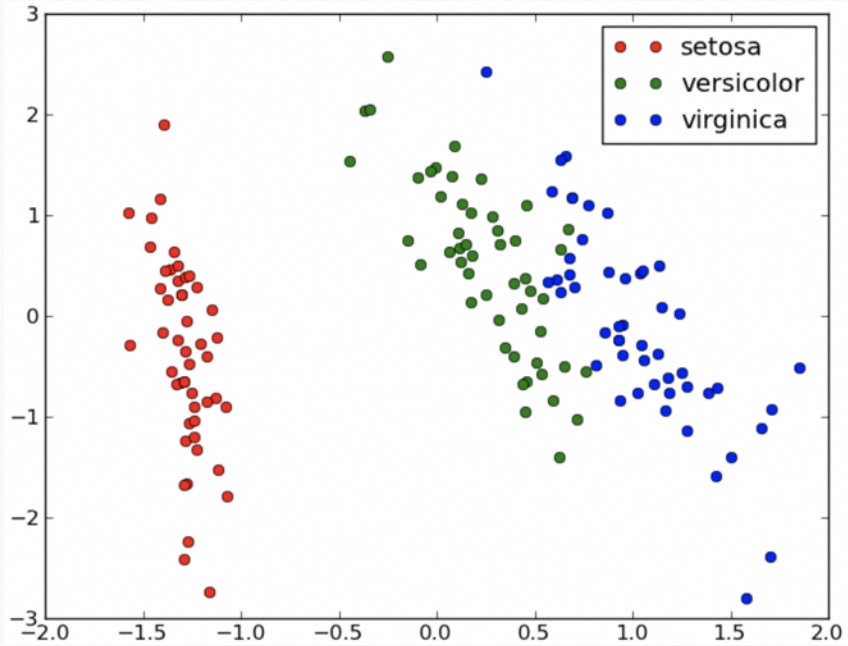
# Reducing complexity

Relationships may be easier to spot by producing multiple plots of lower dimensionality.



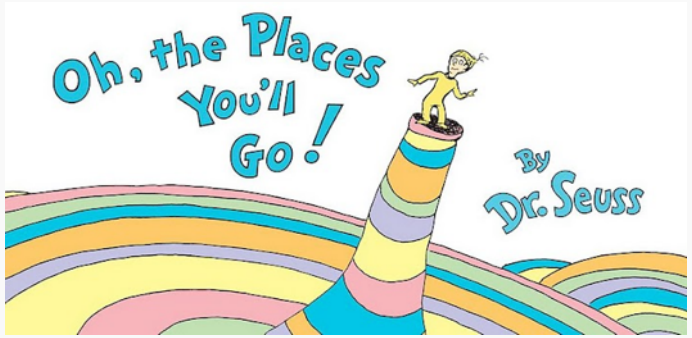
# Reducing complexity

For 3D data, color coding a categorical attribute can be “effective”



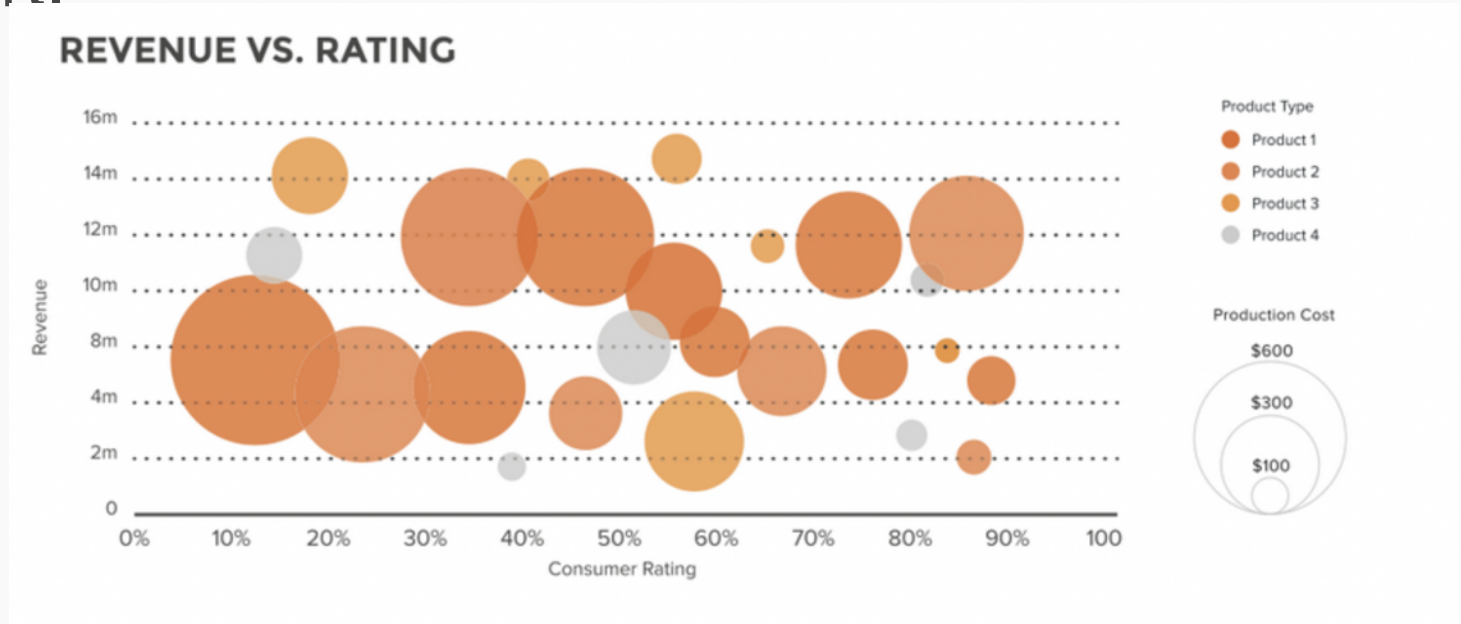

This visualizes a set of Iris measurements. The variables are: petal length, sepal length, Iris type (setosa, versicolor, virginica).

Except when it’s not effective.
What could be a better choice?



# 3D can work

For 3D data, a quantitative attribute can be encoded by size in a bubble chart.




The above visualizes a set of consumer products. The variables are: revenue, consumer rating, product type and product cost.

# **An Example** The Data Science Process

## *Analyzing Hubway Data*

**Introduction:** Hubway (now Blue Bikes) was metro-Boston's public bike share program, with more than 1600 bikes at 160+ stations across the Greater Boston area. Hubway is owned by four municipalities in the area.

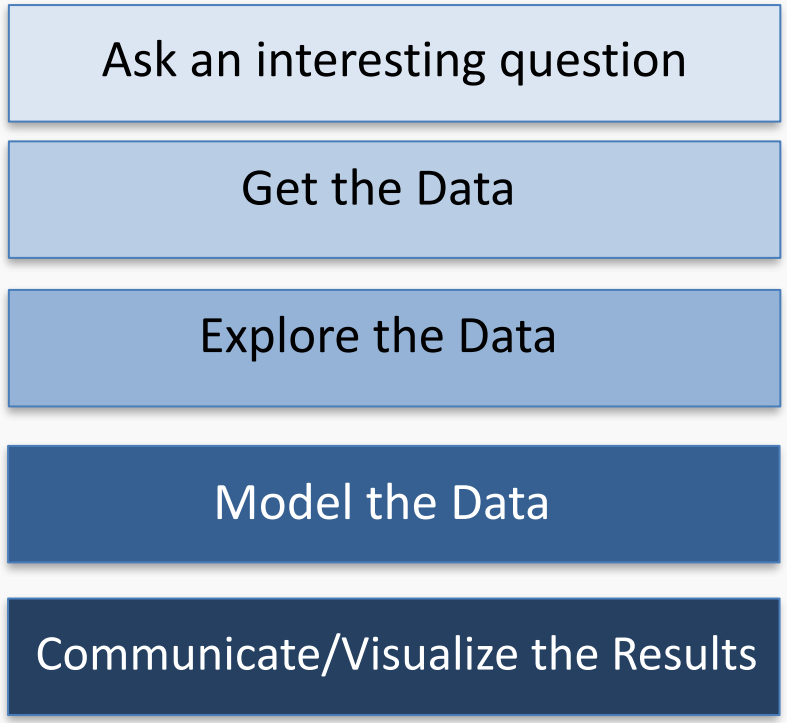
By 2016, Hubway operated 185 stations and 1750 bicycles, with 5 million ride since launching in 2011.

**The Data:** In April 2017, Hubway held a Data Visualization Challenge at the Microsoft NERD Center in Cambridge, releasing a few years of trip data.

**The Question:** What does the data tell us about the ride share program?

# What?

The Data Science Process is similar to the scientific process - one of observation, model building, analysis, and conclusion:




**Note**: This process is by no means linear!

# The Data Exploration/Question Refinement Cycle

Our original question: '**What does the data tell us about the ride share program?**' is a reasonable slogan to promote a hackathon. It is not good for guiding scientific investigation.

Before we can refine the question, we have to look at the data

Based on the data, what kind of questions can we ask?

| | seq_id | hubway_id | status | duration | start_date | strt_statn | end_date | end_statn | bike_nr | subsc_type | zip_code | birth_date | gender |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **0** | 1 | 8 | Closed | 9 | 7/28/2011 10:12:00 | 23.0 | 7/28/2011 10:12:00 | 23.0 | B00468 | Registered | '97217 | 1976.0 | Male |
| **1** | 2 | 9 | Closed | 220 | 7/28/2011 10:21:00 | 23.0 | 7/28/2011 10:25:00 | 23.0 | B00554 | Registered | '02215 | 1966.0 | Male |
| **2** | 3 | 10 | Closed | 56 | 7/28/2011 10:33:00 | 23.0 | 7/28/2011 10:34:00 | 23.0 | B00456 | Registered | '02108 | 1943.0 | Male |
| **3** | 4 | 11 | Closed | 64 | 7/28/2011 10:35:00 | 23.0 | 7/28/2011 10:36:00 | 23.0 | B00554 | Registered | '02116 | 1981.0 | Female |
| **4** | 5 | 12 | Closed | 12 | 7/28/2011 10:37:00 | 23.0 | 7/28/2011 10:37:00 | 23.0 | B00554 | Registered | '97214 | 1983.0 | Female |

# The Data Exploration/Question Refinement Cycle

***Who?*** Who's using the bikes?

Refine into specific hypotheses:

- More men or more women?
- Older or younger people?
- Subscribers or one time users?

***When?*** When are the bikes being checked out?

Refine into specific hypotheses:

- More during the weekend than on the weekdays?
- More during rush hour?
- More during the summer than the fall?

**Sometimes the feature you want to explore doesn't exist in the data, and must be engineered!**

***Where?*** Where are bikes being checked out?

Refine into specific hypotheses:

- More in Boston than Cambridge?
- More in commercial or residential aread?
- More around tourist attractions?
- More near the 'T' (subway)?

**Sometimes the data is given to you in pieces and must be merged!**

# The Data Exploration/Question Refinement Cycle

***Why?*** For what reasons/activities are people checking out bikes?

Refine into specific hypotheses:

- More bikes are used for recreation than commute?
- More bikes are used for touristic purposes?
- Bikes are use to bypass traffic?

**Do we have the data to answer these questions with reasonable certainty?**

**What data do we need to collect in order to answer these questions?**

***How?*** Questions that combine variables.

- How does user demographics impact the duration the bikes are being used? Or where they are being checked out?
- How does weather or traffic conditions impact bike usage?
- How do the characteristics of the station location affect the number of bikes being checked out?

**How questions are about modeling relationships between different variables.**

# Inspirations for Data Viz/Exploration

So how well did we do in formulating creative hypotheses and manipulating the data for answers?

Check out the winners of the Hubway Challenge:

https://www.bluebikes.com/blog/and-the-2017-hubway-data-challenge-winners-are