

Institute of
Data



2020



Data Science and AI

Module 3
Part 1:

Exploratory Data Analysis (EDA)



Agenda: Module 3 Part 1

- Introduction to EDA
- Data **cleaning & profiling**
- Assessing data **quality**
- Data rejection & imputation
- Exploring & visualising **continuous** data
- Exploring & visualising **categorical** data
- **Temporal** data
- **Geographic** data



Python EDA Fundamentals

- Where does data come from?
- What does data look like?
- What is **Exploratory Data Analysis**?
- Where does EDA fit in the **Data Science pipeline**?



Where does data come from?

- **databases**
 - data marts
 - data warehouses
- transaction systems
 - cloud
 - mainframes
- distributed file systems
 - Hadoop
- **APIs**
- scanned documents
- websites
 - downloads of datasets, posts, conversations, etc.
 - web scrapers
- subscribed feeds
 - news
 - IoT devices
- multimedia hosts
 - images
 - video
 - audio
- ?



What does data look like?

- database **tables**
- reports & extracts
- spreadsheets & workbooks
- **structured & semi-structured files**
- **streams**
- encoded files
- bitmaps
- ?



What is Exploratory Data Analysis?

everything we do with a candidate dataset ...

- after it has been rendered essentially **usable**
- before we start **developing analytics and models** that address our original problem
- to determine whether it will make a useful **proxy** for understanding the phenomenon we are interested in.

where does it fit?

- (within the data science pipeline)



How do we make a dataset “usable”?

- ***wrangling***

- sourcing, loading, and precleaning the data so we can see what it really looks like
- fixing critical issues

- ***profiling and cleaning***

- understanding the essential characteristics of the data
- applying preliminary transformations to confer context and meaning
- implementing strategies for missing and invalid data

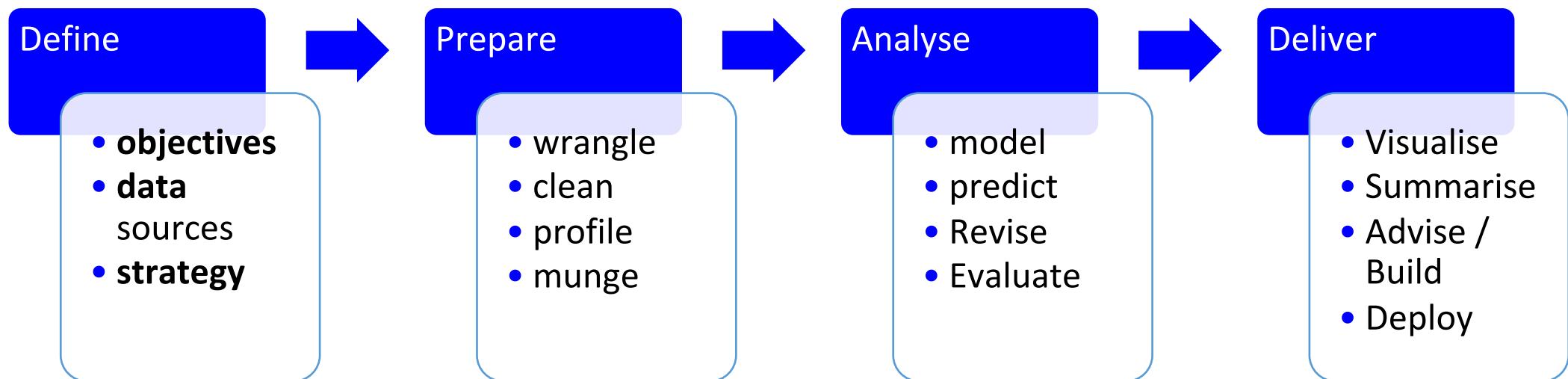
- ***munging***

- reshaping the data to prepare it for analysis



Where does EDA fit?

- (within in the data science pipeline)



Note that this process is never linear!
You will have to **iterate** over each step and over a number of the steps

Exploratory Data Analysis



Data Cleaning & Profiling

- Preliminary data **cleaning**
- Basic data **profiling**
- Assessing data **quality**
- Data rejection and imputation



Data Cleaning & Profiling

def: **Data profiling**

- examining the characteristics of the dataset
 - data **types**
 - data **ranges** (continuous) & categories
 - identifying **issues** with the data

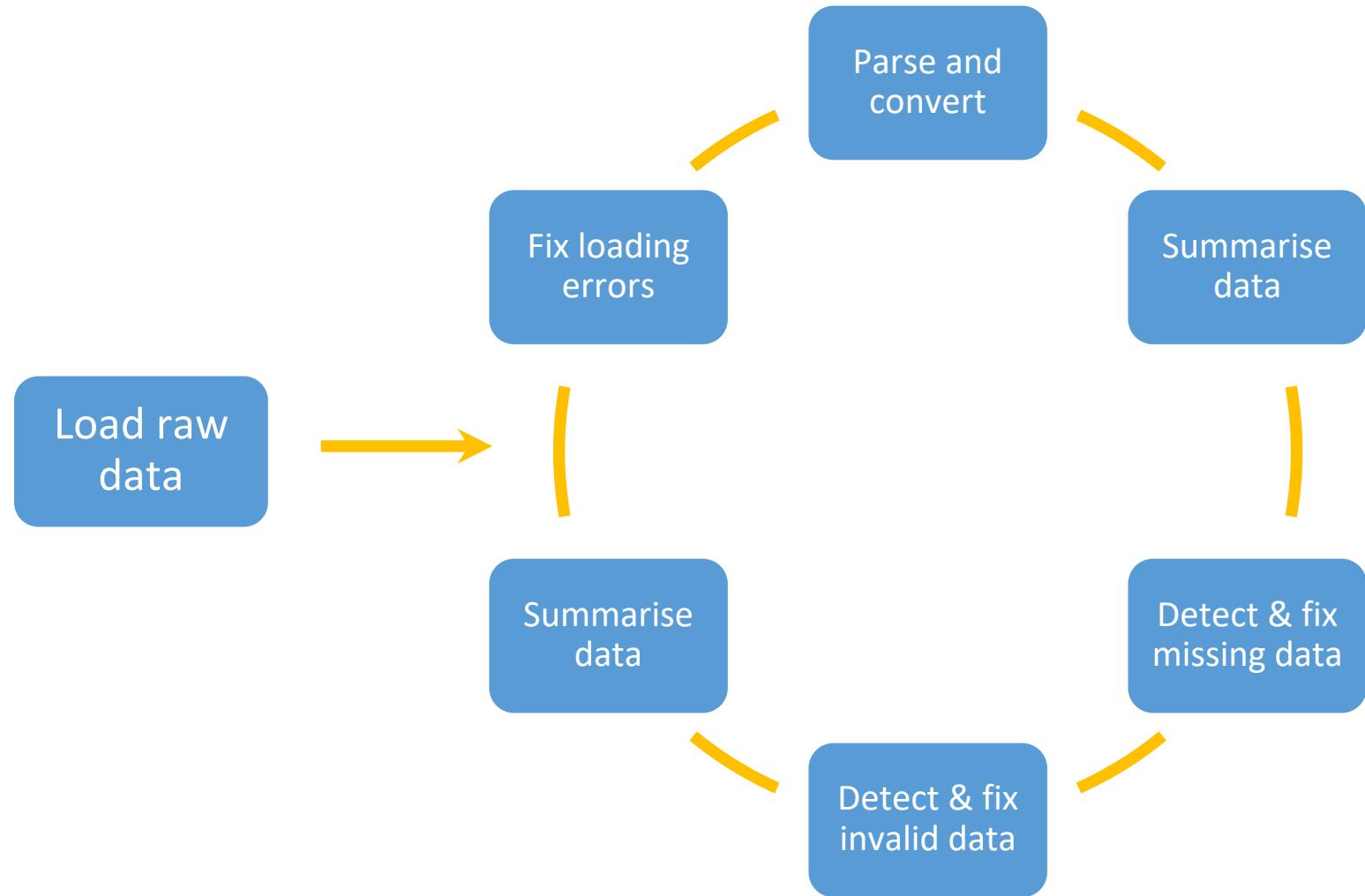
def: **Data cleaning**

- making the data **usable** (preparing it for analysis)
 - reformatting
 - data type **conversion**
 - dealing with **dirty data**



Data Cleaning & Profiling

... is iterative





Data Cleaning & Profiling – Details

Load raw data

- from source system
 - database
 - HFS
 - flat file
 - spreadsheet / workbook
 - semi-structured file (JSON, XML, HTML)
 - API
 - stream (feed, IoT)
 - web scraper
 - scanned text





Data Cleaning & Profiling – Details

Fix loading errors

- missing delimiters
 - e.g. badly written mainframe extracts that suppress trailing commas for empty fields
- unexpected delimiters
 - e.g. ‘|’ or tab character used in “CSV” file
- illegal characters
 - e.g. ‘\u’ is normally interpreted as indicating Unicode
may need to suppress default behaviour of function used to load the data
- missing control characters
 - EOL
 - EOF
- other?



Data Cleaning & Profiling – Details

Parse and convert

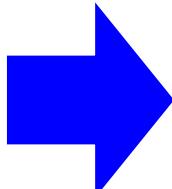
- formatted **date** strings to dates
 - d/m/y, m/d/y, dd/mm/yyyy, dd-mmm-yyyy, day names, month names, ...
- formatted **time** strings to times
 - AM/PM vs 24-hr
 - time zone conversions
- formatted date+time strings to datetimes
- string to int, string to float
- proprietary formats
 - binary, octal, hexadecimal



Data Cleaning & Profiling – Details

What to do when data conversions fail?

- implement a *try* block
 - to catch format conversion failures
- use transformations that **can handle missing values**
 - or deal with missing values first
- document conversion failures
 - these are *limitations* that should be addressed when interpreting the results of analysis



```
def try_parse_int(s, base=10, val=None):  
    try:  
        return int(s, base)  
    except ValueError:  
        return val
```



Data Cleaning & Profiling – Details

Detect & fix missing values

- drop rows
- replace with NA
- impute values
 - mean, median, mode
 - of entire column
 - of similar data (grouped by other fields)
 - nearest neighbour
 - assign value from closest point (according to a suitable distance metric)



Data Cleaning & Profiling – Details

Dealing with missing or bad data

- **replace** with NA
- **impute** values
 - out of range
 - too small: set to minimum possible value?
 - too large: set to maximum possible value?
- **drop rows**
 - impossible values (e.g. out of domain)
 - length = green: drop?
 - salary = -1: drop?
- **drop columns**
 - too many missing or invalid samples



Data Cleaning & Profiling – Details

Summarise data

- counts of **missing** values
- counts of **invalid** values
- **statistical parameters** of distribution
 - continuous variables
 - bin frequencies
 - mean, median, maximum, minimum
 - categorical variables
 - category frequencies
 - most frequent (mode), least frequent



Assessing Data Quality

- accuracy, reliability (veracity)
- currency, relevance (value)
- missing and invalid values
 - overall
 - by column
 - by row

issues:

- can we afford to throw out rows with missing data?
- how will imputation of missing/invalid data affect the outcome?



Assessing Data Quality with Python

let df be a Pandas DataFrame object

- view the first few rows:
`df.head(), df.head(nrows)`
- check for missing values:
`df.isnull(), df.isnull().sum()`
- pairwise correlations:
`df.corr()`
- (continuous) value ranges:
`df.min(), df.max()`
- (discrete) value counts:
`df.value_counts()`
- summary:
`df.describe()`
- pandas_profiling.ProfileReport
- pydqc



Lab 3.1.1: Data Wrangling and Munging

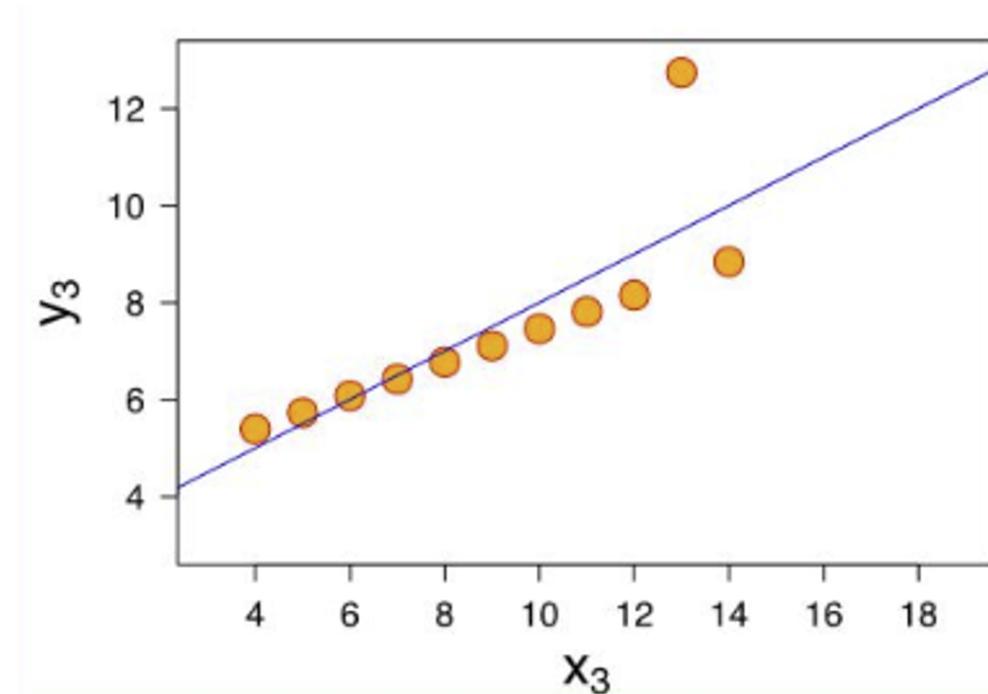
- Purpose:
 - To explore Python methods for wrangling, munging, and profiling datasets
- Materials:
 - ‘Lab 3.1.1.ipynb’



Outliers

def: an observation that is distant from other observations in the sample

- measurement inaccuracy
- measurement errors
 - incl. recording errors
- unusual system behaviour
- external phenomena





Outlier Detection in 1 Dimension

extreme value analysis

- outliers are defined by statistical tests based on mean & variance of sample
 - z-test
- mark points with low score as outliers

probabilistic & statistical models

- based on assumed distribution of data
 - calculate probability that each point belongs to the distribution
 - mark points with low probability as outliers



Outlier Detection in Multiple Dimensions

linear models

- reduce data to lower-dimensional spaces
- calculate distance from each point to a reference hyperplane
- mark points with largest distance as outliers
- similar concept to *principal component analysis* (PCA)

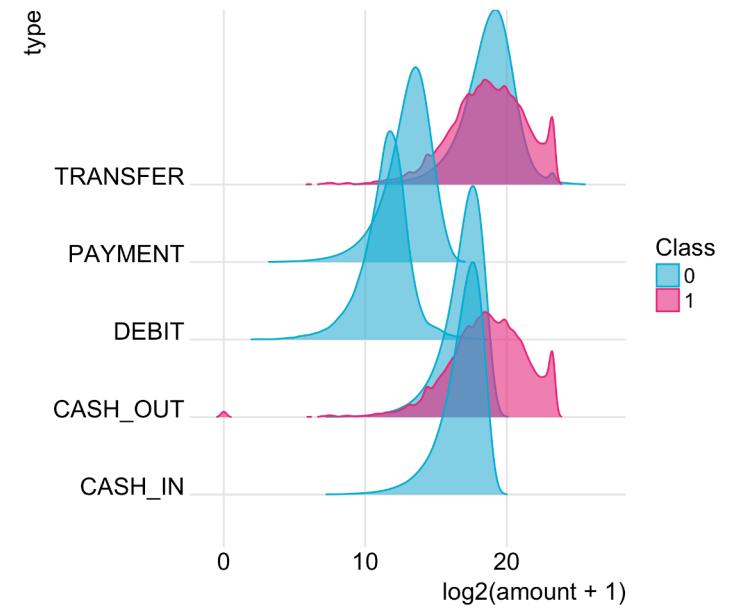
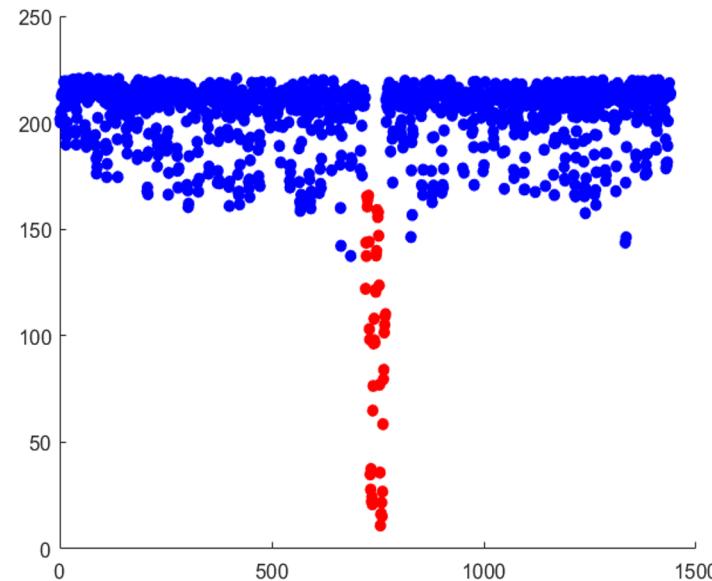
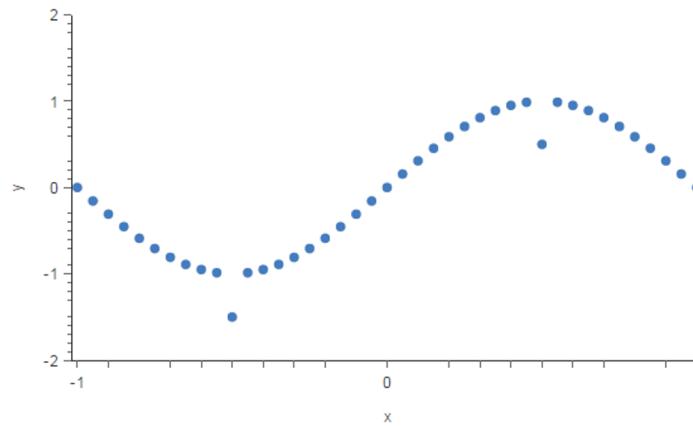
proximity-based models

- define a distance metric and apply to each pair of points
- mark points that are more isolated as outliers
- examples: *cluster analysis*, *density-based analysis*, *nearest-neighbour analysis*



Outlier Detection – cont'd

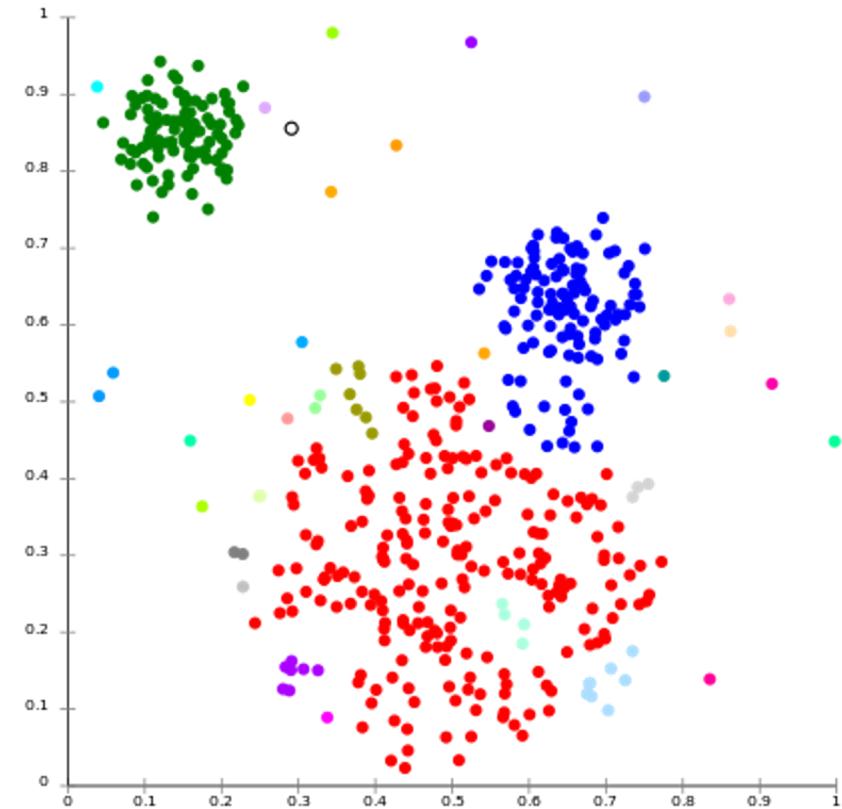
- outliers vs. anomalies
 - if unsure, analyse data with *and* without the outliers





Outlier Detection – cont'd

- outliers may not be obvious in one dimension
 - some points may only get separated from the mainstream when looking at several dimensions at once
 - may indicate subsets of behaviour (“classes”)



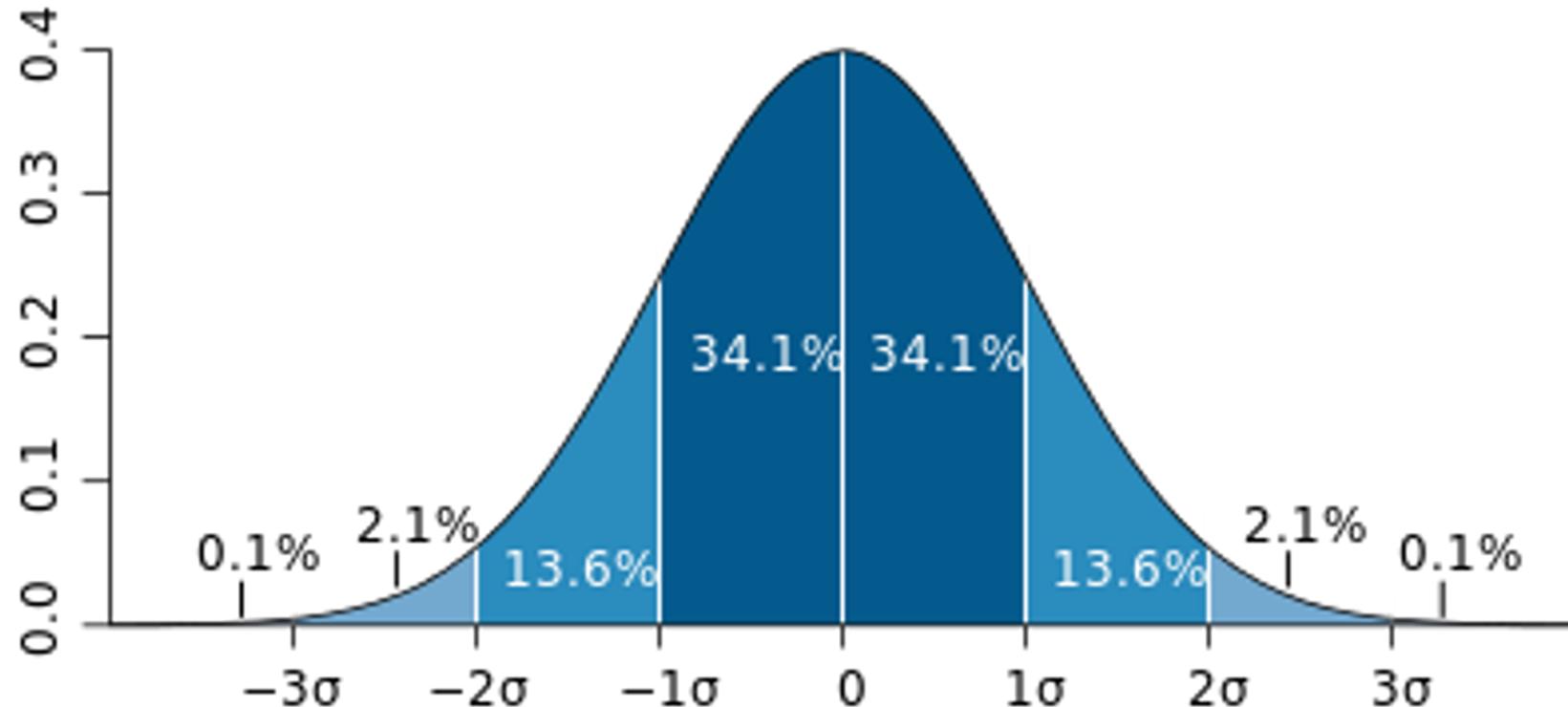


Continuous Data

- Statistics of sample distributions
 - deeper dive: mean, variance, skewness, kurtosis
- Exploring and visualising sample variables
 - histograms
 - box & whisker plots
 - violin plots
- Outlier detection

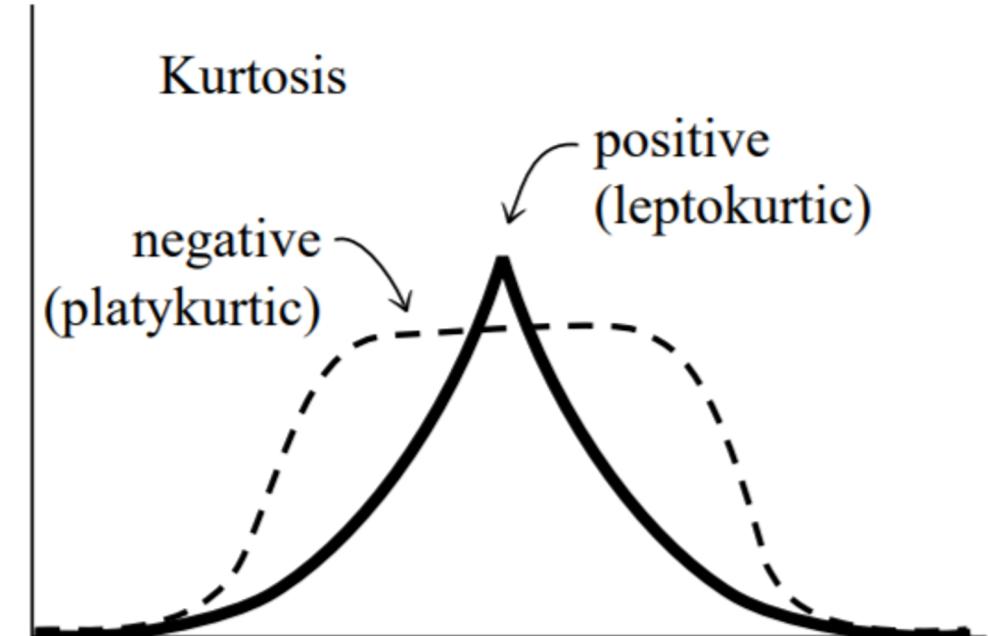
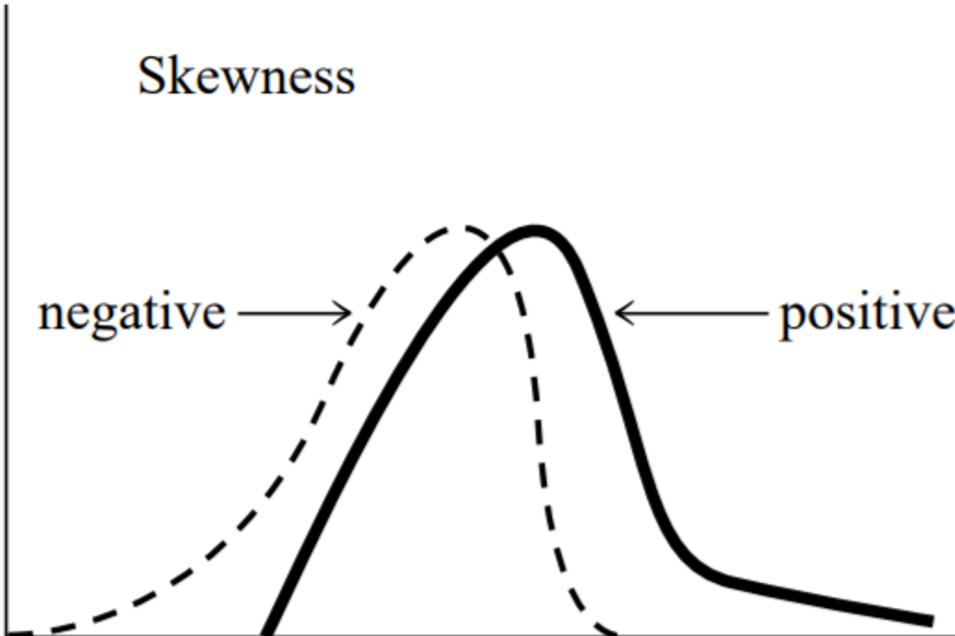


Mean & Variance





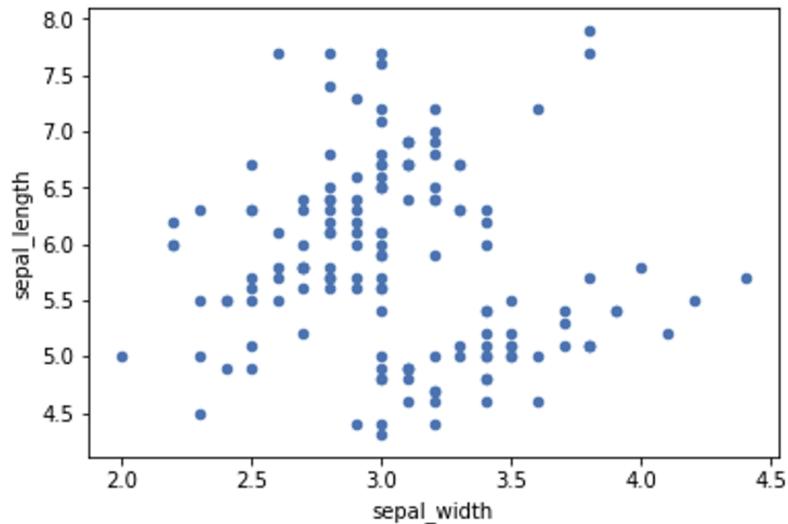
Skewness and Kurtosis



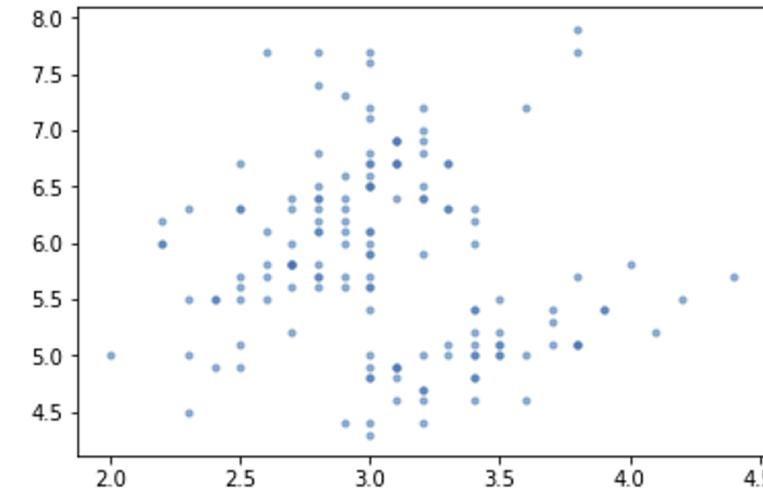


Scatterplot

- shows a 2D relationship within the dataset by plotting one column against another



```
df.plot(kind='scatter', x='sepal_width', y='sepal_length')
```



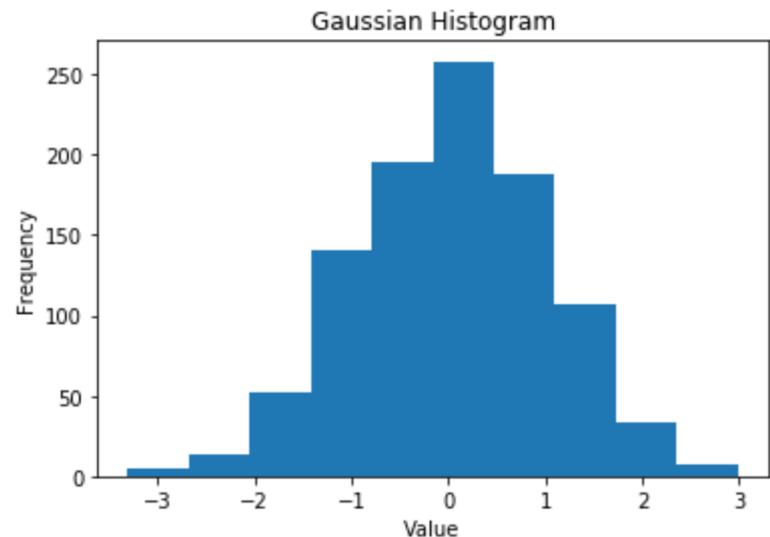
```
plt.scatter(df['sepal_width'], df['sepal_length'], s = 10,  
           linewidths = 1, alpha = 0.5)
```

https://matplotlib.org/api/_as_gen/matplotlib.pyplot.scatter.html

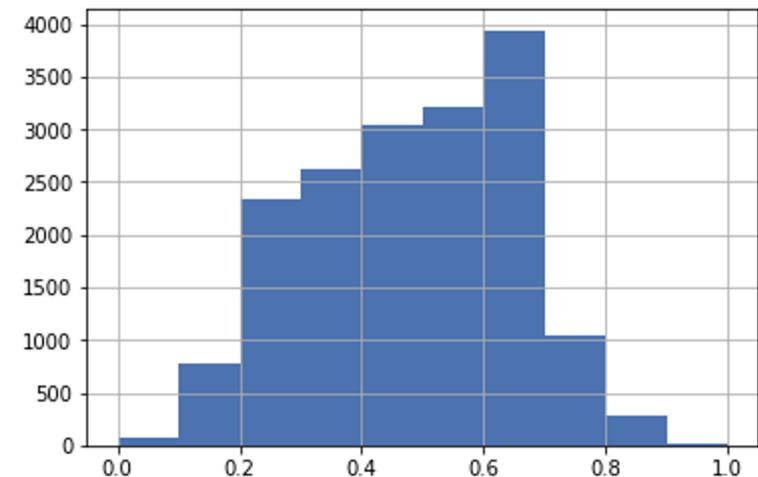


Histogram

shows the properties of the data sample distribution with no loss of information



```
plt.hist(y)
plt.title("Gaussian Histogram")
plt.xlabel("Value")
plt.ylabel("Frequency")
```

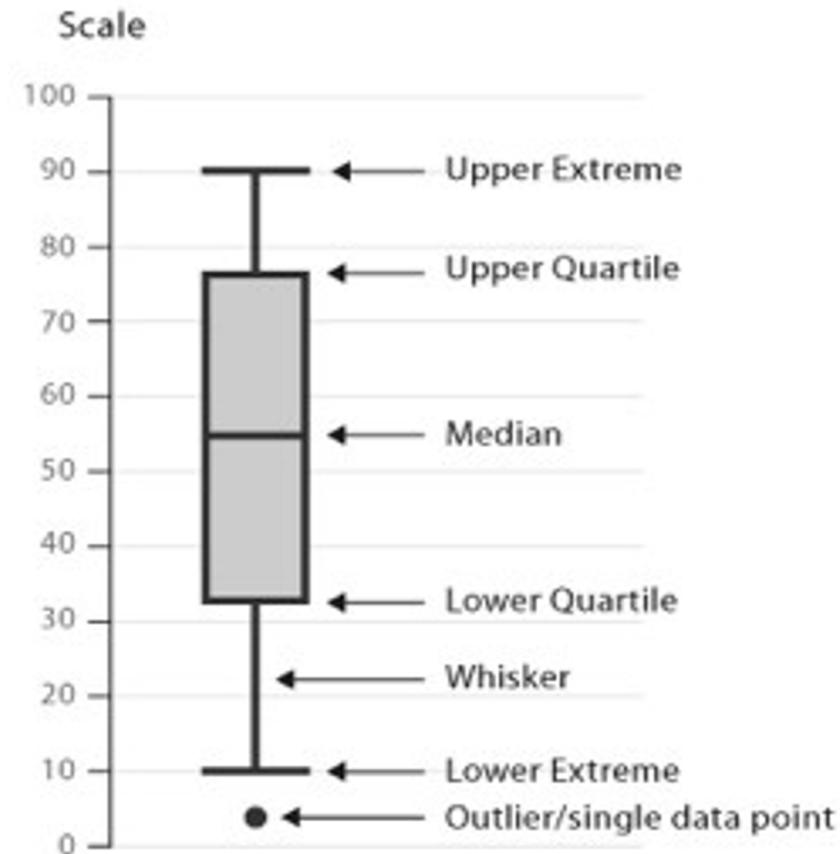


```
df['temp'].hist()
```



Box & Whisker Plots

- shows multiple features of sample distribution
 - median
 - interquartile range
 - 10th, 90th percentiles





Box & Whisker Plots

```
# get 50 random numbers normally  
distributed about -1:
```

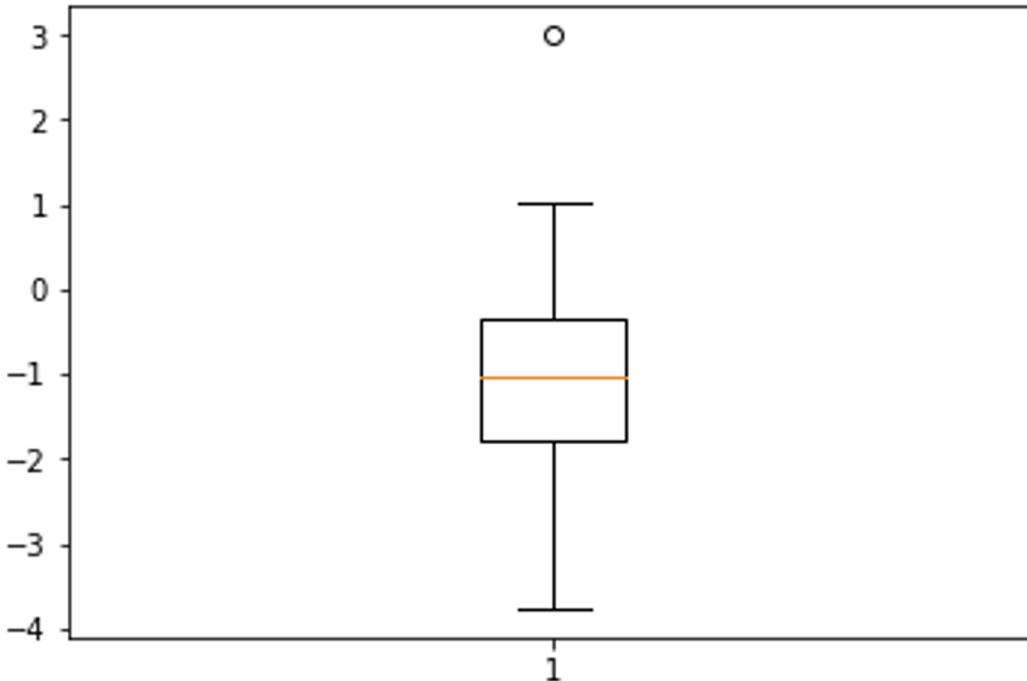
```
y = np.random.randn(50) - 1
```

```
# create an outlier:
```

```
y[49] = 3
```

```
# plot box & whiskers:
```

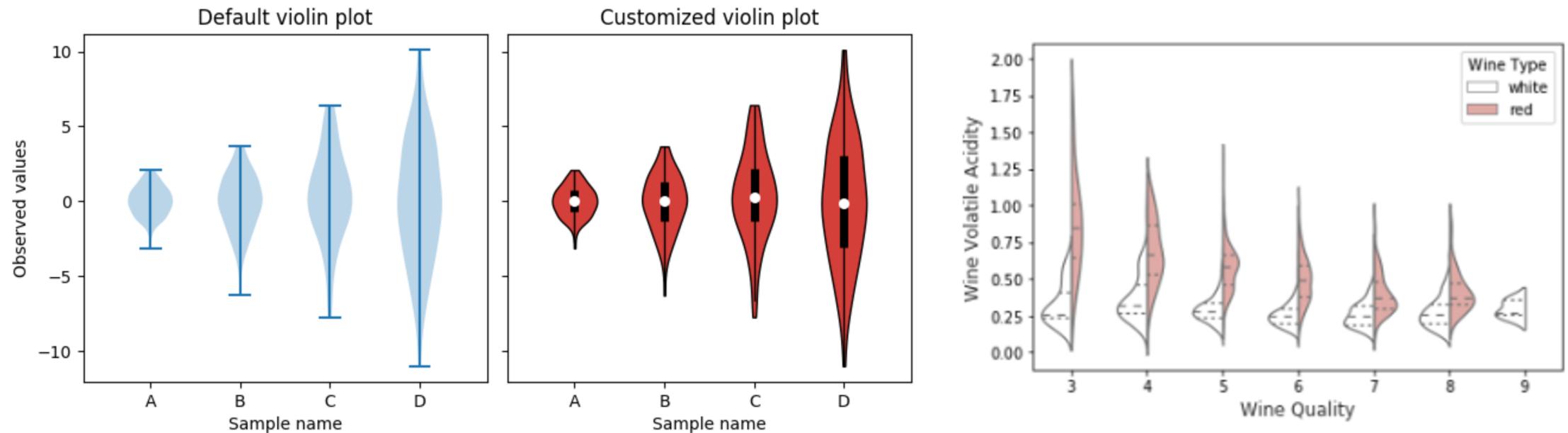
```
plt.boxplot(y)
```





Violin Plots

- shows the sample distribution itself



https://matplotlib.org/gallery/statistics/customized_violin.html



Quantiles

- quantiles are popular in reporting because they help to create a sense of what is “normal”
 - *90% of calls last less than 3 minutes, 22 seconds*
 - *80% of revenue was derived from 22% of the product range*

```
1 bikes['atemp'].quantile(0.5)
```

```
0.4848
```

```
1 bikes['atemp'].quantile((0.1, 0.25, 0.5, 0.75, 0.9))
```

```
0.10    0.2424
0.25    0.3333
0.50    0.4848
0.75    0.6212
0.90    0.6970
Name: atemp, dtype: float64
```

- quantiles are cumulative
 - e.g. 80th percentile is a subset of 90th percentile

Q: what would a plot of all possible quantiles represent?

> the cumulative probability function



Discretisation

- suppose want to look at intervals (“bins”) instead?

```
pandas.cut(x, bins, right=True, labels=None, retbins=False, precision=3,  
           include_lowest=False, duplicates='raise')
```

```
pandas.cut(df['temp'], bins = 4).head()
```

```
(0.25, 0.5]  
(0.25, 0.5]  
(0.5, 0.75]  
(0.25, 0.5]  
(0.5, 0.75]
```

- continuous data can be sorted into specified bins
- **bins** can be a vector of ‘cut’ boundaries (for asymmetric bins)
- bin counts can be plotted as a bar chart (discrete version of histogram)



Continuous n -Dimensional Data

marginal distribution

- the distribution of the entire sample of a given variable from a multivariate sample
- ignores presence of other ($n-1$) covariates

conditional distribution

- the distribution of a given variable *contingent on* values of other ($n-1$) covariates
- for a pair of covariates X, Y
 - joint distribution: $\Pr(X = x, Y = y)$
 - conditional distribution: $\Pr(X = x \mid Y = y)$ Y has been “marginalised out”



Pairwise Correlations in n -Dimensional Data

computes correlation between every pair of columns in a matrix or DataFrame:

```
1 iris.corr()
```

	sepal_length	sepal_width	petal_length	petal_width
sepal_length	1.000000	-0.109369	0.871754	0.817954
sepal_width	-0.109369	1.000000	-0.420516	-0.356544
petal_length	0.871754	-0.420516	1.000000	0.962757
petal_width	0.817954	-0.356544	0.962757	1.000000

- only the figures below (or above) the main diagonal are needed
- uses Pearson's correlation by default

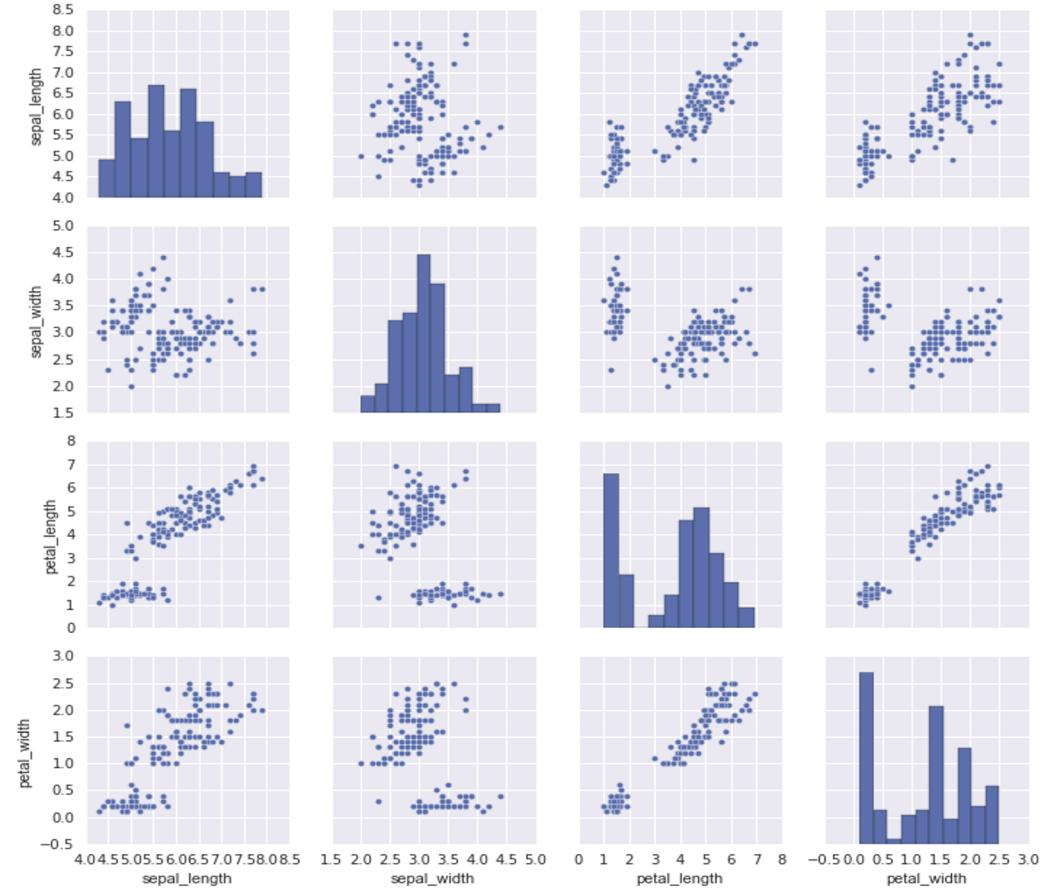


Pairwise Correlations in n -Dimensional Data – cont'd

can visualise correlations as a **pair plot**

```
import seaborn as sns
```

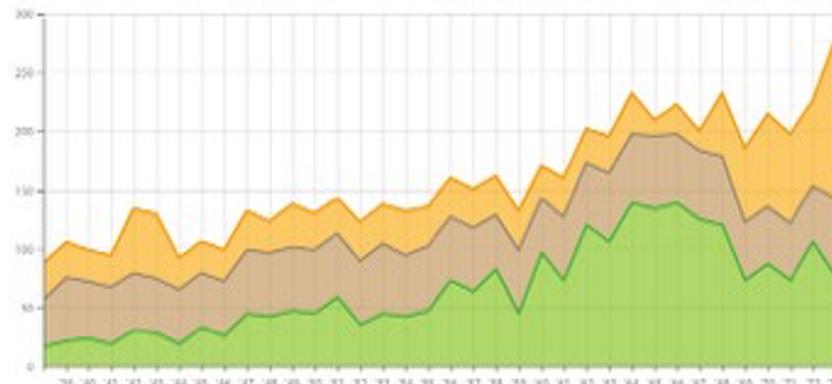
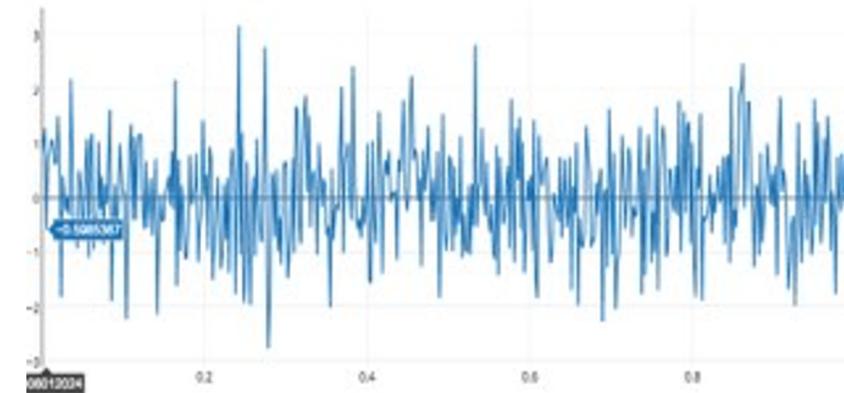
```
sns.pairplot(iris)
```





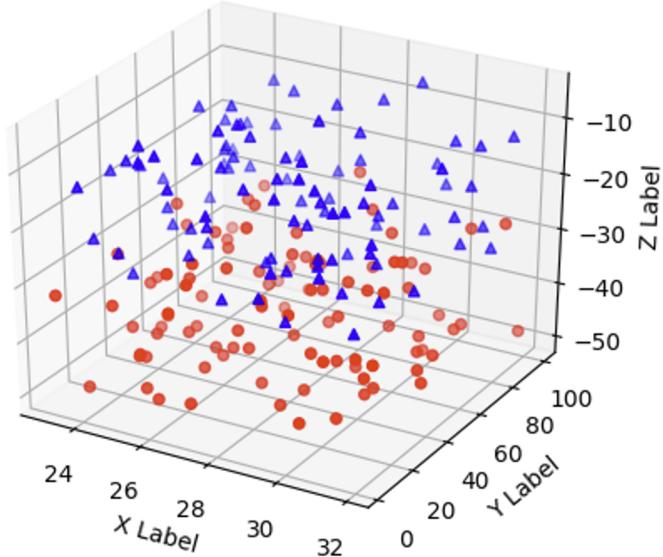
Visualising 2-Dimensional Data

- scatterplot
- line chart
- bar chart (binned horizontal axis)
- stacked area chart
- *many variations of these*

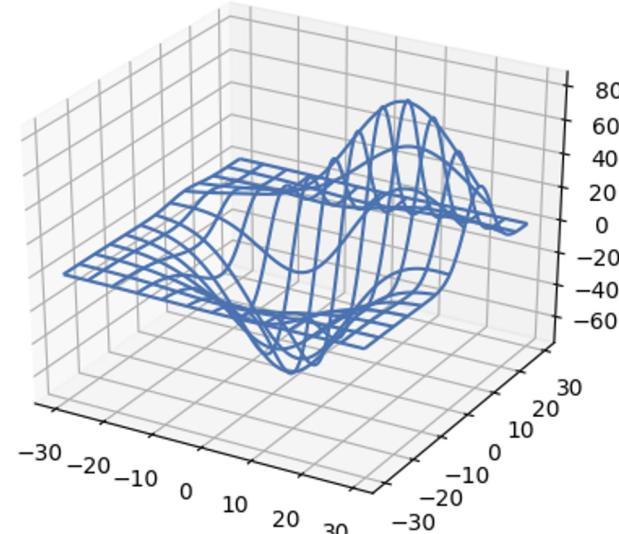




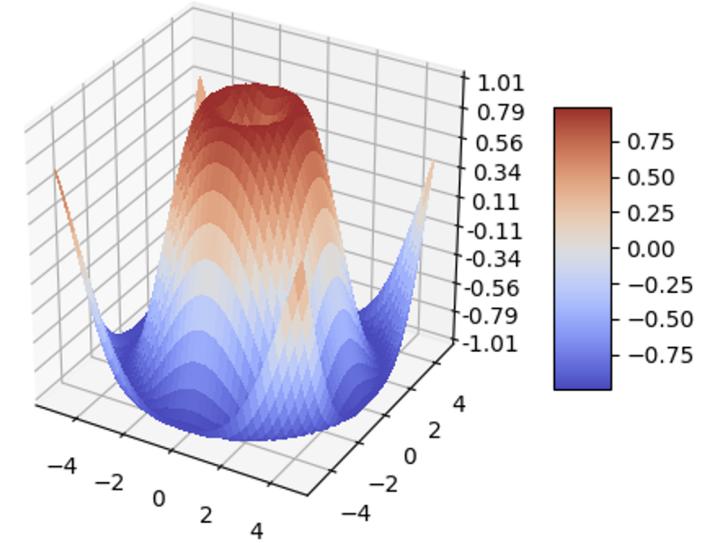
Visualising 3-Dimensional Data



3D Scatterplot



Wireframe Plot



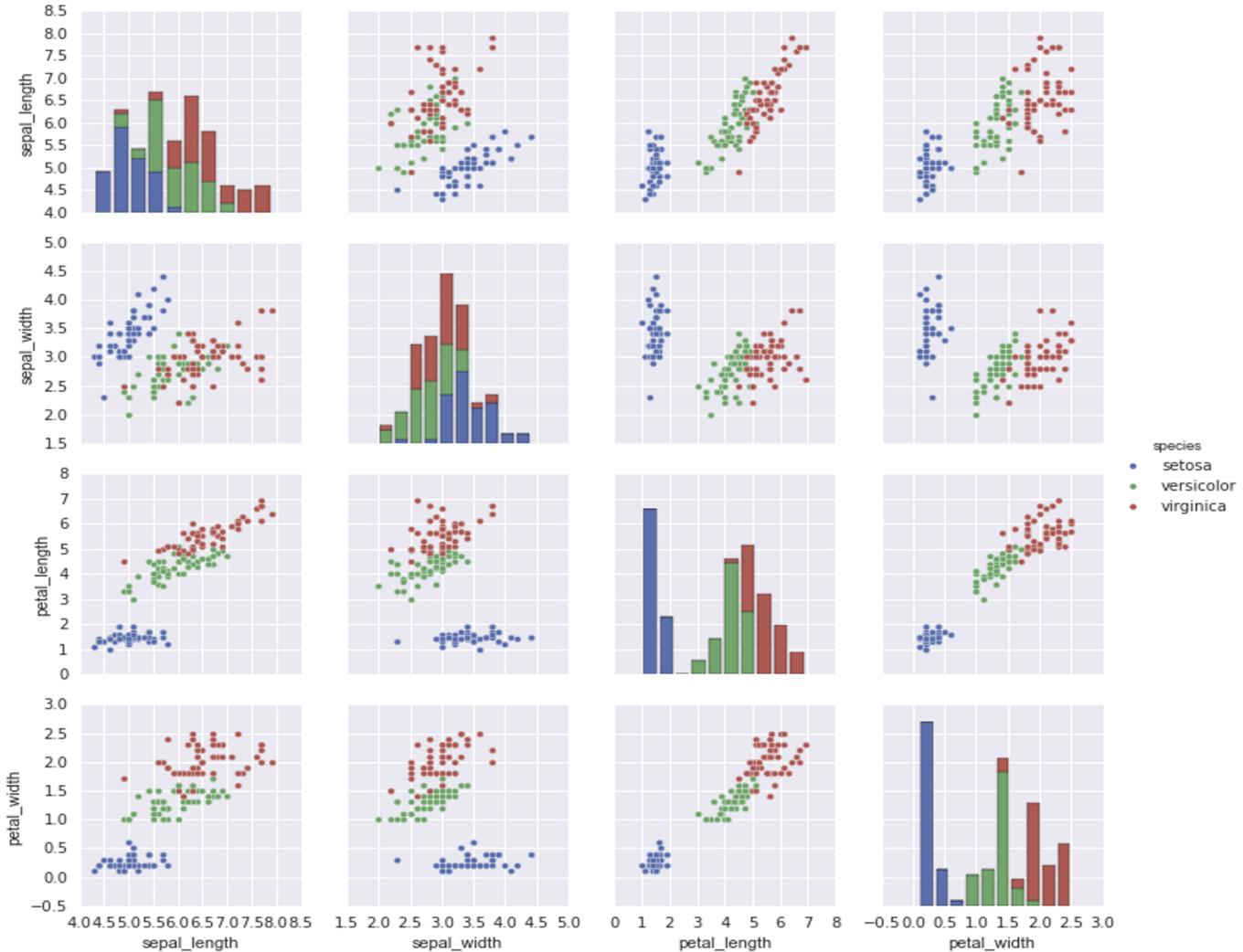
Surface Plot

https://matplotlib.org/mpl_toolkits/mplot3d



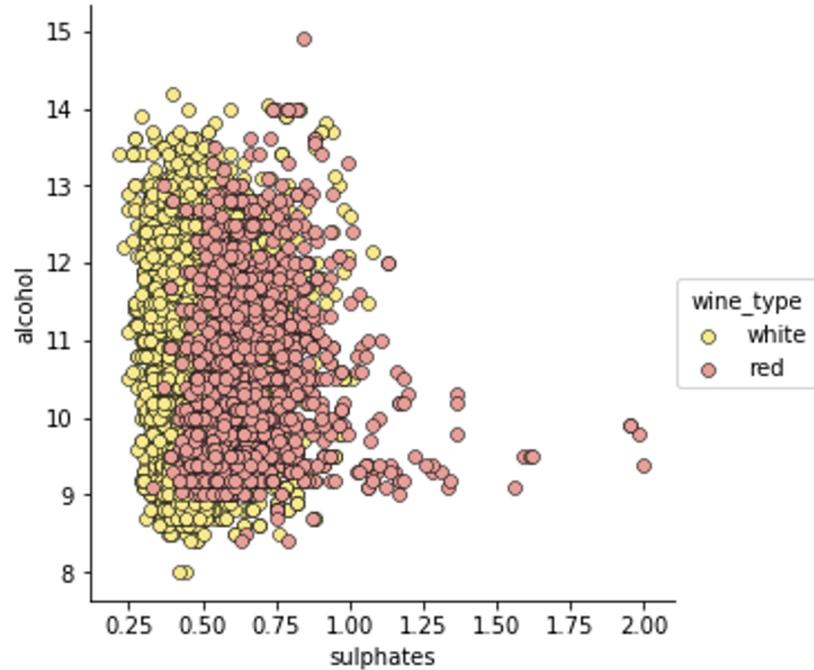
Visualising 3 Dimensions – cont'd

- adding colour allows stratification by a categorical variable (usually called a “class”)

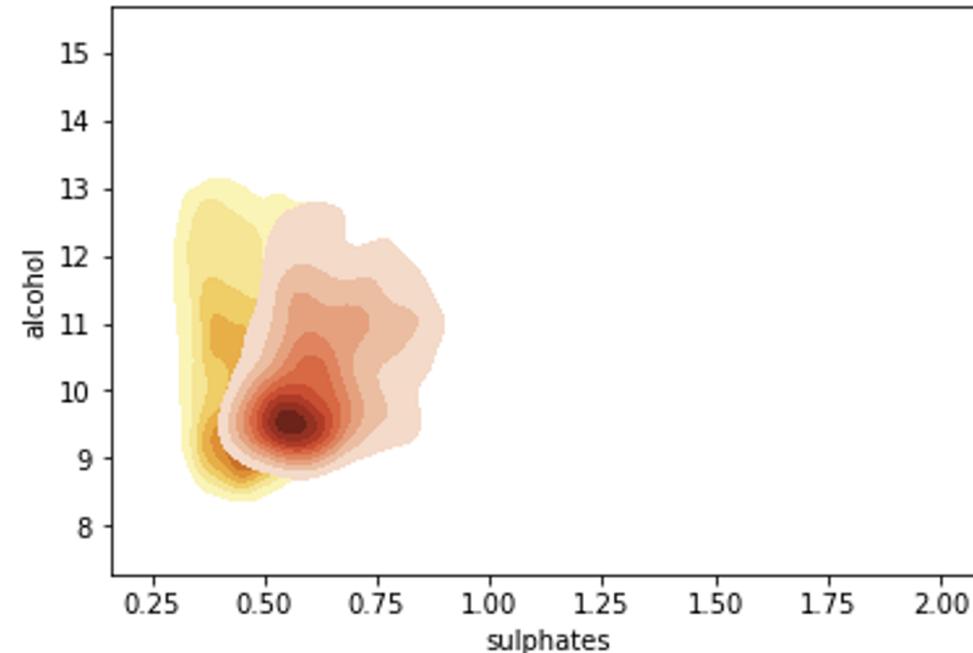




Visualising 3 Dimensions – cont'd



using colour in a scatterplot



using colour and hue in a contour plot

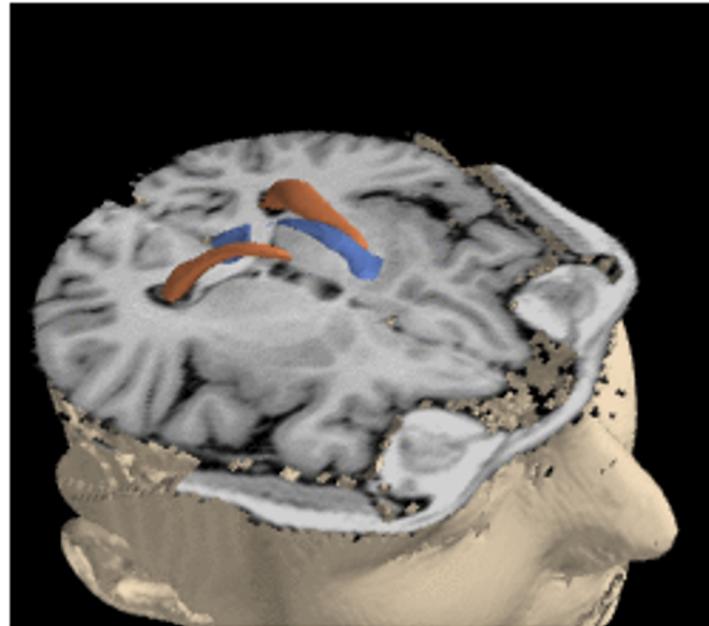
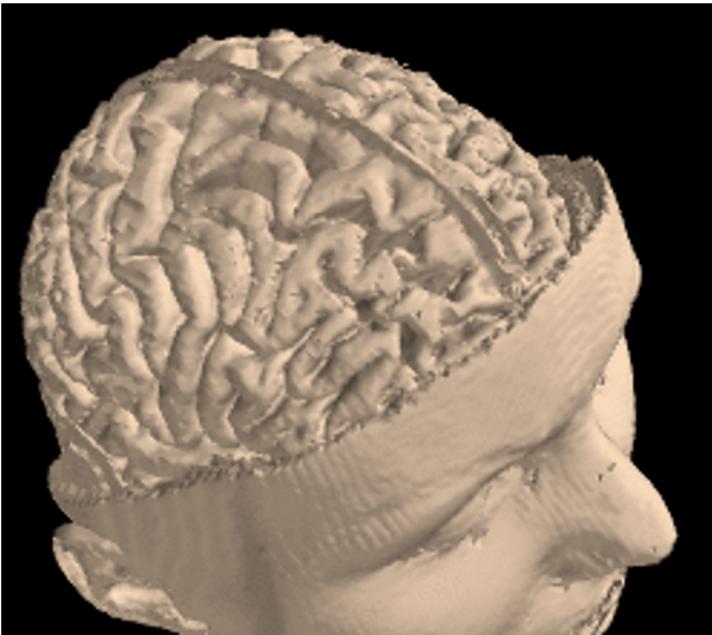
<https://towardsdatascience.com/the-art-of-effective-visualization-of-multi-dimensional-data-6c7202990c57>



Visualising 3 Dimensions – cont'd

Slicing

- reduce dimensionality by viewing a plane
- does not have to be parallel to a dimensional axis

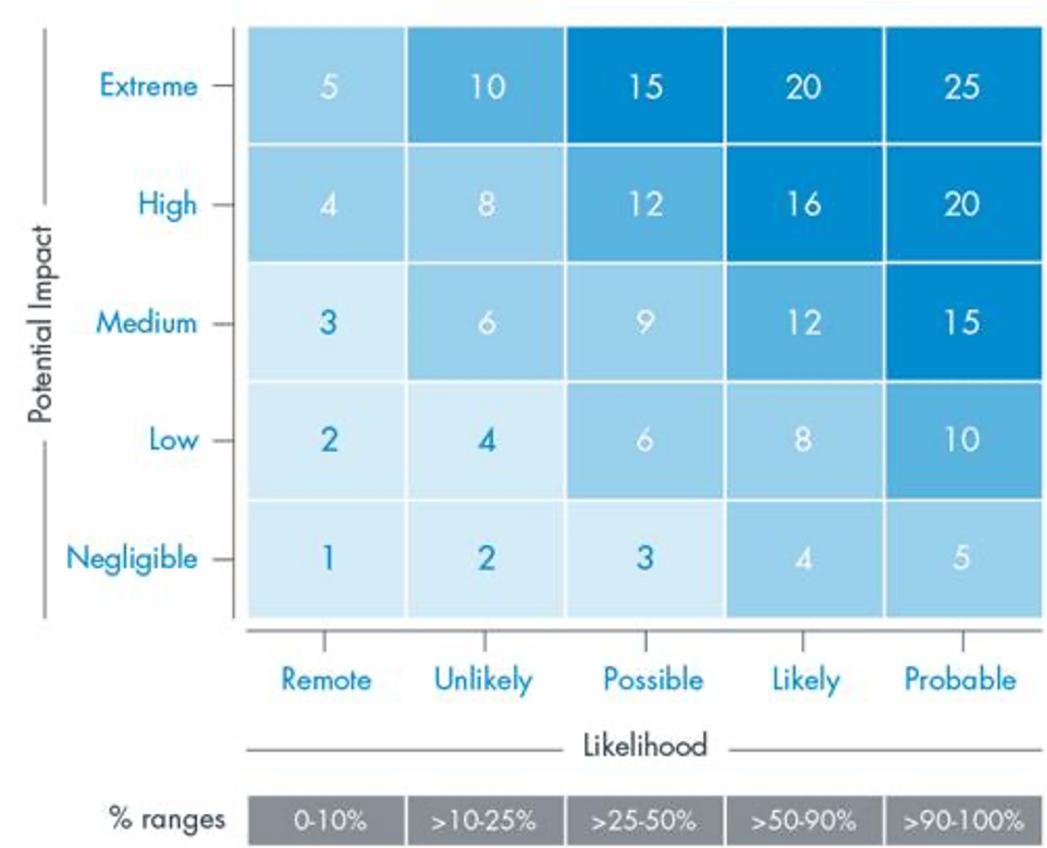
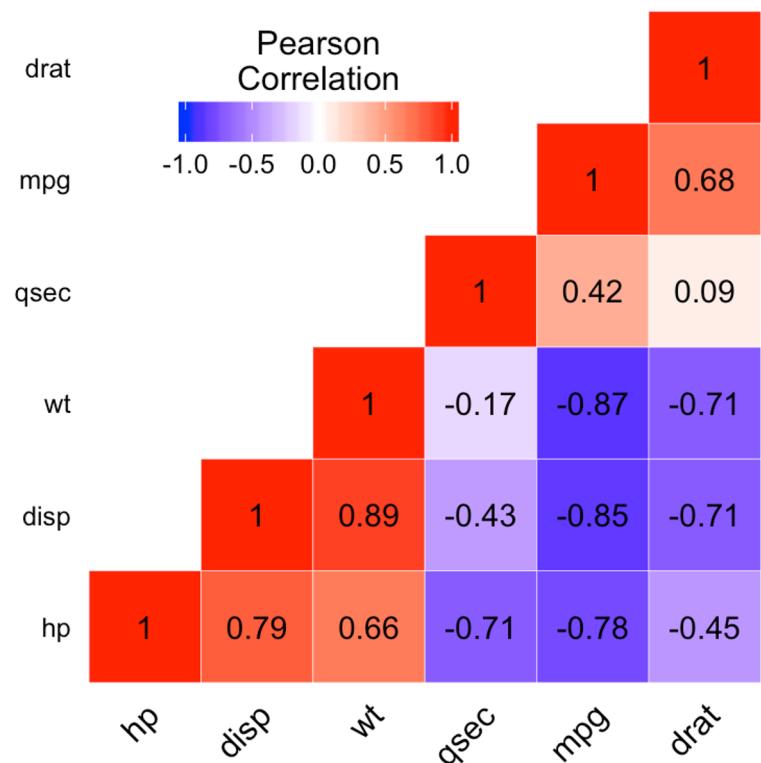


<http://zulko.github.io/blog/2014/11/29/data-animations-with-python-and-moviepy/>



Visualising 3 Dimensions – cont'd

- heat map

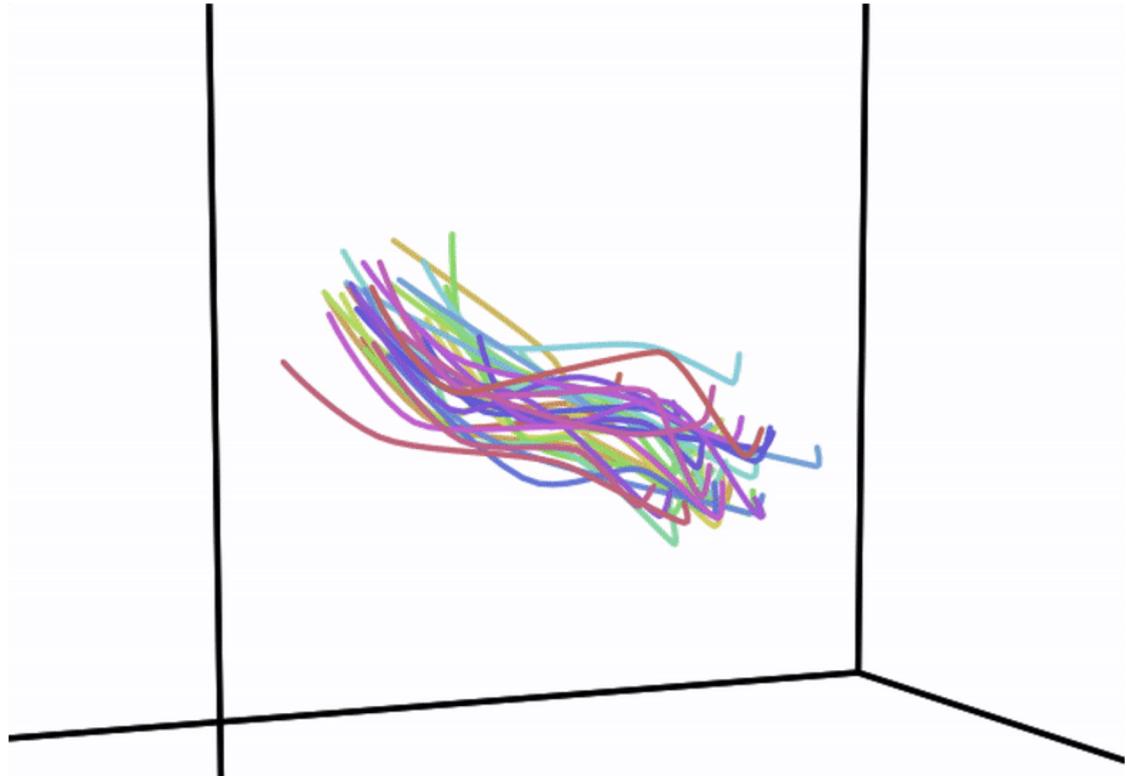




Visualising > 3 Dimensions

- dimensional reduction
 - e.g. to animated trajectories

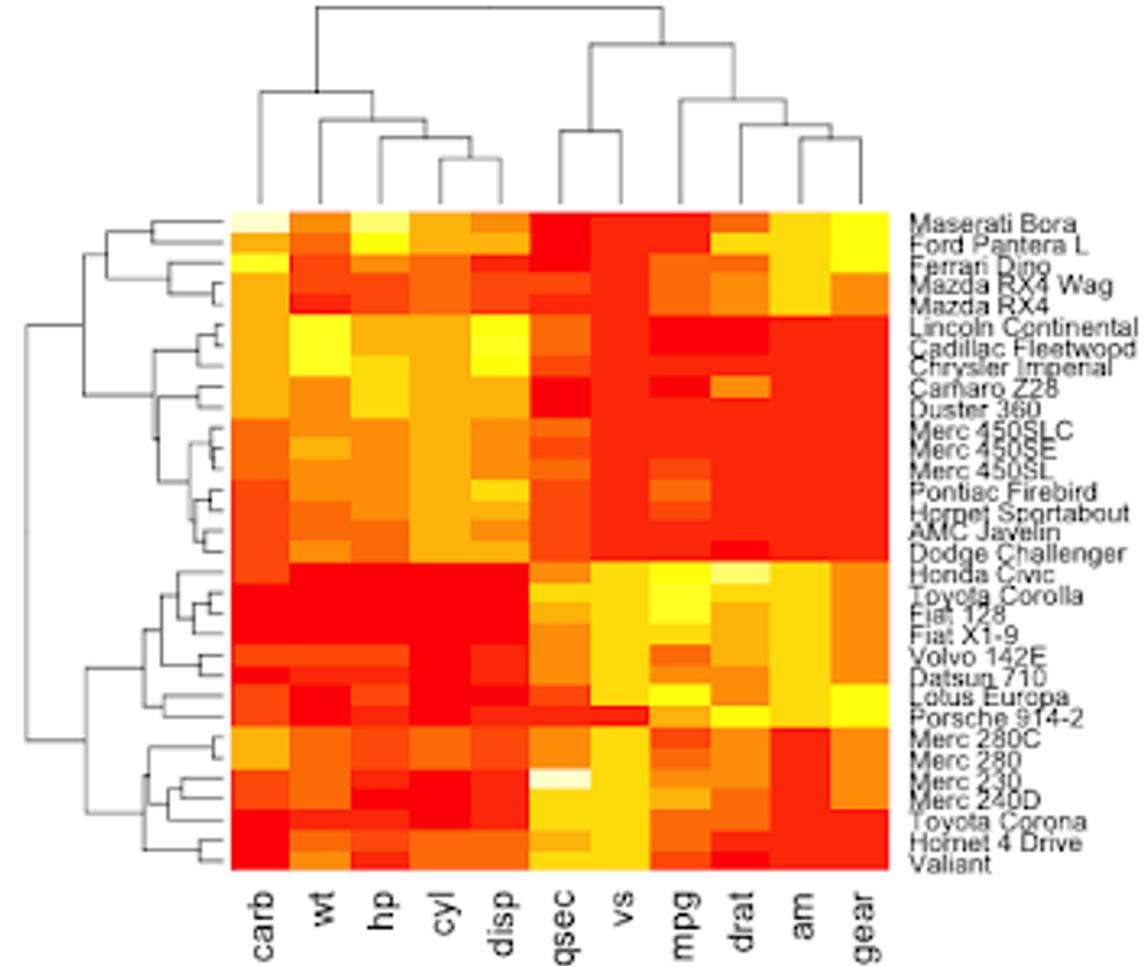
<https://hypertools.readthedocs.io/en/latest/>





Visualising > 3 Dimensions – cont'd

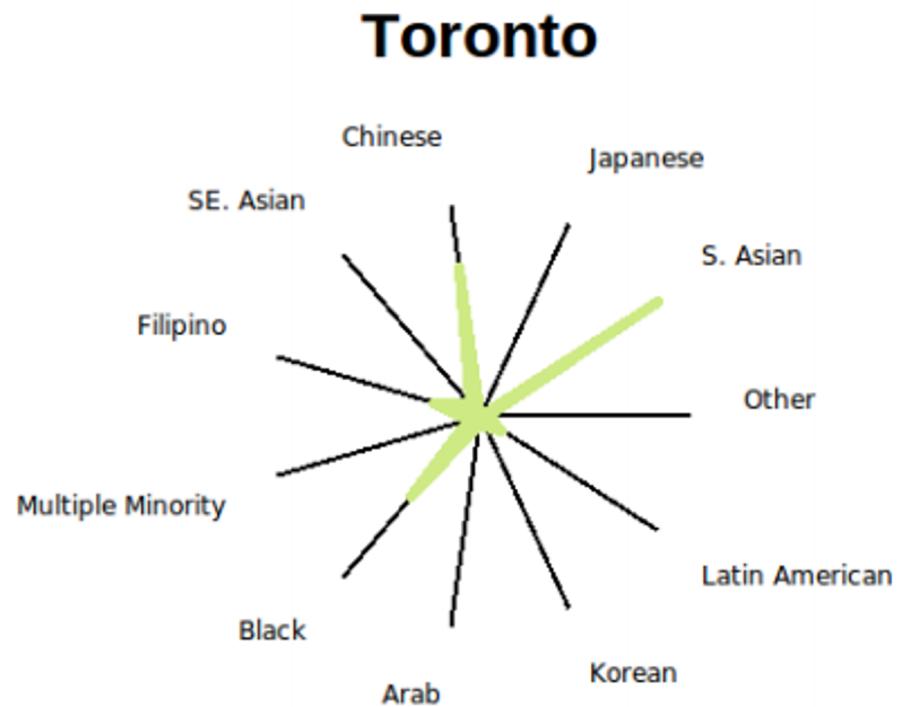
- N-dimensional correlation of categorical dimensions using a heat map
 - vertical axis = cars
 - horizontal = attributes (dimensions)



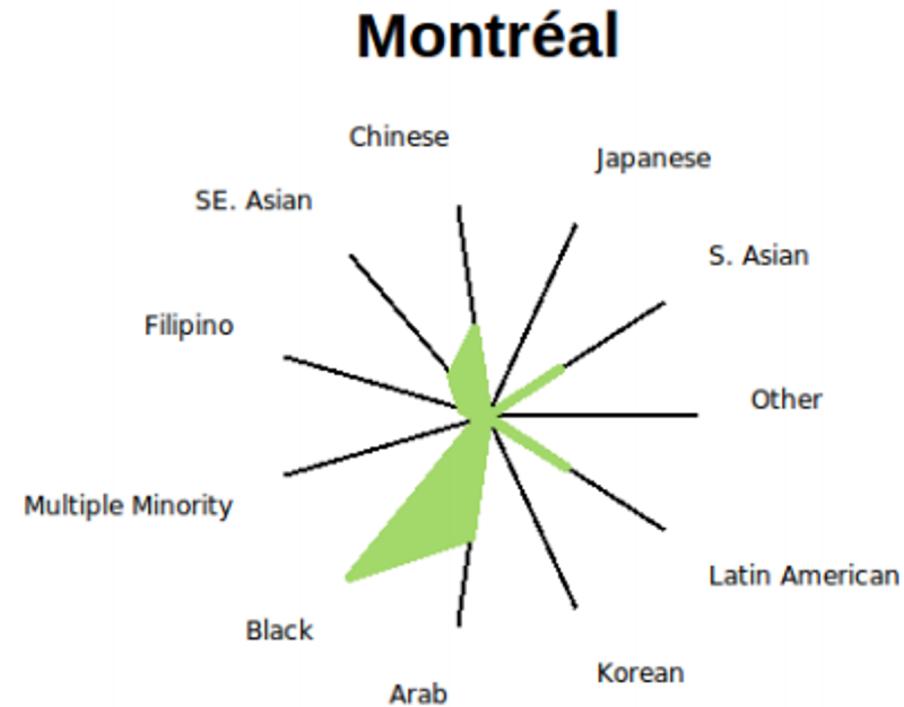


Visualising > 3 Dimensions – cont'd

- radar chart



(a) Largest English speaking city



(b) Largest French speaking city

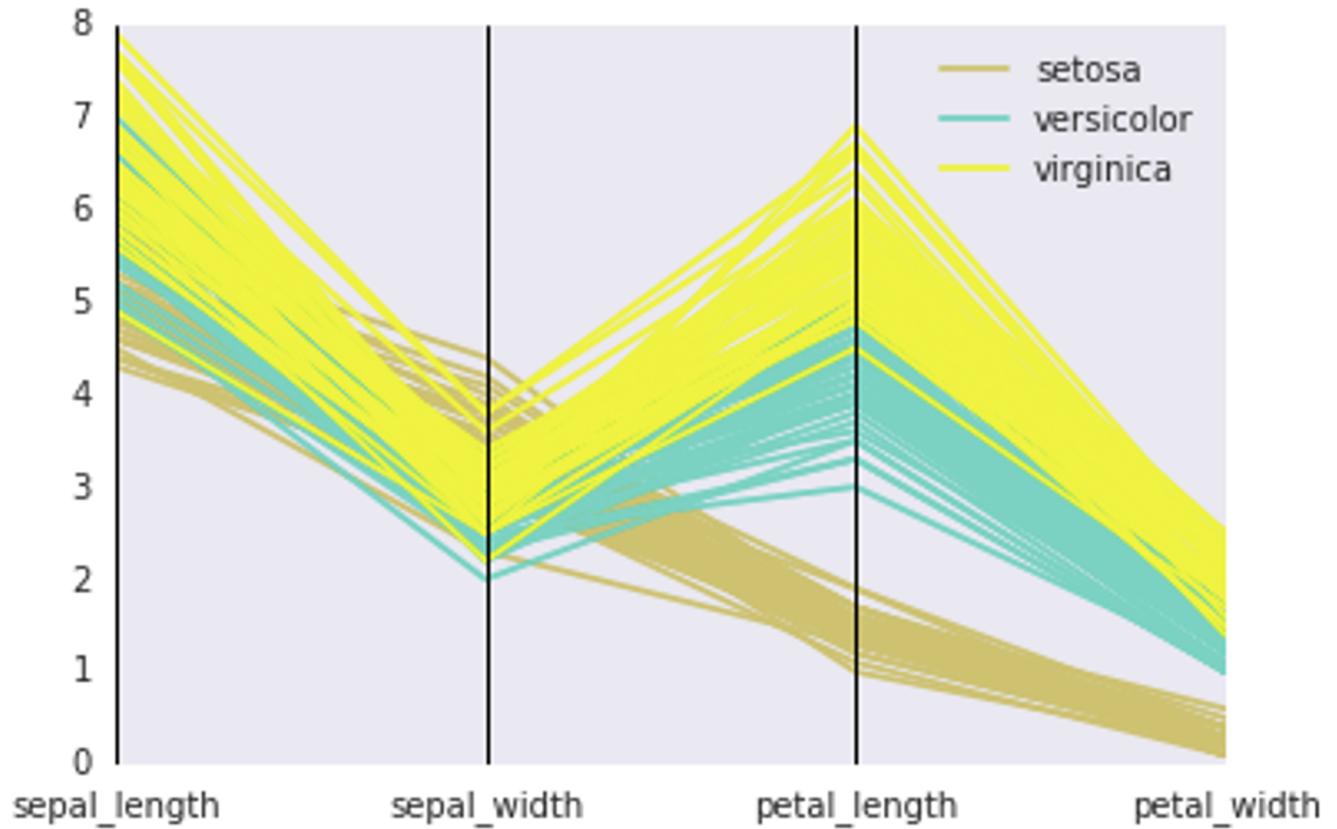


Visualising > 3 Dimensions – cont'd

- parallel coordinates
 - can show multiple variables of same scale
 - especially useful for repeated measures
 - each variable is a time point in a longitudinal study

```
from pandas.tools.plotting import  
parallel_coordinates
```

```
parallel_coordinates(iris, 'species')
```



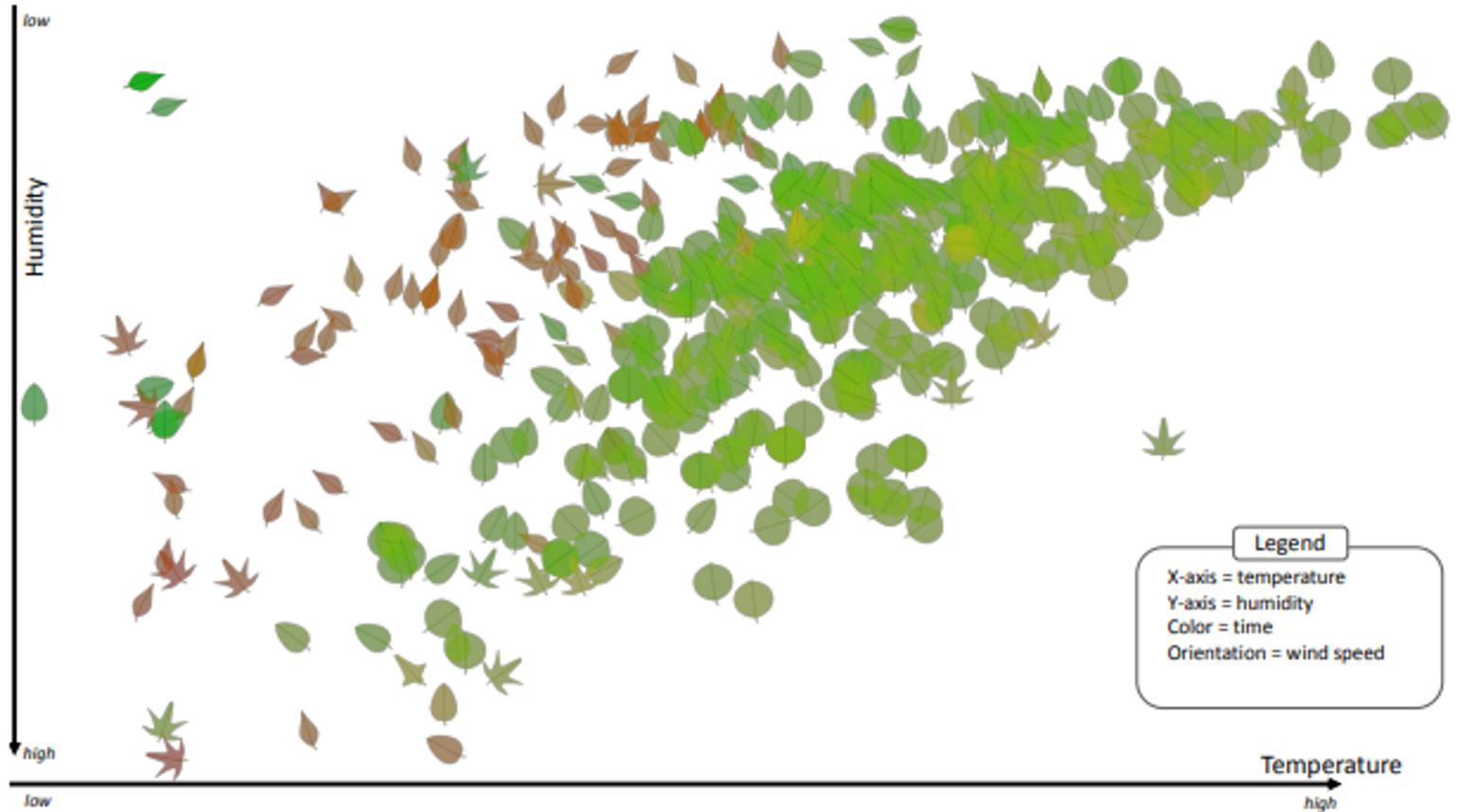


Visualising > 3 Dimensions – cont'd

scatterplot with glyphs

options for
encoding glyphs:

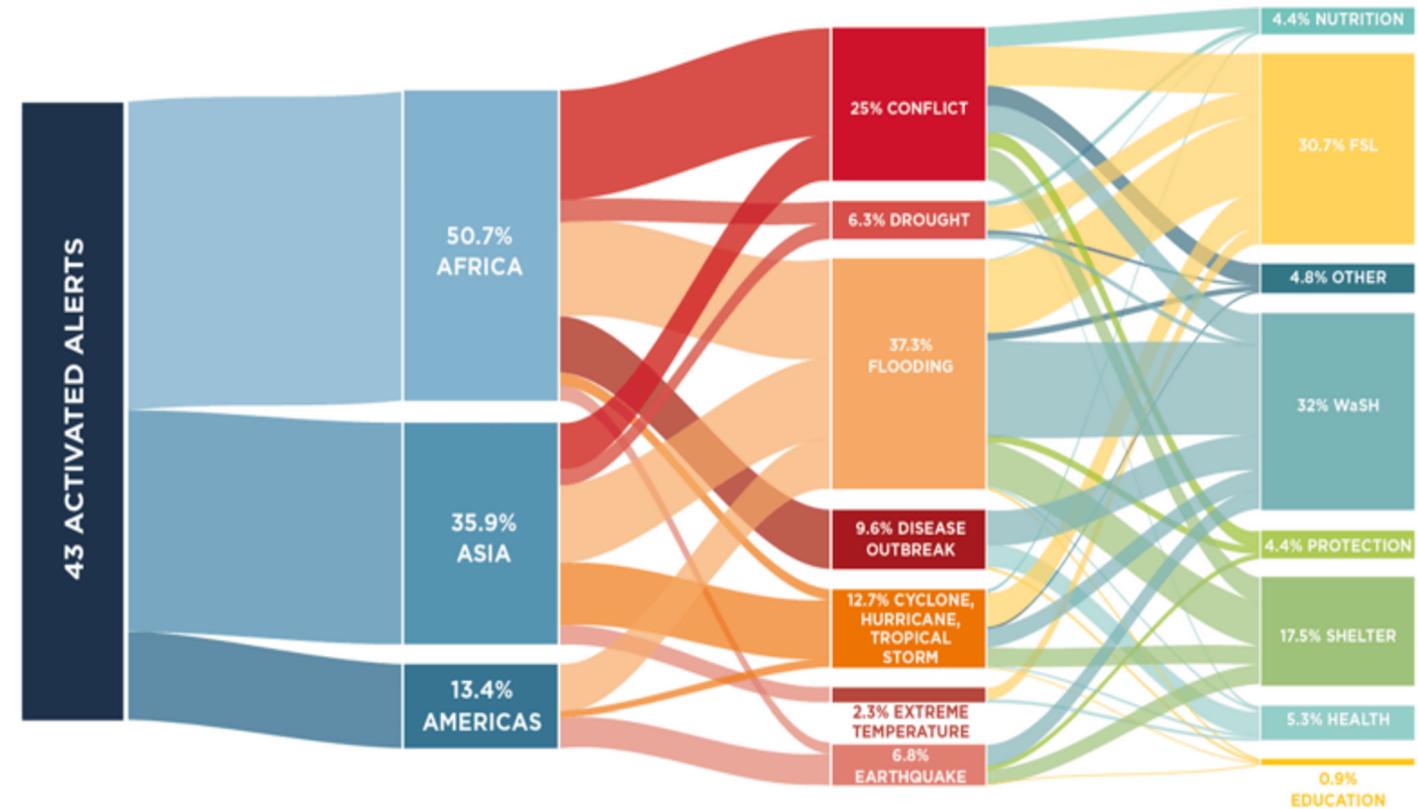
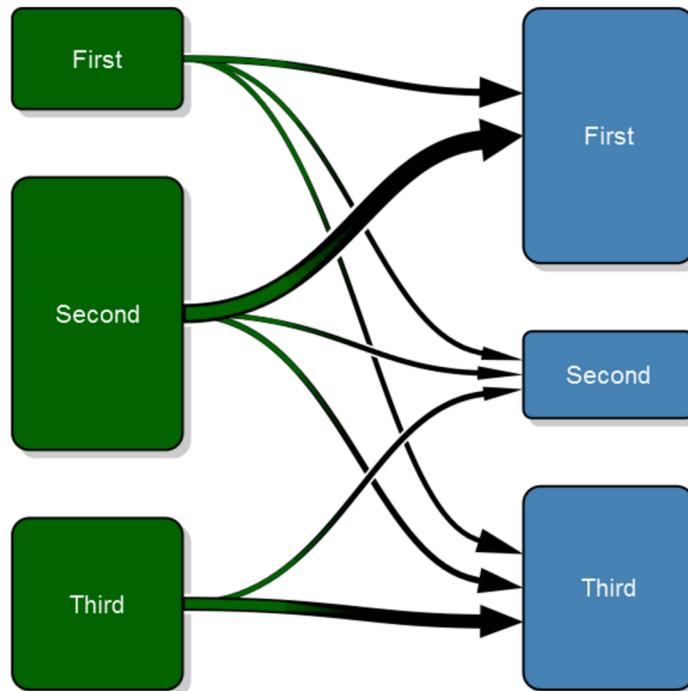
- size
- colour
- intensity
- transparency
- shape
- texture





Sankey Diagram

state changes, class transitions, redistributions





Categorical Data

- Statistics of discrete distributions
 - class frequencies
- Exploring and visualising sample variables
 - bar plots
 - pie / donut charts
- Outlier detection



Marginal Distributions of Discrete Variables

```
# donut chart recipe ==
```

```
# The slices will be ordered and plotted counter-clockwise.
```

```
data = [0.27, 0.67, 0.06]
```

```
labels = 'Low', 'Medium', 'High'
```

```
colors = ['yellowgreen', 'gold', 'lightskyblue']
```

```
plt.pie
```

```
(data, explode=(0,0), labels=labels, colors=colors, autopct='%.1f%%', shadow=False)
```

Income Bracket	
Low	0.27
Medium	0.67
High	0.06

```
#draw a circle at the center of pie to make it look like a donut:
```

```
centre_circle = plt.Circle((0,0), 0.5, fc='white', linewidth=1.25)
```

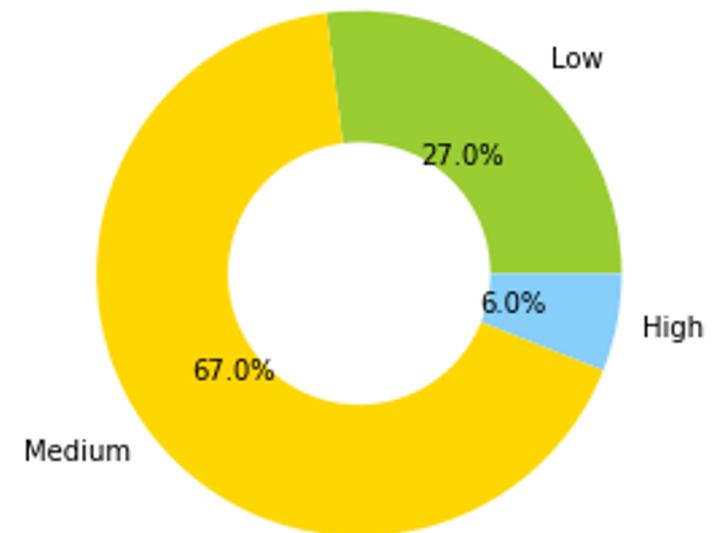
```
fig = plt.gcf()
```

```
fig.gca().add_artist(centre_circle)
```

```
# Set aspect ratio to be equal so that pie is drawn as a circle:
```

```
plt.axis('equal')
```

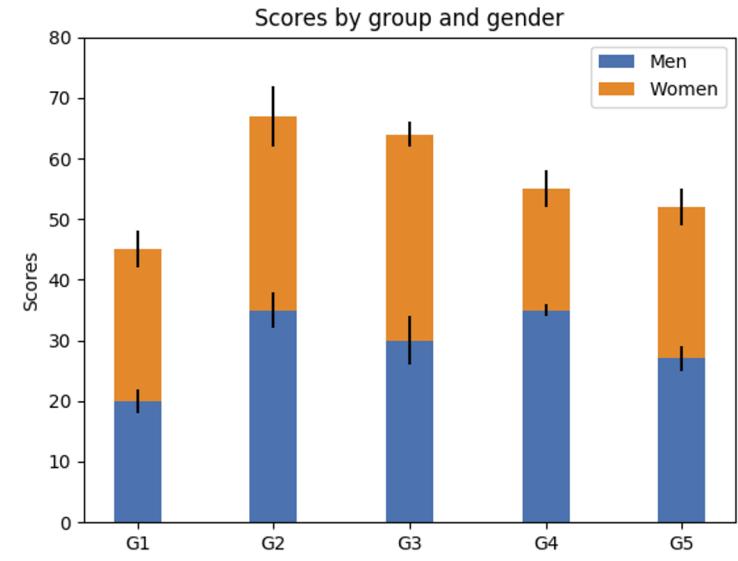
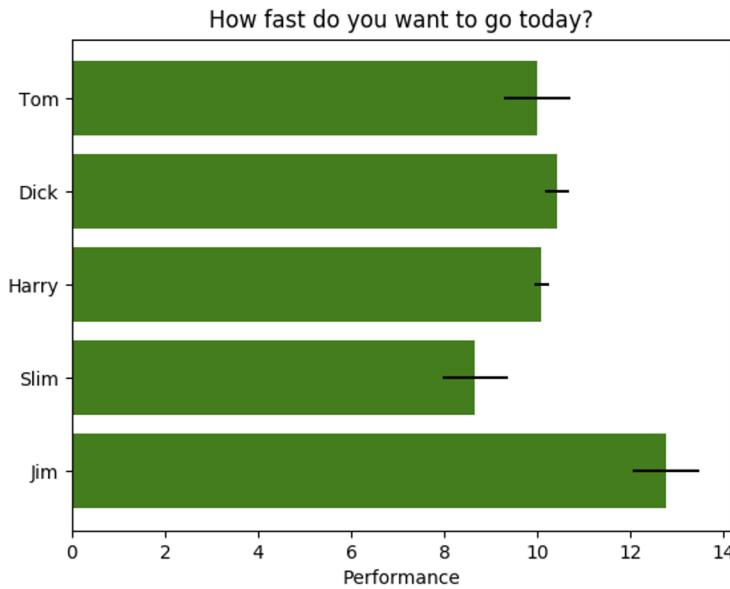
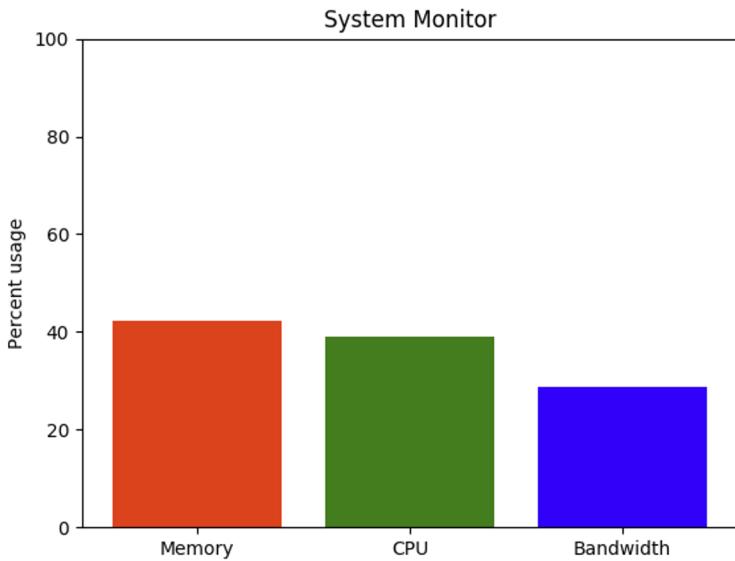
```
plt.show()
```





Bar Plots

- **styles:**
 - horizontal, vertical
 - grouped, stacked





Conditional Distributions of Discrete Variables

- **contingency tables**
 - 2D:
 - var1 = rows, var 2 = columns
 - 3D:
 - var3 = planes (1 table for each value of var3)
 - > 3D:
 - multi-dimensional arrays
 - can be represented in code even if we can't visualise them



Lab 3.1.2: Data Profiling

- Purpose:
 - To explore Python methods for exploring and summarising datasets
- Materials:
 - ‘Lab 3.1.2.ipynb’



Exploring Large Datasets

- randomised sampling

1	bikes.sample(5)																
	instant	dteday	season	yr	mnth	hr	holiday	weekday	workingday	weathersit	temp	atemp	hum	windspeed	casual	registered	cnt
9870	9871	2012-02-21	1	1	2	7	0	2	1	1	0.22	0.2727	0.64	0.0000	6	273	279
16419	16420	2012-11-21	4	1	11	21	0	3	1	1	0.36	0.3788	0.50	0.0000	8	97	105
6558	6559	2011-10-05	4	0	10	20	0	3	1	1	0.52	0.5000	0.77	0.1642	18	228	246
15577	15578	2012-10-16	4	1	10	6	0	2	1	1	0.42	0.4242	0.67	0.1642	4	168	172
16855	16856	2012-12-10	4	1	12	2	0	1	1	2	0.38	0.3939	0.94	0.1045	2	3	5

- repeated sampling
 - collect a number of random subsets from the sample population
 - analyse each subset
 - aggregate the results



The Central Limit Theorem

- Suppose we take n samples from a distribution and compute the mean \bar{x}_k of each sample

then, as $n \rightarrow \infty$

- the set of \bar{x}_k approaches a normal distribution
- the mean of \bar{x}_k approaches the mean of the original distribution

$$\lim_{n \rightarrow \infty} \frac{1}{n} \sum_{k=1}^n \bar{x}_k = \mu$$

- implication:

by repeated resampling of a non-normal distribution, we can apply all (?) the statistical methods that were designed for normal distributions (as long as the samples are independent and identically distributed)



Lab 3.1.3: The Central Limit Theorem

- Purpose:
 - To test the central limit theorem by experiment
- Materials:
 - ‘Lab 3.1.3.ipynb’



Time Series

- What is a time series?
- How are time series represented in Python?



Time Series

def: a sequence of data points representing the state of a system over time

classes of time series:

- temporally deterministic
 - periodic
 - pattern repeats at equal intervals
 - aperiodic
 - state at time t_k is influenced by state at time t_{k-1} but there is no repeating pattern
- stochastic
 - state at time t_k is unrelated to state at time t_{k-1}

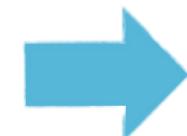


Programming with Time Series

- timebase is usually regular
 - seconds, days, or years (typically)
 - may need to cope with leap years
 - no gaps
 - may need to impute or assign NA for missing time points

example (Pandas):

```
index = pd.DatetimeIndex(['2014-07-04', '2014-08-  
04',  
                           '2015-07-04', '2015-08-04'])  
  
data = pd.Series([0, 1, 2, 3], index=index)  
  
data
```



2014-07-04	0
2014-08-04	1
2015-07-04	2
2015-08-04	3

dtype: int64

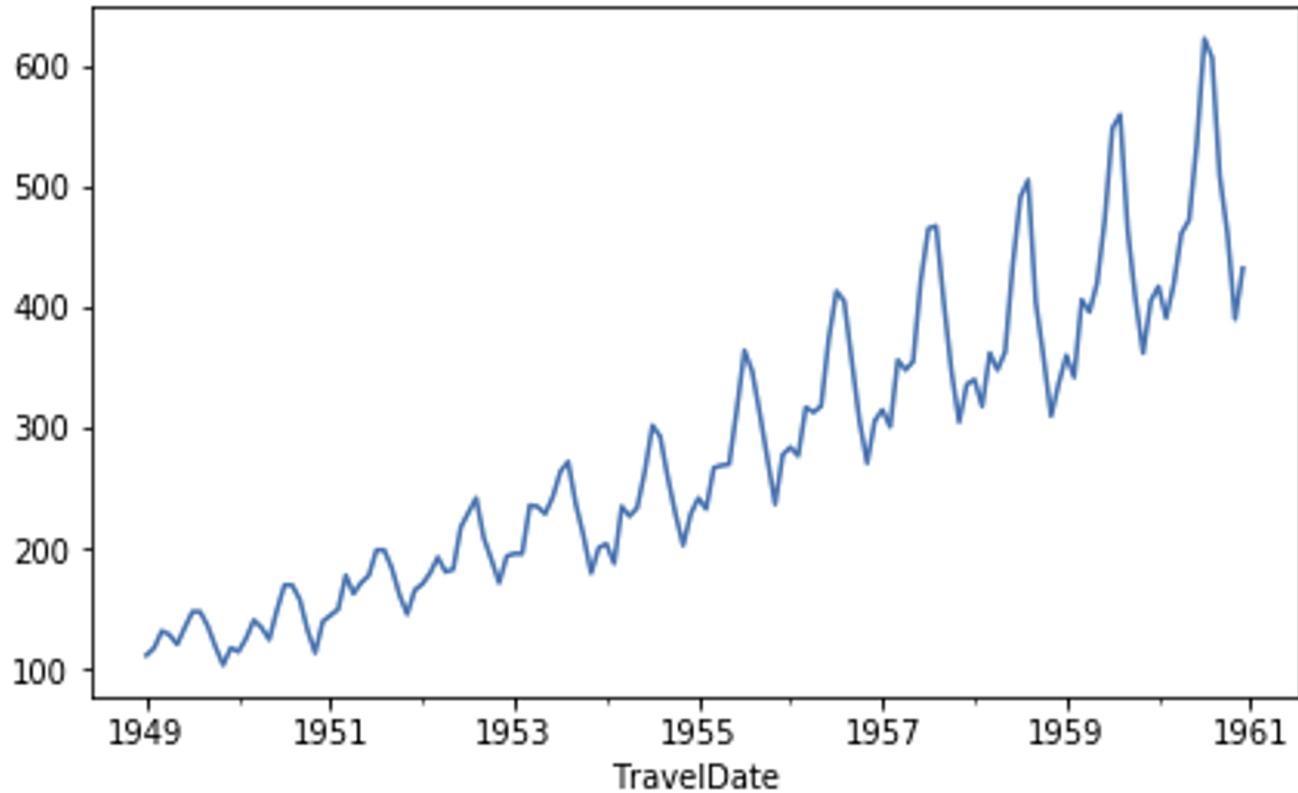


Visualising Time Series

Static time series

- convert DataFrame to Pandas time series
- timebase is an index of the DataFrame
- default axis labelling is aware of timebase

`ts.plot()`





Geospatial Data

- How are geospatial data organised?
- Tools for exploring geospatial data
- Visualising geospatial data in Python



Geospatial Data Formats

- GIS
 - range of open (standard) and proprietary formats
 - raster, vector, grid
 - metadata
- typically
 - a list with nested structure
- arrays / lists
 - coordinates
 - attributes
 - built-in (e.g. elevation)
 - user-defined (e.g. derived statistics)



Geospatial Data Formats – cont'd

Keyhole Markup Language

- primarily used for Google Earth
- .KMZ/.KML

Open Streetmap

- largest crowdsourcing GIS data project of the planet Earth
- .OSM

GeoJSON

- open standard format designed for representing simple geographical features
- .geojson



Tools for Exploring Geospatial Data

- interactive maps/ APIs
- base map may be featureless
 - add ***tiles*** to display features
 - street map
 - topography
 - satellite view
- data organised, rendered in ***layers***
- ability to overlay image data from other sources
 - weather
 - satellite view
 - simulations



ArcGIS





Geospatial Libraries for Python

Folium

- Plot maps

Shapely

- manipulation of geometric objects

Fiona

- read/write vector file formats (e.g. shapefiles or geojson)
- projection conversions

Geopandas

- all of the above



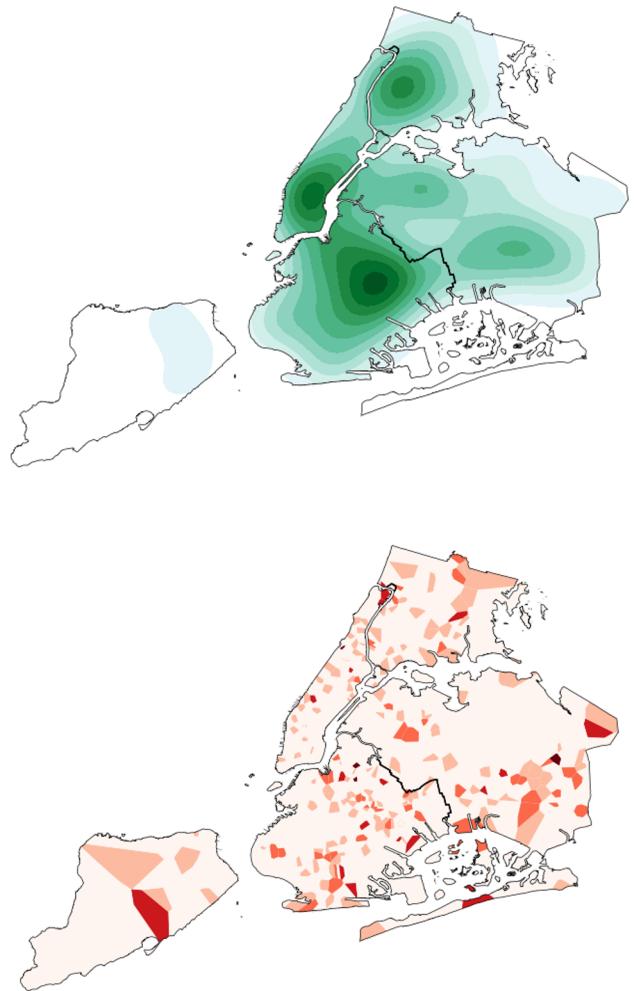
Visualising Geospatial Data

Geoplot

- works with GeoPandas

DataMaps

- interactive SVG maps using D3.js





HOMEWORK

1. Load the ‘titanic’ dataset into a DataFrame
2. Using a Jupyter Notebook, explore/profile the data using the techniques covered in this module
3. Upload your Notebook to your GitHub repo and share the link with the course instructors.