MATH524

Statistical learning and data mining

Szu-Chi Chung

Department of Applied Mathematics, National Sun Yat-sen University

Lectures

- Lecture: Szu-Chi Chung (鍾思齊)
  - Office: 理 SC 2002-4
  - Office hours: Mon. 16:00~18:00 and Wed. 16:00~18:00
- T.A.: 楊竣皓,周柏呈
  - Office: 理 SC 2005-2,理 SC 1015-1
  - TA hour: Thur. 15:00~17:00, 14:00~16:00
- Class hours: Mon. (9:10-12:00)
  - Classroom: 理 SC 4009-1
- Course website: https://phonchi.github.io/nsysu-math524/
- Facebook

Textbook and requirement

- Textbook: *An Introduction to Statistical Learning with Applications in R*
  - Authors: James, Witten, Hastie, and Tibshirani
  - https://www.statlearning.com/
- For a more advanced treatment of these topics: Reference book: *The Elements of Statistical Learning*
  - Authors: Hastie, Tibshirani and Friedman
  - https://web.stanford.edu/~hastie/ElemStatLearn/
- For the programming patterns: Reference book: *Practical Statistics for Data Scientists 50+ Essential Concepts Using R and Python*
  - Authors: Peter Bruce, Andrew Bruce and Peter Gedeck
  - https://github.com/gedeck/practical-statistics-for-data-scientists

Textbook and requirement

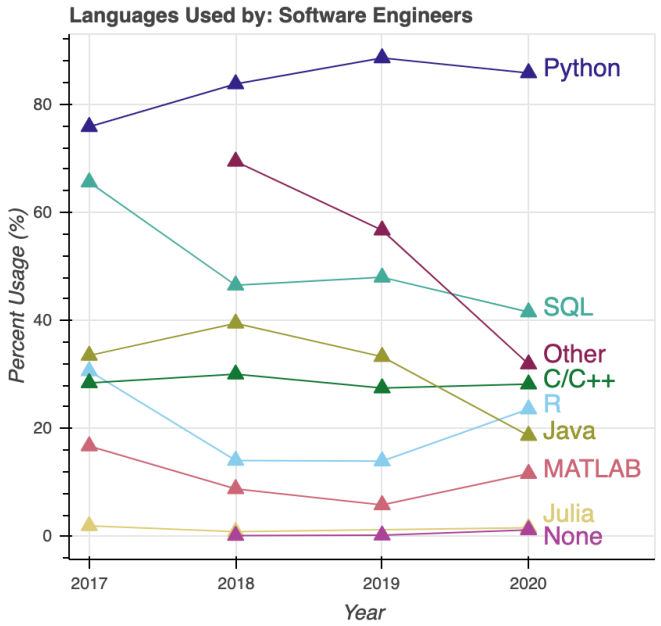
- Slides and videos for Statistical Learning MOOC by Hastie and Tibshirani
  - https://www.statlearning.com/online-course
- For the exercises of each chapter, there is a GitHub repository of solutions provided by students you can use to check your work
  - https://github.com/hardikkamboj/An-Introduction-to-Statistical-Learning
  - http://blog.princehonest.com/stat-learning/
- Programming language: Python
  - You are asked to use python to implement the assignment, midterm and final
  - Since it is the most popular language in the field of data science
  - It is free and easy to learn

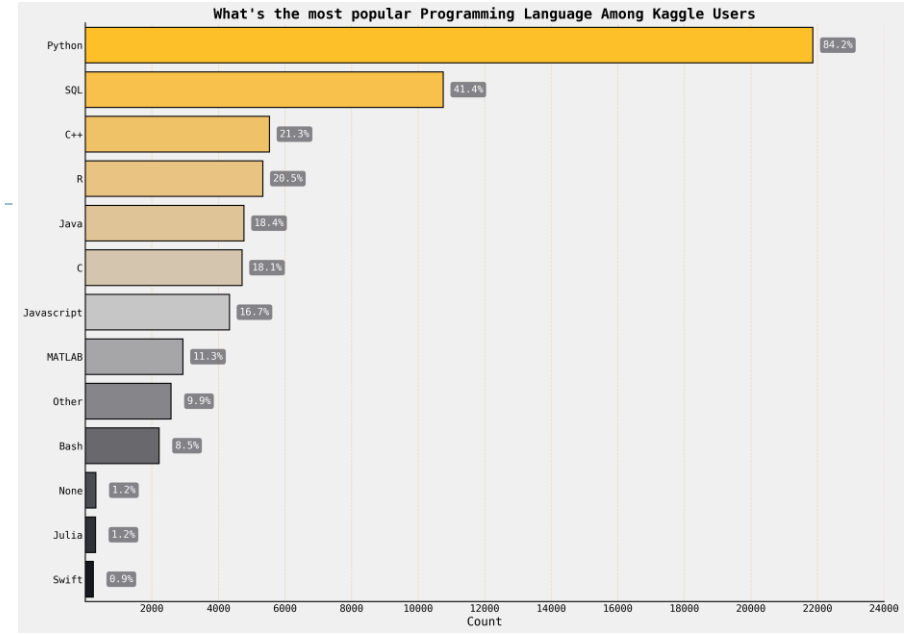
Grading policy

- Grading
  - Weekly Homework 35% (Both conceptual and coding part)
  - Midterm exam 35% (Mostly will be coding parts)
  - Final project 30% (You are free to choose any dataset for analysis)
- Midterm
  - Will be held on 10/31
- Term project:
  - Organize a team of 2 persons
  - The presentation will be held on 12/19 and 12/26
  - Must hand in a report
  - The score will be the summation of students (10%), TA(10%) and lecturer (10%)

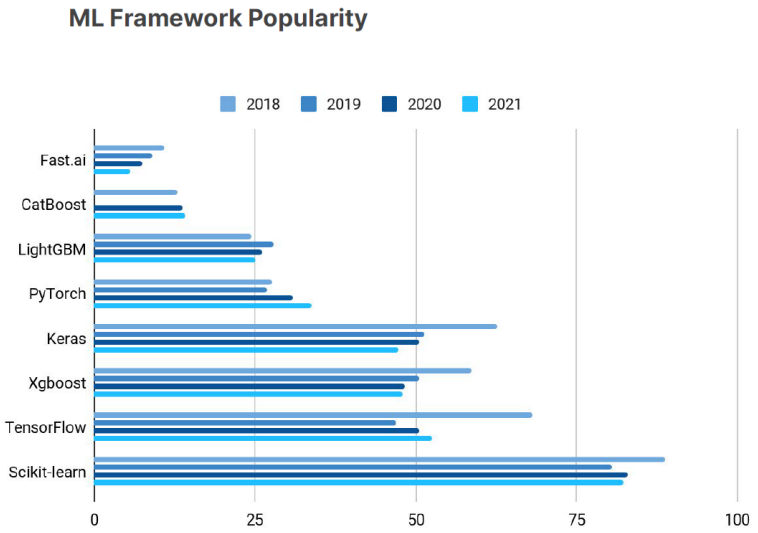
Dataset and competition

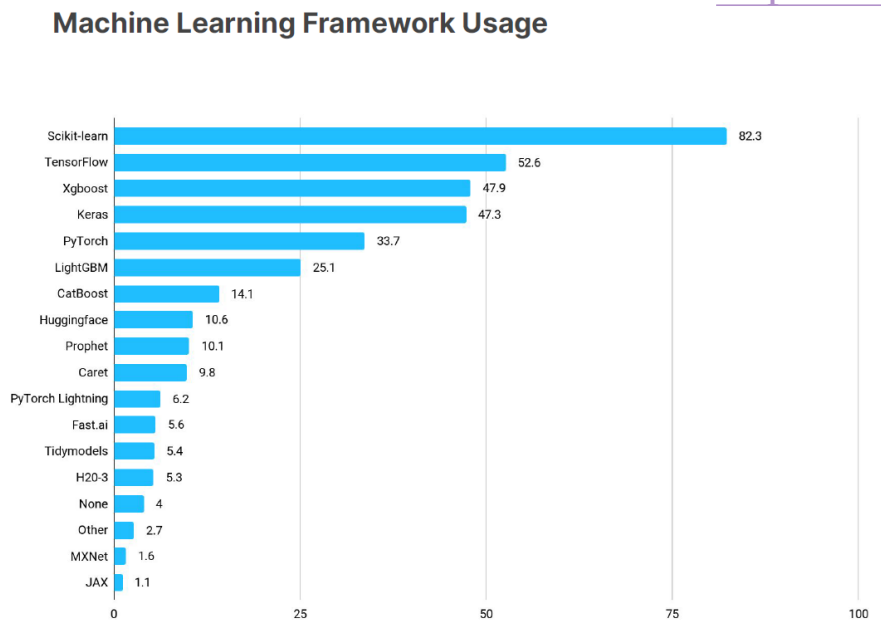
- Dataset
  - 政府資料開放平台
    - https://data.gov.tw/
  - Kaggle
    - https://www.kaggle.com/datasets
  - Google dataset search
    - https://datasetsearch.research.google.com/
- Competition
  - Kaggle
    - https://www.kaggle.com/competitions
  - Tbrain
    - https://tbrain.trendmicro.com.tw/





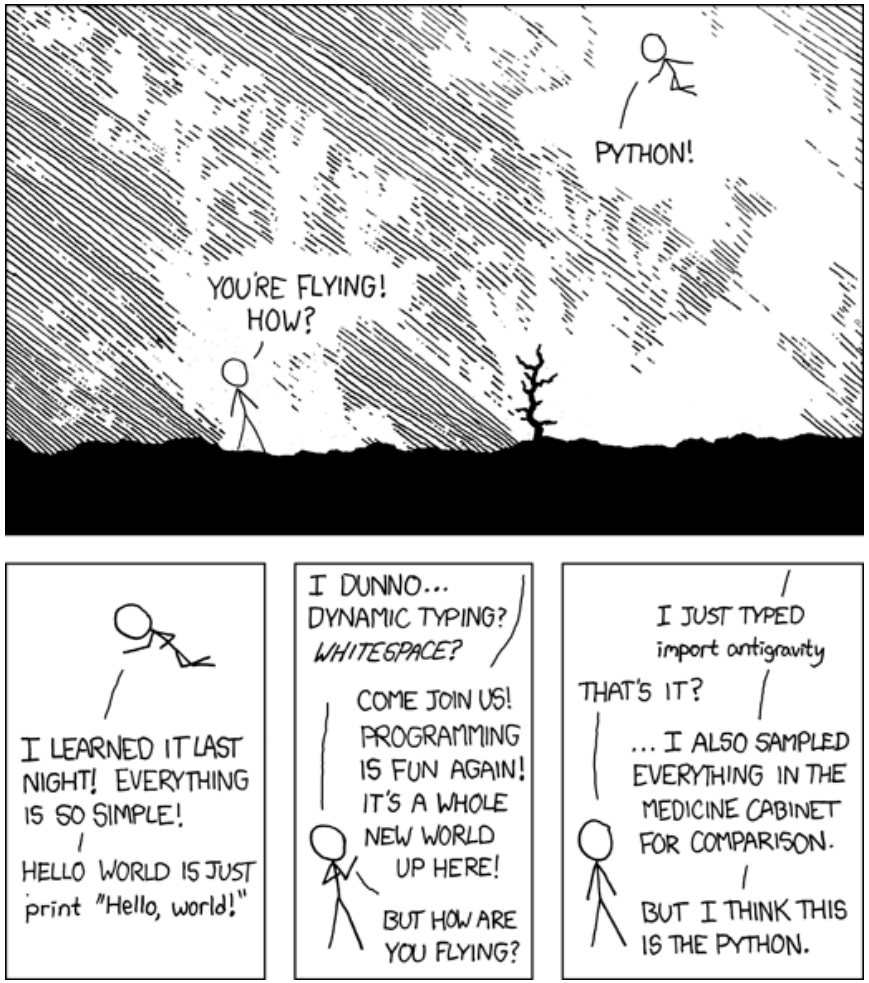
https://www.kaggle.com/kaggle-survey-2021





Learning Python

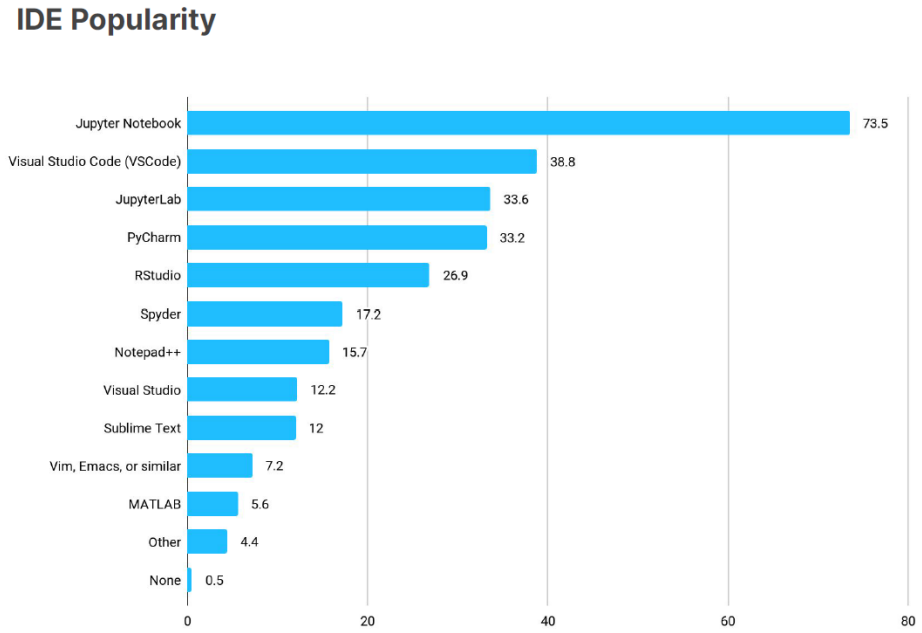
- Python
  - **Learn X in Y minutes**
  - Python for Everybody
  - Kaggle Python tutorial
- Python scientific computing
  - https://scipy-lectures.org/
  - https://wesmckinney.com/book/
  - https://github.com/jakevdp/PythonDataScienceHandbook
- Python for R and Matlab users
  - http://mathesaurus.sourceforge.net/r-numpy.html
  - https://numpy.org/doc/stable/user/numpy-for-matlab-users.html

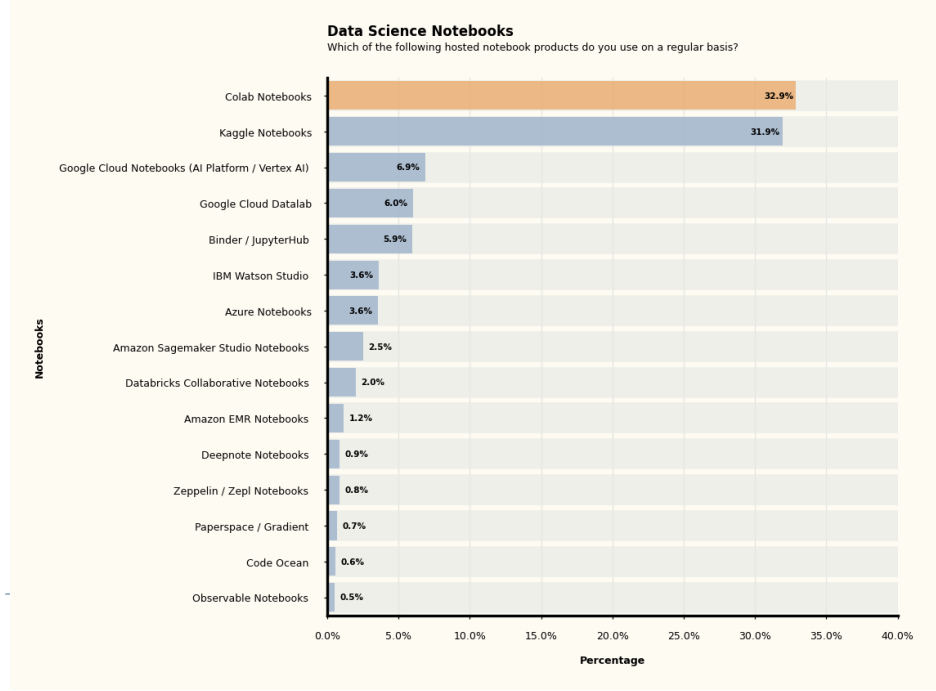


https://xkcd.com/353/

Environment

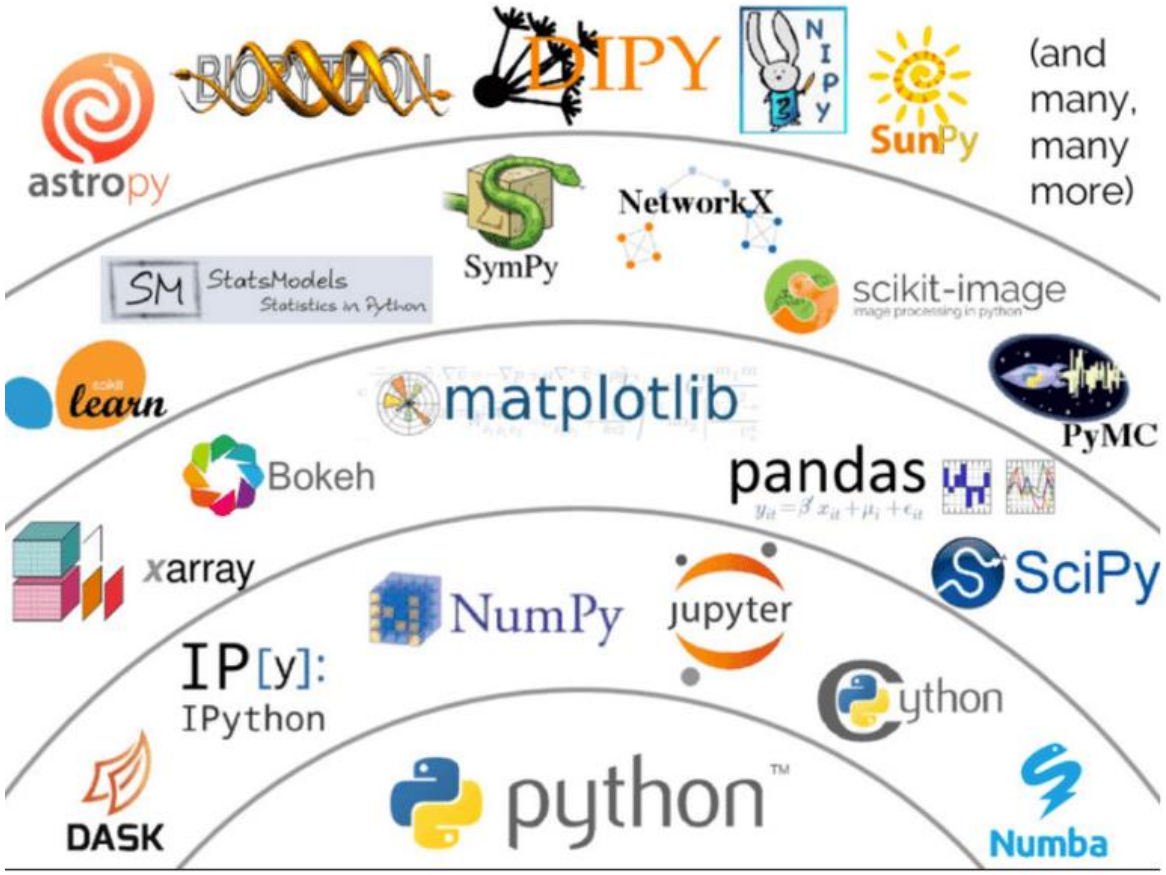
- Jupyter notebook
  - Colab - https://colab.research.google.com/
  - Kaggle - https://www.kaggle.com/docs/notebooks
  - Jupyterlab - https://www.anaconda.com/products/individual
- Markdown
  - Learning
    - https://commonmark.org/
    - https://learnxinyminutes.com/docs/markdown/
  - Usuage
    - https://hackmd.io/
    - https://github.com/
    - Jupyter notebook





The Pydata Stack

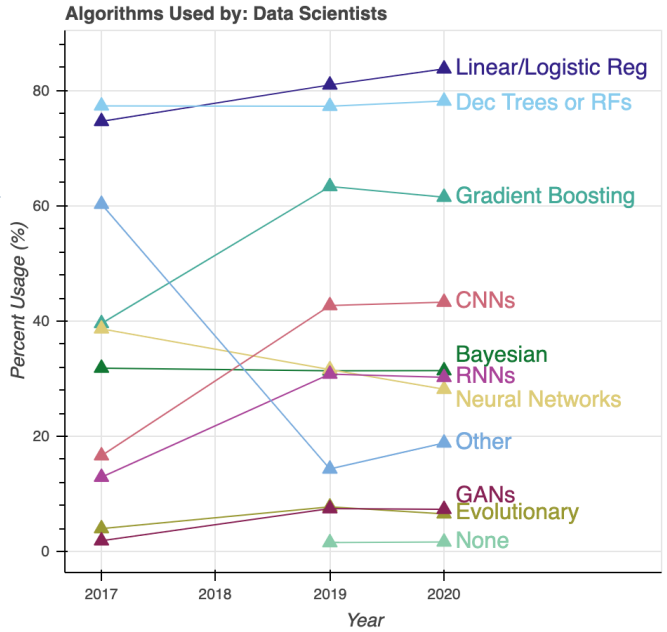
- In 2017, a keynote at PyCon presented a schematic of the scientific Python stack
  - Project Jupyter and IPython for interactive computing and IDEs
  - NumPy for numerical array computing
    - Numba for just-in-time compilation
    - Cython for ahead-of-time compilation
  - Pandas for dataframe (Labeled array)
  - Scikit-learn and Statsmodel for modeling
  - Seaborn for visualization
- Install Anaconda
  - https://www.anaconda.com/products/individual
- Checkout https://rapids.ai/ for gpu-accelerated computing

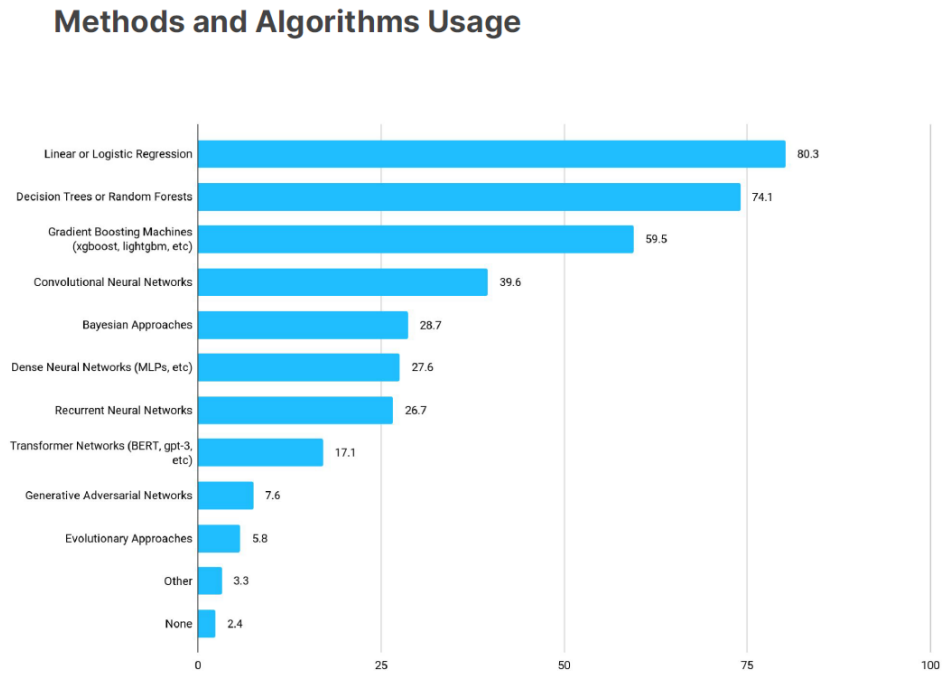


Source: https://coiled.io/pydata-dask/

This course – focus on modeling and interpretation

1. Introduction
2. Statistical learning
3. Regression
4. Classification
5. Resampling methods
6. Linear model selection and regularization
7. Moving Beyond Linearity
8. Tree-Based Methods
9. Support Vector Machines
10. Unsupervised Learning





Related to other course

- More theoretical foundation
  - Mathematical statistics, statistical inference or principles of artificial intelligence
- More accurate prediction
  - Machine learning or (advance) deep learning
- Data wrangling and case study
  - Data science capstone project
- Apply to a specific domain and advance modeling
  - Time series analysis or survival analysis
- Implement from scratch
  - Python and machine learning algorithms or https://dafriedman97.github.io/mlbook/content/introduction.html
- High-performance (Parallel) computing, Database management and systems…

Introduction

Szu-Chi Chung

Department of Applied Mathematics, National Sun Yat-sen University

Statistical Learning In The News

- *"Learning from its mistakes", Watson's software is wired for more that handling natural language processing*. David Ferrucci (PI of Watson DeepQA technology for IBM Research), 2011

- *"I thought AlphaGo was based on probability calculation and that it was merely a machine. But when I saw this move, I changed my mind. Surely, AlphaGo is creative"*. Lee Sedol (Winner of 18 World Go Titiles). 2016

https://deepmind.com/research/case-studies/alphago-the-story-so-far

Statistical Learning In The News

- *"The way AlphaStar was trained, with agents competing against each other in a league, has resulted in gameplay that's unimaginably unusual; it really makes you question how much of StarCraft's diverse possibilities pro players have really explored."* DIEGO SCHWIMER (Player of StarCraft). 2019

- *"Neural networks overtake humans in Gran Turismo racing game"*, Nature, 2022

https://www.techbang.com/posts/94153-nature-gran-turismo-racing?from=home_news

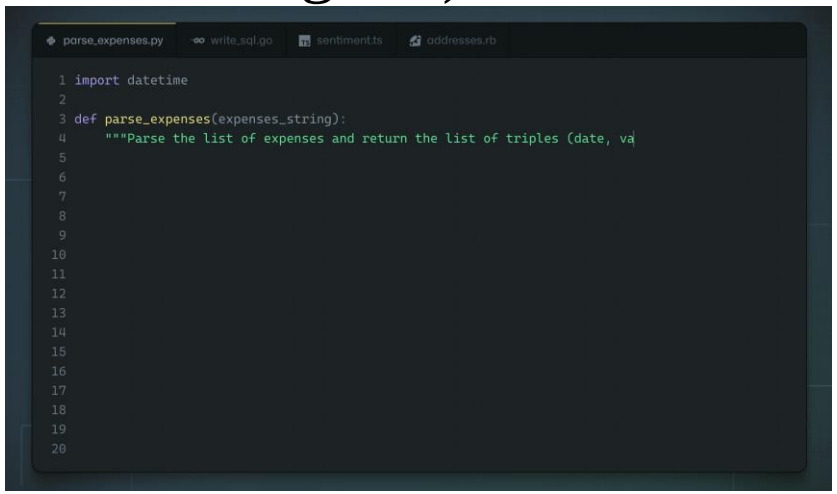
Statistical Learning In The News

"*Our hope is that DALL·E 2 will empower people to express themselves creatively. DALL·E 2 also helps us understand how advanced AI systems see and understand our world, which is critical to our mission of creating AI that benefits humanity*." OpenAI, 2022

https://openai.com/dall-e-2/
https://github.com/borisdayma/dalle-mini
https://clkaozh.substack.com/p/why-stable-diffusion-is-a-big-deal

Statistical Learning In The News

- *"In the first day, GitHub Copilot already taught me about a nuance in Javascript object comparison and is as comfortable with our database schema as I am. This is the single most mind-blowing application of ML I've ever seen."* Mike Krieger (Co-founder, Instagram). 2021

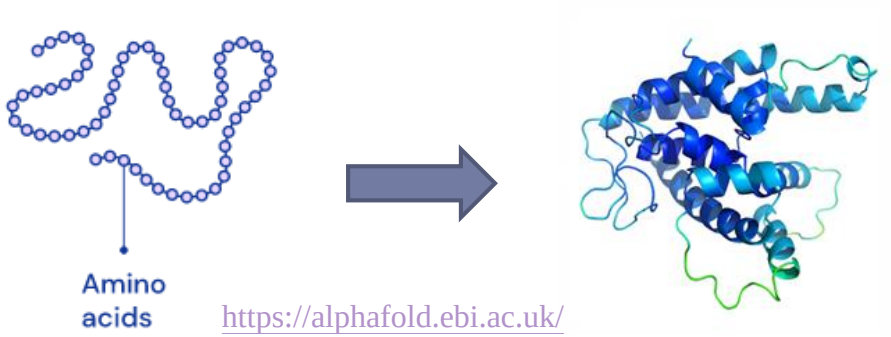


https://copilot.github.com/

- *"OpenAI's Statement Curriculum Learning Method Cracks High School Olympiad Level Mathematics Problems"* news (Synced). 2022

Statistical Learning In The News

- *"We have been stuck on this one problem – how do proteins fold up – for nearly 50 years. To see DeepMind produce a solution for this, having worked personally on this problem for so long and after so many stops and starts, wondering if we'd ever get there, is a very special moment."* John Moult (Co-founder and Chair of CASP, University Of Maryland). 2020



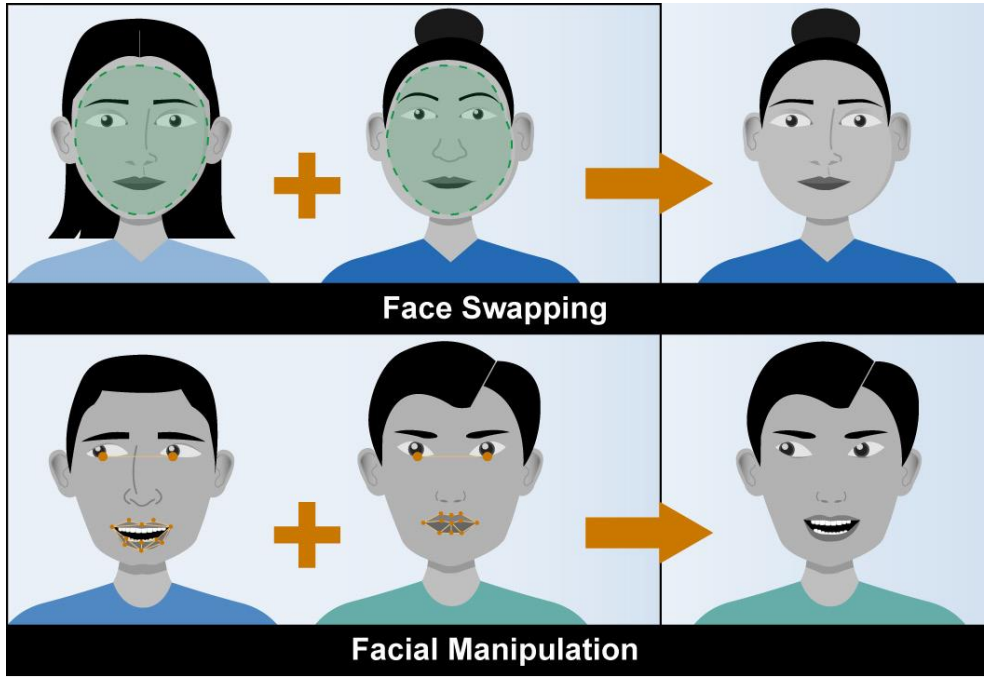
https://alphafold.ebi.ac.uk/

https://deepmind.com/blog/article/putting-the-power-of-alphafold-into-the-worlds-hands

- It's learning allows the computer to become smarter as it tries to answer questions - and to learn as it gets them right or wrong

Statistical Learning In The News

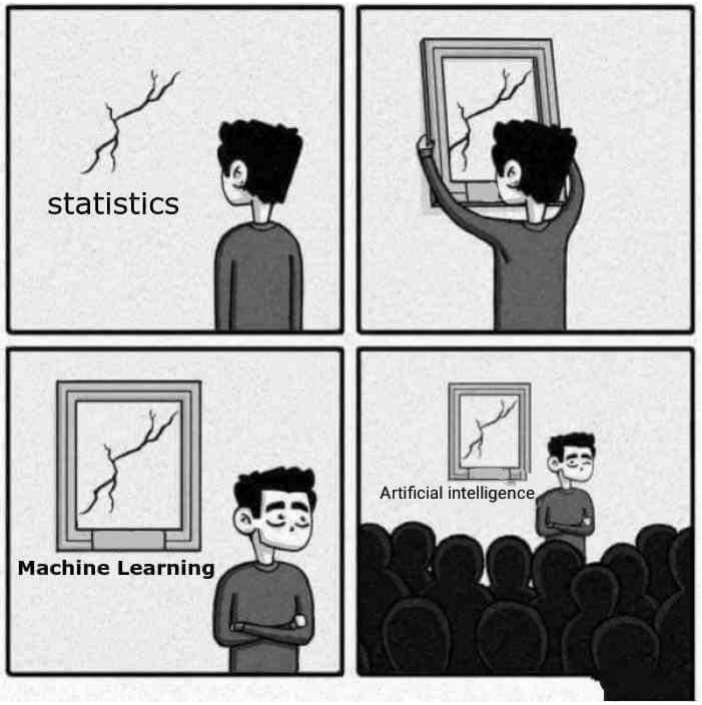
- *"Deepfakes and the New AI-Generated Fake Media Creation-Detection Arms Race"* Scientific America, 2020



Source: GAO. | GAO-20-379SP

https://pansci.asia/archives/342421

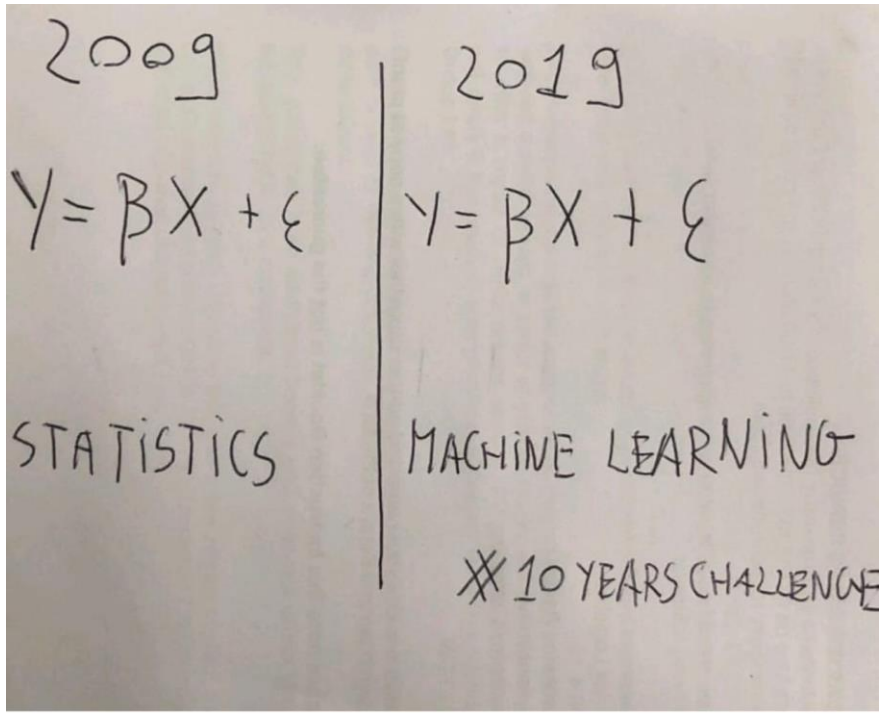
What is the difference between statistics, machine learning, data mining, statistical learning, AI….?



https://laptrinhx.com/what-actually-is-artificial-intelligence-a-beginners-guide-249021669/

Let's see who you really are machine learning

https://medium.com/analytics-vidhya/statistics-in-machine-learning-a1eb88b88da2



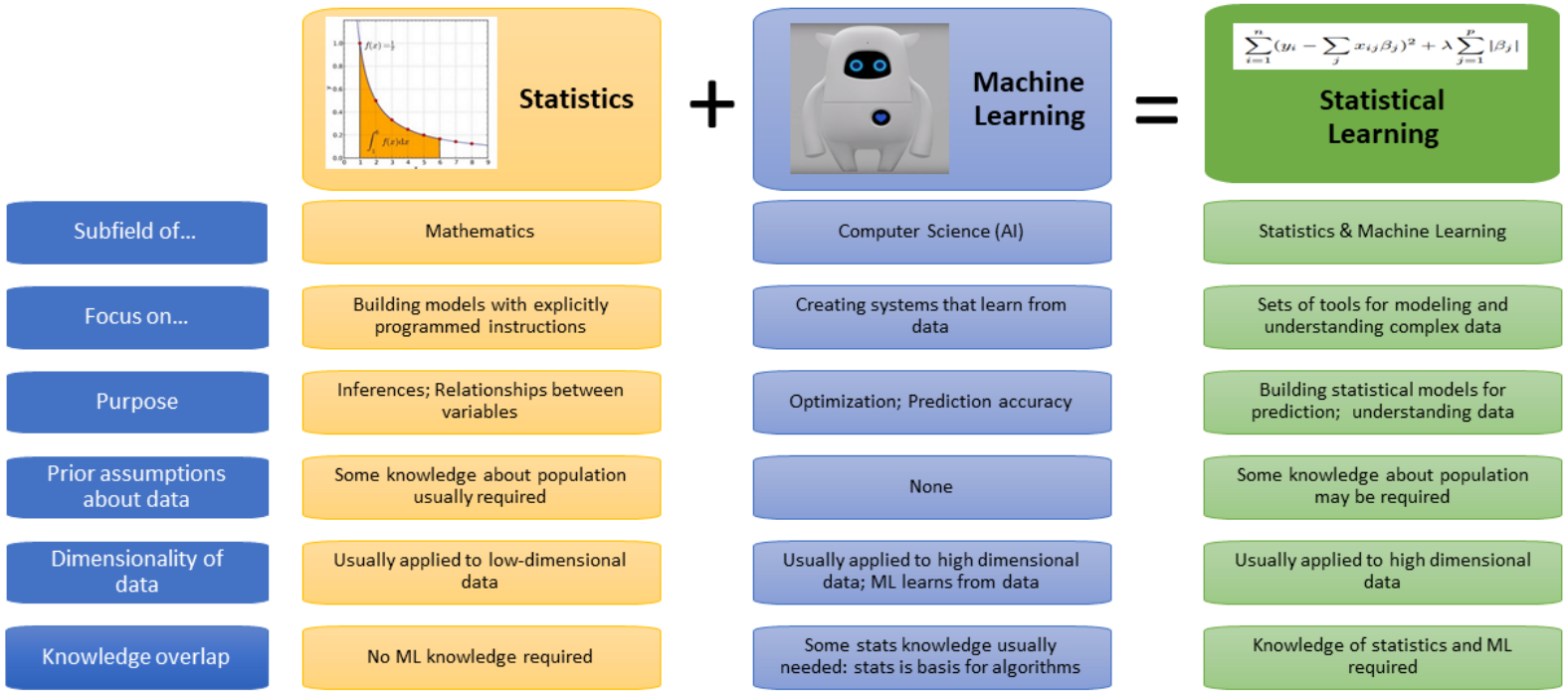
https://towardsdatascience.com/the-actual-difference-between-statistics-and-machine-learning-64b49f07ea3

Statistical Learning versus Machine Learning – textbook author's view

- Machine learning arose as a subfield of Artificial Intelligence.
- Statistical learning arose as a subfield of Statistics.
- There is much overlap - both fields focus on supervised and unsupervised problems:
  - Machine learning has a greater emphasis on large-scale applications and prediction accuracy
  - Statistical learning emphasizes models and their interpretability, and precision and uncertainty
  - But the distinction has become more and more blurred, and there is a great deal of "cross-fertilization"
- Machine learning put more focus on the use of computational power to solve a problem

Statistical Learning versus Machine Learning – a personal view

- *Statistical learning*, the use of machine learning and statistics techniques with most of the goal is statistical inference: drawing conclusions on the data at hand



https://www.datasciencecentral.com/profiles/blogs/machine-learning-vs-statistics-in-one-picture

Data Scientist: The Sexiest Job of the 21st Century

- The shortage of data scientists is becoming a serious constraint
- Data analysis is a process of
  - **Inspecting data**
  - Cleaning data
  - Transforming data
  - **Modeling data**
- With the goal of
  - Discovering useful info
  - Suggesting conclusion
  - Supporting decision making

104玩數據公布【2021十大新興熱門職務】

職務	2021年1-8月 平均每月工作機會數(個)	5年同期 工作機會數增幅	近5年擔任相關工作 平均月薪(元)
數位轉型專家	503	963%	70,434
客戶成功經理	156	873%	56,938
資料科學家	325	284%	78,426
DevOps工程師	923	246%	69,012
線上互動教師	492	238%	41,130
資安工程師	1293	158%	57,867
全端工程師	568	133%	59,930
生理訊號工程師	166	115%	65,414
沉浸式體驗工程師	148	111%	59,707
商務拓展經理	569	92%	78,550

https://blog.104.com.tw/104data-digitize-rising-position/?utm_source=digitize-rising-%E8%81%B7%E5%A0%B4%E5%8A%9B&utm_campaign=digitize-rising-%E8%81%B7%E5%A0%B4%E5%8A%9B

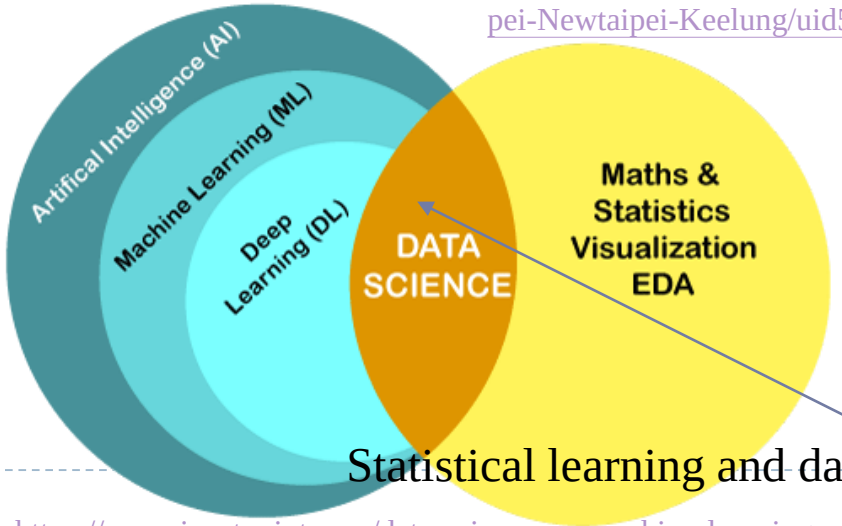
太報 Tai Sounds

十大新興職務

	2022年1~7月 平均工作機會數	五年增幅	月薪平均數	月薪中位數
數位轉型專家	1044	828%	70,942	62,000
客戶成功經理	241	614%	57,825	50,000
線上互動教師	671	390%	43,113	42,000
資料科學家	423	214%	80,417	66,150
資安工程師	1883	177%	57,940	50,000
生理訊號研發工程師	208	151%	65,014	60,000
沉浸式體驗工程師	235	147%	61,301	51,000
商務拓展	777	135%	77,852	65,000
DevOps工程師	1029	128%	69,480	61,500
全端工程師	797	128%	58,004	50,910

備註：增減幅為與2018年同期每月平均工作機會數進行比較；薪資為近五年工作經歷的月薪平均&中位數

https://www.taisounds.com/Taiwan/Local/Taipei-Newtaipei-Keelung/uid5111635112



Statistical learning and data mining

https://www.javatpoint.com/data-science-vs-machine-learning

The Supervised Learning Problem (topics 3-9)

- Starting point:
  - Outcome measurement Y (also called the dependent variable, response, target)
  - Vector of p predictor measurements X (also called inputs, regressors, covariates, features, independent variables)
  - In the regression problem, Y is quantitative (e.g., price, blood pressure)
  - In the classification problem, Y takes values in a finite, unordered set (survived/died, digit 0-9, cancer class of tissue sample)
  - We have training data $(x_1, y_1), \ldots, (x_n, y_n)$. These are observations (examples, instances) of these measurements

Objectives and Philosophy

- On the basis of the training data, we would like to:
  - Accurately predict unseen test cases
  - **Understand which inputs affect the outcome and how**
  - **Assess the quality of our predictions and inferences**
- It is important to understand the *ideas* behind the various techniques in order to know how and when to use them
  - One has to understand the simpler methods first in order to grasp the more sophisticated ones
  - It is important to accurately assess the performance of a method, to know how well or how badly it is working [simpler methods often perform as well as fancier ones!]
  - This is an exciting research area, having important applications in science, industry and finance
  - Statistical learning is a fundamental ingredient in the training of a modern data scientist

The Unsupervised Learning Problem (topic 10)

- No outcome variable, just a set of predictors (features) measured on a set of samples
- Objective is more fuzzier - find groups of samples that behave similarly, find features that behave similarly, and find linear combinations of features with the most variation
- Difficult to know how well you are doing
- Different from supervised learning, but can be useful as a pre-processing step for supervised learning

The Netflix prize

- The competition started in October 2006. Training data is ratings for 18,000 movies by 400,000 Netflix customers, each rating between 1 and 5
  - Training data is very sparse - about 98% missing
- The objective is to predict the rating for a set of 1 million customer-movie pairs that are missing in the training data
  - Netflix's original algorithm achieved a root MSE of 0.953. The first team to achieve a 10% improvement wins one million dollars
  - Is this a supervised or unsupervised problem?

Recommendation System

- A recommendation system can use supervised or unsupervised learning; it is neither of them because it's a concept at a different level
- A recommendation system can:
  - Use **supervised learning** to classify items into elements to be recommended/not recommended
  - "Supervised" because it works with labeled data: user profiles: past items, ratings,...

  Or
  - Use **unsupervised learning** to make sense of the user-item feature space
  - For instance, performing clustering analysis or PCA to understand the dataset

Top 10 Ideas in Statistics That Have Powered the AI Revolution

1. Hirotugu Akaike (1973). Information Theory and an Extension of the Maximum Likelihood Principle. *Proceedings of the Second International Symposium on Information Theory.*
2. John Tukey (1977). Exploratory Data Analysis.
3. Grace Wahba (1978). Improper Priors, Spline Smoothing and the Problem of Guarding Against Model Errors in Regression. *Journal of the Royal Statistical Society.*
4. Bradley Efron (1979). Bootstrap Methods: Another Look at the Jackknife. *Annals of Statistics.*
5. Alan Gelfand and Adrian Smith (1990). Sampling-based Approaches to Calculating Marginal Densities. *Journal of the American Statistical Association.*
6. Guido Imbens and Joshua Angrist (1994). Identification and Estimation of Local Average Treatment Effects. *Econometrica.*
7. Robert Tibshirani (1996). Regression Shrinkage and Selection Via the Lasso. *Journal of the Royal Statistical Society.*
8. Leland Wilkinson (1999). The Grammar of Graphics.
9. Ian Goodfellow, Jean Pouget-Abadie, Mehdi Mirza, Bing Xu, David Warde-Farley, Sherjil Ozair, Aaron Courville, and Yoshua Bengio (2014). Generative Adversarial Networks. *Proceedings of the International Conference on Neural Information Processing Systems.*
10. Yoshua Bengio, Yann LeCun, and Geoffrey Hinton (2015). Deep Learning. *Nature*.

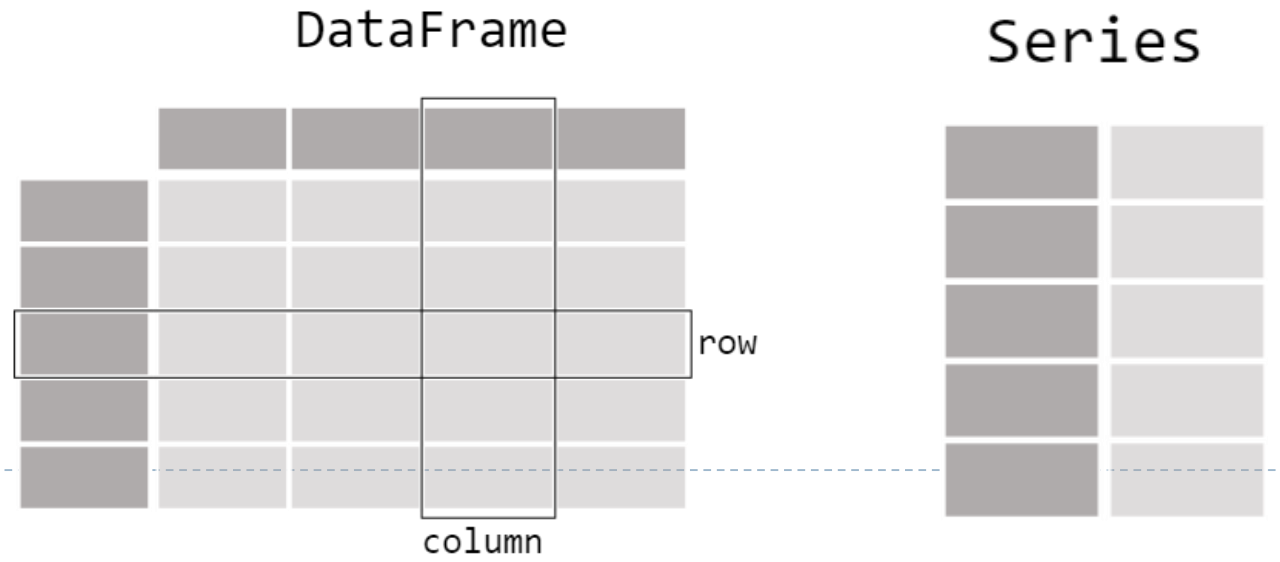
Exploratory Data Analysis (EDA) and Data Mining

- The field of exploratory data analysis was established with Tukey's 1977 now-classic book *Exploratory Data Analysis* [Tukey-1977]. Tukey presented simple plots (e.g., boxplots, scatterplots) that, along with summary statistics (mean, median, quantiles, etc.), help paint a picture of a dataset
  - It is important to understand what you *can do* before you learn to measure how well you seem to have done it
  - Allow the data to *speak for themselves* before standard assumptions or formal modeling
  - The greatest value of a picture is when it forces us to notice what we *never expected to see*

https://en.wikipedia.org/wiki/John_Tukey

DataFrame

- It is a 2-dimensional data structure that can store data of different types (including characters, integers, floating-point values, categorical data and more) in columns
  - It is similar to a spreadsheet, a SQL table or the data.frame in R
    - https://pandas.pydata.org/docs/getting_started/index.html
    - https://pandas.pydata.org/Pandas_Cheat_Sheet.pdf
  - Rows indicating records (cases) and columns indicating features (variables)

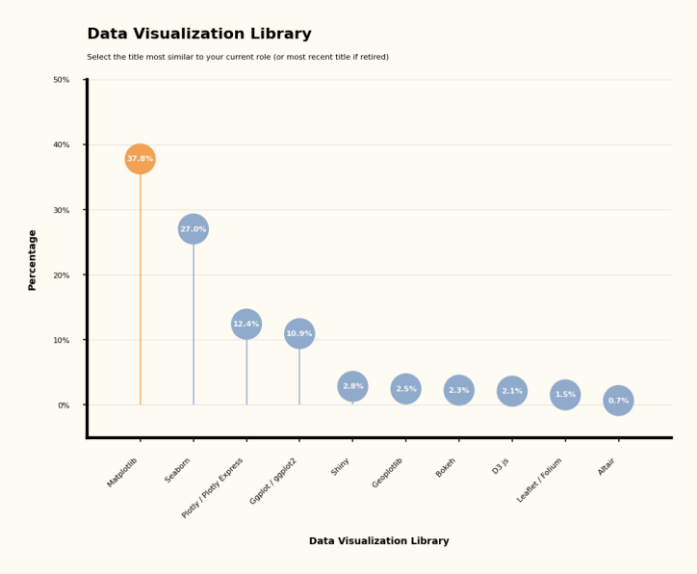


Some common statistics

- Operation on Dataframe
  - Estimate of location
    - Mean, median, trimed mean, mode
  - Estimate of variability
    - Variance, Mean (median) absolute deviation, percentile, interquartile range (IQR, difference between 25^{th} and 75^{th} percentile)
  - Basic filtering, reshaping and combining

Visualization

- Seaborn combines simple statistical fits with plotting on pandas dataframes that built upon matplotlib



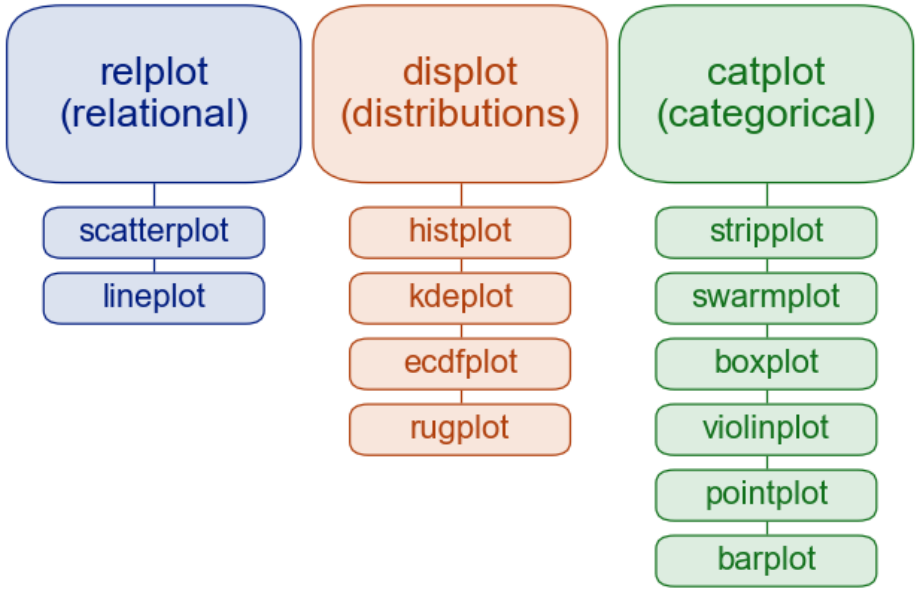


figure-level function (multiple subplots)

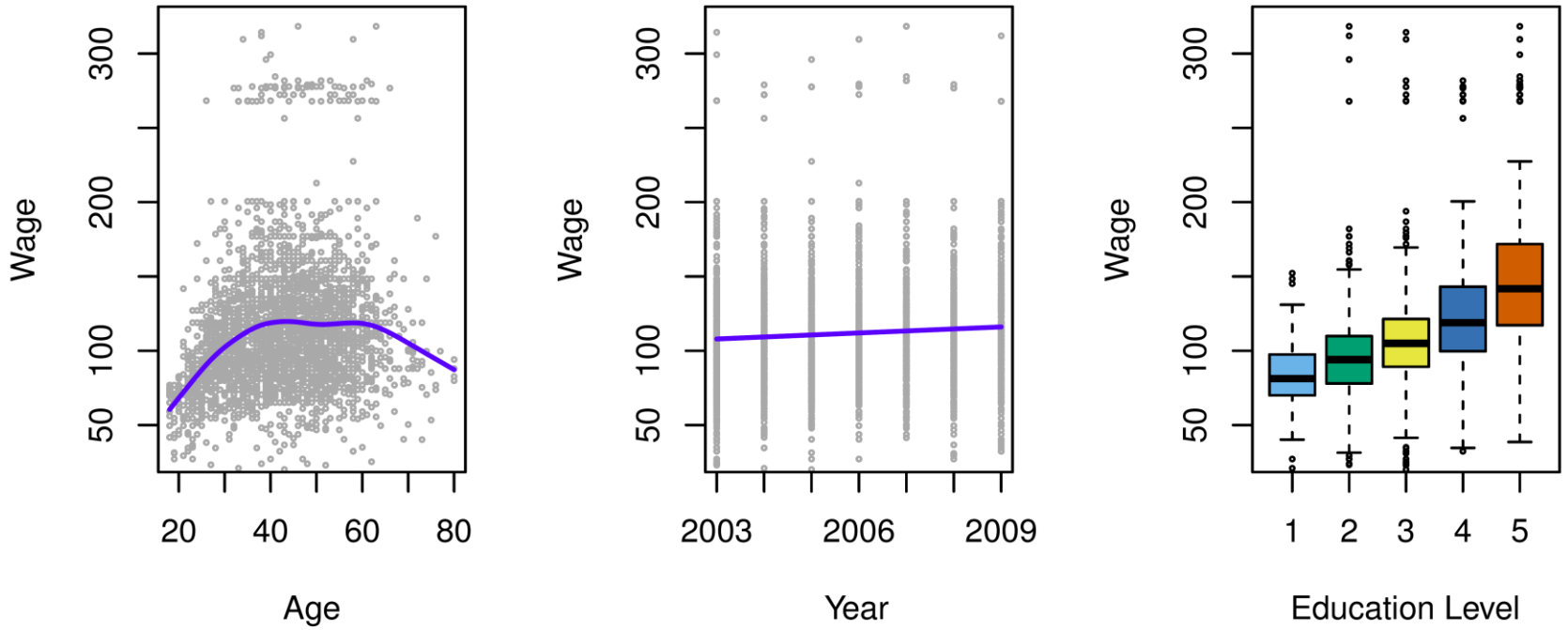
axes-level function

- Multiple plot - joinplot and pairplot
- Regression plot – lmplot, regplot and residplot
- Matrix plot – heatmap and clusterplot

Name	Description	n	p
Advertising	Sales in different markets, together with advertising budgets in different media channels	200 (with index)	4
Auto	Gas mileage, horsepower, and other information for cars.	392 (with index)	9
Bikeshare	Hourly usage of a bike sharing program in Washington, DC.	8,645 (with index)	15
Boston	Housing values and other information about Boston census tracts.	506 (with index)	13
BrainCancer	Survival times for patients diagnosed with brain cancer.	88 (with index)	8
Caravan	Information about individuals offered caravan insurance.	5,822	86
Carseats (Simulated)	Information about car seat sales in 400 stores.	400	11
College	Demographic characteristics, tuition, and more for USA colleges.	777 (with college name)	18
Credit (Simulated)	Information about credit card debt for 10,000 customers.	400	11
Default (Simulated)	Customer default records for a credit card company.	10,000	4
Fund (Simulated)	Returns of 2,000 hedge fund managers over 50 months.	2,000 (transpose)	50
Hitters	Records and salaries for baseball players.	322	20
Khan	Gene expression measurements for four cancer types.	63 (with index, test in other file)	2,308
NCI60	Gene expression measurements for 64 cancer cell lines.	64 (with index, vector in other file)	6,830
NYSE	Returns, volatility, and volume for the New York Stock Exchange.	6,051 (with index)	6
OJ	Sales information for Citrus Hill and Minute Maid orange juice.	1,070	18
Portfolio (Simulated)	Past values of financial assets, for use in portfolio allocation.	100	2
Publication	Time to publication for 244 clinical trials.	244 (with index)	9
Smarket	Daily percentage returns for S&P 500 over a 5-year period.	1,250	9
USArrests	Crime statistics per 100,000 residents in 50 states of USA.	50 (with state name)	4
Wage	Income survey data for men in central Atlantic region of USA.	3,000	11
Weekly	1,089 weekly stock market returns for 21 years.	1,089	9

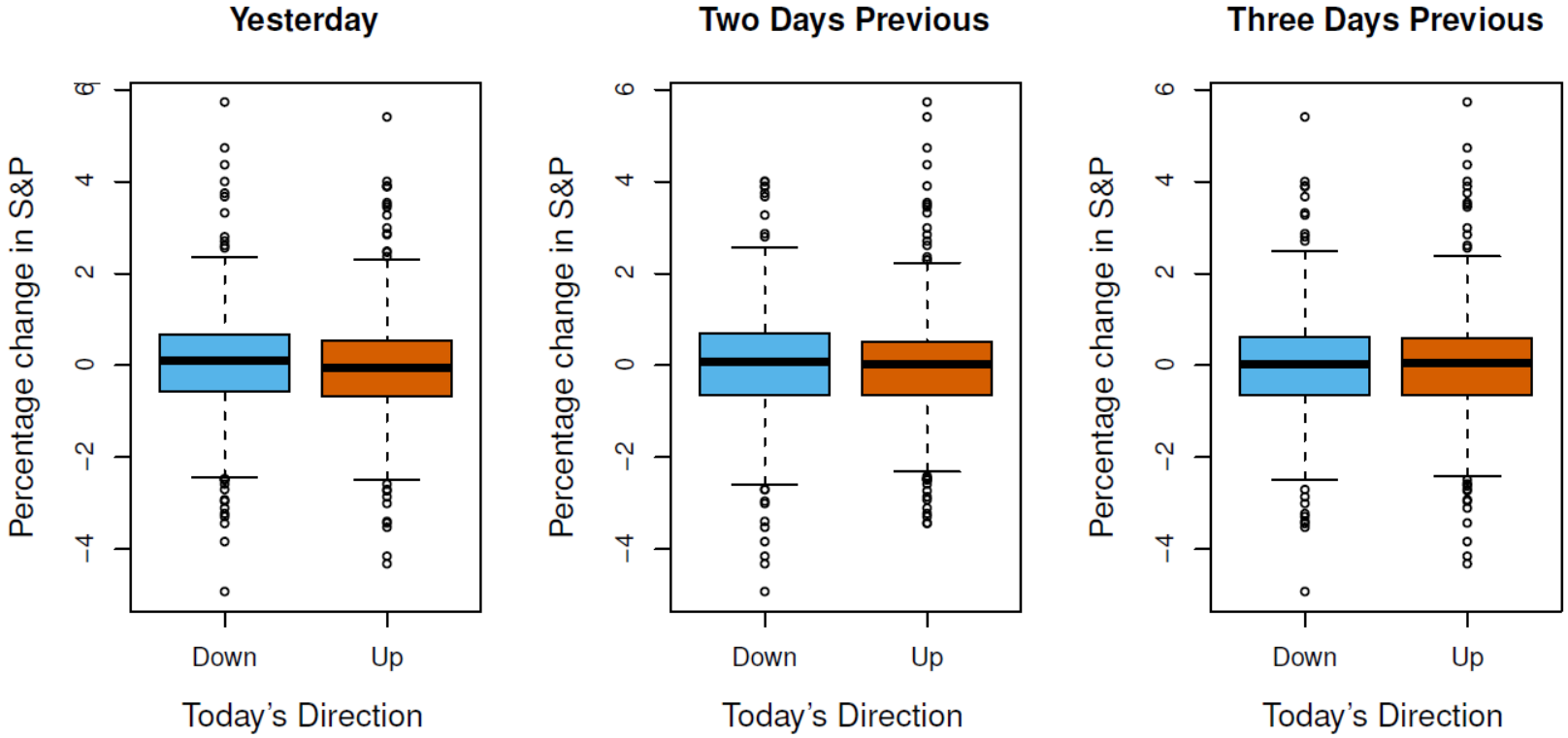
Wage data

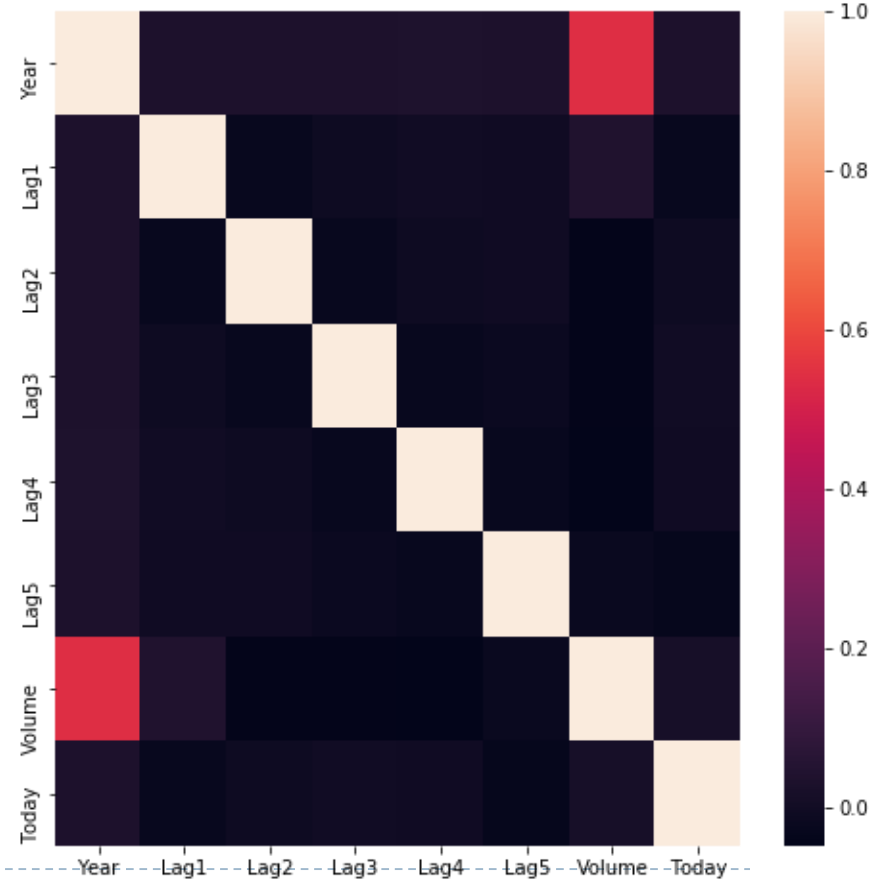
- Wage data for a group of 3,000 male workers in the Mid-Atlantic region
  - Scatterplot and Boxplot



Stock Market data

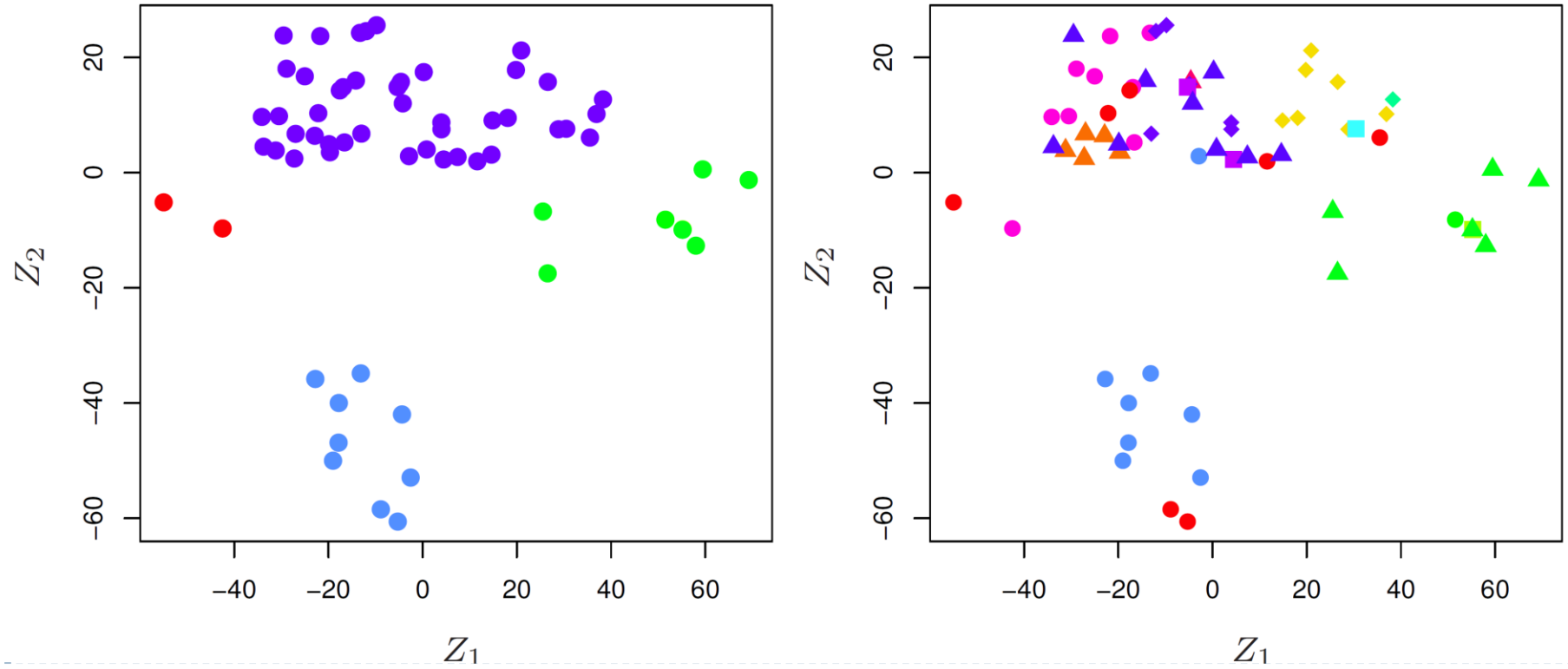
- Daily percentage returns for the S&P 500 stock index between 2001 and 2005
  - Boxplot and heatmap





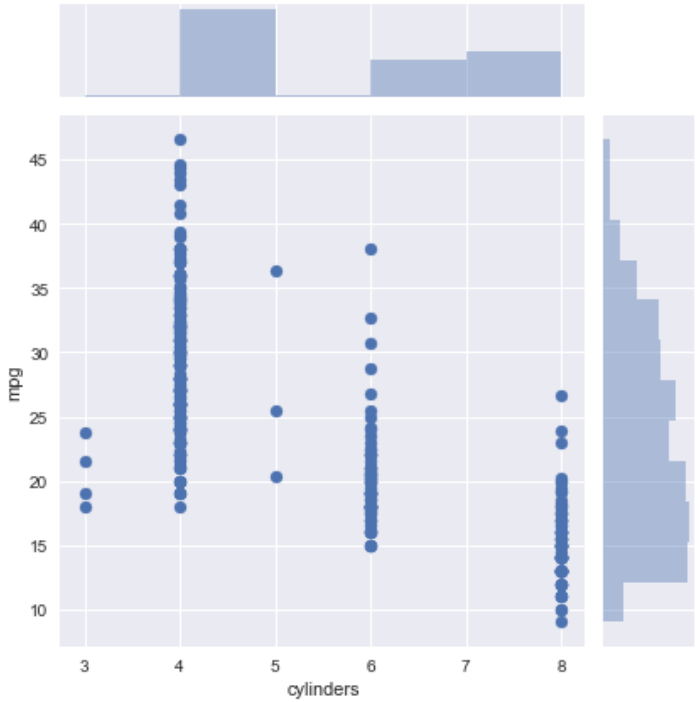
Gene Expression Data

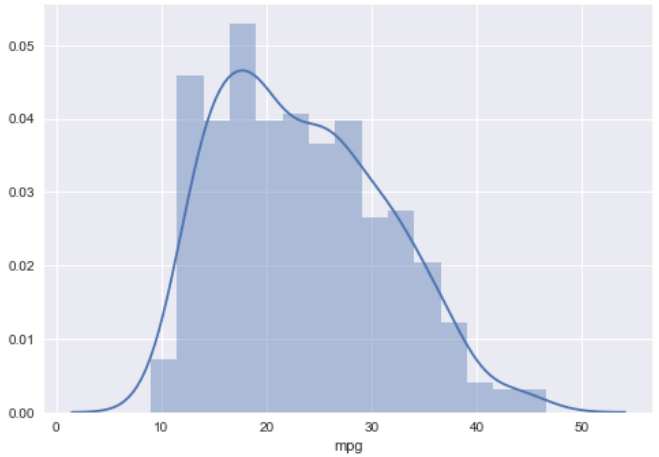
- NCI microarray data. The data contains expression levels on 6,830 genes from 64 cancer cell lines. Cancer type is also recorded
  - Scatterplot

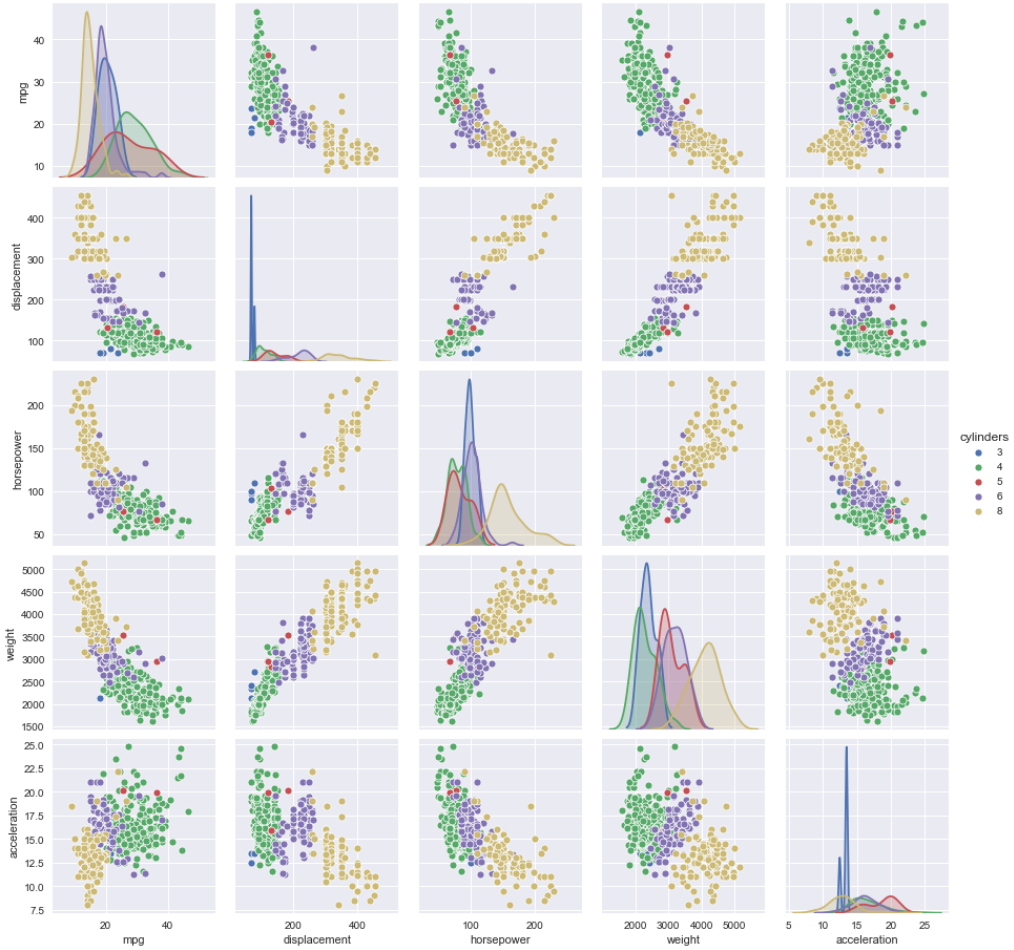


Auto data

- Gas mileage, horsepower, and other information for 392 vehicles
  - Pairplot, displot and joinplot

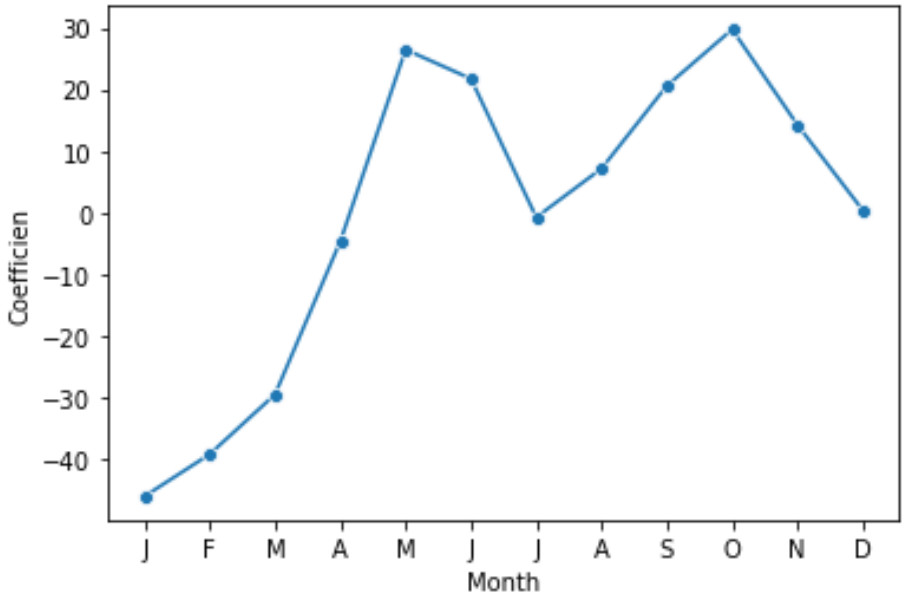


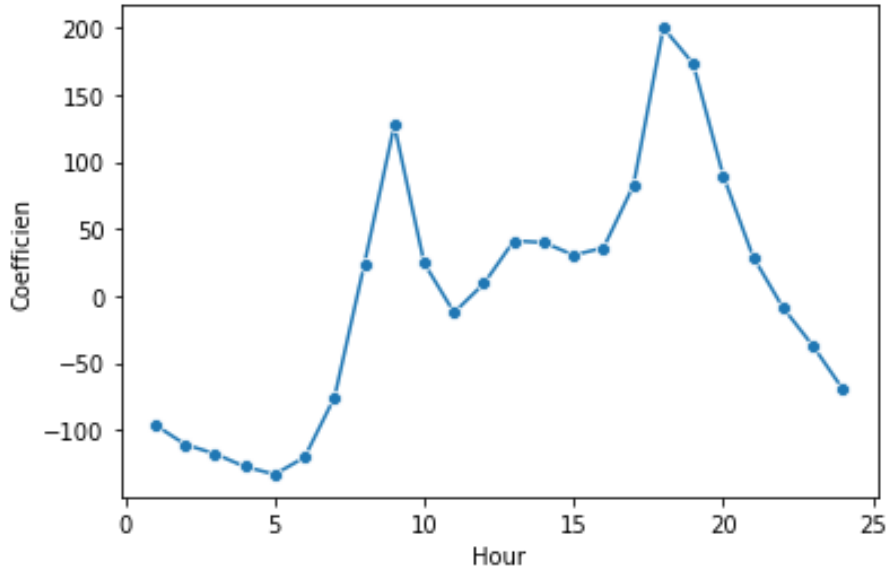




Bikeshare Data

- This data set contains the hourly and daily count of rental bikes between years 2011 and 2012 in Capital bikeshare system, along with weather and seasonal information
  - line plot





Conclusion

- Exploratory data analysis (EDA), pioneered by John Tukey, set a foundation for the field of data science. The key idea of EDA is that the first and most important step in any project based on data is to *look at the data*. By summarizing and visualizing the data, you can gain valuable intuition and understanding of the project
  - Exploratory analysis should be a cornerstone of any data science project
  - Other tools that use unsupervised learning will be discussed in chapter 12