Introduction to Machine Learning

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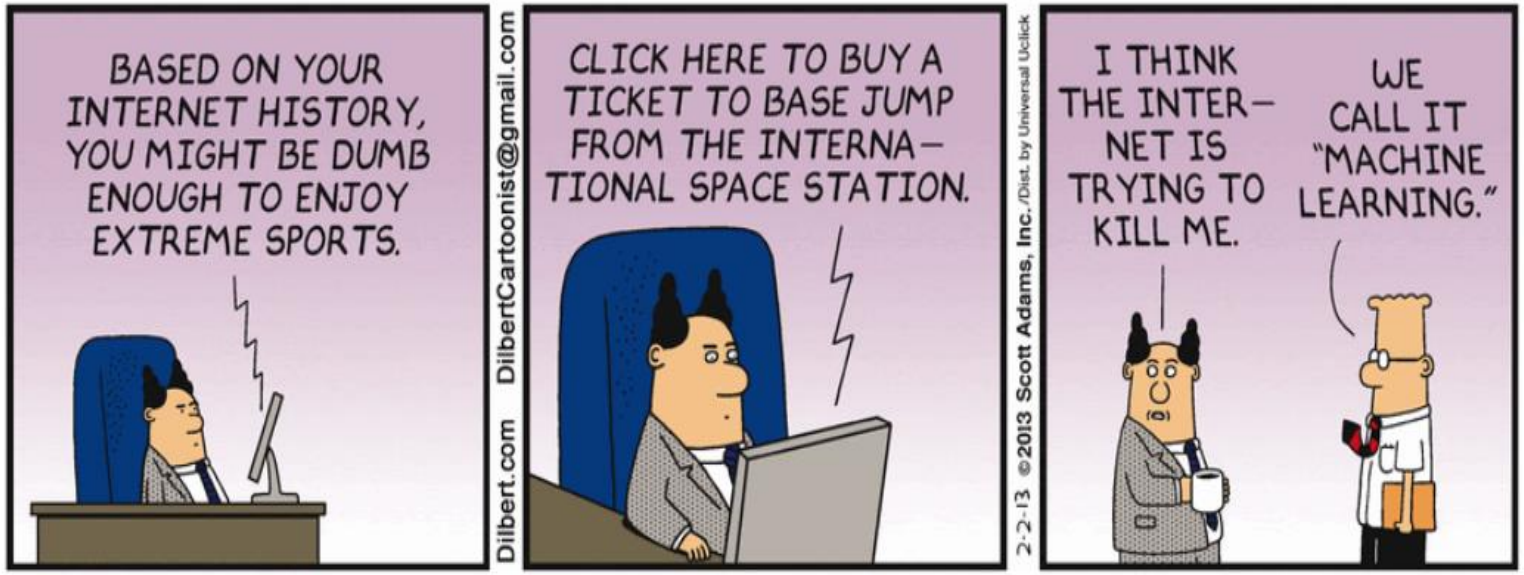
How much Data is Created Every Day?

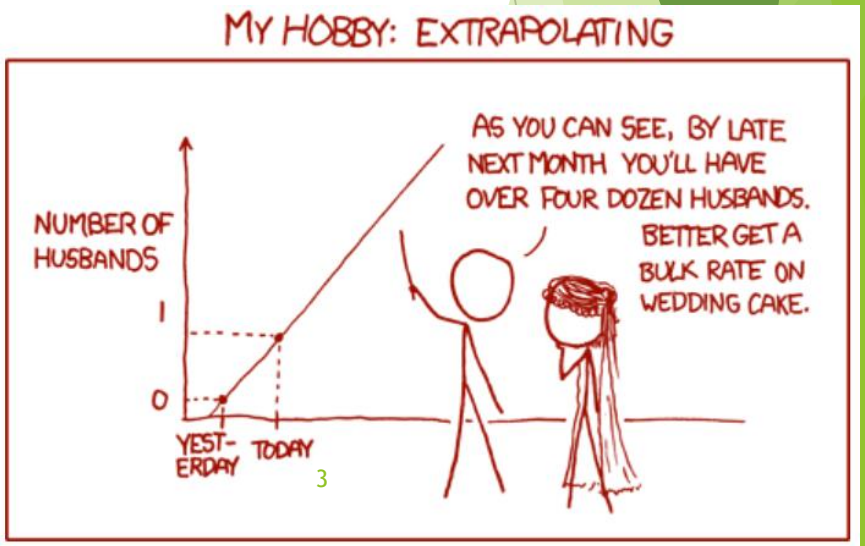
- 'Google' has become a Verb! (**3.5 billion** search queries every day)
- **2.5 quintillion bytes** of data are produced by us every day. (18 Zeroes!)
- ~90% of the World's Data created in last 2 years – Accelerating Pace
- **Every Day-**
  - ~250 billion emails are sent (**45% are Spam-** Hit the Unsubscribe button**!)**
  - 100+ million photos and videos are shared on Instagram
  - ~500 million Tweets are made (~45% of Covid-19 tweets estd to be **Bot-Generated**!)
- By the end of 2020, **~31 Billion IoT devices**. The estimated size of the entire digital universe will be a whopping **44 zettabytes** (21 Zeroes in a ZB!)
- **What to do with all these Data?**

Source- Statista, IEEE, TechJury, ILS, Raconteur, NPR, Sendpulse

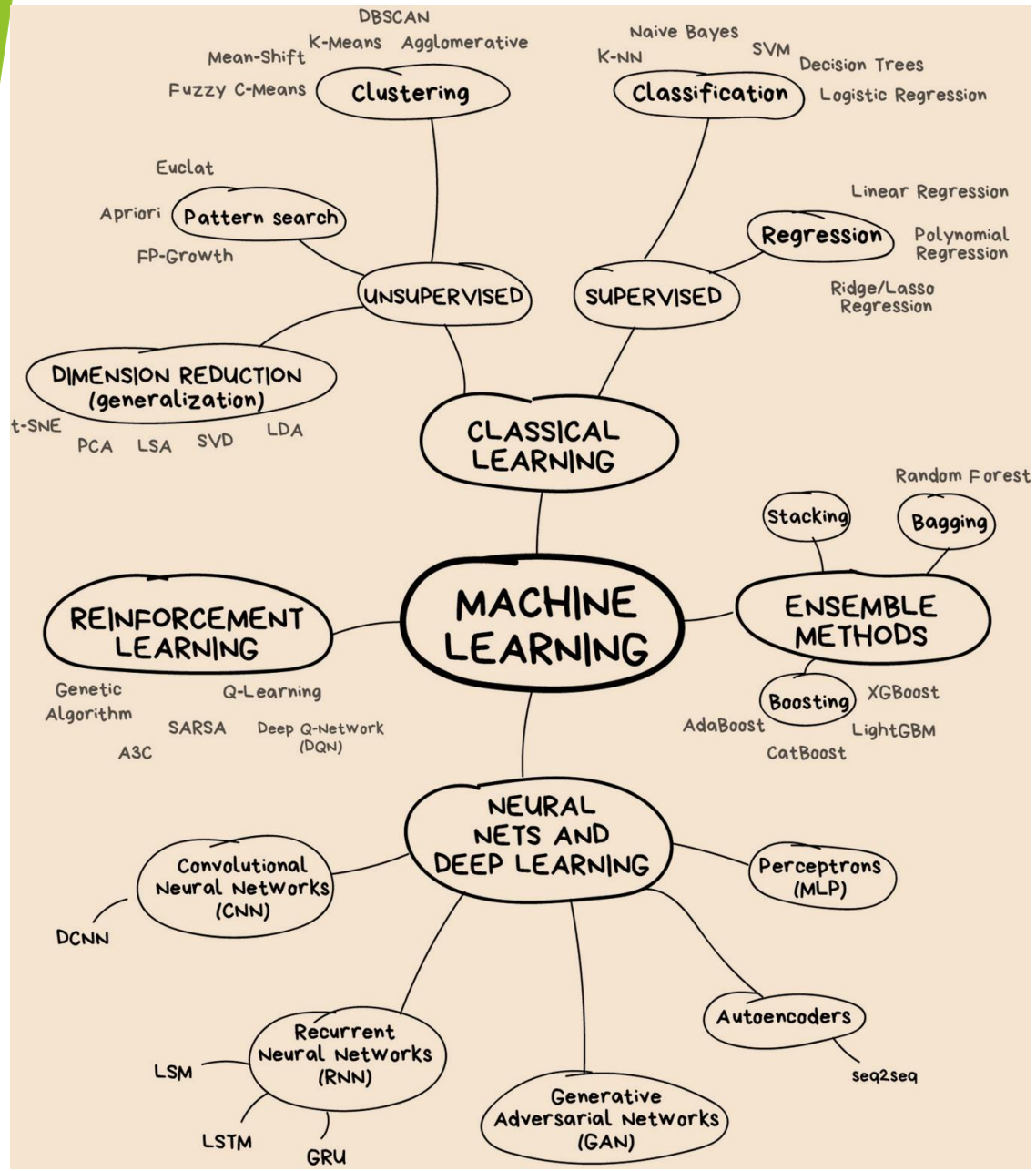
Machine Learning- The Art and Science of Learning from Data

- *We are drowning in Information and starving for Knowledge — **John Naisbitt** (Author of 'Megatrends')*
- Is Learning Possible?
- **Generalization**/ Pattern Recognition (Easy) **vs** **Extrapolation**/ Finding Higher Dimensional Insights (Hard)





The ML Family Tree



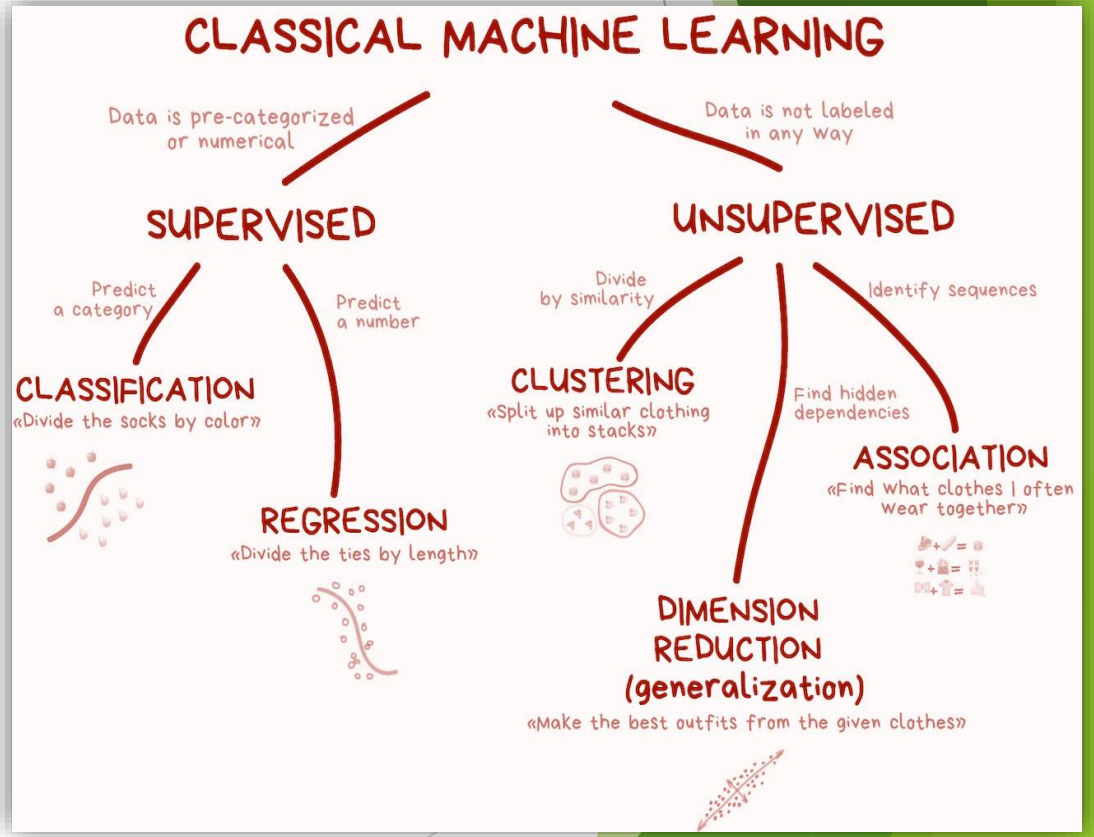


Image Credit: Vas3k, https://noeliagorod.com/

Classification- Split into Categories

- **Usage**: Fraud Detection (Online Transaction), Spam Filtering (Email), Sentiment Analysis (+ve/-ve/neutral), Handwriting Recognition (MNIST) etc.
- **Overview of Popular Algorithms**
  - **Logistic Regression** (GLM* with Logit link), Multinomial Logit
  - **Decision Tree**, Bagging, Random Forest, Boosting
  - **Naïve Bayes** (Conditional Independence b/w Features, Given a Category)

$$\mathbf{X}\boldsymbol{\beta} = \ln\left(\frac{\mu}{1-\mu}\right)$$

$$p(C_k \mid x_1, \ldots, x_n) = \frac{1}{Z} p(C_k) \prod_{i=1}^{n} p(x_i \mid C_k)$$

where the evidence $Z = p(\mathbf{x}) = \sum_k p(C_k)\, p(\mathbf{x} \mid C_k)$

* Allows Response (Dependent) Variables to have error distribution models other than a normal distribution

Classification (Contd.)

- KNN (**K-Nearest Neighbors**) Algorithm

  (Idea: Find Closest K Neighbors)
- Distance Measures: Euclidean distance, Mahalanobis distance, Manhattan distance, Cosine Distance etc
- **Support Vector Machine** and Kernel Trick

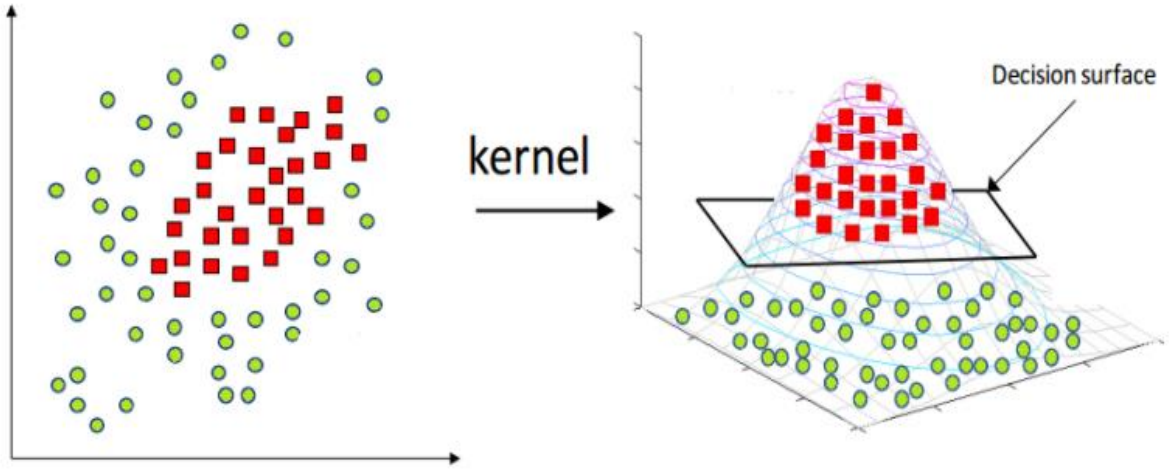
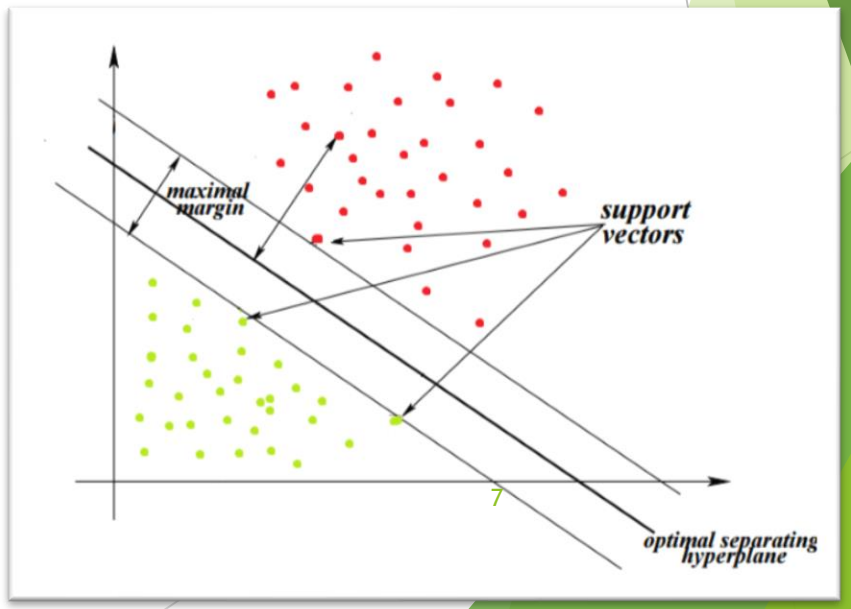


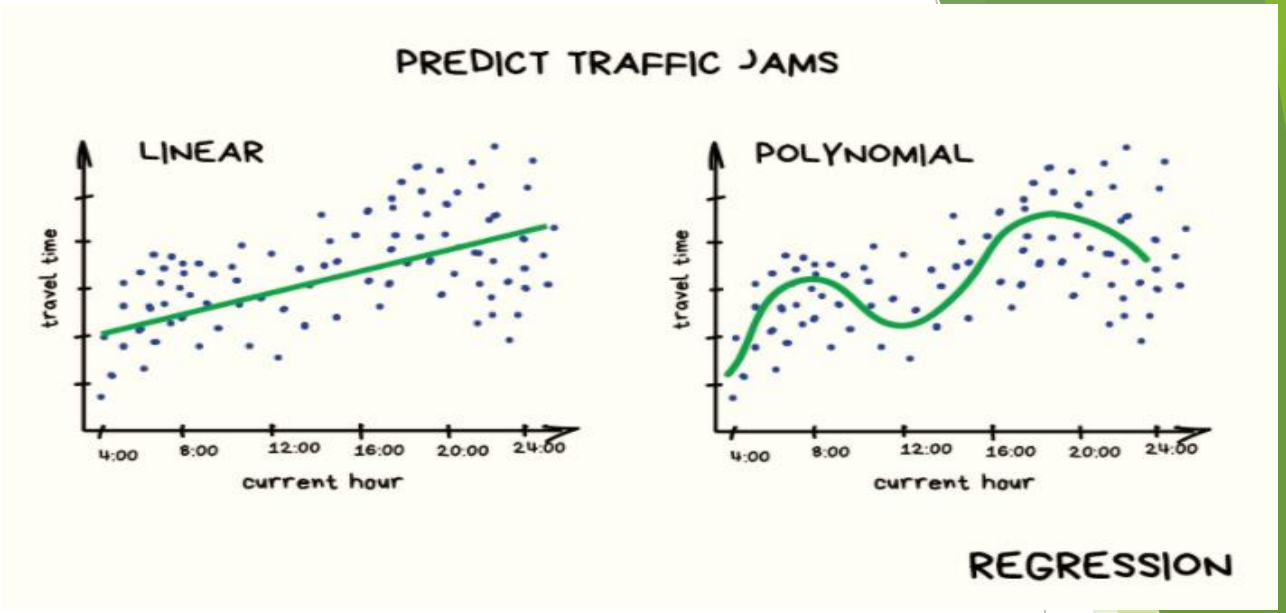
Image Credit: Towards data science



Regression

- Multiple **Linear** Regression (Discussed in earlier classes in detail)
- **Ordinary Least Square** Method: Computes the unique line (or hyperplane) that minimizes the sum of squared distances (usually vertical) between the true data and that line
- **Ridge Regression** and **LASSO** (reducing model complexity to prevent overfitting, Variable Selection)

Image Credit: ISLR book (Ref 3)



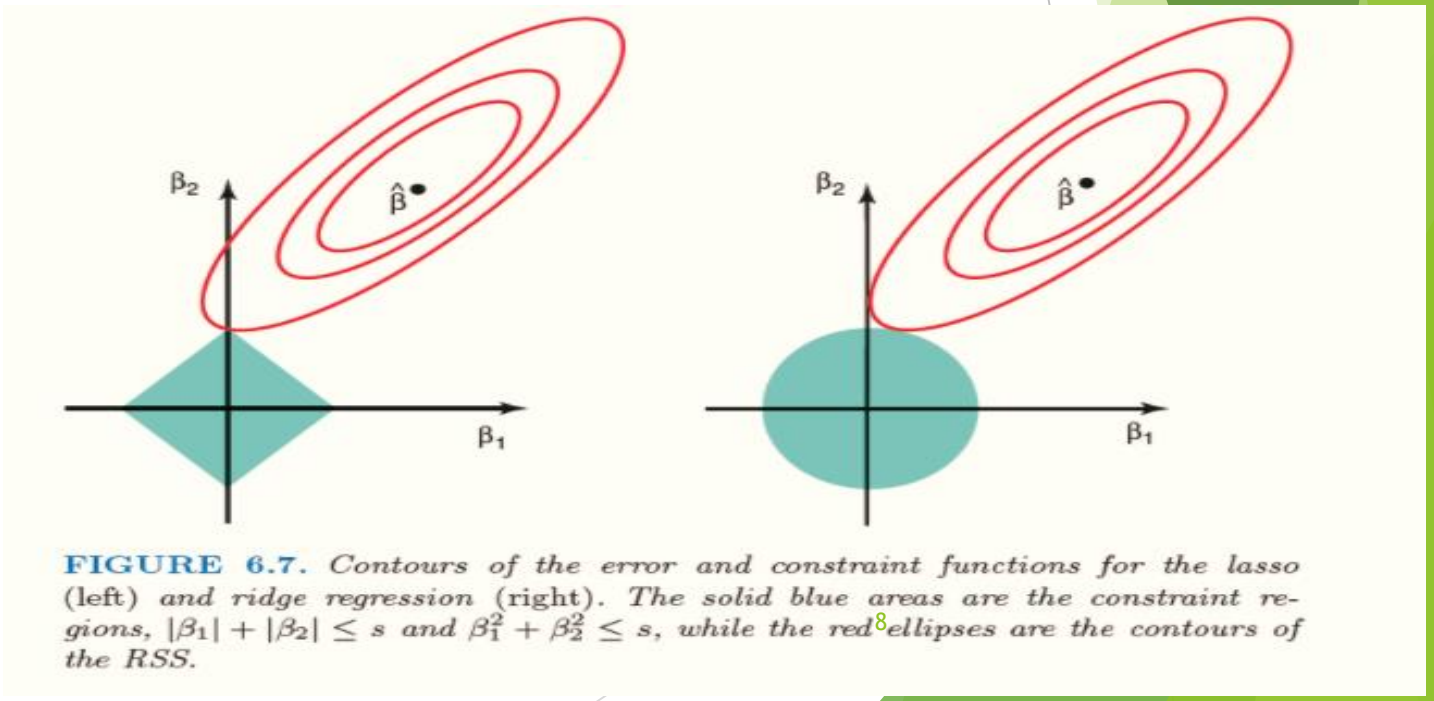
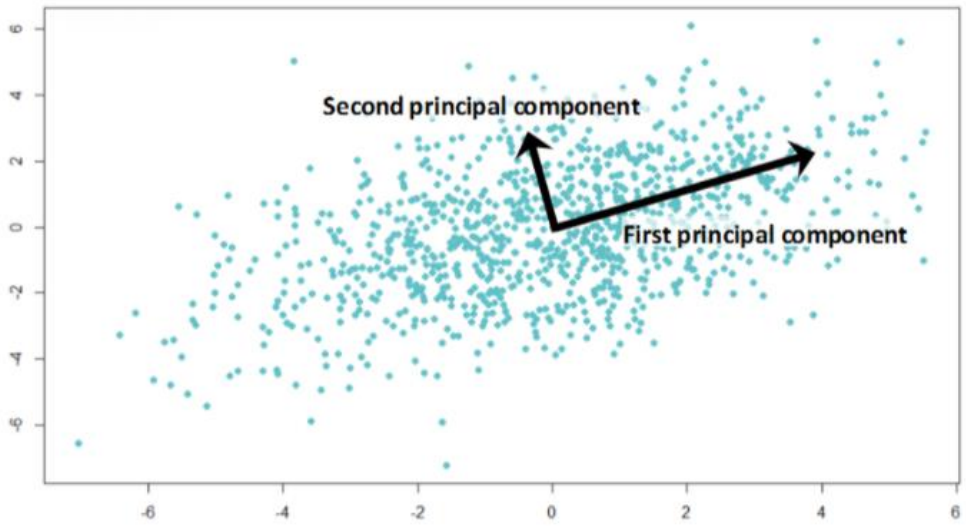


FIGURE 6.7. *Contours of the error and constraint functions for the lasso* (left) *and ridge regression* (right). *The solid blue areas are the constraint regions,* $|\beta_1| + |\beta_2| \leq s$ *and* $\beta_1^2 + \beta_2^2 \leq s$, *while the red ellipses are the contours of the RSS.*

Unsupervised Learning

- Market Segmentation (**Clustering**), Anomaly Detection, Image Compression (**Dimensionality Reduction**) etc
- **K-means Clustering**
- **Principal Component Analysis** (Projection into Lower Dimensional Space, Summarizing Information)



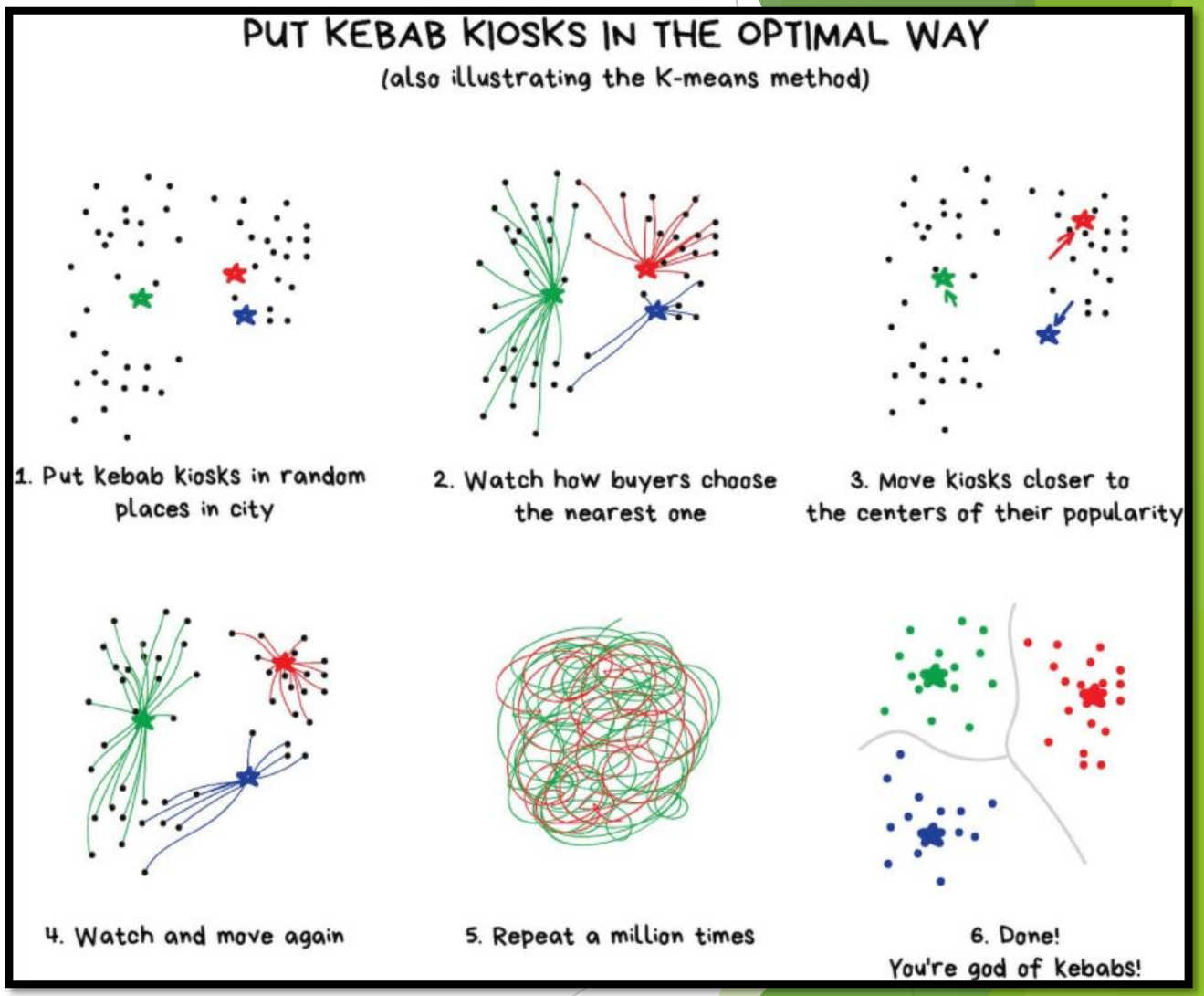


Image Credit:Vas3K

Unsupervised Learning

- **Hierarchical Clustering**
- Distance between Clusters
  - Single Linkage (Min)
  - Complete Linkage (Max)
  - Average Linkage (All Pairs)
  - Centroid Linkage
- **Association Rule Mining** (Looking for patterns, eg, analyzing Shopping behavior, Marketing Strategy)

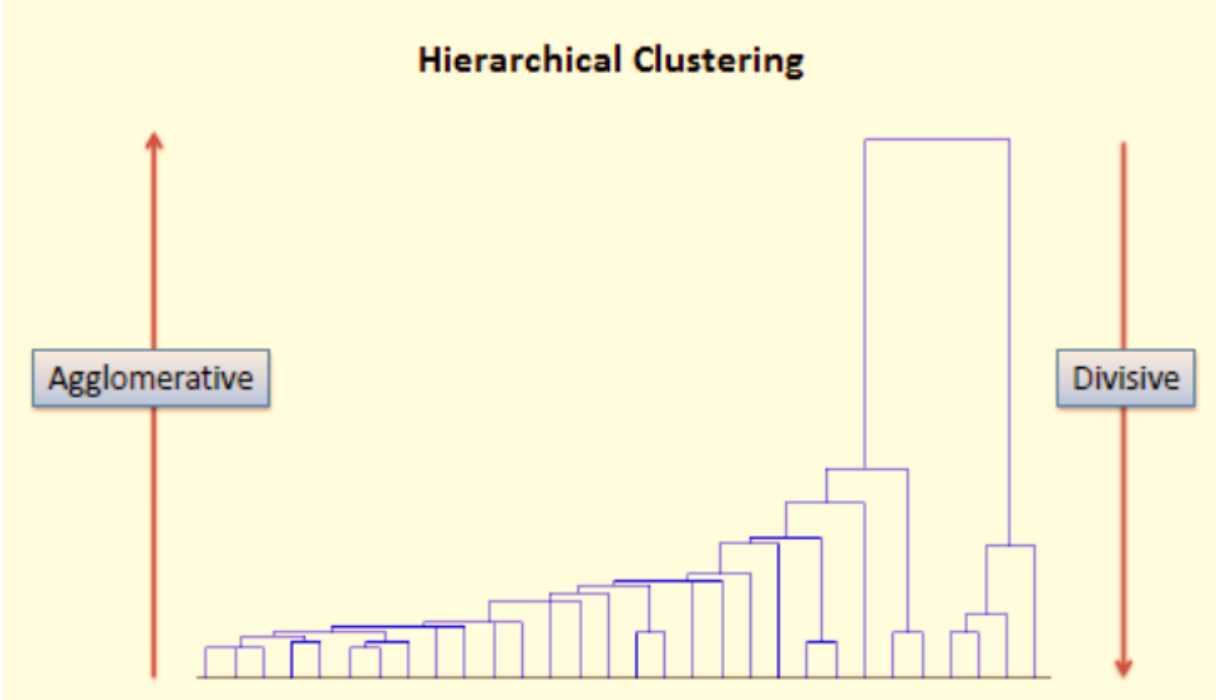


Image Credit: saedsayad.com

Reinforcement Learning

- Model is trained by having an Agent interact with environment
- **Desired Action gets Rewarded**
- "Good Behaviors are Reinforced"
- One of **Three fundamental ML Paradigms** (along with Supervised learning and Unsupervised learning)
- When in an active Environment, like Video Games (Super Mario!), **Self Driving Car** etc
- Goal is to Minimize Error (maybe difficult to predict all possible moves)

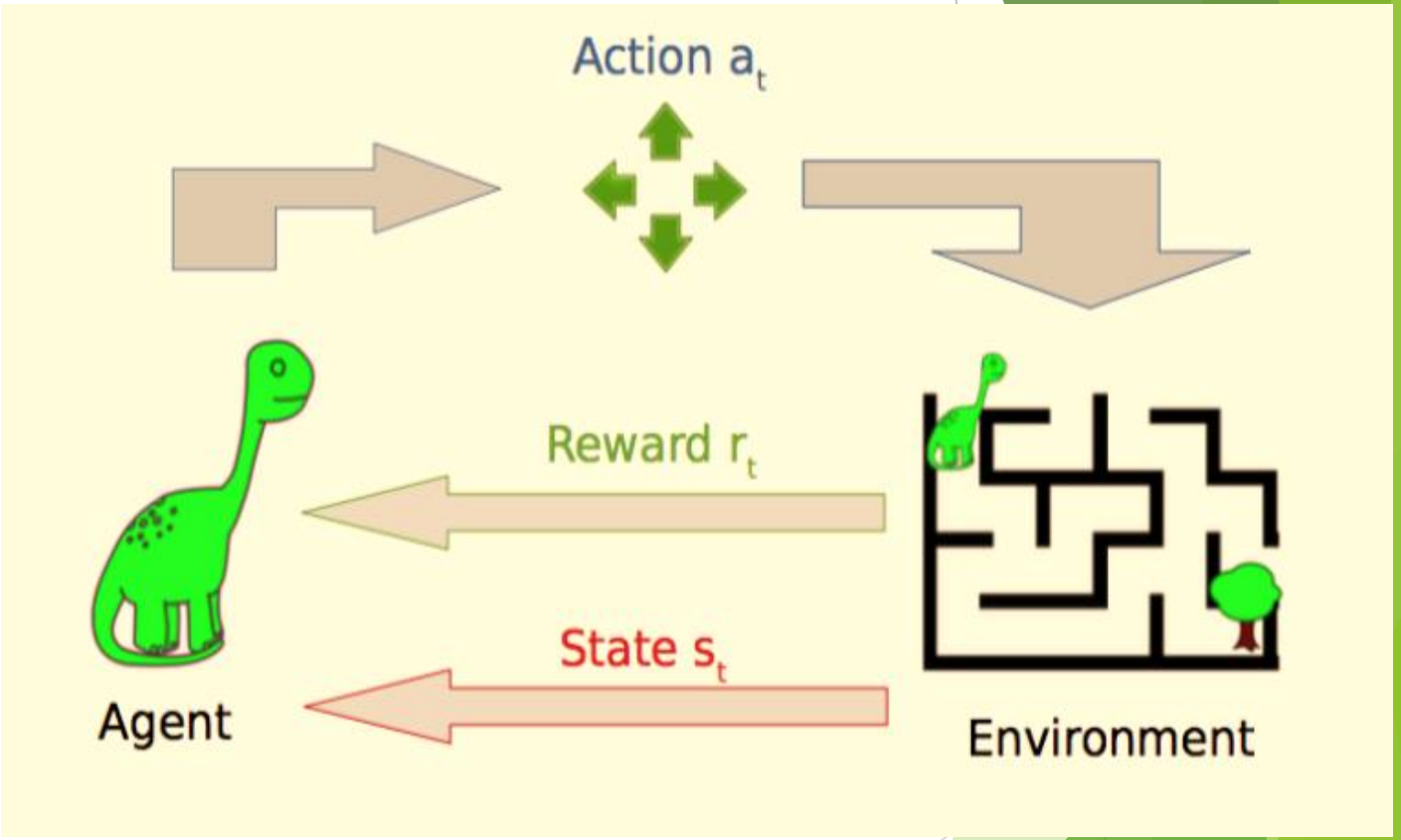


Image Credit: TWIML Online

Diving Deeper into some Core Ideas

Correlation does not Imply Causation

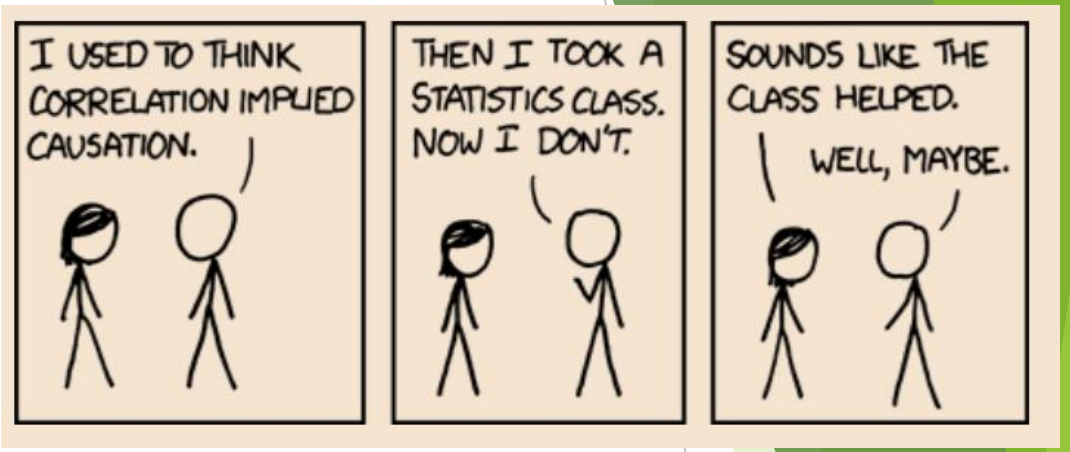
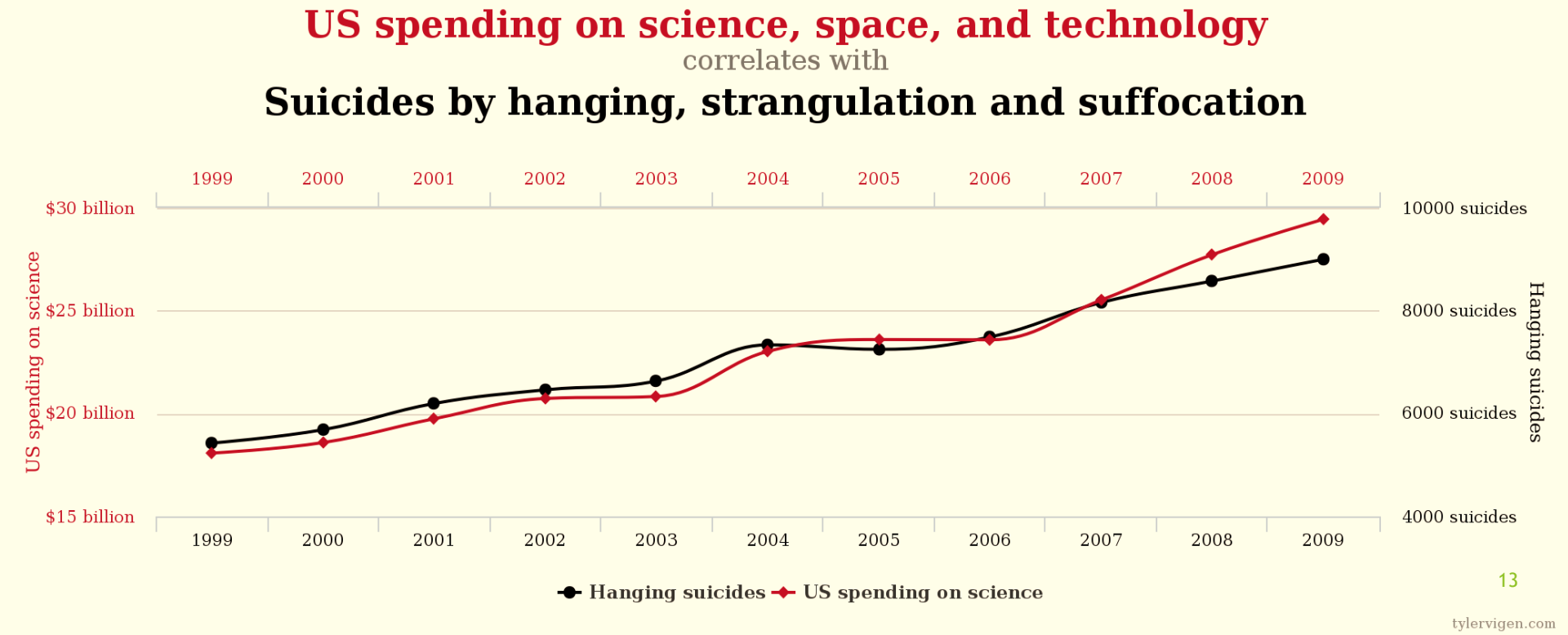


Image Credit: xkcd



Bias-Variance Tradeoff: Underfitting vs Overfitting

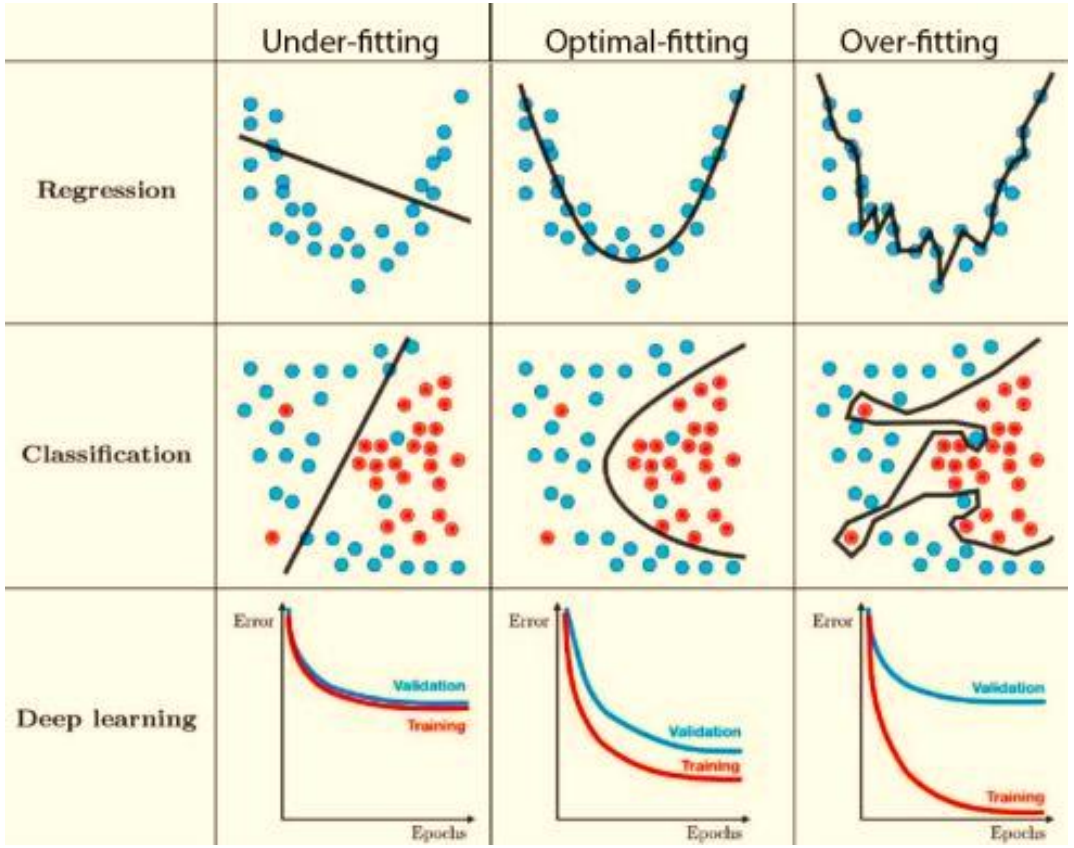
$$\mathbf{E}_D\left[(y-\hat{f}(x;D))^2\right] = \left(\mathbf{Bias}_D\left[\hat{f}(x;D)\right]\right)^2 + \mathbf{Var}_D\left[\hat{f}(x;D)\right] + \sigma^2$$

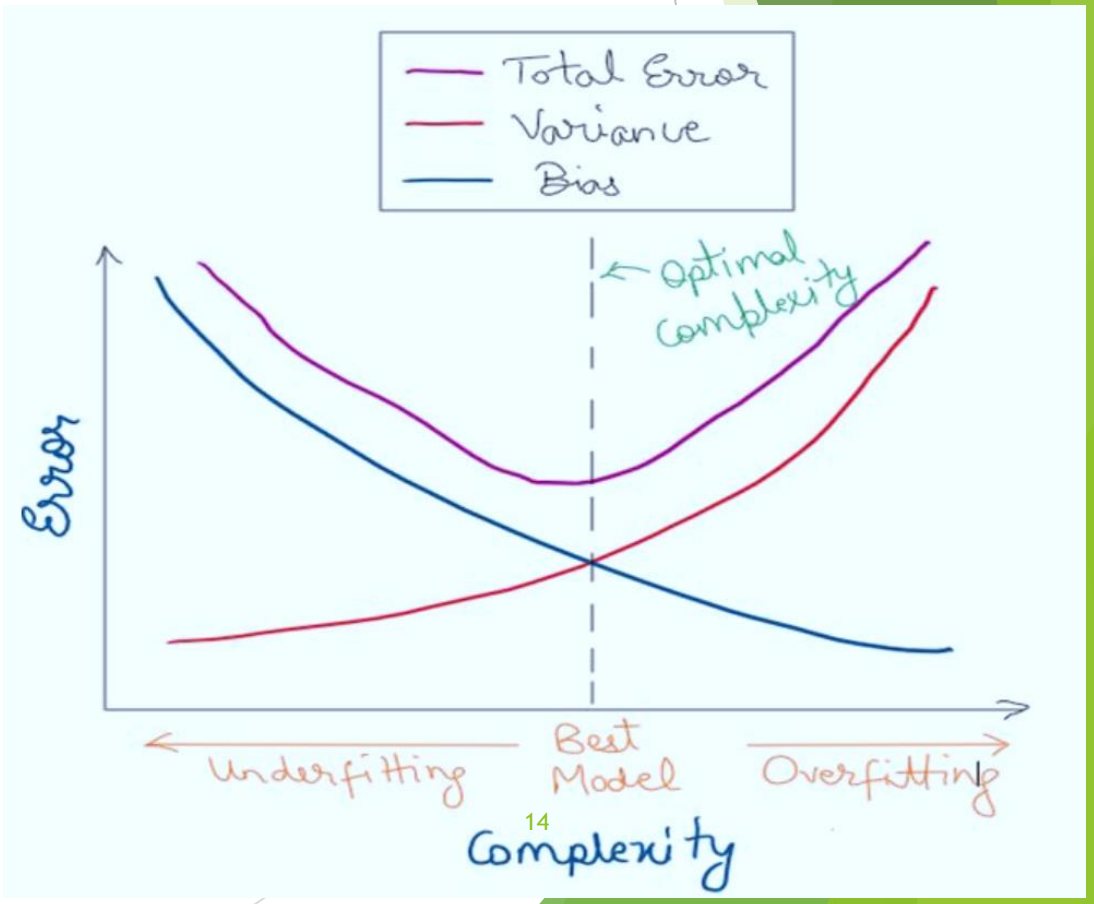
where

$$\mathbf{Bias}_D\left[\hat{f}(x;D)\right] = \mathbf{E}_D\left[\hat{f}(x;D)\right] - f(x)$$

and

$$\mathbf{Var}_D\left[\hat{f}(x;D)\right] = \mathbf{E}_D[\hat{f}(x;D)^2] - \mathbf{E}_D[\hat{f}(x;D)]^2.$$





Curse of Dimensionality

- Problems in High Dimension due to Data Sparsity
- Adding each new dimension (ie, adding a feature) increases the data set requirement exponentially
- Separation of Wind Turbines- 2D vs 3D view

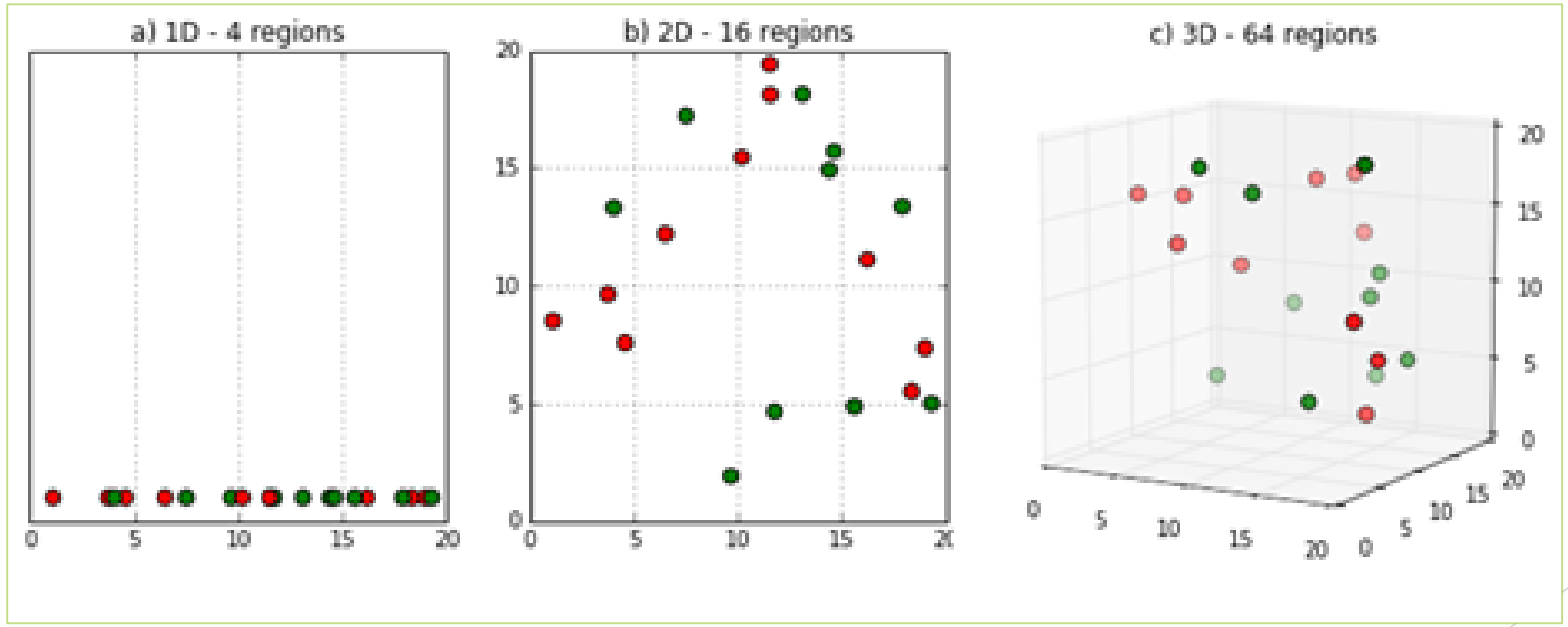


Image Credit: deepai.org

Comparison of some Popular Algorithms

TYPE	NAME	DESCRIPTION	ADVANTAGES	DISADVANTAGES
Linear	Linear regression	**The "best fit" line** through all data points. Predictions are numerical.	Easy to understand -- you clearly see what the biggest drivers of the model are.	X Sometimes too simple to capture complex relationships between variables. X Tendency for the model to "overfit".
	Logistic regression	The adaptation of **linear regression** to problems of classification (e.g., yes/no questions, groups, etc.)	Also easy to understand.	X Sometimes too simple to capture complex relationships between variables. X Tendency for the model to "overfit".
Tree-based	Decision tree	A graph that uses a **branching method** to match all possible outcomes of a decision.	Easy to understand and implement.	X Not often used on its own for prediction because it's also often too simple and not powerful enough for complex data.
	Random Forest	Takes the average of many decision trees, each of which is made with a sample of the data. Each tree is weaker than a full decision tree, but **by combining them we get better overall performance.**	A sort of "wisdom of the crowd". Tends to result in very high quality models. Fast to train.	X Can be slow to output predictions relative to other algorithms. X Not easy to understand predictions.
	Gradient Boosting	Uses even weaker decision trees, that are increasingly **focused on "hard" examples.**	High-performing.	X A small change in the feature set or training set can create radical changes in the model. X Not easy to understand predictions.
Neural networks	Neural networks	Mimics the behavior of the brain. Neural networks are interconnected neurons that pass messages to each other. Deep learning uses several **layers of neural networks put one after the other.**	Can handle extremely complex tasks - no other algorithm comes close in image recognition.	X Very, very slow to train, because they have so many layers. Require a lot of power. X Almost impossible to understand predictions.

Table Credit: dataiku.com

Things to keep in mind

- **Splitting the Dataset**:
  - Training Set (Data Sample used to Fit the Model, to get the Parameters)
  - Validation Set (Tuning Hyperparameters to choose final model)
  - Test Set (To evaluate the final model, should not be used for training)
- Other **Common Pitfalls** in ML (Violation of Assumptions):
  - Non-Linearity (Plotting Residuals against Fitted Values, Non-linear Transformation)
  - High Leverage Points (Cook's Distance Plot)
  - Correlation of Error Terms (eg, Time Series data)- Controlled Experiment
  - Heteroscedasticity (Non-constant Variance of Error Term)
  - Multicollinearity (Correlated Predictors, eg. Dummy Variable Trap)

That's All, Friends!

STAT&ML Lab is a non-profit organization to bring young minds into research projects on Statistics & Machine Learning.

We aim to provide training and research projects on Statistics, Data Science, and ML.

The primary goal of this lab is to promote research in Statistics in India and throughout the world

Thanks & References

1) Special Thanks to All the Participants, **BKC College, WBSU and STAT & ML Lab:** https://www.ctanujit.org/statml-lab.html
2) Image Credit- Wikipedia, Reddit, SlideShare, me.me, Imgflip, xkcd,
3) http://faculty.marshall.usc.edu/gareth-james/ISL/ (ISLR Book)
4) https://developers.google.com/machine-learning/guides/good-data-analysis
5) https://hackernoon.com/choosing-the-right-machine-learning-algorithm-68126944ce1f
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