MODUL 03

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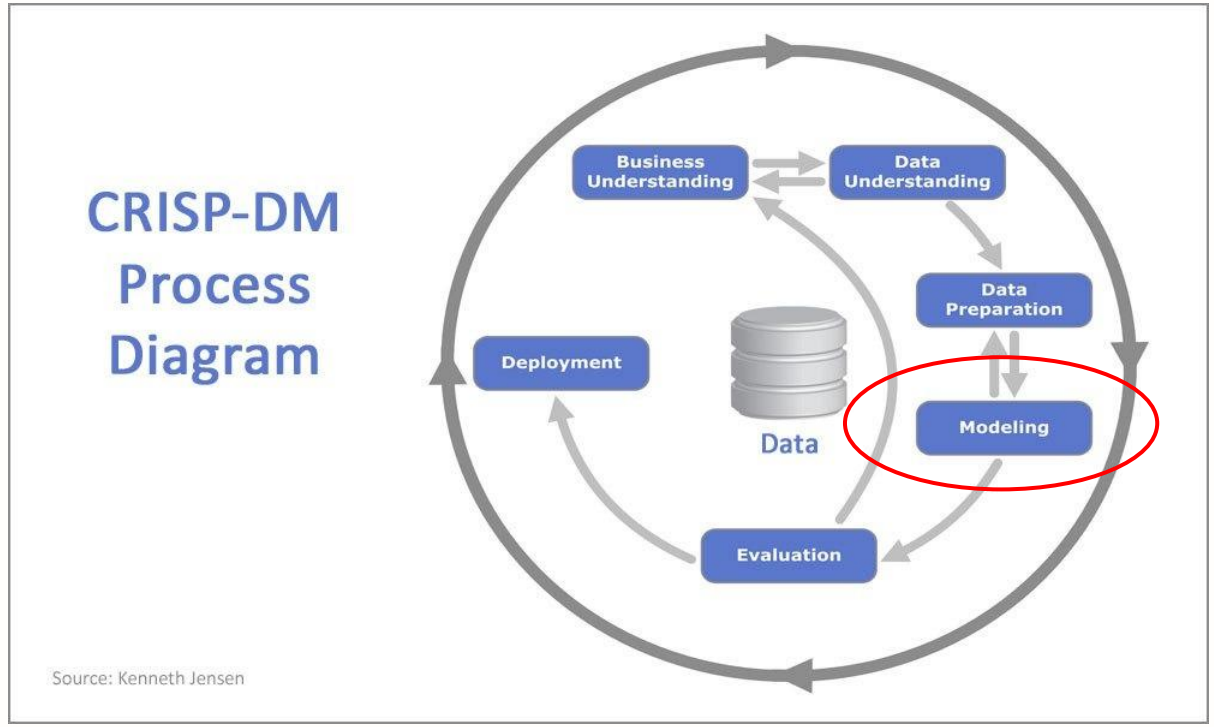
Supervised Learning: **Classification**

Data Science Program

Job Connector Program

Outline

- What is Classification ?
- Methods in Classification
- Logistics Regression
- KNN
- Decision Tree



What is Classification ?

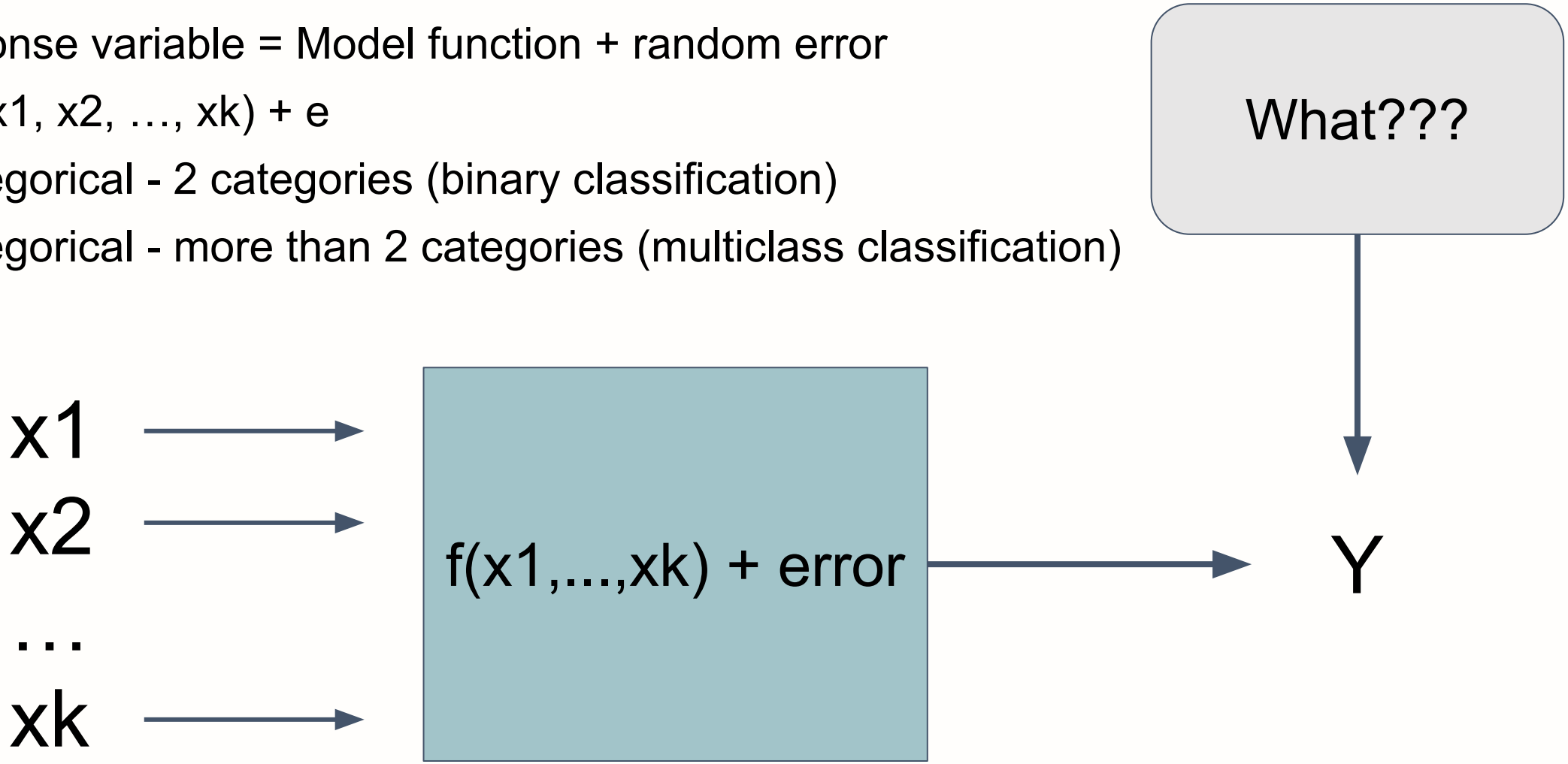
What Is Classification ?

Response variable = Model function + random error

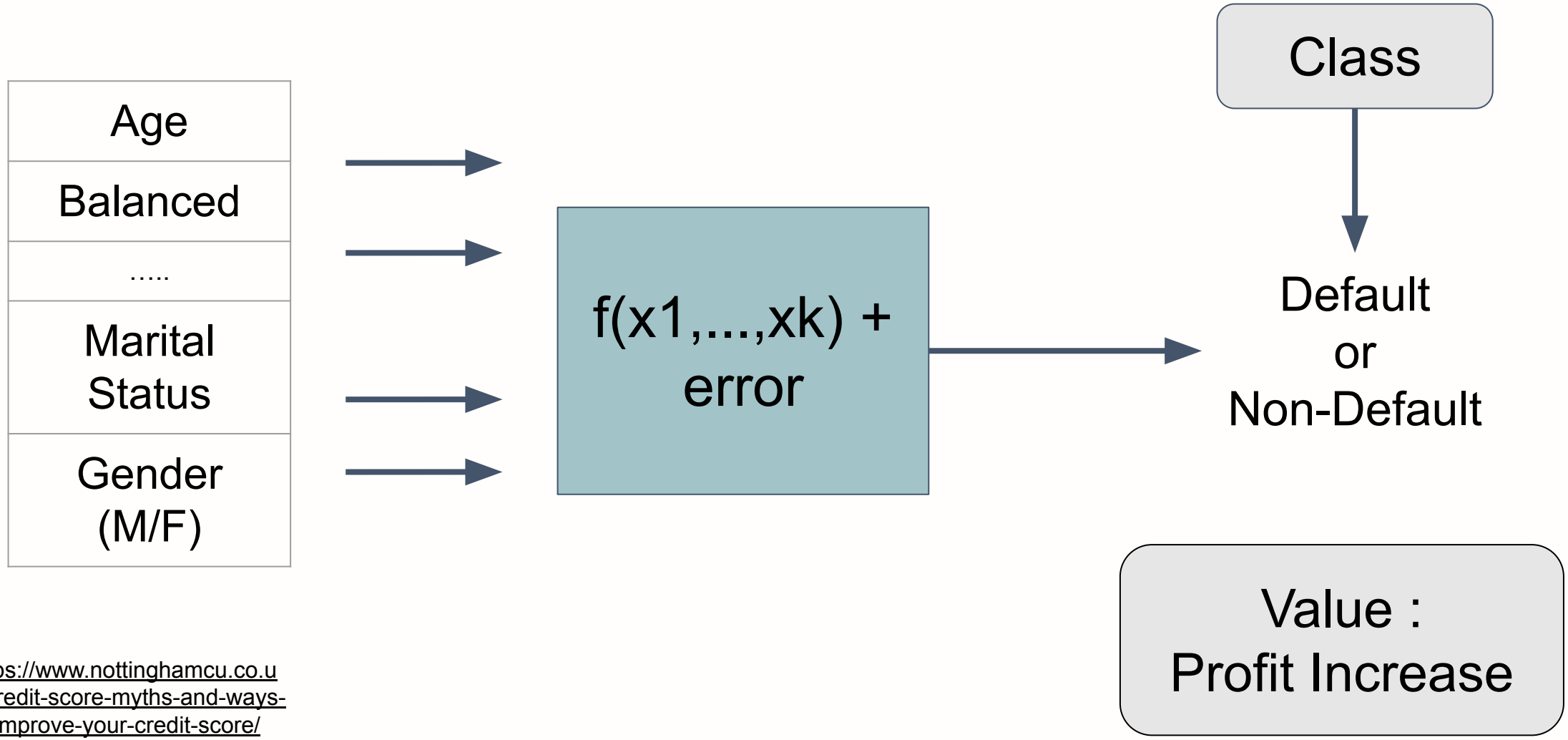
Y = f(x1, x2, …, xk) + e

Y categorical - 2 categories (binary classification)

Y categorical - more than 2 categories (multiclass classification)



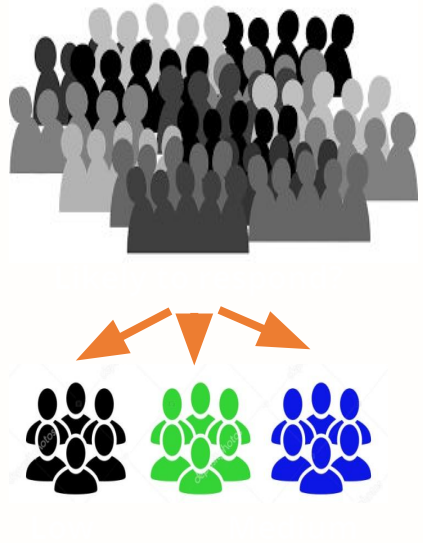
Credit Scoring (Binary)



https://www.nottinghamcu.co.uk/credit-score-myths-and-ways-to-improve-your-credit-score/

Classification Cases

Churn Analysis



Propensity Analysis

Human Resources
“The Rising Star”

Some Method Usually Used In Classification

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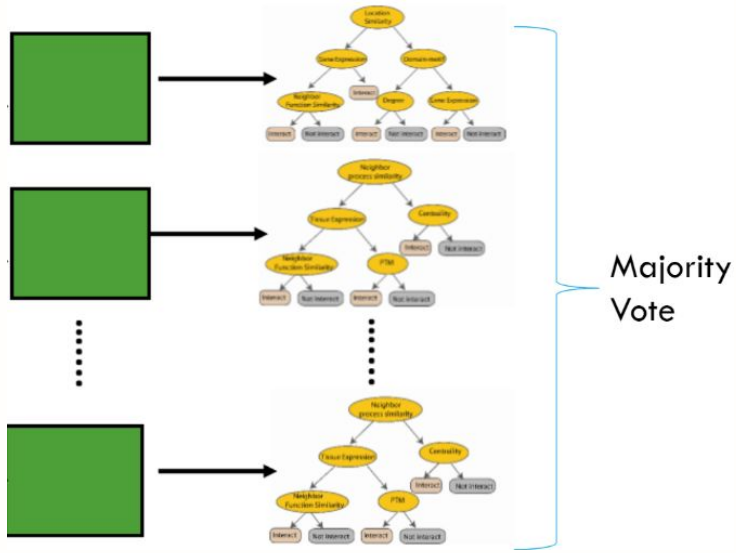
Logistic Regression:

$$P(Y=1)=\frac{\exp(\beta_0+\beta_1 x_1+\ldots+\beta_k x_k)}{1+\exp(\beta_0+\beta_1 x_1+\ldots+\beta_k x_k)}$$

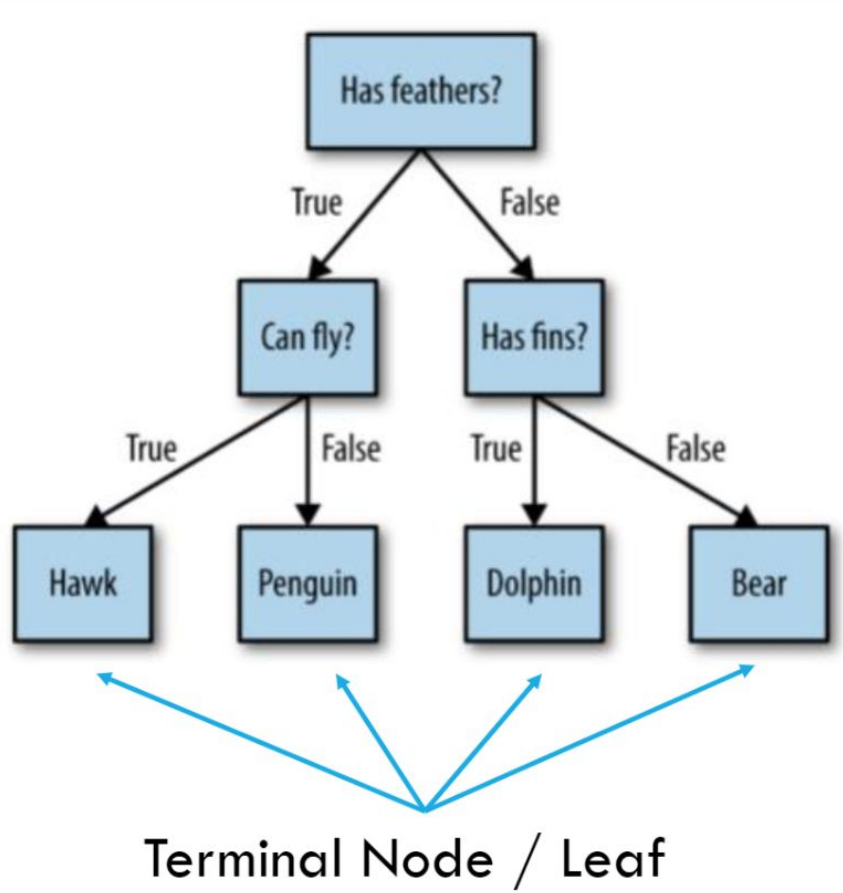
Ensemble Method:



Other models:

- Discriminant Analysis,
- K-Nearest Neighbor (KNN),
- Support Vector Machine (SVM),
- Ensemble – Bagging,
- Random Forest, Boosting,
- etc.

Decision Tree Classifier:



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Binary Logistics Regression

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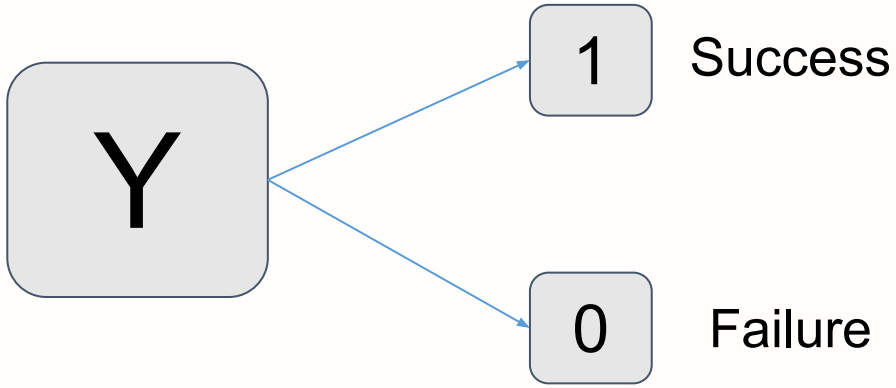
Logistic Regression

1. Binary Logistic Regression, binary label
2. Multinomial Logistic Regression, multinomial label
3. Ordinal Logistic Regression, ordinal label

What is Binary Logistic Regression ?



Remember that binary logistic regression models **the success rate/probability**

Has more interest in success event

Case	1	0
Credit scoring	Bad	Good
Churn Analysis	Turn Over	Stay
Propensity	Buy	Not Buy

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What is Binary Logistic Regression ?

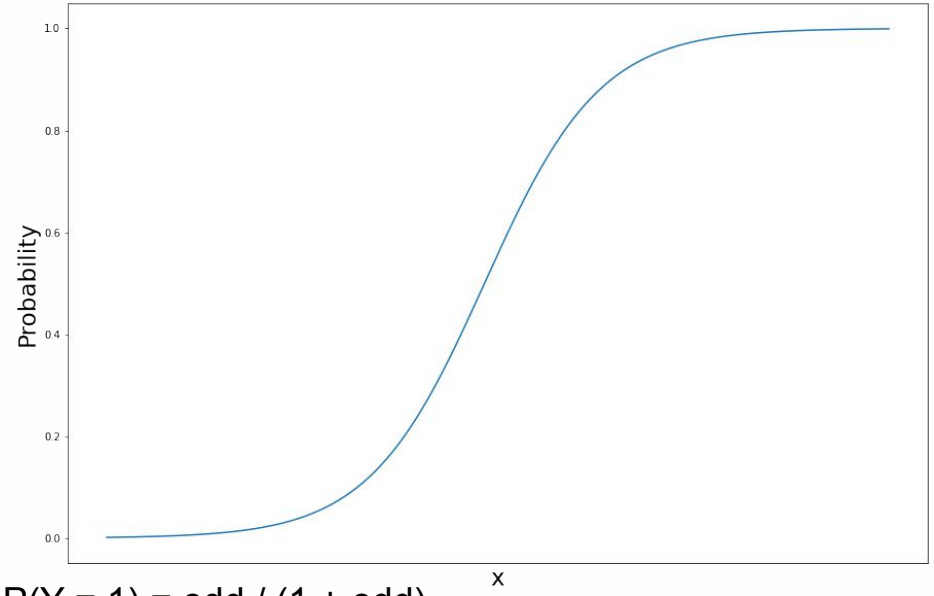
$$P(Y = 1) = \frac{\exp(\beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k)}{1 + \exp(\beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k)}$$

*exp(B0 + B1x1 + … + B1xk) is approximately equal to 2.71^(B0 + B1x1 + … + B1xk)

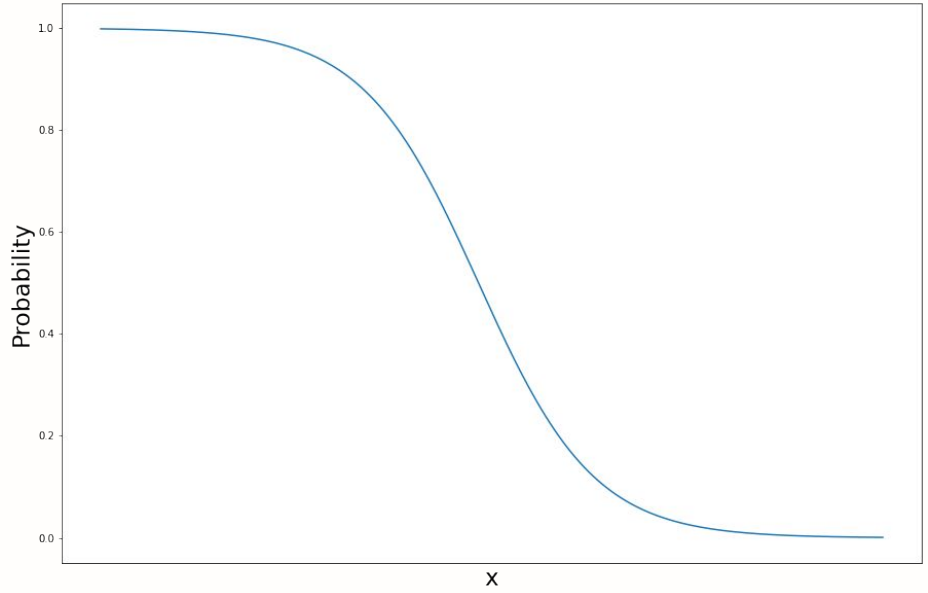
- Probability to success P(Y = 1) and Probability to fail P(Y = 0) = 1 - P(Y = 1)
- Another notation Success (+) Failed (-)
- odds = exp(B0 + B1x1 + … + B1xk), ratio between probability to success and probability to fail
- B0 B1 B2 … Bk, Regression Parameter
- x1 x2 … xk, Features/Independent Variable

Sigmoid Curve

b > 0, success rate increase when X increase



b < 0, success rate decrease when X increase



P(Y = 1) = odd / (1 + odd),

with

- 0 < P(Y = 1) < 1
- Y = dependent variable, succes (Y = 1) failure (Y = 0)
- odd = exp(a + bx)
- x = independent variable

Why do we need to use Logistic Regression?

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- Instead of linear regression, logistic regression is more suitable when the response variable are categorical
- Linear regression was designed for numerical variable
- Linear regression can give meaningless out-of-range prediction
- Linear regression gives wrong p-value when Y categorical due to violation in normality assumption and equal variance assumption (homoscedasticity)
- Logistic Regression has high interpretability, remember that purpose of the modeling is not always about prediction.

Example : Loan repayment comparison by gender

Features (x)
Gender (M/F)

x = 1 (Male)
x = 0 (Female)

$$P(Y=1) = \exp(-2.1972 + 1.086x)/(1+\exp(-2.1972 + 1.086x))$$

Default (Y=1) or Non-Default (Y=0)

Analysis

MALE:

P(Y = 1 | Male) = exp(-2.1972 + 1.086 (1))/(1+exp(-2.1972 + 1.086 (1))) = 0.25

P(Y = 0 | Male) = 1 - P(Y = 0 | Male) = 1 - 0.25 = 0.75

Odd(Male) = 0.25/0.75 = ⅓, men is 3 times less likely to default

FEMALE:

P(Y = 1 | Female) = exp(-2.1972 + 1.086 (0))/(1+exp(-2.1972 + 1.086 (0))) = 0.1

P(Y = 0 | Female) = 1 - P(Y = 0 | Female) = 1 - 0.25 = 0.9

Odd(Female) = 0.1/0.9 = 1/9, women is 9 times less likely to default

Odds-Ratio (OR)

- Odds-ratio is used to interpret logistic regression
- Odds-ratios indicate how likely a successful event is to occur in one condition compared to other conditions

Example:
Odds-Ratio = Odd(Male)/Odd(Female) = 3, Men have three times greater tendency / risk to default than women

How To Interpret Bi

In binary logistic regression, If a unit observation with Xi = c and another unit observation with Xi = d. Odd ratio between those unit observations are :

OR = exp(Bi (c-d))

for c > d :

- if Bi > 0, then OR > 1
- if Bi = 0, then OR = 1
- if Bi < 0, then OR < 1

How To Interpret Bi

When interpret Bi, it is assumed that no changes in another variable

Binary logistic regression requires no multicollinearity between independent variables

It is not recommended to interpret outside range of interval

if OR > 1, c > d :

Success rate increase when Xi increase

Unit observations which have Xi = c have OR times more likely to achieve success event than unit observations which have Xi = d. where OR = exp(Bi(c-d)).

if OR < 1, c > d:

Success rate decrease when Xi increase

Unit observations which have Xi = d have 1/OR times more likely to achieve success event than unit observations which have Xi = c. where OR = exp(Bi(c-d)).

Example : Loan repayment comparison by Age

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Features (x)
Age

P(Y=1) = Odd(age)/(1+Odd(age))

Default (Y=1)

or

Non-Default (Y=0)

age (20 - 56 year)

Odd(age) = exp(0.3669 - 0.0411age)

Analysis

Age	Odd(Age)	Prob(Age)
20	0.6343	0.3881
21	0.6088	0.3784
22	0.5843	0.3688
...	...	
25	0.5165	0.3406
...	...	
30	0.4205	0.2960
...	...	...
56	0.1444	0.1262

P(Y=1) = Odd(age)/(1+Odd(age)), with
Odd(age) = exp(0.3669 - 0.0411age)

OR = exp(B-age (c-d))

c = 38
d = 20
OR = exp(-0.0411*18) = 0.4772 < 1

odd(20)/odd(38) = 2.095
odd(21)/odd(39) = 2.095
odd(22)/odd(40) = 2.095
…
odd(38)/odd(56) = 2.095

Interpretation, OR < 1:

Probability to default decrease when age increase
people with age 20 (mention the d first) have about 2.095 times more likely to default than people with age 38.

Analysis

Age	Odd(Age)	Prob(Age)
20	0.6343	0.3881
21	0.6088	0.3784
22	0.5843	0.3688
...	...	
25	0.5165	0.3406
...	...	
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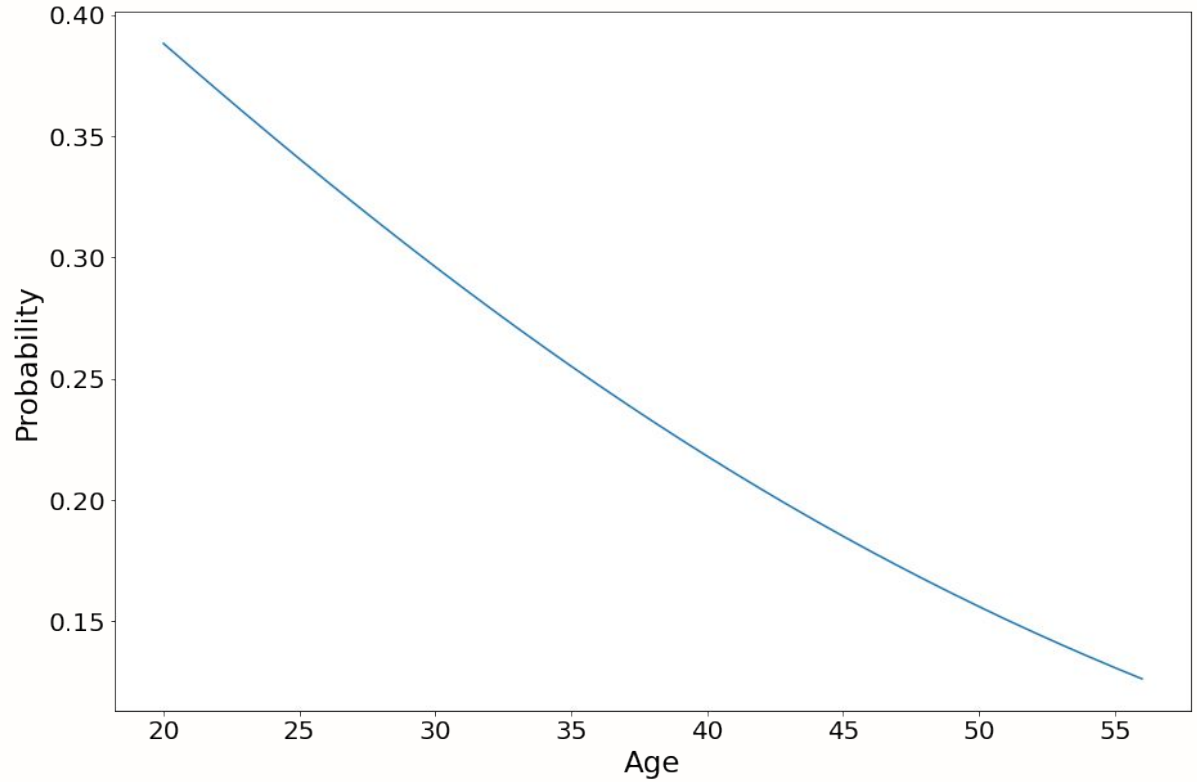
...	...	...
56	0.1444	0.1262



Log-Likelihood Ratio Test (LLR-Test)

- LLR-Test in Logistic Regression is analogous to F-Test in Linear Regression
- LLR-Test check for overall significance of multiple regression model.
- LLR-Test checks if there is a statistically significant relationship between Y (dependent variable) and any of the independent variables

Hypothesis:

$$H_0 : \beta_1 = \beta_2 = ... = \beta_k = 0$$

$$H_A : \text{Not all } \beta \text{ values are zero}$$

Test Statistics : Log Likelihood Ratio

Rejection Criteria : P-value ≤ α (two-sided)

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Wald Test

- Wald-Test in Logistic Regression is analogous to T-Test in Linear Regression
- Wald-test checks if there is a statistically significant relationship between Y (dependent variable) and each of the independent variables

Hypothesis:

Ho : **Bi** = **0**

Ha : **Bi** ≠ **0** (two sided)

Bi > 0 or **Bi** < 0 (one sided)

Test Statistics : Wald-Statistics

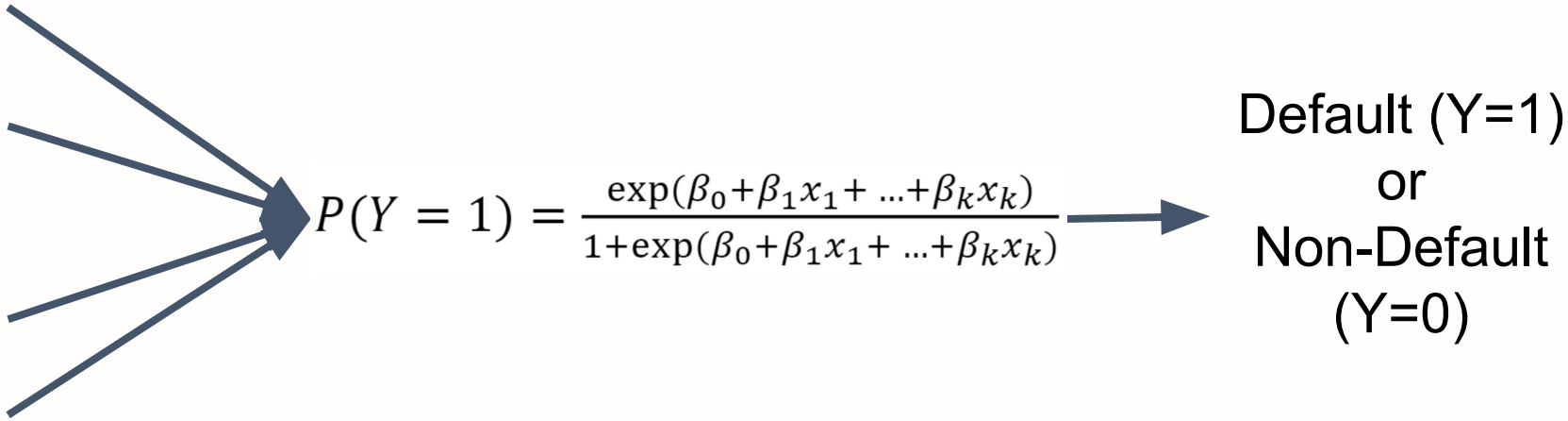
Rejection Criteria:

P-value ≤ α (two-sided)

P-value/2 ≤ α (one-sided)

Example : Credit Scoring

Features
Age
Balanced
.....
Marital Status
Gender (M/F)



https://www.nottinghamcu.co.uk/credit-score-myths-and-ways-to-improve-your-credit-score/

Example : Credit Scoring

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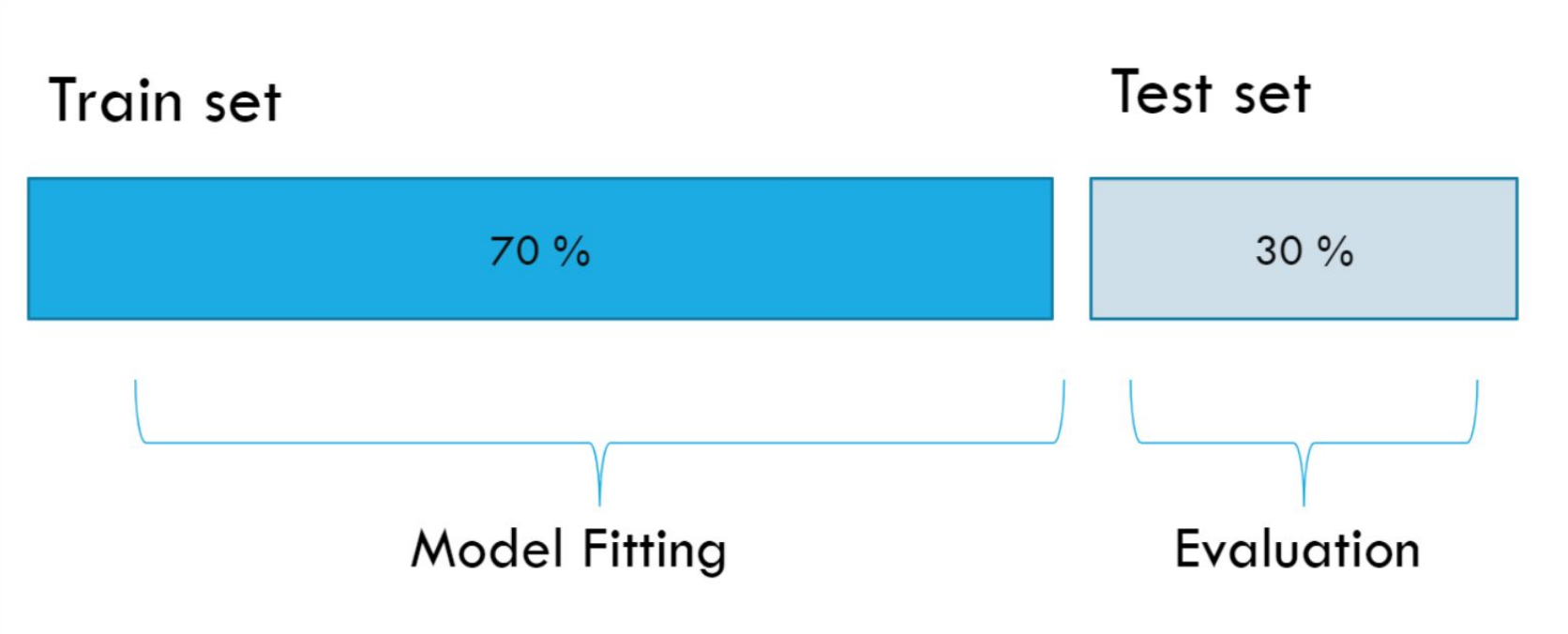
Problem	How to predict **default risk of the new applicant** so we can **allocate loan efficiently** and **increase profit** from loan ?
Data	- What is being predicted ? default risk of the new applicant - What is needed in prediction ? Demographical, Transaction behaviour, income, ect
ML Objective	Maximize (profit - potential revenue lost)
Action	Do not allocate loan to a customer when the risk is too high, higher than 50%
Value	Profit Increase

Validation Method



Measuring Performance of Classification Method

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No	Prediction	Actual
1	1	1
2	1	0
3	0	1
..	...	...
499	0	0
500	0	1

Prediction	Actual	
	0	1
0	120	23
1	27	330

Accuracy Of Prediction = (120+330) / 500 x 100%

= 90.0%

Our model will correctly predict 9 of 10 People

Python Exercise : Logistic Regression

Analyze data bankloan.csv

- Build a logistics regression model
  - Target : default
  - Features : employ, debtinc, creddebt, othdebt
- Interpret The Result
- Validate the model using accuracy in 20% testing data

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K-Nearest Neighbour

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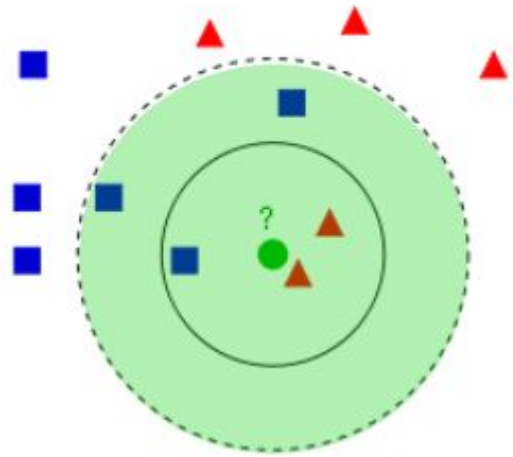
What is K-Nearest Neighbour ?

"Predict based on majority class of the top k similar observation or also called nearest neighbour"



- Works both for Classification and Regression
- Non-parametric method, knn doesn't produce a model

Why Do We Need K-Nearest Neighbor?

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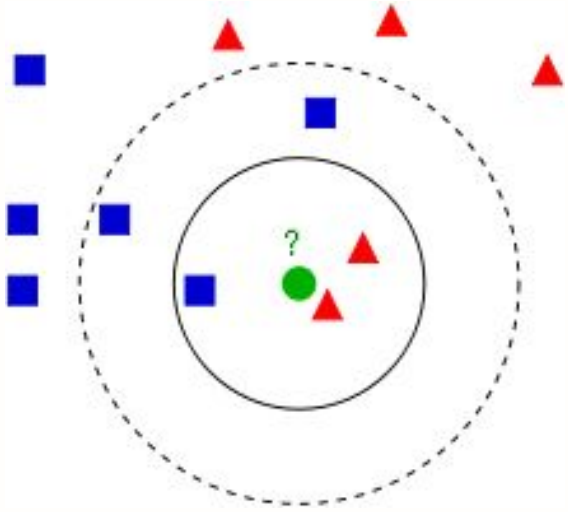
- Parametric method like linear regression and logistic regression make strong assumption about the form of the model. Ex.
  - y = a + bx + e
  - P(Y = 1) = odd/(1+odd)
- If the specified functional form is far from the truth, the model will perform poorly because of the bad prediction result.
- A nonparametric method like KNN do not explicitly assume any form of model.
- In term of prediction, it’s more flexible approach and It can capture any type of relationship.

Basic Idea

- Store/keep training data
- Classify new observation based on similarity to the observation in training data
- Use majority decision rule to classify the records



Training data

Test data (New observation)

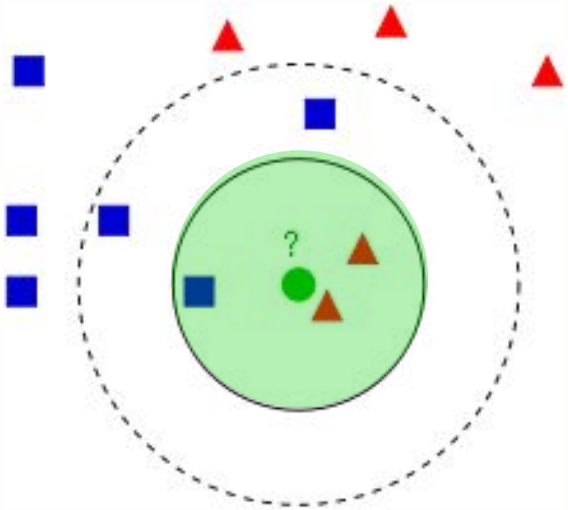
Test data will be classified as ■ or ▲ ?

(Ignore circle line for now)

Basic Idea

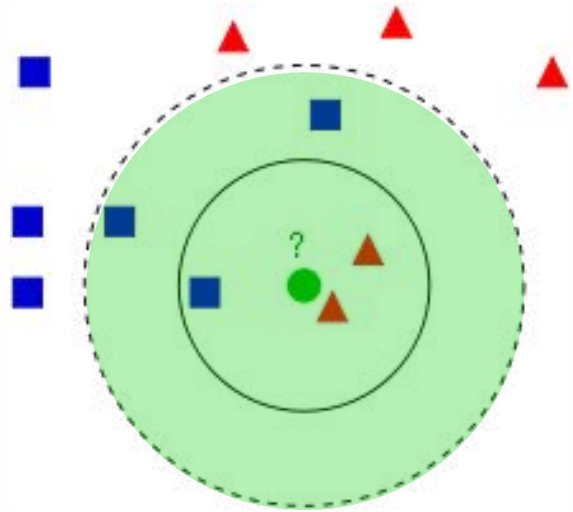
With **k=3** nearest neighbors

Test data classified into ▲

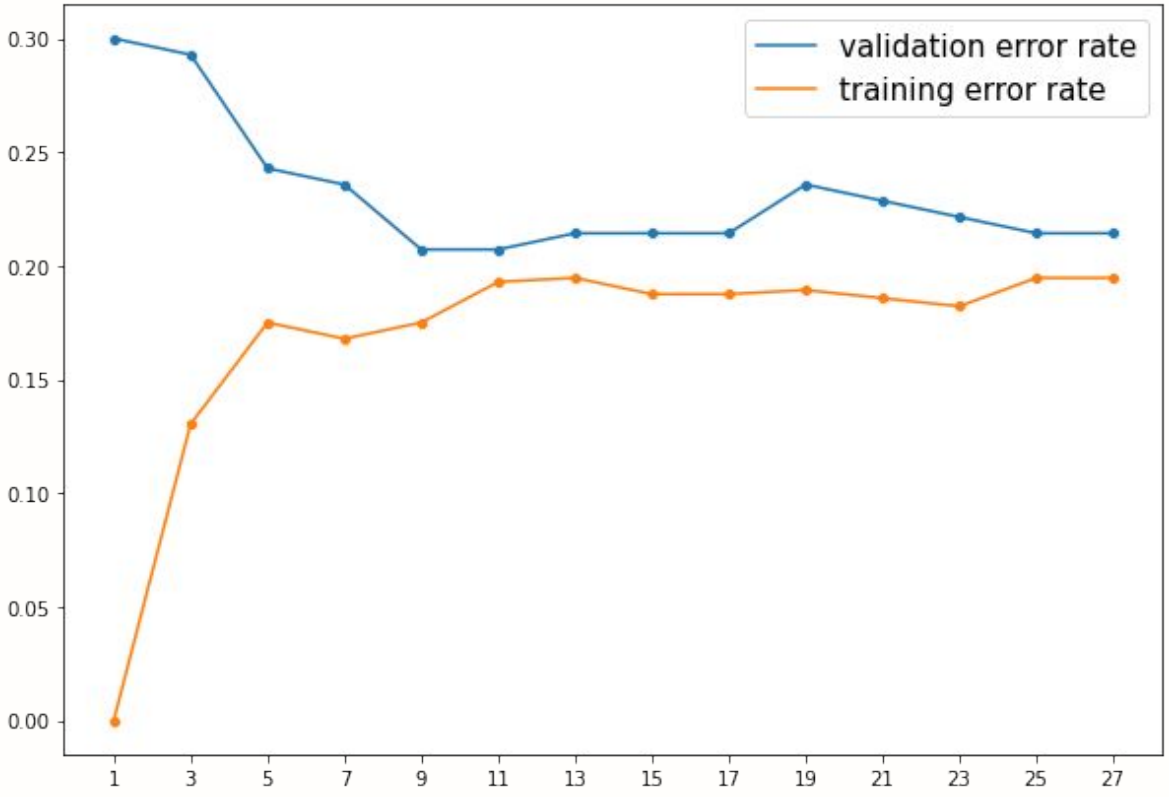


With **k=5** nearest neighbors

Test data classified into ■



How do we choose factor K?



- Tips 1: Use odd number of K
- Tips 2: Evaluate using validation data set

Best k = 9

- Error rate at K=1 can perfectly predict training sample, closest point to any data point is itself

- Our goal is to predict new data so we want good performance in validation data set
- Performance at K=1 not acceptable to predict new data
- Error rate in validation set generally decreases with increases K
- We choose k with minimum error rate in validation dataset

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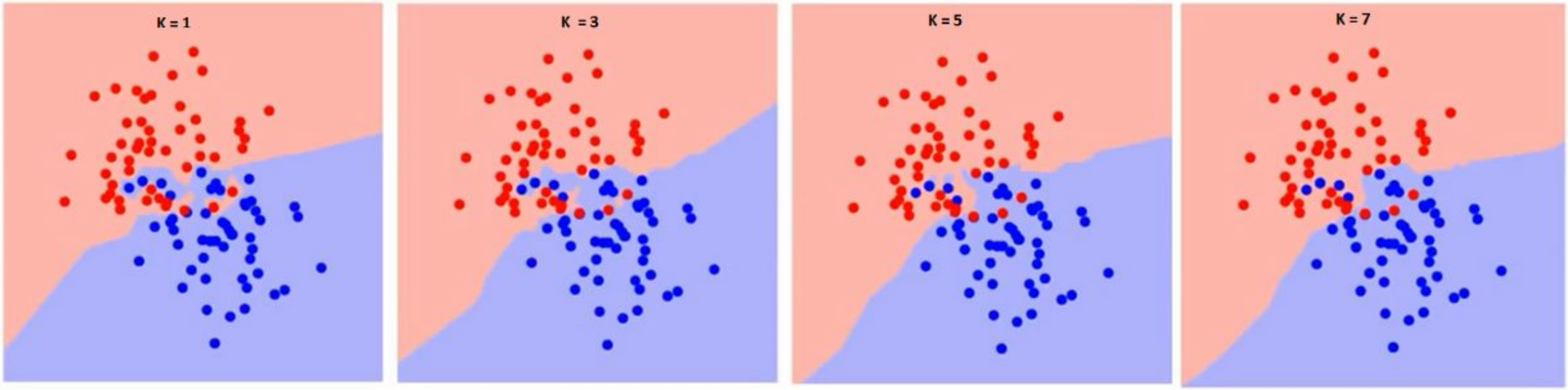
How do we choose factor K?

k=1 k=3 k=5 k=7



- Boundary becomes smoother with increase value of K
- With K increases to inf, finally becomes all-blue/all-red depending on total majority

Measuring distance 1 Dimension

- Closest neighbor is identified based on the distance
- There are several method to measure distance. The popular one is Euclidean.

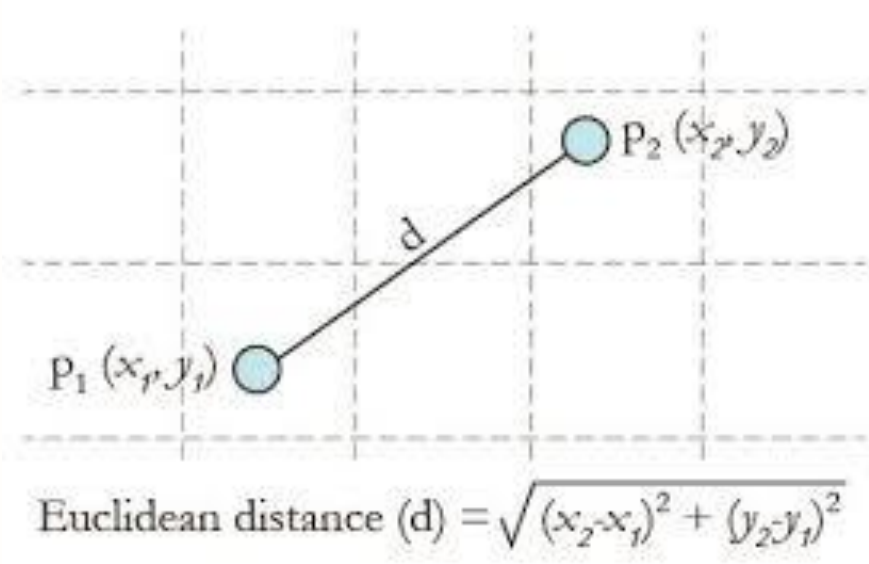
x = 1 x = 5

Simple Illustration

The distance is simply :

Distance = 5 - 1
= 4

Measuring distance 2 Dimension



Illustration

(x1, y1) = (1, 2)

(x2, y2) = (5, 4)

Euclidean distance

$= \sqrt{(5-1)^2 + (4-2)^2}$

$= \sqrt{(4)^2 + (2)^2}$

$= \sqrt{20}$

= 4.47

Measuring distance > 2 Dimension

$$Distance = \sqrt{(x2 - x1)^2 + (y2 - y1)^2 + (z2 - z1)^2 + \ldots}$$

data points	x	y	z
1	12	15	16
2	12	16	17

$$Distance = \sqrt{(12 - 12)^2 + (16 - 15)^2 + (17 - 16)^2} = 1.414.$$

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Measuring distance

- Distance calculations are performed for each data point against other data points.

data points	x1	x2	x3
1	12	15	16
2	12	16	17
3	20	13	18
4	9	14	18
5	17	15	20

data points	1	2	3	4	5
1	0				
2	1.414	0			
3	8.485	8.602	0		
4	3.741	3.7741	11.045	0	
5	6.403	5.916	4.123	8.306	0

Measuring distance

- The Closest Data Points

data points	1	2	3	4	5
1	0				
2	1.414	0			
3	8.485	8.602	0		
4	3.741	3.7741	11.045	0	
5	6.403	5.916	4.123	8.306	0

Distance Matrix

Data Points	1st closest	2nd closest	...
1	2	4	...
2	1	4	...
3	5	1	...
4	1	2	...
5	3	2	...

Issue with Euclidean Distance

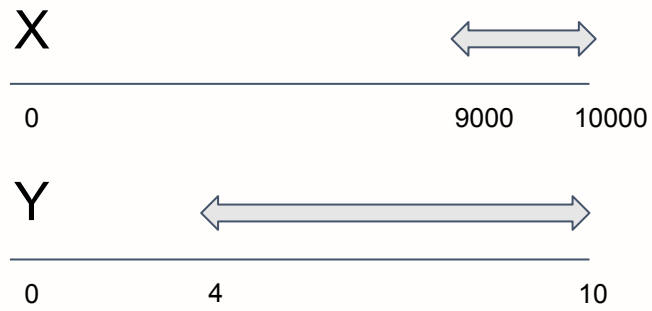
- Given X is Area with unit of hectare
- Given Y is Corn Production with unit of quintals.

X	Y
4000	5
5000	4.5
2000	3
6000	4.5
7000	4.6
8000	4
9000	10

Look at the two last data points:

- in term of area (X) the diff is 9000 - 8000 = 1000 hectare
- in term of production (Y) the diff is 10 - 6 = 4 kg

Distance contribution from X (1000) is far surpassed by contribution from Y (4) due to different scale. So, when Euclidean distance used, variable with large scale will have larger effect on the distance.



Relatively, distance contribution from X is surpassed by distance contribution from Y. So, when Euclidean distance used, there should be any treatment like scaler or normalization.

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Issue with distance

Solution to solve scale issue is **Normalization**.

- **Min-Max Scaling**

  Uses *MinMaxScaler*

  Transform to defined range

$$y = \frac{x - \min x_i}{\max x_i - \min x_i}$$

- **Standardization**

  Uses *StandardScaler*

  Transform to mean=0, sd=1

$$y = \frac{x - \bar{x}}{s}$$

Where

$\bar{x}$ = mean

s = Standard deviation

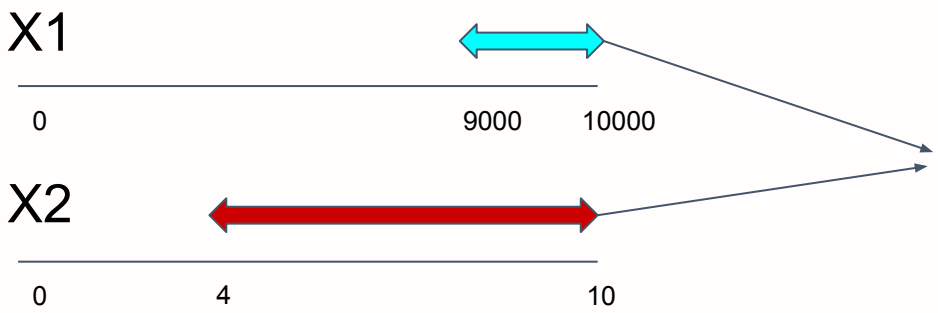
Min-Max Scaling

Bigger Contribution
"area"

Look at the two last data points as example:

Variable	diff before	diff after
area	1000 hectare	0.143
production	6 Kw	0.858

Bigger Contribution
"production"



Contribution in reality

The Process

	area	production
0	4000	5.0
1	5000	4.5
2	2000	3.0
3	6000	4.5
4	7000	4.6
5	8000	4.0
6	9000	10.0

	area	production
0	0.285714	0.285714
1	0.428571	0.214286
2	0.000000	0.000000
3	0.571429	0.214286
4	0.714286	0.228571
5	0.857143	0.142857
6	1.000000	1.000000

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Advantages and Disadvantages KNN

Advantages ?

- Able to provide decent accuracy in any situation
- Easy to learn
- Easy to program
- Training is fast

Disadvantages ?

- Need more space as the training data grow
- Low interpretability
- KNN doesn’t know which feature are actually important

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Python Exercise : KNN

Analyze data white_wine.csv

- Apply KNN Method (k = 3)
  - target : quality (quality >6 → Y = 1)
  - features : density alcohol
- Validate the model using accuracy in 20% testing data
- Apply scaling and Validate the model using accuracy in 20% testing data
- Apply scaling Choose Factor K based on accuracy:
  - K = (1, 3, 5,.., 29)

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Decision Tree Classifier

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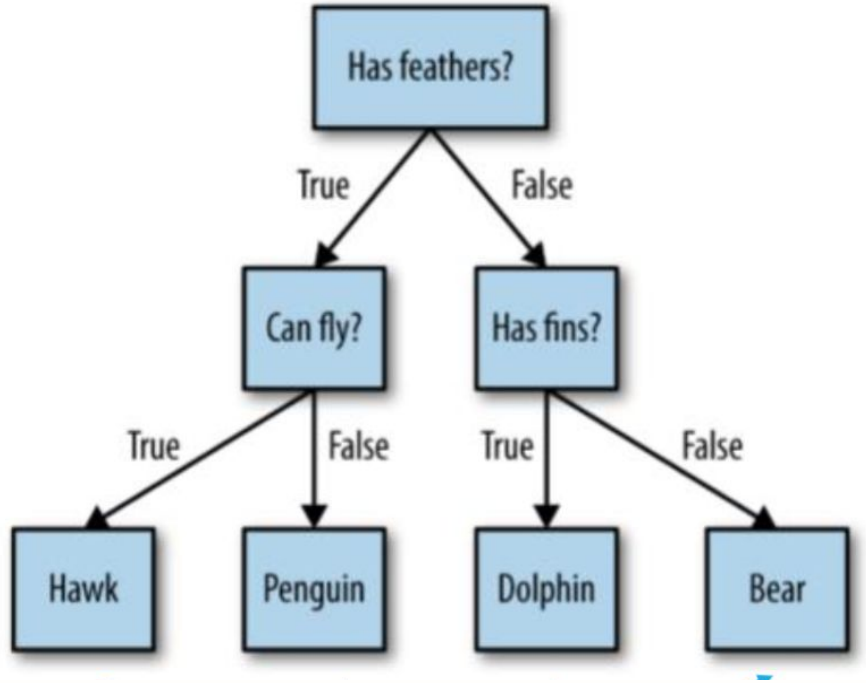
What is Decision Tree ?

Essentially, Decision Tree is a hierarchy of if/else questions, leading to a decision.

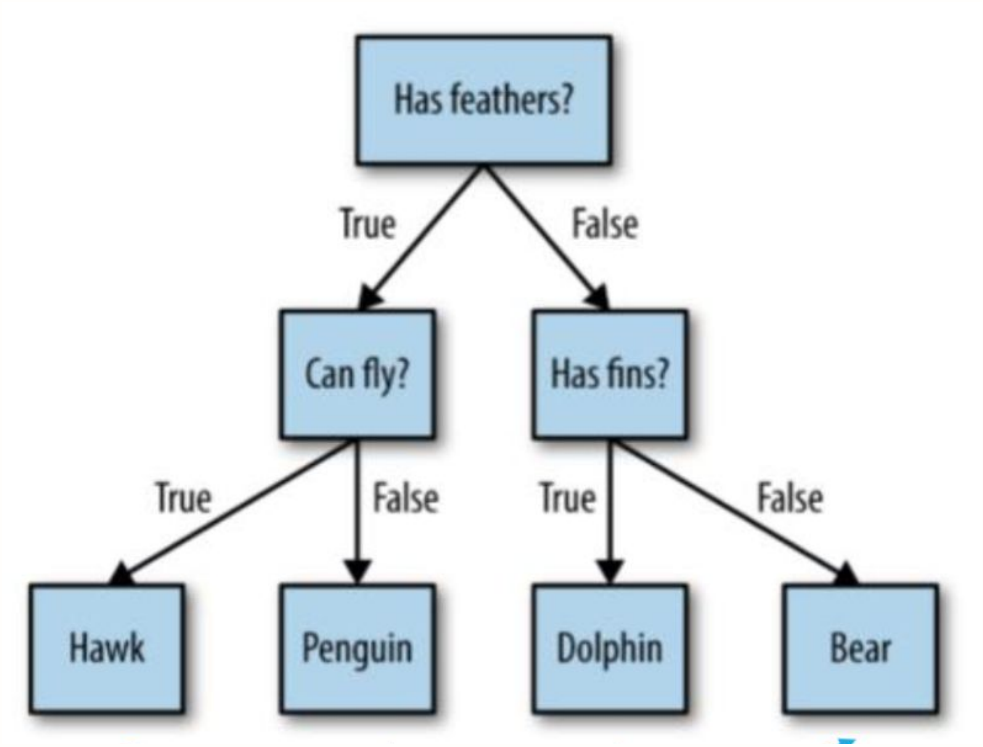


- Decision Tree is widely used ML Algorithm
- Decision Tree also can be applied to regression problem

Why do We Need Decision Tree ?

- It’s also a nonparametric approach like KNN
  - we don’t need to make any strong assumption about the form of the model
  - it’s more flexible approach to capture any type of relationship.
- You want a fast, flexible model with high interpretability

Decision Analogy



Analogies:

- Here we want to differentiate Hawk, Penguin, Dolphin. Bear by using characteristics as few as possible
- In term of classification:
  - Animals (Hawk, Penguin, Dolphin, Bear) → Target
  - Characteristics → feature
- We must be thinking what characteristics can differentiate them:
  - Among These animals, which one has feathers
    - feathers yes : Hawk and Penguin
    - feathers no : Dolphin and Bear
  - This is not enough we still need additional information
  - feather yes : add can fly or not
    - fly : Hawk
    - do not fly : Penguin
  - feather no : has fins or not
    - Has Fins : Dolphin
    - No Fins : Bear

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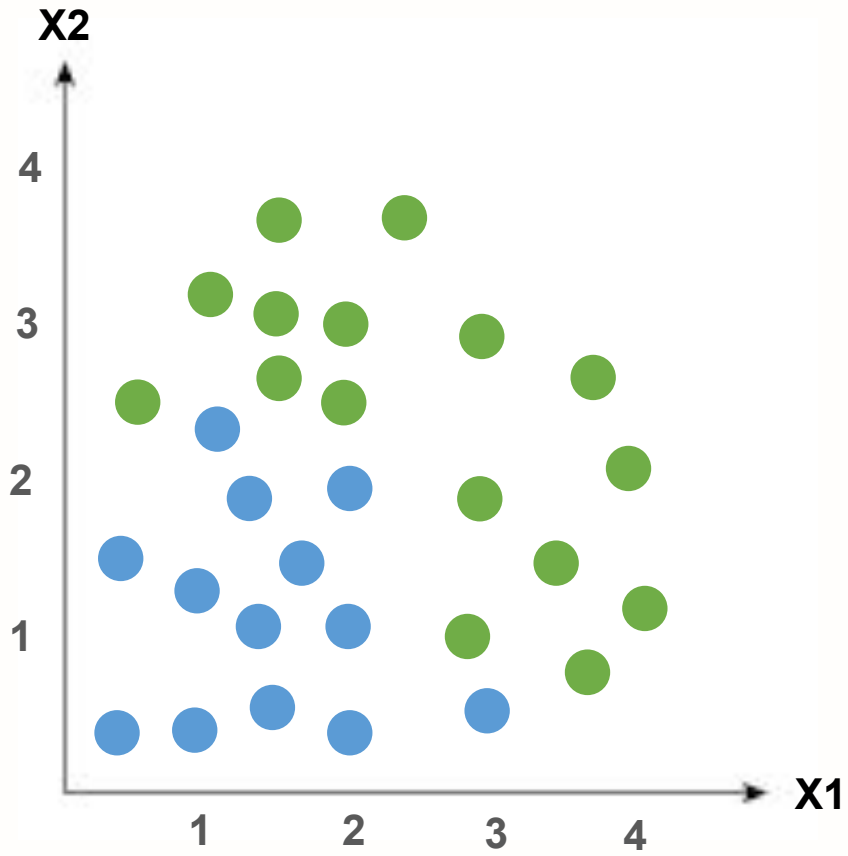
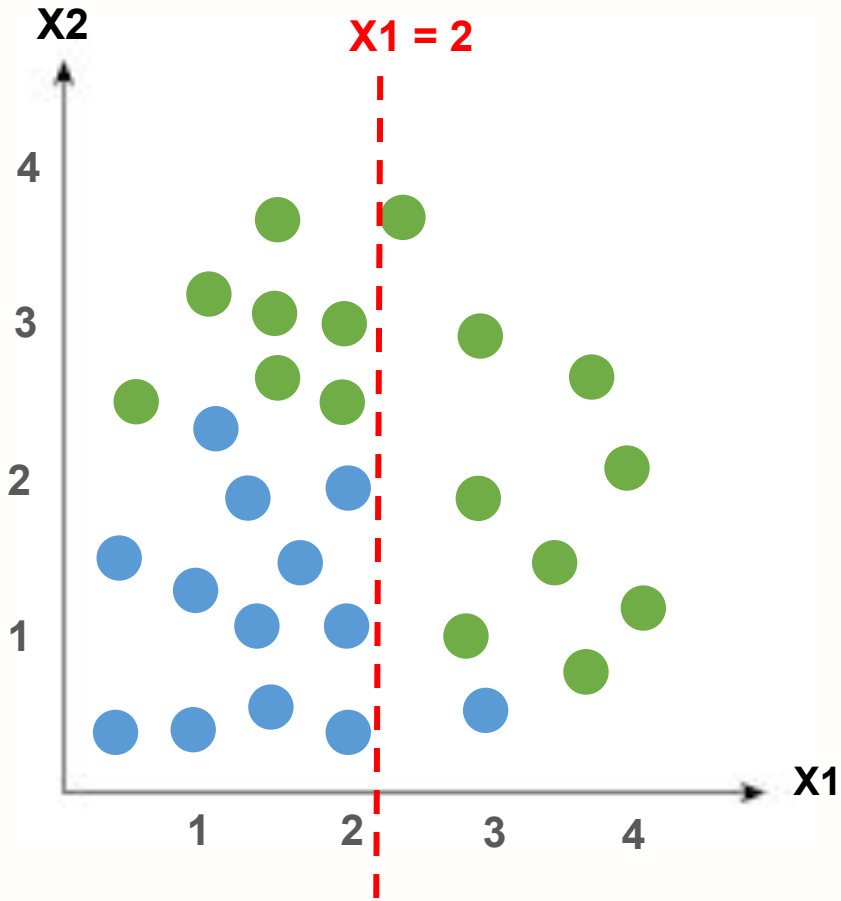
Basic Idea



- **16 obs.**
- **13 obs.**

- Find the best splitter between X1 & X2
- Best splitter is the one results most homogenous element in each class
- Splitter X1 = 2, X1 = 3, etc.

Basic Idea



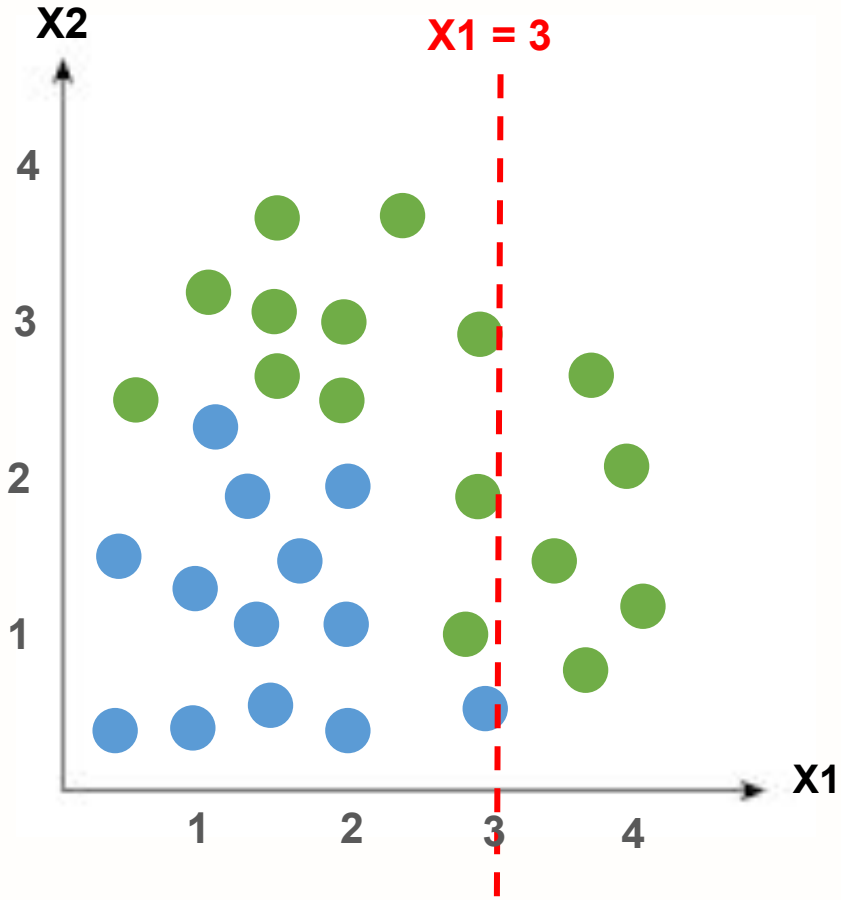
- Splitting at X1 = 2
- Split to 2 subset

Subset X1 < 2
- 7 obs.
- 12 obs.

Subset X1 > 2
- 9 obs.
- 1 obs.

How good is this split?

Basic Idea



- Splitting at X1 = 3
- Split to 2 classes

Class X1 < 3
- 11 obs.
- 13 obs.

Class X1 > 3
- 5 obs.
- 0 obs.

Is this split better?

Entropy

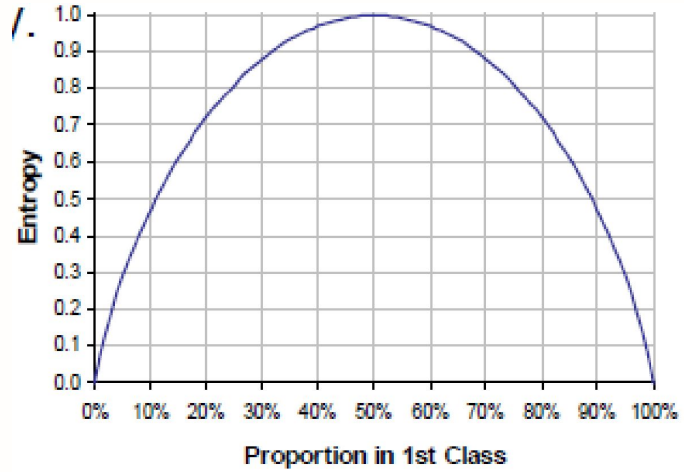
Entropy is a measure of heterogeneity

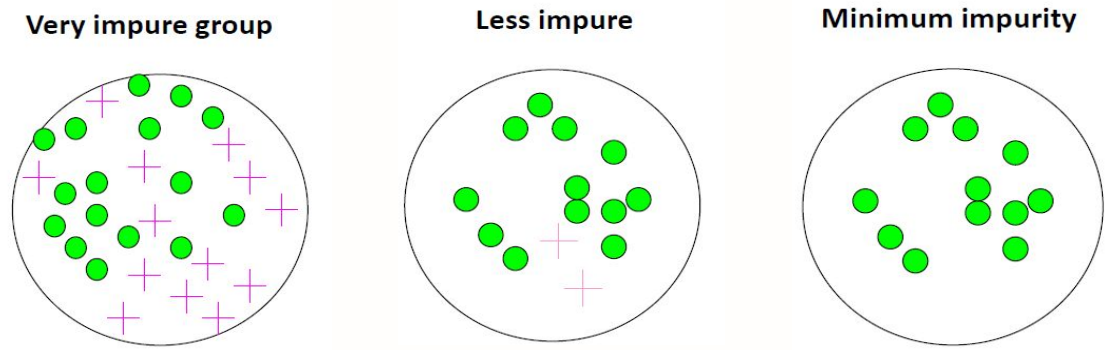
- given dataset or subset D, consist of 2 class YES and NO
- entropy :

$$E(D) = -(p \log_2 p + q \log_2 q)$$

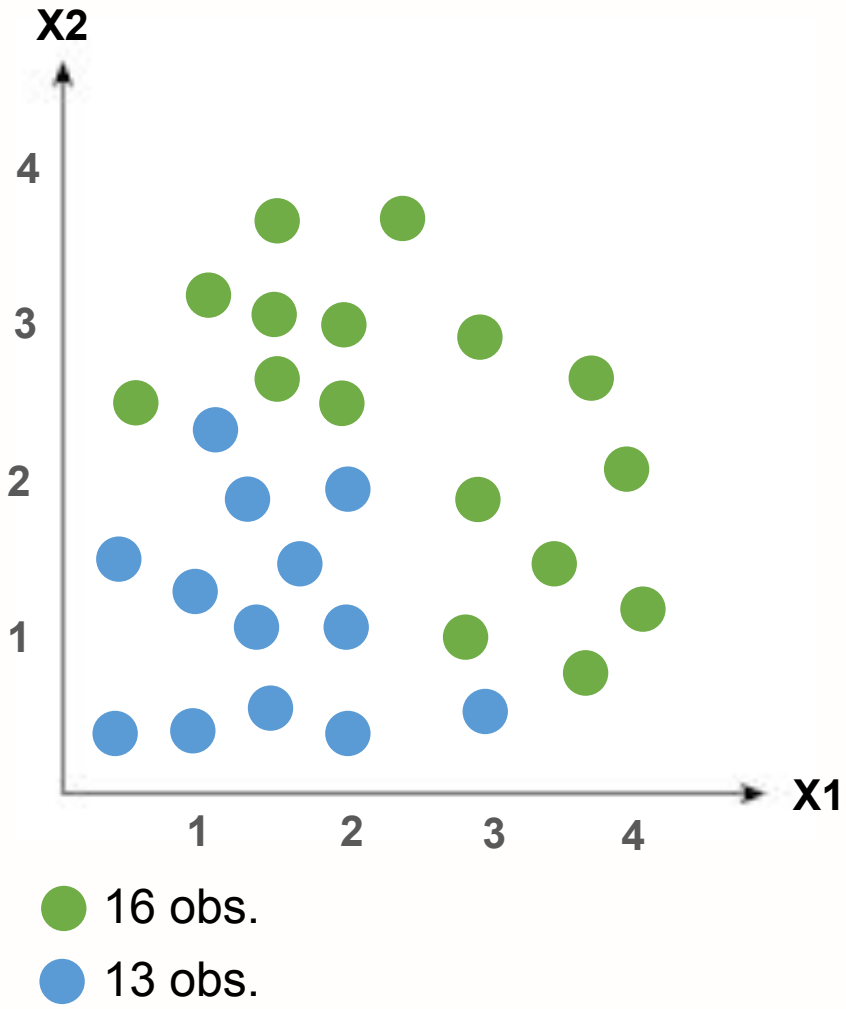
with p is YES class proportion and q is NO proportion

- Dataset or subset with all-YES or all-NO will have E(D) = 0
- Entropy will have its maximum value when p = 0.5





Entropy Dataset



Entropy for this data set is
p = green proportion = 16/29
q = blue proportion = 13/29

E(D) = - (p log2 p + q log q)
= - (16/29 log (16/29) + 13/29 log (13/29))
= 0.9922...

Information Gain

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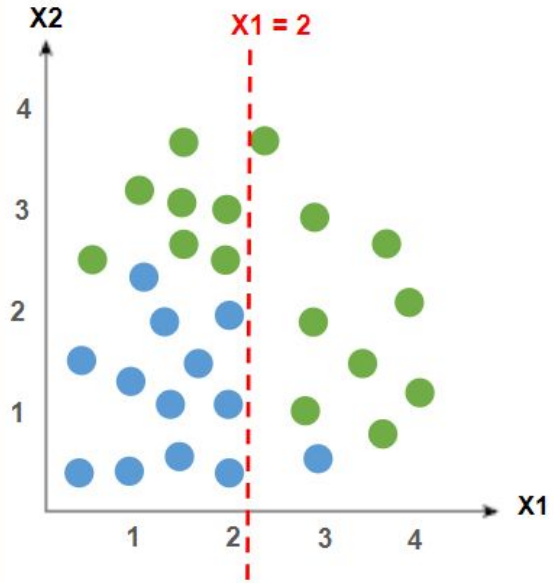
- Information gain measure the quality of a split.
- Better splitter = Higher Information Gain
- Let’s say dataset D is split into several groups D1, D2, ... , Dk based on variable V.
- Ex. X1 < 2 and X1 > 2; Single, Married and Divorce, variable marital status.
- For every Di, Entropy can be calculated as E(Di) = - pi log pi - (1-pi) log (1-pi)
- Information Gain:

Information Gain = E(D) - E(Split)

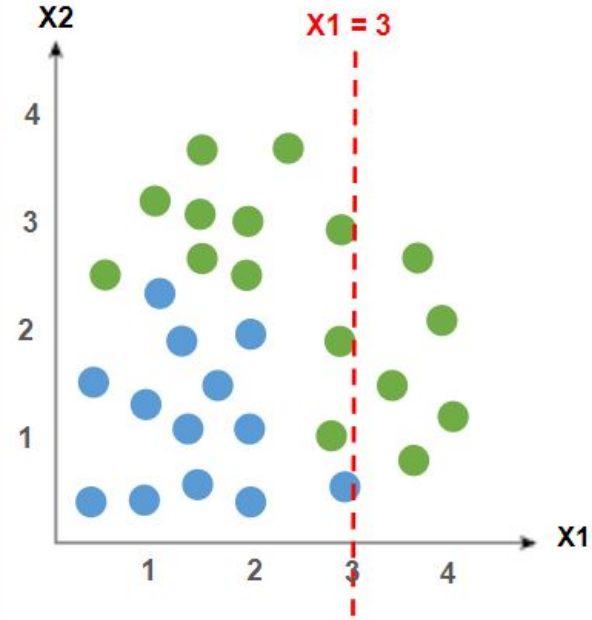
* E(split) = Weighted_Average (E(D1), E(D2), ..., E(Dk))

Back to Basic Idea

Which one is better?

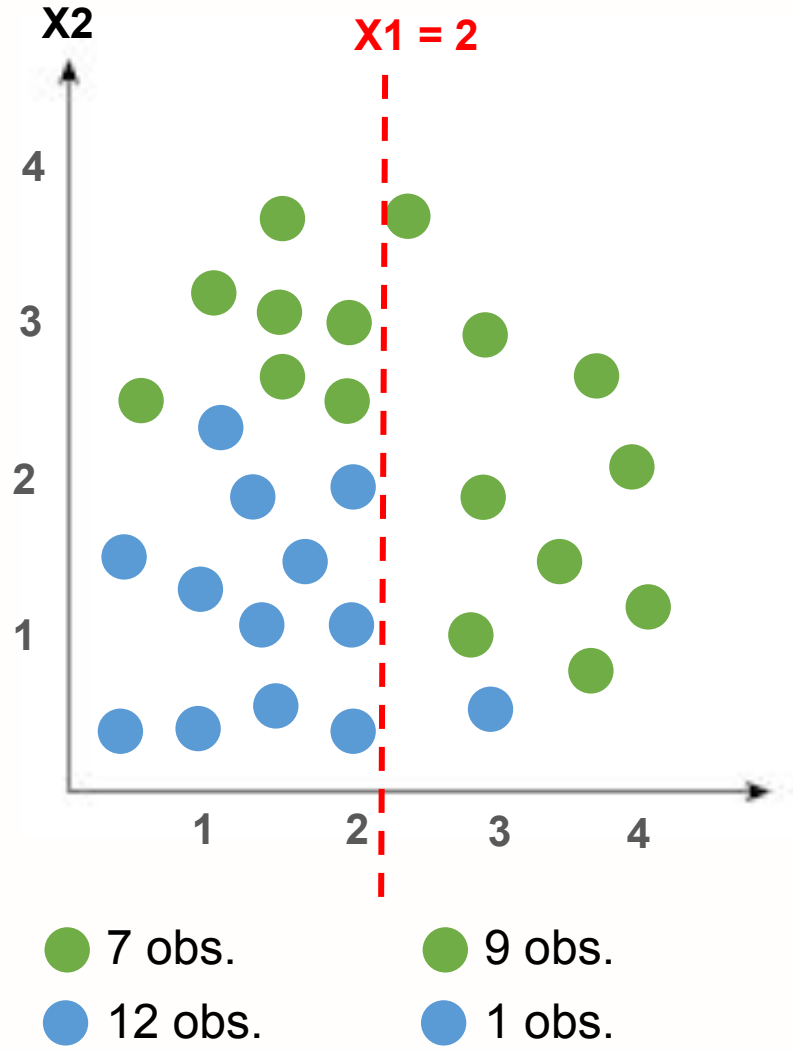


- 7 obs.
- 9 obs.
- 12 obs.
- 1 obs.



- 11 obs.
- 5 obs.
- 13 obs.
- 0 obs.

Entropy Split



X1 < 2:
p = green proportion = 7/19
q = blue = 12/19

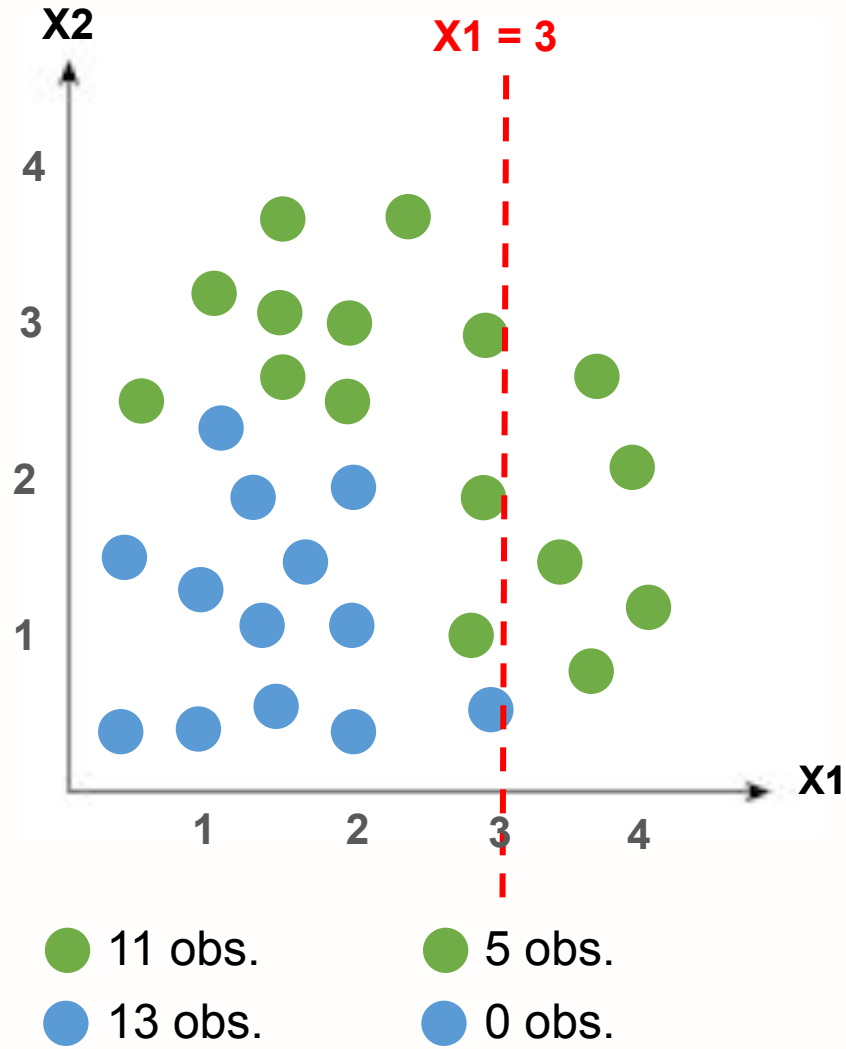
E(X1 < 2) = - (p log2 p + q log q)
= - (7/19 log (7/19) + 12/19 log (12/19)) =
0.9494...

X1 > 2:
p = green proportion = 9/10
q = blue = 1/10

E(X1 > 2) = - (p log2 p + q log q)
= - (9/10 log (16/29) + 1/10 log (1/10))
= 0.4689...

Entropy Split :
E(S) = 19/29 (0.9494...) + 10/29 (0.4689...) = 0.78377
IG = E(D) - E(S) = 0.9922... - 0.7837... = 0.2084...

Entropy Split



X1 < 3:
p = green proportion = 11/24
q = blue = 13/24

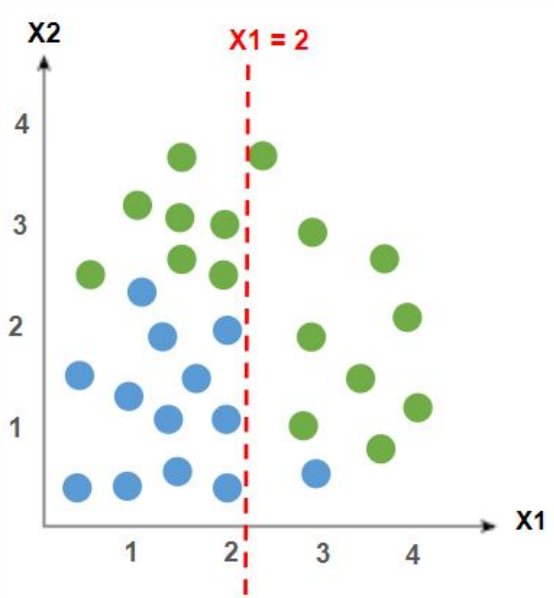
E(X1 < 3) = - (p log2 p + q log q)
= - (11/24 log (11/24) + 13/24 log (13/24))
= 0.9949...

X1 > 3:
p = green proportion = 5/5
q = blue = 0/5

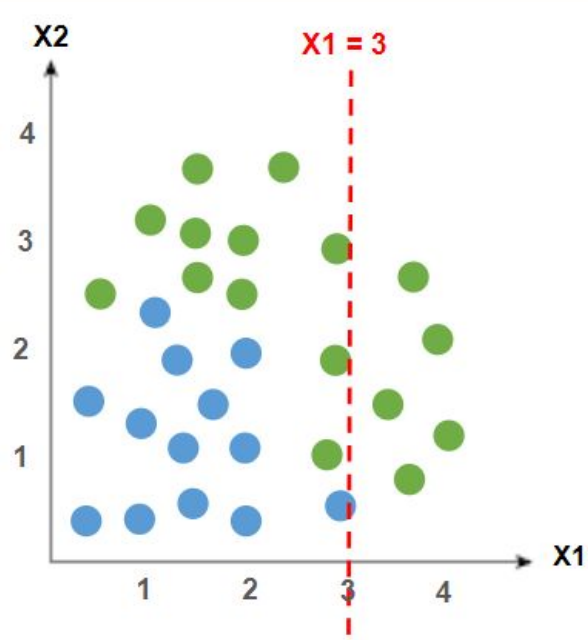
E(X1 > 2) = - (p log2 p + q log q)
= - (5/5 log (5/5) + 0/5 log (0/5))
= 0

Entropy Split :
E(S) = 24/29 (0.9949...) + 5/29 (0) = 0.8234 …
IG = E(D) - E(S) = 0.9922... - 0.8234... = 0.1688...

Information Gain



16 obs.
13 obs.



7 obs. 9 obs.
12 obs. 1 obs.

11 obs. 5 obs.
13 obs. 0 obs.

IG = 0.2084

IG = 0.1688

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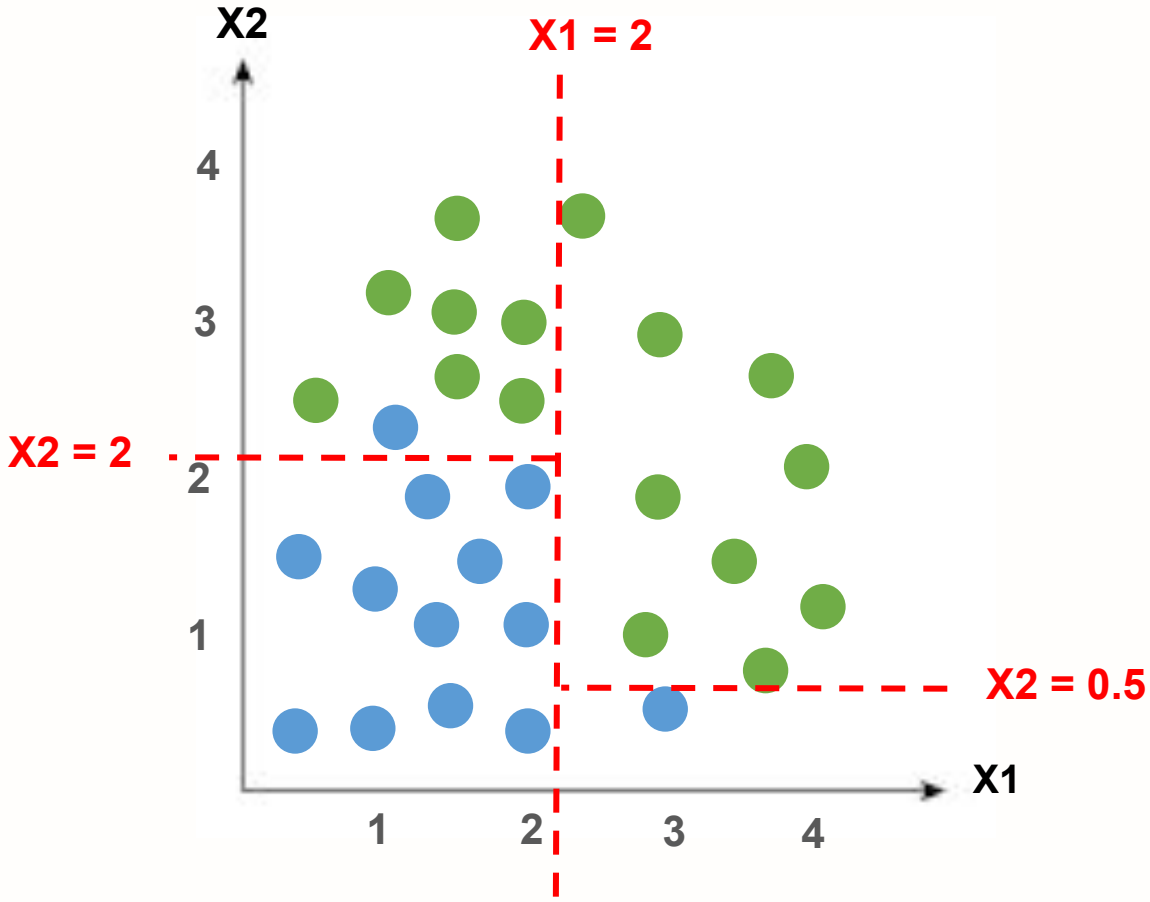
Basic Idea – Continue Splitting

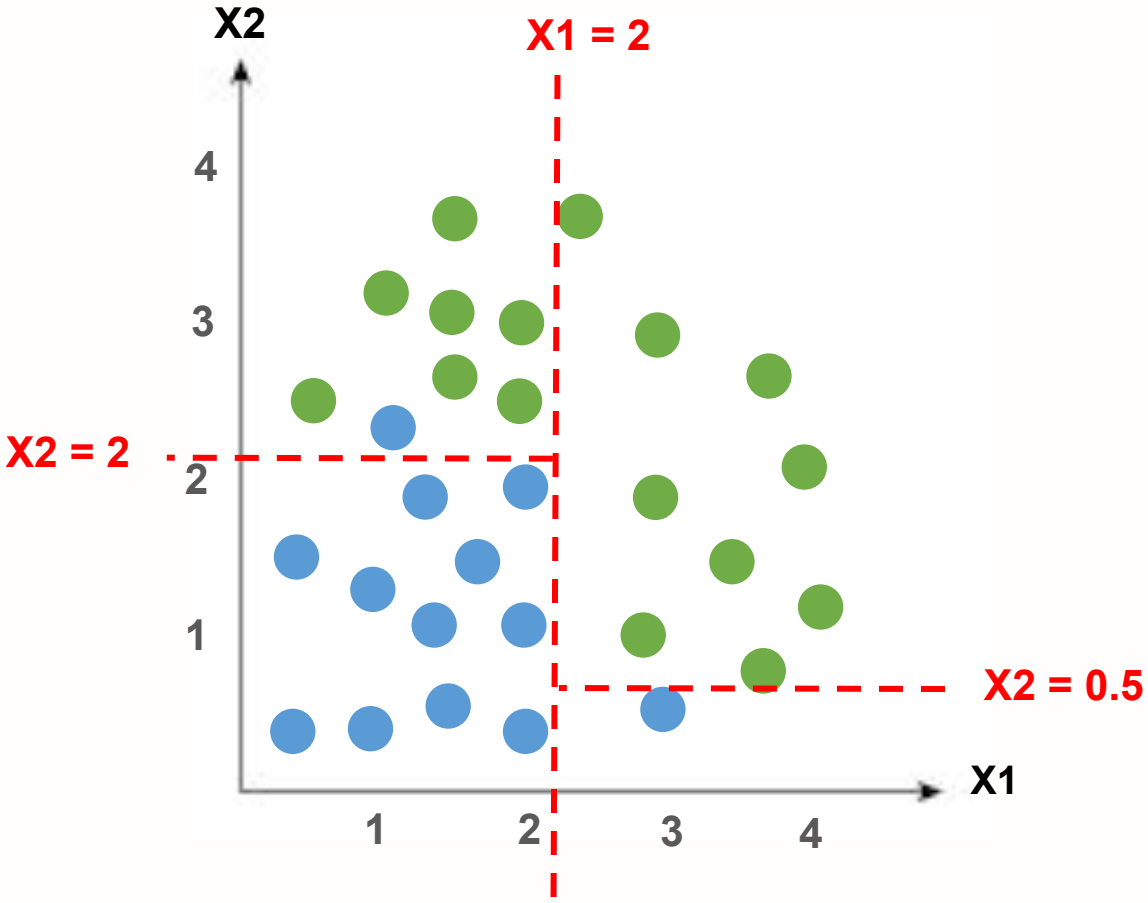


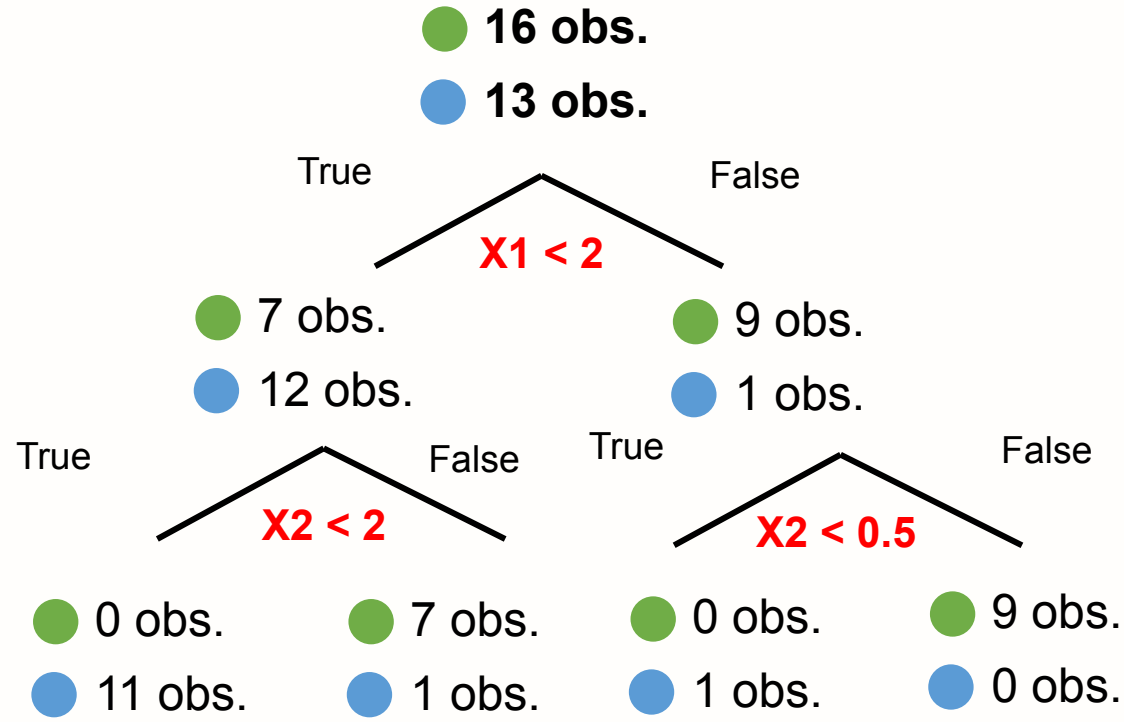
Continue splitting on each subset.

At X2 = 2 for class X1 < 2

At X2 = 0.5 for class X1 > 2

Basic Idea – Continue Splitting

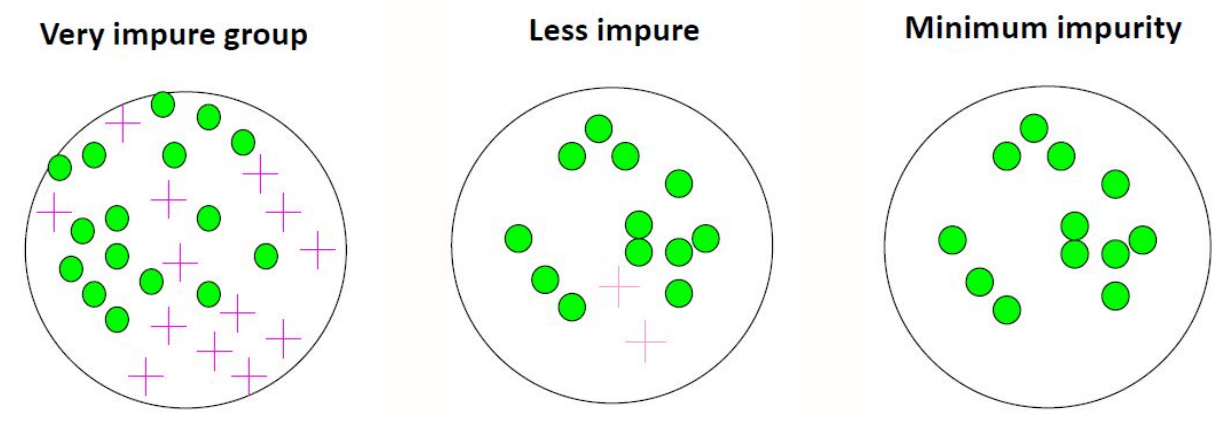


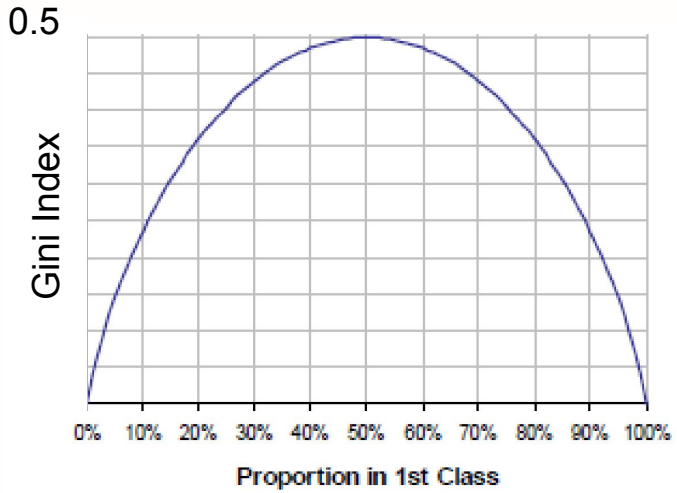


Gini Index

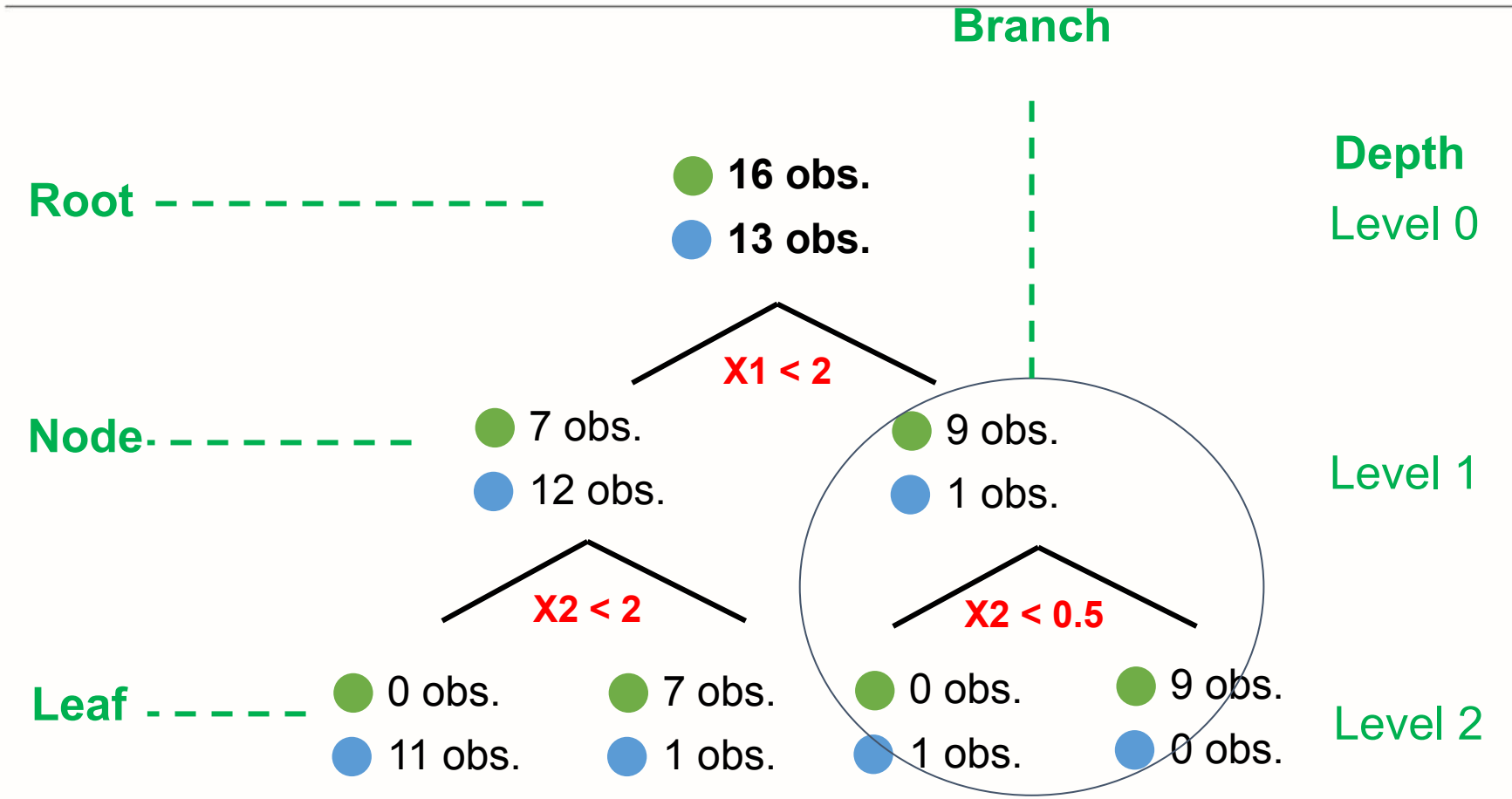
Gini is a measure of heterogeneity

- given dataset or subset D, consist of 2 class YES and NO
- gini : G(D) = p q + q p, with p is YES class proportion and q is NO proportion
- Dataset or subset with all-YES or all-NO will have G(D) = 0
- Entropy will have its maximum value when p = 0.5





Terminologies



Basic Algorithm

Perform 3 steps for every single Node and its splitting result

Step-1

- Find best splitter on each variable

Step-2

- Select best variable for splitting (based on Information Gain or Gini Impurity)

Step-3

- Perform splitting based on result on Step-2.
- Keep doing the splitting and check if the splitting should stop.

Stop-splitting Condition

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Splitting will stop if any of below conditions met

- Node contains only 1 class of response variable
- Number of observation in a node before splitting is less than pre-defined number
- Number of observation in a node after splitting is less than pre-defined number
- Tree depth has reached its maximum

There are parameters in the scikit learn to control the Tree Size

- Minimum sample of node split
- Minimum sample of leaf
- Maximum depth of tree
- Maximum number of terminal node

Advantages and Disadvantages

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Advantages

- Easy to understand
- Useful in data exploration.
- Can be visualized graphically
- Information of importance variables, variables which relates each other.
- Data type is not a constraint (works for numerical and categorical too)

Disadvantages

- Often not stable/overfitting
- Loses information of continuous numeric variable when it categorized into different categories
- Cant compete with method like bagging, random forest and boosting in many situation
- Deeper tree are harder to interpret

Python Exercise : Decision Tree Classifier

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- Analyze data white_wine.csv
- Apply Decision Tree Classification Method (max_depth = 2)
  - target : quality (quality > 6 → Y = 1)
  - features : density alcohol
- Validate the model using accuracy in 20% testing data
- Apply scaling and Validate the model using accuracy in 20% testing data
- Check the performance: is there any difference whether we applied scaling or not ?
- Check the tree: is there any difference whether we applied scaling or not ?

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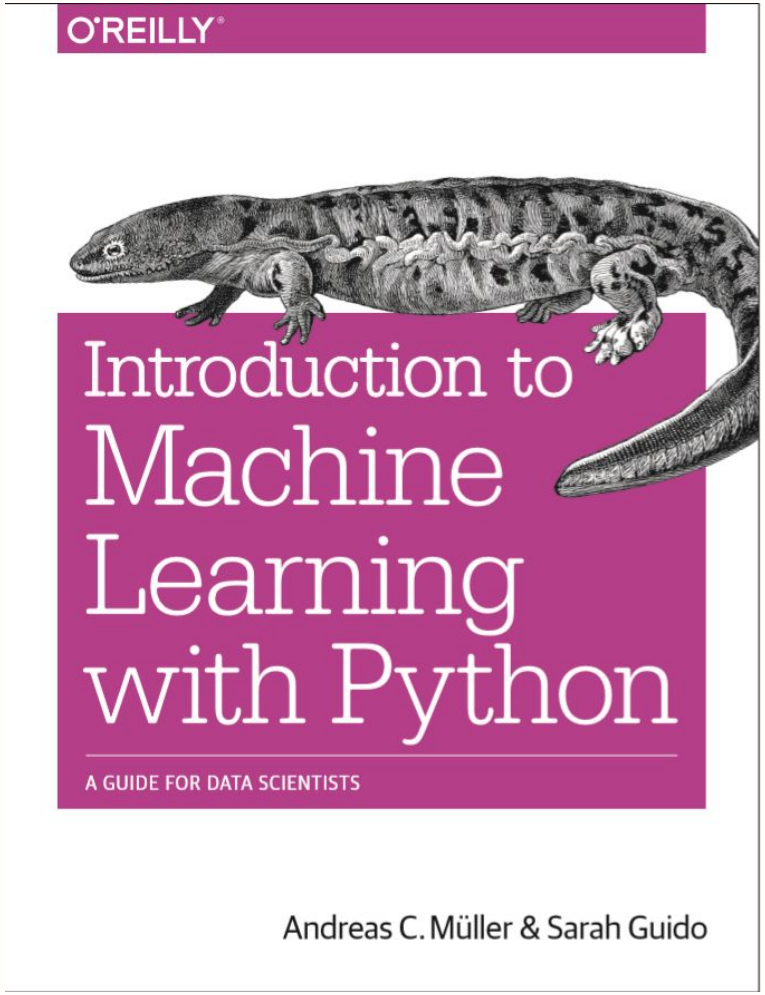
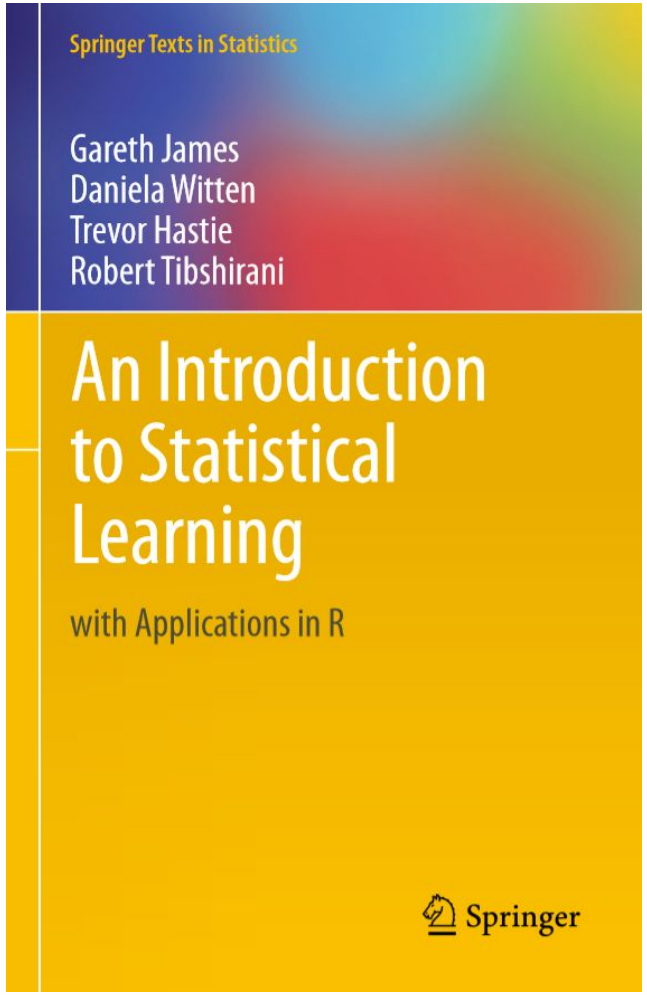
References





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