

This will create more power at once.

Pg 101

Statistics for Machine Learning

Types of statistics

- 1) Descriptive statistics \Rightarrow helps us describe or summarize data in a meaningful way. It includes
- * Measure of central tendency (mean, median, mode)
 - * Measures of dispersion (variance, standard deviation, Range, IQR)
 - * Data visualizations (Histogram, Boxplots, scatterplots)

- 2) Inferential statistics: It allows us to make predictions of generalization about a larger population based on sample data. It includes
- * Hypothesis testing
 - * Confidence Intervals
 - * Regression Analysis

- # Sampling techniques: process of selecting a subset (sample)
- 1) Simple random sampling from a larger group (population) to make conclusion about the whole ~~world~~.

Probability sampling (Random and unbiased)

- 1) Simple random sampling: Each sample is chosen randomly from a university with 100 students.
- g.: picking 100 students randomly from a university with 1000 students.

- 2) Stratified sampling: The population is divided into sub groups based on characteristics like age, gender, income etc and then randomly samples are taken from each group.

Eg:- If a company has 70% full time employees and 30% part time employees, you take accordingly to maintain the same ratio.

1/0/2

3) Systematic Sampling : Pick every k^{th} - individuals from a list after a random starting point.

Eg: Selecting every 10th customer from a store visitor list.

4) Cluster Sampling

The population is divided into groups (clusters) and entire clusters are randomly selected.

Eg:- choosing 5 random schools in a city and surveying all students in those schools.

Non-Probabilistic Sampling (Biased and non-Random)

5) Convenience sampling: Sampling people who are easily accessible.

Eg:- interviewing only people at a near by coffee shop instead of random people from the city.

6) Quota Sampling: similar to stratified sampling, but selection is not random - you choose based on convenience.

Eg:- Selecting 50 men and 50 women for a survey, but picking them without randomization.

7) Purposive (Judgemental sampling)

Selecting individuals based on researchers judgement.

8) snowball sampling

used when the population is hard to find.

Population vs Sample

(03)

Population: A population refers to the entire set of individuals. eg:- All students in India.

Sample: A sample is a smaller group selected from the population to represent it.

Variable: A variable is any characteristic, number, or quantity that can change or take different values in a dataset. It represents data that we measure or observe.

Example:-

student	Age	height	Gender	Marks('%)
A				
B				
C				

here the columns age, height, gender, marks all are variables.

Types of variables

a) Based on data type numerical

1) Quantitative variables: Variables that represent measurable numerical values.

↳ Discrete variables (countable) eg: marks, no. of

↳ continuous variables (infinite values within range)

g:- height, weight, temperature.

2) Qualitative values (Categorical): Variables that represent categories or group. (not members)

↳ Nominal variables (no natural order) g:- M/F, blood groups

↳ Ordinal variables (have a meaningful order)

eg:- Highschool < Bachelor < Masters

b) Based on Role analysis

1) Independent Variable (Predictor): A variable that causes or influences changes in another variable.

eg:- In a study on weight LBM, diet and exercise are independent Variable

2) Dependent variable: A variable that depends on a weight loss, diet and cause infinitesimal change in another variable depends on or is affected by the independent variables. $y = mx + c \Rightarrow y = \text{dependent variable}$ 04

Variable measurement scale

A variable measurement scale defines how data is categorized, ordered and mathematically processed. It determines the type of statistical analysis we can perform.

Type

1) Nominal Scale:- (categorical, no order)

→ Represent categories without a natural order.

→ No mathematical operation (like addition and subtraction) can be performed.

→ only counting and grouping are meaningful.

Eg:- Gender (Male, Female), Blood Type (A, B, AB, O), Country (India, USA, Germany)

Allowed operation:- Counting, Mode, Frequency.

Eg:- Number of students in India.

2) Ordinal Scale (categorical, ordered)

→ Represents categories with a meaningful order, but the difference between them are unknown.

Eg:- Education level (high school < Bachelor < Masters)

Customer satisfaction (Poor < average < good < excellent)

Military ranks (Private < Sergeant < Captain)

→ we rank the values but can't perform precise arithmetic.

Allowed operation: Counting, Mode, Median, ranking.

Example operation: what is the most common customer satisfaction level.

3) Interval scale:

→ Represents numerical values with equal intervals b/w them.

- Addition and subtraction are meaningful, but ratios are not.
- NO True zero (zero doesn't mean nothing)

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Examples

Temperature (0°C or 0°F) → (0° ≠ no temperature, it's just a reference point)

IQ Score → An IQ of 100 is not "twice as intelligent as 50")

Year (2020, 2021, 2022) → There's no "year zero".

Allowed operations: Addition, subtraction, mean, median, mode.

Example questions: "what is the average temperature in January?"

4) Ratio Scale (Numerical, True zero exists)

- Like the interval scale, but with a true zero (zero means the absence of quantity)
- All mathematical operation (addition, subtraction, multiplication, division) are possible.

Example:

1) Height (10 cm means twice height) and same with others like weight, salary, distance etc.

Allowed operation: All mathematical operation (mean, median, mode, ratios, percentages)

Example questions: A person earning \$50,000 earn twice as much as someone earning \$25,000

Measure of Central Tendency

is used to describe the center of dataset.

1) Mean (Average)

The mean is the sum of all values divided by the total number of values.

$$\text{Mean} = \frac{\sum x}{N}$$

where x = individual values

N = total number of values.

(6b)

Eg:- age of 5 student = 18, 20, 22, 24, 26

$$\text{Mean} = \frac{18 + 20 + 22 + 24 + 26}{5} = 22$$

2) Median (middle value)

The median is the middle value when the data is arranged in ascending order.

If N is odd \rightarrow median is the middle value.

If N is even \rightarrow the median is the average of the two middle values.

Eg:- 18, 20, 22, 24, 26 \Rightarrow median is 22

Eg:- 18, 20, 22, 24 \Rightarrow median is $(20+22)/2 = 21$

3) Mode (Most Frequent element)

The mode is the most frequently occurring value in a data set.

Eg:- Test scores 85, 90, 92, 85, 88, 85, 91, 92, 92

\rightarrow 85 appears 3 times

\rightarrow 92 appears 3 times

\rightarrow other numbers appear only once.

Mode = 85 and 92 (Bimodal dataset)

Measure of Dispersion in statistics

Measures of dispersion describe how spread out or scattered data values are in a dataset. They help us understand variability in the data.

D) Range - It is the difference between maximum and minimum values in the dataset.

$$\text{Range} = \text{Max.}(x) - \text{Min.}(x)$$

2) Variance: Variance tells how far each value is from the mean, on average.

$$\sigma^2 = \frac{\sum (x_i - \mu)^2}{N}$$

(67)

x_i = individual data point

μ = mean

N = number of values.

$$\therefore \mu = \frac{\sum x_i}{N}$$

1) deviation from the mean is $x_i - \mu$

2) squaring the deviation $(x_i - \mu)^2 \Rightarrow$ this will ensure all deviations are positive.

$$\therefore \text{Mean} = \frac{\sum (x_i - \mu)^2}{N}$$

$$\text{hence } \sigma^2 = \frac{\sum (x_i - \mu)^2}{N}$$

#3) Standard deviation: It is a key concept in statistics that measure how much data points deviate from the mean.

→ It tells us how spread out the data is from the average.

→ A small standard deviation means data is closer to the mean (less spread)

→ A large standard deviation means data is widely spread.

$$S.D = \sqrt{\sigma^2} = \sqrt{\frac{\sum (x_i - \mu)^2}{N}}$$

Intuition behind standard deviation

Imagine two classes taking a math test

Student	Class A Score	Class B Scores
1	85	60
2	87	90
3	88	55
4	86	95
5	84	90

$$\text{Class A mean} = \mu_A = 86$$
$$\text{Class B mean} = \mu_B = 70$$

(b3)

$$\text{Class A variance} = \sigma_A^2 = 2$$
$$\text{Class B variance} = \sigma_B^2 = 350$$

$$\text{S.D of Class A} = \sigma_A \approx 1.41$$
$$\text{S.D of Class B} = \sigma_B \approx 18.71$$

Interpretation

For class A

- Scores are closely packed around 86
- Students performed similarly with less variation in marks.

For class B

- Scores are widely spread from the mean (70)
- Some students scored very high, while others scored very low.

larger S.D \Rightarrow more spread out data.

smaller S.D \Rightarrow more consistent data.

#4) Interquartile Range (IQR)

Interquartile range is the measure of how spread out the middle 50% of dataset is. It helps to find the range of values that are not affected by extreme outliers.

Example

Score of 10 student. \Rightarrow 10, 20, 25, 30, 35, 40, 45, 50, 55, 60

Step 1 \Rightarrow In ascending order

Step 2 \Rightarrow Find Q_1 (1st quartile) \rightarrow This is the 25th percentile
(middle of the lower half)

\rightarrow lower half: [10, 20, 25, 30, 35]

$\rightarrow Q_1 = 25$ (median of lower half)

Step 3: Find Q_3 (3rd quartile) \rightarrow This is the 75th percentile (middle of the upper half):
 → upper half [40, 45, 50, 55, 90] (pg)
 → $Q_3 = 50$ (median of the upper half)

Step 4: Compute IQR

$$IQR = Q_3 - Q_1 = 50 - 25 = 25$$

This means the middle 50% of scores lie between 25 and 50, ignoring the extreme values like 10, and 90

Probability distributions

1) Normal or Gaussian distribution

It is a continuous prob. distribution that describes the data that divers around a mean (average) value. The normal distribution is defined by its probability density function (P.D.F), which gives probability density at a particular value x .

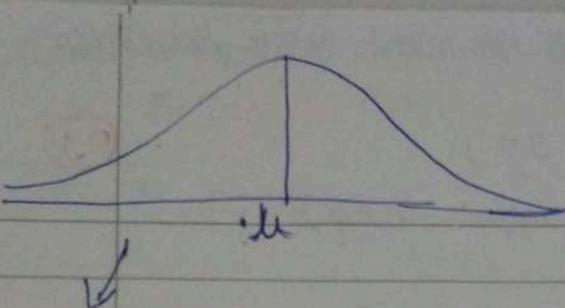
$$f(x) = \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

\because the normal distribution is continuous, the probability of any single exact value is zero, instead we look at the probability of x being within a small range dx , which is given by

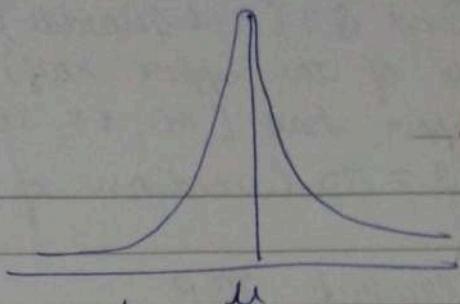
$$P(a \leq x \leq b) = \int_a^b f(x) dx$$

Higher $f(x)$ value $\rightarrow x$ is more likely to occur.
 Lower $f(x)$ value $\rightarrow x$ is less likely to occur.
 Peak at $x=\mu \Rightarrow$ The most frequent or most likely value in the mean.

This function integration at any a, b will give an approximate probability that x falls within the range a, b .

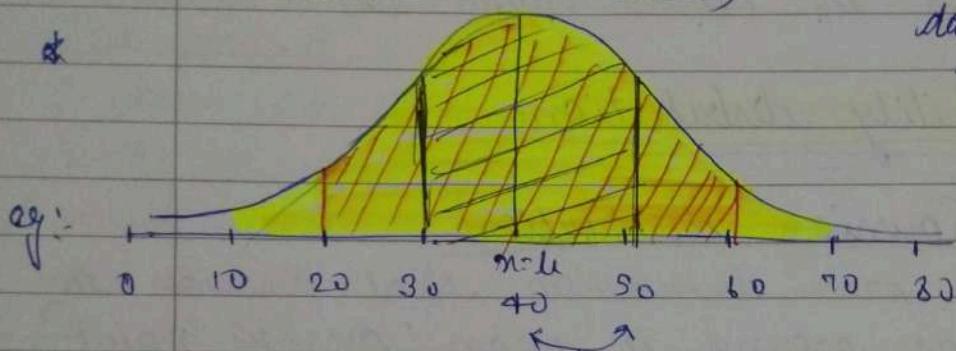


high standard deviation (mean maximum data are more scattered)

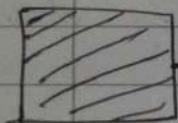


low standard deviation.

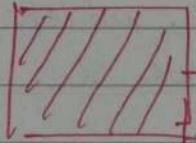
means maximum data lies near mean.



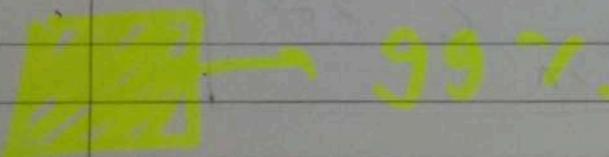
one standard deviation (i.e., 10)



→ 65 %.



→ 95 %.



→ 99 %.

→ Bell shaped curve

→ Mean = Median = Mode

→ $\pm 1\text{SD}$ covers $\rightarrow 68\%$, $\pm 2\text{SD}$ covers $\rightarrow 95\%$, $\pm 3\text{SD} \rightarrow 99.7\%$.

→ Total probability = 1

→ Asymptotic behavior

Proof -

1) $f(x) \geq 0$ (No negative condition) $\forall x \in (-\infty, +\infty)$

2)

$$\int_{-\infty}^{\infty} f(x) dx = 1$$

Step 1. General form of the gaussian function

$$f(x) = Ae^{-B(x-\mu)^2}$$

here A and B are constants

$$\therefore \int_{-\infty}^{\infty} A e^{-B(x-u)^2} dx = 1$$

(11)

on comparing
we get

As we know, $\int_{-\infty}^{\infty} e^{-ax^2} dx = \sqrt{\frac{\pi}{a}}$, $a > 0$

here we set $a = \frac{1}{2\sigma^2}$

here we set $a = \frac{1}{2\sigma^2}$
Standard gaussian integral formula.

so that normal distribution inherently follows a bell curve and to normalize it (make prob. = 1) we need to solve the integral

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-u)^2}{2\sigma^2}}$$

A, B

and to normalize it (make prob. = 1) we need to solve the integral

by doing so we transform the equation into a standard gaussian integral which has known solution.

2) Uniform distribution

Type of prob distribution where all outcomes in a given range are equally likely. This means that every value within the specified range has the same probability of occurring

The PDF for a continuous uniform distribution in the range $[a, b]$ is given by:

$$f(x) = \frac{1}{b-a}$$

a = lower bound $f(x) = \text{constant probability}$,

b = upper bound. the PMF

$$P(X=x) = \frac{1}{n}, x \in \{x_1, x_2, \dots, x_n\}$$

3) Binomial

3) Poisson Distribution

Binomial distribution is formed when

i) All the trials are independent

ii) Number n of trials are finite.

iii) The prob. p of success is same of each trial.

The prob. of n successes in n trials taken in any order is given by addition theorem of prob.

as $P(x) = {}^n C_x p^x q^{n-x}$ (PMF)

where p = probability of success
 q = probability of failure.

(12)

- ① $P(n) \geq 0$ } condition
② $\sum P(n) = 1$

* mean $= E(n) = np$

* Variance $= \text{Var}(X) = np(1-p)$

Proof

$$E(n) = \sum n P(n)$$

$$= \sum n {}^n C_n p^n q^{n-n}$$

$$= \sum n \times \frac{n!}{n!(n-n)!} p^n q^{n-n}$$

$$= \sum \frac{n!}{(n-1)!} p^{(n-1)} q^{(n-1)-(n-1)}$$

$$= np \frac{(n-1)! p^{(n-1)} q^{(n-1)-(n-1)}}{(n-1)! (n-1)-(n-1)!}$$

$$= np \frac{\cancel{(n-1)!} p^{(n-1)} q^{(n-1)-(n-1)}}{\cancel{(n-1)!} (n-1)-(n-1)!}$$

$$\therefore E(n) = np$$

hence $\text{Var}(X) = E(n^2) - (E(n))^2 = np(1-p)$

∴ This equals to 1

Discrete random variable

A variable which takes finite or at most countable number of values called discrete random variable

Eg:- no. of head obtain when two coins are tossed.

continuous random variable

A random variable which can take infinite number of values in an interval is known as C.R.V.

Probability density fn

if $f(n)$ is called P.D.F if

$$\int_{-\infty}^{\infty} f(n) dn = 1 \text{ and } f(n) \geq 0$$

Mathematical expectation (also called or mean) 1.2.2
 also called the value ($E(x)$) is the average value you would expect from a random variable over a large number of trials. It represents the long term average of an experiment. (13)

Definition

For a discrete random variables x with possible values x_1, x_2, \dots, x_n and their corresponding probabilities $P(X = x_1), P(X = x_2), \dots, P(X = x_n)$, the expected value is given by

$$\mu = \boxed{E(X) = \sum x_i P(X=x_i)} \text{ or mean}$$

For continuous random , the expected value is given by

$$\mu = \boxed{E(X) = \int_{-\infty}^{+\infty} x f(x) dx} \text{ or mean.}$$

e.g:- Think of the expected value as the weighted average of all possible values, where each value is weighted by its probability.

$$\begin{aligned} E(X) &= 1 \cdot \frac{1}{6} + 2 \cdot \frac{1}{6} + 3 \cdot \frac{1}{6} + 4 \cdot \frac{1}{6} + 5 \cdot \frac{1}{6} + 6 \cdot \frac{1}{6} \\ &= 3.5 \end{aligned}$$

This means that if we roll the dice many times, the average result will approach 3.5

$$\boxed{E(X) = \mu}$$

used in theoretical term used in statistical term

Now we know what is mean (μ) i.e,

$$\boxed{\mu = E(X)}$$

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So, we will now find ~~the~~ formula for variance.

The formula is:

$$\boxed{\text{Var}(X) = E(X^2) - (E(X))^2}$$

how?

As we know, variance measure how spread out the values of a random variable X are around the mean $\mu = E(X)$

∴ From upper definition we have

$$\text{Var}(X) = E[(X-\mu)^2]$$

$$\Rightarrow \text{Var}(X) = E[X^2 + \mu^2 - 2X\mu]$$

using linear of expectation, we can distribute E over addition/Subtraction, we have,

$$E[(X-\mu)^2] = E[X^2] + E[\mu^2] - E[2X\mu]$$

Now, As we know $E[c] = c$ (where c is constant)

$$\therefore E[(X-\mu)^2] = E[X^2] + \mu^2 - 2\mu E[X] \rightarrow \mu$$

$$= E[X^2] + \mu^2 - 2\mu^2$$

$$= E[X^2] - \mu^2$$

$$= E[X^2] - (E[X])^2$$

$$\therefore \boxed{\text{Var}(X) = E[X^2] - (E[X])^2}$$

Proof of probability density function of Normal distribution

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1) As we know, the most important result in prob. and statistics is the Gaussian integral.

Very imp.

$$\int_{-\infty}^{+\infty} e^{-\frac{a x^2}{2}} dx = \sqrt{\frac{\pi}{a}}, \text{ for } a > 0 \quad \text{---(i)}$$

2) Now the probability density fn of a normal distribution is

$$f(x) = A e^{-B(x-u)^2} \quad \text{---(ii)}$$

$A \Rightarrow$ normalization constant (to make sure that the total prob. sum to 1)

$B \Rightarrow$ is the coefficient inside the exponent, controlling the spread of distribution.

Now, we knew that $E[x] = u$, so we will find $E[x^2]$ to compute variance.

$$\text{Var}(x) = E[x^2] - (E(x))^2$$

$$E(n) = \int_{-\infty}^{+\infty} x f(n) dx$$

$$\therefore E(n^2) = \int_{-\infty}^{+\infty} x^2 f(n) dx$$

Before solving this we first understand the normalization of the fn.

from eq(i) we know any equation of the form

$$\int_{-\infty}^{+\infty} e^{-ax^2} dx \text{ the value is } \sqrt{\frac{\pi}{a}}$$

$$\therefore \left[\int_{-\infty}^{+\infty} A e^{-B(x-u)^2} du = 1 \right] \quad \text{--- (iii)}$$

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if $f(n) = 1$ (for probability distribution function)

on comparing eq.(i) and (iii) we get

$$\boxed{A \cdot \sqrt{\frac{\pi}{B}} = 1} \quad \text{--- (iv)}$$

Now,

$$E(X^2) = \int_{-\infty}^{+\infty} x^2 f(n) dx$$

$$\Rightarrow E(X^2) = \int_{-\infty}^{+\infty} x^2 A e^{-B(x-u)^2} dx$$

$$\Rightarrow \text{let } x-u=y$$

$$\therefore x = y + u \quad \therefore du = dy$$

$$\Rightarrow E(X^2) = \int_{-\infty}^{+\infty} (y+u)^2 \cdot A \cdot e^{-By^2} dy$$

$$\Rightarrow E(X^2) = \int_{-\infty}^{+\infty} (y^2 + u^2 + 2yu) \cdot A \cdot e^{-By^2} dy$$

$$\Rightarrow E(X^2) = A \int_{-\infty}^{+\infty} y^2 e^{-By^2} dy + \underbrace{2uA \int_{-\infty}^{+\infty} y e^{-By^2} dy}_{\text{becomes 0 since it is a odd f.}} + Au^2 \int_{-\infty}^{+\infty} e^{-By^2} dy$$

\downarrow
from eq(i)

$$\Rightarrow E(X^2) = A \int_{-\infty}^{\infty} y^2 e^{-By^2} dy + \underbrace{Au^2 \sqrt{\frac{\pi}{B}}}_{\downarrow} \rightarrow u^2 \text{ (from eq iv)}$$

$$\therefore \rightarrow E(x^2) = A \int_{-\infty}^{+\infty} y^2 e^{-By^2} dy + \mu^2$$

use Integral by part

and use ISLATE i.e., 1st f'n is y^2 and
second f'n is e^{-By^2}

(1)

$$\therefore E(x^2) = A \times \frac{1}{2B} \sqrt{\frac{\pi}{B}} + \mu^2$$

$$E(x^2) = \frac{1}{2B} + \mu^2 \quad \text{--- (v)}$$

$$\text{Now, Variance} = \sigma^2 = E(x^2) - (E(x))^2$$

$$\sigma^2 = \frac{1}{2B} + \mu^2 - \mu^2$$

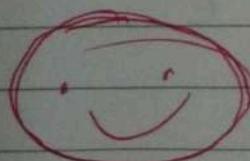
$$B = \frac{1}{2\sigma^2} \quad \text{--- (vi)}$$

$$A = \sqrt{\frac{B}{\pi}} = \sqrt{\frac{1}{2\sigma^2 \pi}}$$

$$A = \frac{1}{\sigma \sqrt{2\pi}}$$

$$\text{hence } f(n) = A e^{-B(n-\mu)^2} \quad \left. - \frac{(n-\mu)^2}{2\sigma^2} \right\} \Rightarrow \text{PDF}$$

$$f(n) = \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{(n-\mu)^2}{2\sigma^2}}$$



$$\text{and } \int_{-\infty}^{+\infty} f(n) = 1$$

Poisson distribution: is a discrete prob. distribution that extrunes the prob. of a given number of events occurring in a fixed interval of time or space, given that these events occur with a known constant mean 18 rate and are independent of the time since the last event. e.g. number of calls received at a call center per hour.

$$\text{PMF} \Rightarrow P(X=k) = \frac{e^{-\lambda} \lambda^k}{k!}, k=0, 1, 2, 3, \dots$$

$k \Rightarrow$ number of occurrence

$\lambda \Rightarrow$ (mean rate) expected number of occurrence in the given interval.

$e \Rightarrow$ euler's number.

It is the limiting case of binomial distribution as n is very large and probability p is very small

$$P(X=k) = {}^n C_k p^k (1-p)^{n-k}$$

$$= \frac{n!}{k! (n-k)!} p^k e^{-np}$$

$\lim_{n \rightarrow \infty} (1-p)^n = e^{-np}$

see in limits theory

$$= \frac{n(n-1)(n-2) \dots (n-(k+1)) (n-k)!}{k! (n-k)!} p^k e^{-np}$$

$$= \frac{n^k}{k!} p^k e^{-np}$$

$$\text{let } np = \lambda$$

$$p = \frac{\lambda}{n}$$

$$\therefore \frac{n^k}{k!} \lambda^k n^{-k} e^{-\lambda}$$

$$\therefore P(X=k) = \frac{e^{-\lambda} \lambda^k}{k!}$$

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Exponential distribution is a continuous prob. distribution used to model the time between events in a poisson process. It is process in which events happens continuously and independently at a constant average rate.

$$f(x|\lambda) = \begin{cases} \lambda e^{-\lambda x} & \text{for } x > 0 \\ 0 & \text{for } x < 0 \end{cases}$$

λ is called the distribution rate.

$$\text{Mean} = E(x) = \int_{-\infty}^{\infty} x f(x) dx$$

$$= \int_{-\infty}^0 x f(x) dx + \int_0^{\infty} x f(x) dx$$

$$= \lambda \left[1 - \frac{1}{\lambda} e^{-\lambda x} \right] \Big|_0^\infty + \frac{1}{\lambda} \int_0^\infty x e^{-\lambda x} dx$$

$$= \lambda \left[0 + \frac{1}{\lambda} \cdot \frac{1}{\lambda} e^{-\lambda x} \right] \Big|_0^\infty = \frac{1}{\lambda}$$

$$\text{Var} = E(x^2) - (E(x))^2 = \frac{\lambda^2}{\lambda^2} - \frac{1}{\lambda^2} = \boxed{\frac{1}{\lambda^2}}$$

Normalization and standardization

(20)

Standardization:- **FEATURE SCALING** Suppose we have two features in an

ML model: age (20-80 years) and income (\$10,000-\$50,000)
→ here income is way larger than age. If we don't standardize, the model focus too much on income.

So, we use $Z = \frac{x - \mu}{\sigma} \rightarrow$ original value
 $\downarrow \quad \downarrow \quad \downarrow$ S. D.

Z is the standardize value

e.g:-

$$\begin{bmatrix} 20 & 10000 \\ 40 & 50000 \\ 60 & 200000 \\ 80 & 500000 \end{bmatrix} \xrightarrow{\text{After}} \begin{bmatrix} -1.34 & -0.93 \\ -0.44 & -0.72 \\ 0.44 & 0.05 \\ 0.34 & 1.61 \end{bmatrix}$$

centered around 0

This is called standardize normal distribution

Now, the question is why we use $Z = \frac{x - \mu}{\sigma}$

There is two reason behind this

↓
ans called Z score

① Standardization shifts the mean to 0

$$\therefore \text{New Mean} = \frac{1}{n} \sum z_i$$

$$= \frac{1}{n} \sum \frac{x_i - \mu}{\sigma}$$

$$= \frac{1}{n\sigma} (\sum x_i - n\mu) \rightarrow 0$$

= 0

hence New Mean = 0.

Now, there can be a question that New mean can be zero without the mu 0 F. This will be explained in the 2nd point

② Standardization scales the standard deviation to 1.

New standard deviation = $\sqrt{\frac{1}{n} \sum (Z_i - 0)^2}$. (21)

$$\text{as. S.D.} = \sqrt{\frac{1}{n} \sum (x_i - u)^2}$$

$$\text{New S.D.} = \sqrt{\frac{1}{n} \sum \left(\frac{(x_i - u)}{\sigma}\right)^2}$$

$$= \sqrt{\frac{1}{n} \sum (x_i - u)^2}$$

$$\text{Now As we know } \sigma^2 = \sqrt{\frac{\sum (x_i - u)^2}{n}}$$

$$\therefore \sigma^2 = \frac{\sum (x_i - u)^2}{n}$$

$$\therefore \text{New S.D.} = \sqrt{\frac{1}{\sigma^2} \times \sigma^2} = 1$$

$$\therefore \text{New S.D.} = 1$$

This ensures all values have a uniform spread, making it easier in ML models to process data efficiently.

Normalization

Normalization scales data between a fixed range typically $[0, 1]$ or $[-1, 1]$. It doesn't change the shape of the data like standardization but rather compresses it into a fixed range.

- Some ML models (like NN, KNN) work better when all input features are within similar range.
- Normalization ensures no feature dominates due to differences in scale.

$$X' = \frac{X - X_{\min}}{X_{\max} - X_{\min}} \rightarrow \text{min max scalar}$$

(22)

X = original data point

X_{\min} = min value of data set

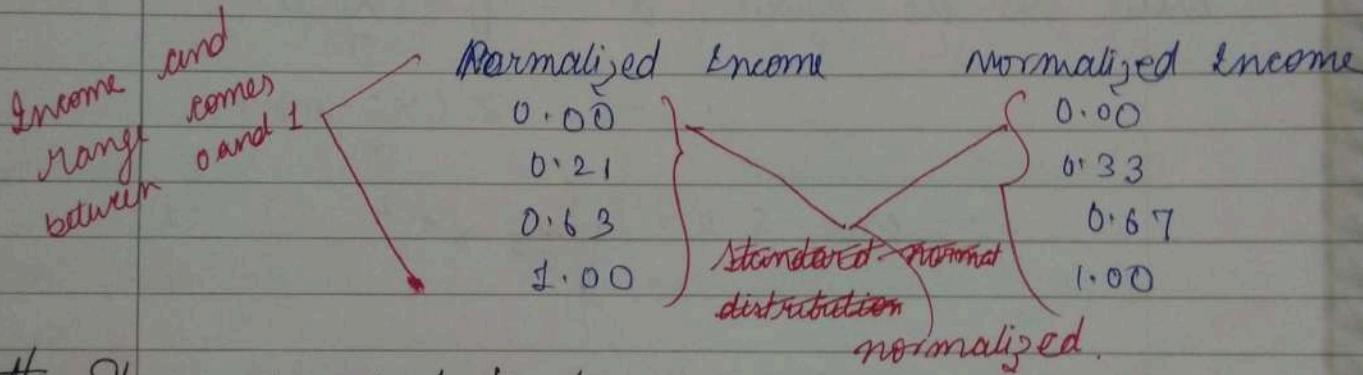
X_{\max} = max " "

X' = normalized value (btw 0 and 1)

e.g. Person

	Income (\$)
A	10,000
B	50,000
C	200,000
D	500,000

	Age
A	20
B	40
C	60
D	80



Skewness and kurtosis

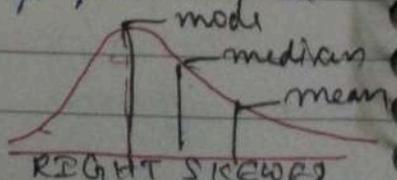
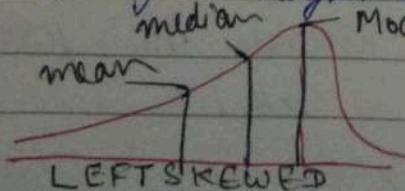
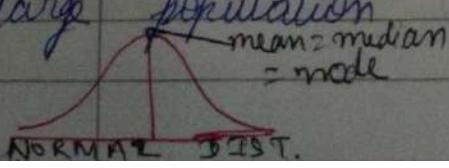
Skewness tells us whether a distribution is symmetrical or asymmetrical around the mean.

→ Positive Skew :- The right tail is longer, meaning most data points are concentrated on the left. e.g. - income distribution, where a few people are significantly more than the majority.

→ Negative Skew :- The left tail is longer, meaning most data points are concentrated on the right.

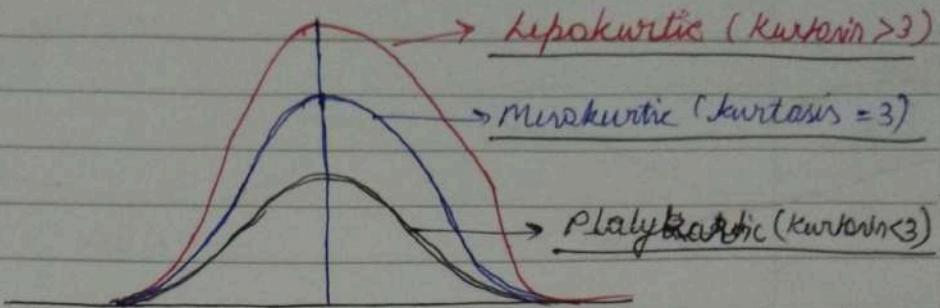
e.g. - Exam scores where most students score high, but a few score very low.

→ Zero Skewness (symmetrical distribution) → The distribution is perfectly balanced on both sides of the mean, like normal distribution e.g. heights of people in a large population



Kurtosis: tells us how much of the data is in the tails of the distribution compared to a normal distribution.

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Law of Large numbers.

It states that if we repeat an experiment many times, the average of the results will get closer and closer to the true expected value.

e.g.:-

Imagine if we flip a coin. The probability of getting head is 50% (0.5). But if we flip the coin just few times (let's say 10 times), you might get heads 7 times or only 3 times. This doesn't match the true prob. Now, imagine flipping the coin 1000 times, the percentage of head will likely be closer to 50%. If you increase the flips to 10,000 times, the percentage will even closer to 50%. This happens because as the number of trials increases, the observed average gets closer to the true probability.

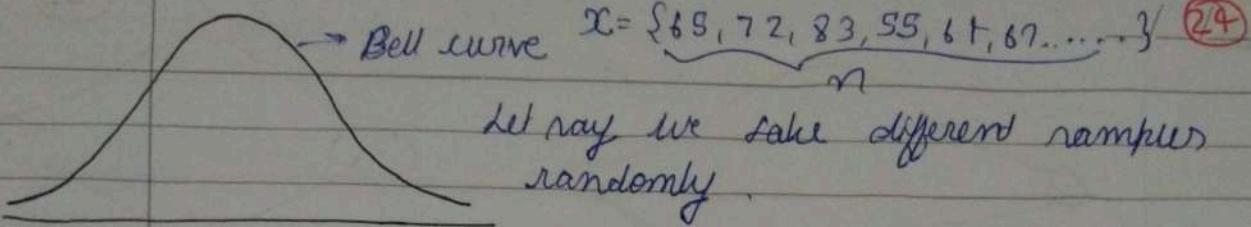
That distribution can be any distribution

Central limit theorem

It states that the distribution of a sample will approximately a normal distribution as the sample size becomes larger, regardless of the population's actual distribution shape.

- There must be large number of sample data (> 30)
- average of the sample means and S.D. will equal the population mean and S.D.
- Used in finance, investing etc.

* practical explanation of central limit theorem



$$S_1 = \{x_1, x_2, x_3, \dots\} \rightarrow \bar{x}_1$$

$$S_2 = \{x_1, x_2, x_3, \dots\} \rightarrow \bar{x}_2$$

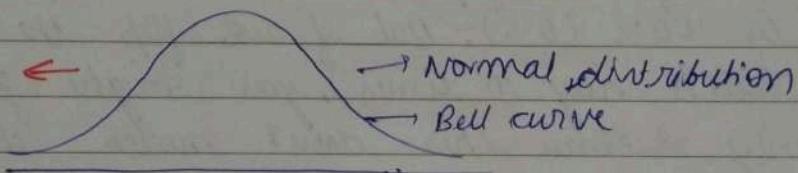
$$S_n = \{x_1, x_2, x_3, \dots\} \rightarrow \bar{x}_n$$

Now, we have collection of sample means as

$$\bar{S} = \{\bar{x}_1, \bar{x}_2, \bar{x}_3, \dots, \bar{x}_n\}$$

Now, if we plot this sample mean in histogram then it will form normal distribution

distribution of sample mean



Log Normal distribution

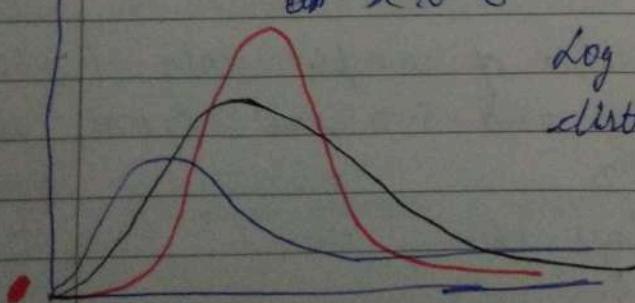
A log normal distribution is a probability distribution of a random variable whose logarithm is normally distributed

if $x \approx$ log normal distribution
then

$$y \approx \ln(x) \Rightarrow \text{Normal distribution.}$$

$$x \approx e^y$$

Log normal is a right skewed distribution



Bernoulli Distribution

(25)

Z-Score

Z - Score

Z-Score tells us how far a data is from the mean of the data set, in terms of standard deviation. It helps us to understand whether a value is above or below the mean and by how much.

→ lines

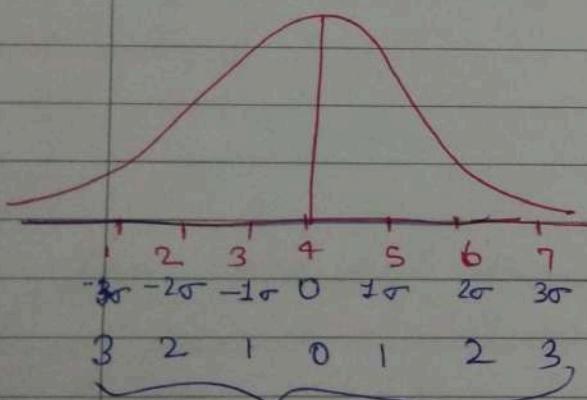
- It standardizes different datasets, making them comparable
 - It identifies outliers (extreme value in data)
 - It is used in probability calculations (e.g. normal).

$$Z = \frac{X - \mu}{\sigma} \rightarrow \text{The mean}$$

The data point

 The data point
our data is
Number of S.D away from the mean.

eg:-



here $\mu = 4$

Q = 1

$$\therefore \angle f = \frac{44}{1} - 3$$

$$Z(6) = \frac{6-4}{1} = 2$$

$$Z(4) = \frac{4-4}{4} = 0$$

Standard normal distribution

Percentiles and Quartiles

Percentage : 1, 2, 3, 4, 5

1. of the numbers that are odd?

$\% = \frac{\text{no. of numbers that are odd}}{\text{Total numbers}}$

$$= \frac{3}{5} = 0.6 = 60\%$$

Percentiles: A percentile is a value below which a certain percentage of observation lie.

Data set: 2, 2, 3, 4, 5, 5, 5, 6, 7, 8, 8, 8, 8, 8, 9, 9

(27)

① what is the percentile ranking of 10

∴ Percentile ranking of 10 is = no. of values below $\frac{n}{100}$
total number of values.

$$= \frac{16}{20} \times 100 = 80 \text{ percentile}$$

e.g.: Imagine 100 people took a test, if you are in the
→ 90th percentile → You did better than 90% people.
→ 50% " " " " " " " " " " 50% "

② What value exists at percentile ranking of 25%?

$$\text{Value} = \frac{\text{Percentile}}{100} \times (n+1)$$

$$= \frac{25}{100} \times 21 = 5.25 \rightarrow \text{no take average of value as index } 5 \text{ and } 6, \text{ which will comes out to be } 5.$$

Five number Summary

- 1) Minimum (S) Maximum.
- 2) First Quartile (Q₁)
- 3) Median
- 4) Third Quartile

Removing the outlier

1, 2, 2, 2, 3, 3, 4, 5, 5, 5, 6, 6, 6, 6, 7, 8, 8, 9, 27

all numbers before it are outlier

lower fence ← → higher fence

all numbers after it are outlier.

$$\text{lower fence} = Q_1 - 1.5(IQR)$$

$$\text{upper fence} = Q_3 + 1.5(IQR)$$

$$\text{and } IQR = Q_3 - Q_1$$

(2B)

Q_3 = third quartile or 75 percentile

$$\therefore \text{Value} = \frac{75}{100} \times 20 = 15 \rightarrow \text{index 7}$$

Q_1 = first quartile or 25 percentile

$$\therefore \text{Value} = \frac{25}{100} \times 20 = 5 \rightarrow \text{index 3}$$

$$\therefore IQR = 7 - 3 = 4.$$

$$\therefore \text{lower fence} = 3 - 1.5 \times 4 = 3 - 6 = -3$$

$$\text{upper fence} = 7 + 1.5 \times 4 = 13$$

\therefore value above 13 are outlier and value less than -3 are outlier.

\therefore Remaining data is 1, 2, 2, 2, 3, 3, 4, 5, 5, 5, 6, 6, 6, 6, 7, 8, 8, 9.

1) minimum = 1

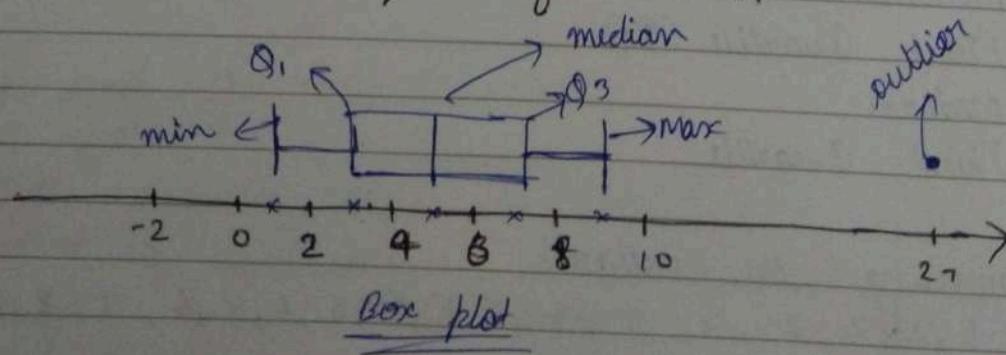
2) First quartile is $= Q_1 = 3$

3) Median is $\frac{5+5}{2} = 5$

4) Third quartile is $Q_3 = 7$

5) maximum is 9

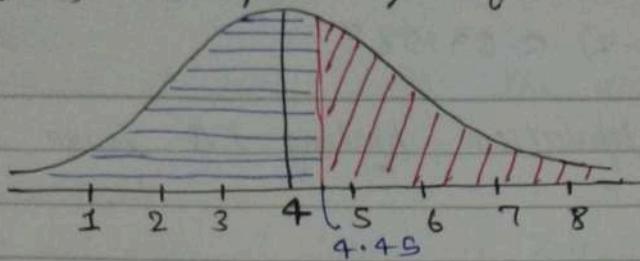
Now we plot the box plot for this.



use of Z-table

Eg) what is the percentage of score falls above 4.45?

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→ So basically we need to find the area of the red side.

Step 1: Calculate the Z-score:

The formula for Z-score is

$$Z = \frac{x - \mu}{\sigma}$$

$$\text{So, } Z = \frac{4.45 - 4}{1} = 0.45$$

Step 2: A Z-table gives the area (probability) to the left of the Z-score in a standard normal distribution. Here for $Z = 0.45$ it gives the area of the blue part.

According to the ~~left~~ left Z-table

$$P(Z < 0.45) \approx 0.6736$$

Step 3: Find the percentage above the Z-score since we want the percentage of score above 4.45, we need:

$$P(Z > 0.45) = 1 - P(Z < 0.45) = 1 - 0.6736 = 0.3264$$

hence 32.64% of score falls above 4.5 in this normal distribution

Q) In India the avg. IQ is 100, with a standard deviation of 15. What percentage of population would you expect to have an IQ lower than 85?

$$\Rightarrow z\text{ score} = \frac{85 - 100}{15} = -1$$

for $P(Z = -1) \approx 0.1587$

(30)

∴ percentage of population having IQ lower than 85 is 15.87 %.

~~# Hypothesis testing~~

Inferential Statistics

Hypothesis testing

It is the statistical method used to make decision or inference about a population based on sample data. It's commonly used to test claim or ideas (hypothesis) about a population parameter.

In brief

hypothesis is like checking a claim using data.

Imagine, you are a detective and someone says
"The coin is not fair! It gives more head
than tails."

Now you want to test the claim. You flip the coin 100 times and record the results. That's hypothesis testing using data to check if a claim is likely true or false.

* The two hypotheses

In every hypothesis test, we start with two opp. ideas:

- ⇒ Null hypothesis (H_0): The default belief "The coin is fair".
- ⇒ Alternative hypothesis (H_1): The claim we want to check, "The coin is biased (not fair)"

our job is to use our data to decide:

- Do I have enough evidence to reject the null hypothesis.
- or should I stick with the null hypothesis.

(31)

Simple example:

Let's say we flip a coin 100 times and get 60 heads.

- If the coin is really fair, you would expect about 50 heads, right?
- But if we got 60 heads, is that just luck or is the coin actually biased?

New comes the P-value to help us decide

What is P-value

The P-value is a key concept in hypothesis testing. It's like a measure of how surprising your data is if the null hypothesis is true.

The P-value is the answer to the question:

"If the coin were truly fair, what is the chance I would see something as extreme as 60 heads (or more)?"

In simple terms:-

→ A small P-value (like 0.001 or 0.03) means: wow! getting 60 heads is pretty rare if the coin is fair; so maybe the coin isn't fair.

This means our observed data is quite unlikely if the null hypothesis were true.

→ A big P-value (like 0.4 or 0.6) means: "getting 60 heads is not that weird". So we can't say the coin is biased.

This means our observed data is reasonably likely to occur even if the null hypothesis were true.

we usually compare the P-value to a threshold called alpha (α), often 0.05 (5%).

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- If P-value $< 0.05 \rightarrow$ Reject the null hypothesis
- If P-value $> 0.05 \rightarrow$ do not reject the null hypothesis.
→ alpha (α) or significance value

Coin example.

Let say our P-value comes out to be 0.03 (3%).
This means:

"There's only a 3% chance I would get 60 or more heads just by luck if the coin were fair."
since $0.03 < 0.05$, we reject the null hypothesis
and say: "I have enough evidence to believe the coin might be biased".

Calculation of P-value

~~What might do~~

and

"To calculate the P-value, I need a z-score, to get that, I need the correct mean and standard deviation. But how do I know the which distribution to use, and which formula go with it?"

Answer:- Identify the type of data or situation.

The type of problem will tell which probability we should use.

1) Problem type 1 : Flipping coins / success-failure (fixed trials).

- Distribution used \Rightarrow Binomial
- Mean formula $\Rightarrow \mu = np$
- S.D formula $\Rightarrow \sigma = \sqrt{np(1-p)}$

- 3) Problem type 2: Rare events per time or space (e.g. calls/min, bacteria/cm²)
- Distribution used \Rightarrow Poisson
 - mean formula $\Rightarrow \mu = \lambda$
 - S.D. formula $\Rightarrow \sigma = \sqrt{\lambda}$

(33)

4) Measurements like height

- 3) Problem type 3: Measurements like height, weight, test scores (continuous data)
- Distribution used \Rightarrow Normal
 - Mean formula \Rightarrow Based on data
 - S.D. formula \Rightarrow Based on data.

4) Problem type 4:

• Averages from samples (sample mean)

- Distribution used \Rightarrow Normal (sampling distribution)
- Mean formula $\Rightarrow \mu = \text{population mean}$.
- S.D. formula $\Rightarrow \sigma = \sigma / \sqrt{n}$

5) Problem type 5:

• Comparing two means or small samples (with unknown σ)

- Distribution used \Rightarrow t-distribution
- Mean formula \Rightarrow depends on data.
- S.D. formula \Rightarrow depends on data.

6) Problem type 6: comparing categories like observed vs expected).

- Distribution used \Rightarrow chi-square
- Mean formula \Rightarrow NA
- S.D. formula \Rightarrow NA.

Since here we are counting how many times we get head out of 100 flips, and each flip has two outcomes (head or tail), we are binomial distribution.

But when the flip is large (like 100), we often approximate it using a normal distribution. (because it is easier to calculate). (34)

Now, we will calculate the mean and S.D.

$$\begin{aligned}\text{mean} &= \text{expected no. of heads} = n \times p \\ &= 100 \times 0.5 = 50 \\ \text{S.D.} &= \sqrt{n p (1-p)} = \sqrt{100 \times 0.5 \times 0.5} = 5\end{aligned}$$

Calculate the Z-score so as to know how much far our data is from the mean of the data set in terms of S.D.

$$\begin{aligned}Z &= \frac{\text{My value} - \text{Mean}}{\text{S.D.}} \\ &= \frac{60 - 50}{5} = 2\end{aligned}$$

Now, we check: what is the prob. of getting a Z score this extreme or more?

From Z-table (standard normal distribution)
the probability of getting a $Z \geq 2$ is about 0.0228.

Since we are doing a two-tailed test (because we are checking for bias in either direction, more heads or more tails), we double this

$$P\text{-value} = 2 \times 0.0228 = 0.0456$$

Final decision

$$\rightarrow P\text{-value} = 0.0456$$

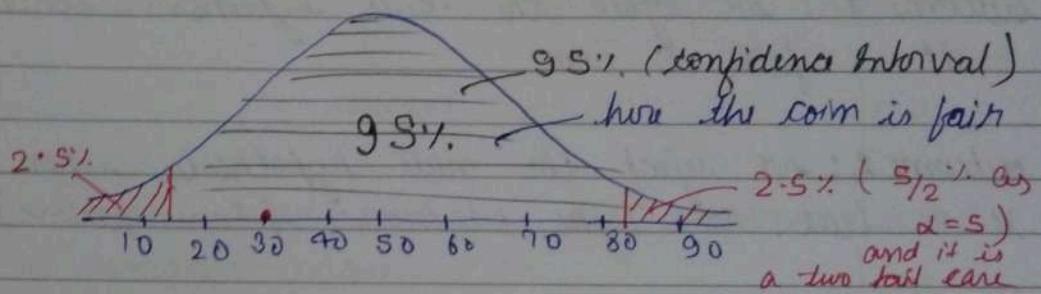
$$\rightarrow \alpha = 0.05 \quad \text{alpha}$$

Since $0.0456 < 0.05$, we reject the null hypothesis hence, "there's enough evidence to say the coin might be biased."

Now the question is what is alpha (α) or significance value.

Significance value:- It is the threshold set before a hypothesis test that defines the maximum probability we are willing to accept for making a wrong decision by rejecting a true null hypothesis.
In simpler word,

it is the cutoff point used to decide whether a result is statistically significant or just due to random chance.



Suppose we get 30 head so how do we know that the coin is biased or not.

So far this to define it is always said that our experiment should be nearer to the mean

Now how do we define that how far it can be away from the mean. So for that we use the property of significance value (α).

Suppose $\alpha = 0.05$ or 5% (defined by domain expert)

↓
This means
that $100 - 5 = 95\%$ is
my confidence interval

Range of values that we believe contains some the true value we are trying to estimate.

means the person who is doing the experiment or someone who understand the field very well decides how much risk of being wrong they are willing to except before they do the test.

Type 1 and Type 2 Error

Null hypothesis (H_0) = coin is fair

(36)

Alternate hypothesis (H_1) = coin is not fair.

Reality check

Null hypothesis is true or Null hypothesis is false.

Decision

Null hypothesis is true or Null hypothesis is false

outcome 1: we reject the null hypothesis when in reality it is false \Rightarrow True

outcome 2: we reject the null hypothesis when in reality it is true. \Rightarrow Type 1 error (False positive)

outcome 3: we accept the null hypothesis when in reality it is false. \Rightarrow Type 2 error. (False negative)

outcome 4: we accept the null hypothesis when in reality it is true. True

Conclusion matrix

Reality: H_0 is true

We reject H_0

Type 1 error

Reality: H_0 is false

correct (Power of test)

We fail to reject H_0

correct decision

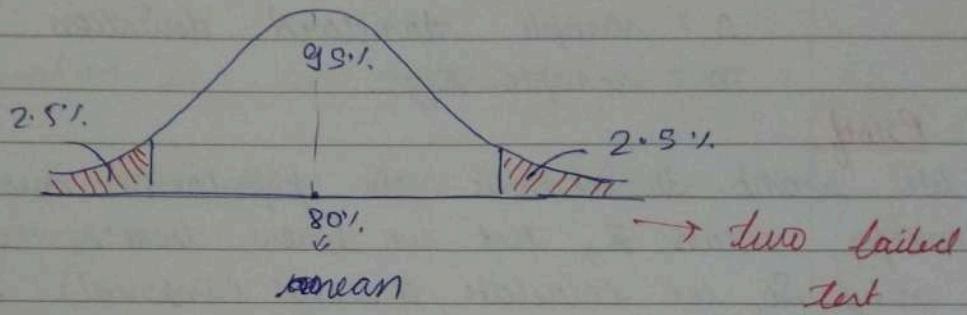
Type 2 error

One tailed and two tailed test

(31)

e.g.: Colleges in a state have an 85% placement rate. A new college was recently opened and it was found that a sample of 150 students had a placement rate of 88%. with a standard deviation 4%. Does this college has a different placement rate?

\Rightarrow Let say $\alpha = 0.05$

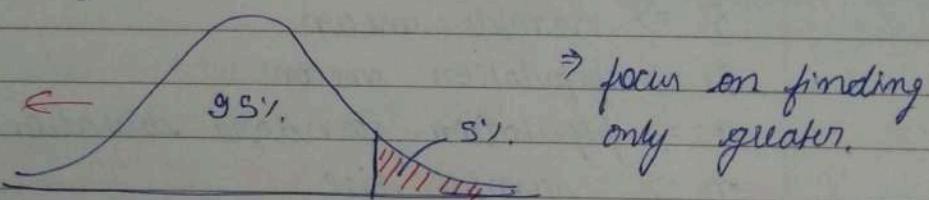


Since here we are asked whether the placement rate is greater or smaller than 85%.

But if we are asked does the college have a placement rate greater than 85%. \Rightarrow one tailed test

$$\alpha = 0.05$$

one tailed test



Confidence Intervals

A confidence interval is a range of values that we believe the true population value (like mean, average etc) falls into, based on sample data.

e.g.: we might choose a confidence level, like 95%, which means:

I am 95% confident the true values lies inside the range.

Formula for C.I

$$C.I = \bar{x} \pm z \times \left(\frac{s}{\sqrt{n}} \right)$$

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\bar{x} = sample mean

z = Z-score based on confidence level (for 95% it is 1.96)

s = sample standard deviation

n = sample size.

Proof

We want to estimate the population mean μ using a sample mean \bar{x} , but we know there's some uncertainty. So, we calculate a range (interval) that is likely to contain the true population mean - that's the confidence interval.

$$Z = \frac{\bar{x} - \mu}{\sigma/\sqrt{n}}$$

This is called Z-test.

\bar{x} \Rightarrow sample mean

μ \Rightarrow population mean

σ \Rightarrow population standard deviation

n \Rightarrow sample size

σ/\sqrt{n} \Rightarrow standard error

Z \Rightarrow how many S.E away our sample mean is from the \Rightarrow from the definition of Z score

$$\Rightarrow Z = \frac{\bar{x} - \mu}{\sigma/\sqrt{n}}$$

$$\Rightarrow Z \cdot \frac{\sigma}{\sqrt{n}} = \bar{x} - \mu$$

$$\Rightarrow \mu = \bar{x} - Z \cdot \frac{\sigma}{\sqrt{n}}$$

But that give only one bound since we want a range, we use ± 2 (positive and negative side):

(39)

$$\mu \in \bar{x} \pm 2 \cdot \frac{\sigma}{\sqrt{n}}$$

$$C.I = \bar{x} \pm 2 \cdot \frac{\sigma}{\sqrt{n}}$$

* Now the question is how standard error = $\frac{\sigma}{\sqrt{n}}$

To get there I start from basic statistics and properties of variance.

why
 \sqrt{n}
why not
 n

- ① Let's say we have a population with:
 - \Rightarrow mean = μ
 - \Rightarrow standard deviation = σ

- ② We take random samples of n independent values:
 X_1, X_2, \dots, X_n consider it as a ^{sample of means} _{a marks of student in the exam from the population of students}

* Each value has variance

$$\text{Var}(X_i) = \sigma^2 \quad (\because \text{it is sample for all the sample})$$

HINDI

Saare sample ka aapna aapna variance

* Variance of the sum of observations:

Let's say we add all n observations: $HINDI$

$$S = X_1 + X_2 + X_3 + \dots + X_n \quad \begin{array}{l} \text{Saare sample} \\ \text{ka aapna aapna sum} \end{array}$$

Since all X_i are independent, the variance adds.
 This will be calculated if we are taking it.

$$Var(S) = Var(X_1 + X_2 + X_3 + \dots + X_n) = n\sigma^2 \quad \begin{array}{l} \text{HINDI} \\ \text{Saare sample ka aapna aapna sum ka variance} \end{array}$$

* Now we define the sample mean:

$$\bar{X} = \frac{S}{n} = \frac{X_1 + X_2 + \dots + X_n}{n}$$

\therefore Sample Variance

Variance of sample mean = $\text{Var}(\bar{X})$

HINGLISH

AD

[Saare alog alog sample ke mean ka variance]

$$\therefore \bar{X} = \frac{S}{n}$$

$$\text{Var}(\bar{X}) = \text{Var}\left(\frac{S}{n}\right) \quad (\text{eq i})$$

Now, As we know,

$$\text{Var}(x) = E[x^2] - (E(x))^2 \quad (\text{Page: 14})$$

$$\begin{aligned} \therefore \text{Var}(ax) &= E[a^2 x^2] - (E(ax))^2 \\ &= a^2 E(x^2) - \cancel{a^2} (a E(x))^2 \\ &= a^2 E(x^2) - a^2 (E(x))^2 \end{aligned}$$

$$\text{Var}(ax) = a^2 (\text{Var}(x))$$

Similarly.

$$\text{Var}\left(\frac{x}{n}\right) = \frac{1}{n^2} \text{Var}(x)$$

NOTE

See the central limit

theorem, then you will understand how statistician derived this formula by performing the experiment.

Pg - 23, 24

$$\text{Var}(\bar{X}) = \frac{1}{n^2} \text{Var}(S)$$

$$\text{Var}(\bar{X}) = \frac{1}{n^2} \times \sigma^2 n \quad (\text{from eq i})$$

$$\text{Var}(\bar{X}) = \frac{\sigma^2}{n}$$

\Rightarrow variance of sample mean

$$S.D = \sqrt{\text{Var}(\bar{X})}$$

$$S.D = \frac{\sigma}{\sqrt{n}}$$

\Rightarrow standard deviation of sample mean or standard error.

Summary

Let ~~say~~ I have a population of students in a college. I take one sample of more than 30 students (say, 36). (4) Calculate the sample mean.

Since the sample mean can vary from sample to sample, we calculate its standard error, which is

$$SE = \frac{\sigma}{\sqrt{n}}$$

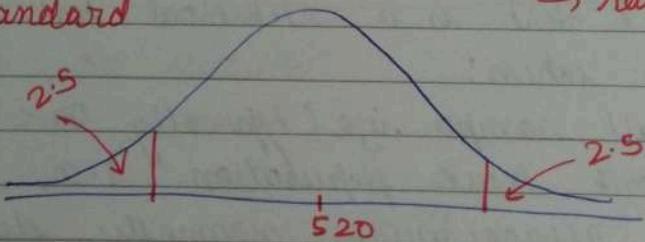
The S.E. tells us how much our sample mean might vary from the true population mean. Then we use this S.E. to construct a confidence interval around our sample mean - which gives us a range where we are reasonably confident (e.g. 95%) the true population mean lies.

Q) On the Quant test of CAT exam, the standard deviation is known to be 100. A sample of 25 test takers has a mean of 520 score. Construct a 95% CI about the mean?

$$\Rightarrow \sigma = 100, n = 25, \alpha = 0.05, \bar{x} = 520$$

Population standard deviation

sample mean



① If population std. is given, then we will apply Z test

∴ Point Estimate ± margin of error

② $n \geq 30$ (here we take $n = 25$ for simple calculation)

$$\bar{x} \pm Z_{\alpha/2} \frac{\sigma}{\sqrt{n}}$$

$$\text{Upper bound of C.I} = \bar{x} + Z_{0.05/2} \frac{100}{\sqrt{25}}$$

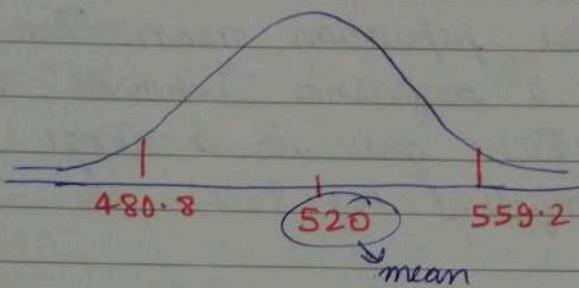
(4/2)

$$= 520 + (1.96)(20)$$

↳ from z-table

$$= 559.2$$

$$\text{Lower bound of C.I} = \bar{x} - Z_{0.05/2} \frac{100}{\sqrt{25}} = 480.8$$



* But what if population standard deviation is not given. \Rightarrow then we use t-test

T-test - A t-test is a statistical test used to compare means when:

- we have small sample size (typically $n < 30$)
- when we don't have population S.D.
- The data is approximately normally distributed.

In simple terms:

"I want to check if the average of my sample is really different from a known value or another sample."

e.g.: let say:

- I believe student sleep 7 hours on average
- we take sample of 15 students, and their average sleep is 6.5 hours with sample standard deviation of 0.8 hours

We want to check:

"Is this difference (6.5 instead of 7) statistically significant or just random?"

(43)

$$\text{Sample mean } (\bar{x}) = 6.5$$

$$\text{Hypothesized population mean } (\mu) = 7$$

$$\text{Sample std. dev. } (s) = 0.8$$

$$\text{sample size } (n) = 15$$

$$\text{degree of freedom } (df) = n - 1 = 14 \quad \text{Success}$$

Why $n - 1$?

Suppose we have 3 numbers and their average is 10

$$\therefore \frac{x_1 + x_2 + x_3}{3} = 10$$

$$\Rightarrow x_1 + x_2 + x_3 = 30$$

Now, we can choose any two numbers, like

$$x_1 = 8, x_2 = 12$$

But then the third ~~$x_3 = 10$~~ must be fixed

hence even though we have 3 numbers, only 2 are free to vary.

Now, comes to question.

t-test formula

$$t = \frac{\bar{x} - \mu}{s/\sqrt{n}} = \frac{6.5 - 7}{0.8/\sqrt{15}} \approx -2.43$$

Now, acc. to t-value for df = 14 at 95% C.I. $\rightarrow \sim 2.145$
our $|t| = 2.43$ is greater than 2.145

so, we reject the assumption that average is 7 hours

Q) On the quant test of CAT exam, a sample of 25 test takers has a mean of 520 within a standard deviation of 80. construct 95% of confidence interval about the mean.

Ans: - $n = 25$, $\bar{x} = 520$, $(S) = 80$

✓ Sample S.D

(44)

Population S.D not given hence t-test.

Point estimation \pm margin of error

$$\bar{x} \pm t_{\alpha/2} \left(\frac{S}{\sqrt{n}} \right) \rightarrow \text{standard error}$$

For t we use D.O.F which is $25-1 = 24$

\therefore for $t_{0.025}$ (as $\alpha = 0.05$) and D.O.F = 24
we have $t = 2.064$

$$\begin{aligned}\text{upper bound} &= \bar{x} + t_{\alpha/2} \left(\frac{S}{\sqrt{n}} \right) \\ &= 520 + 2.064 \left(\frac{80}{\sqrt{25}} \right) \\ &= 553.024\end{aligned}$$

$$\begin{aligned}\text{lower bound} &= \bar{x} - t_{\alpha/2} \left(\frac{S}{\sqrt{n}} \right) \\ &= 520 - 2.064 \left(\frac{80}{\sqrt{25}} \right) \\ &= 486.97\end{aligned}$$

One Sample Z-test

Q) In the population, the average IQ is 100 within a S.D of 15. Researcher wants to test a new medication to see if there is a positive or negative effect on intelligence, or no effect at all. A sample of 30 participants who have taken the medication, has a mean ^{IQ} of 140. Did the medication affect the intelligence? $\alpha = 0.05$ (C.I = 95%).



Population mean (μ) = 100
population S.D (σ) = 15

Sample size (n) = 30

Sample mean (\bar{x}) = 140

Significance level (α) = 0.05 (for 95% CI, by default)

(45)

Test type = Two-tailed (we want to check if IQ is increased or decreased)

Step 1: Set hypothesis

- Null hypothesis (H_0) $\Rightarrow \mu = 100$ (no effect)
- Alternate hypothesis (H_1) $\Rightarrow \mu \neq 100$ (effect present either increase or decrease)

Step 2: Calculate standard error (SE)

$$S.E = \frac{\sigma}{\sqrt{n}} = \frac{15}{\sqrt{30}} \approx 2.738$$

We use this formula for SE when S.D is known.

Step 3: Calculate Z-score

Z-score tells us how many SEs the sample mean from the population mean:

$$Z = \frac{\bar{x} - \mu}{S.E} = \frac{140 - 100}{2.738} \approx \frac{40}{2.738} \approx 14.61$$

Step 4: Find critical Z-value

Since it's a two-tailed test and we are using 95% confidence

- critical Z-values = ± 1.96

Step 5: compare and conclude

We calculated $Z = 14.61$, which is far outside the range of ± 1.96 to ± 1.96 .

Final conclusion

There is strong statistical evidence that the medication affects intelligence, because the sample mean is significantly different from the population mean.

One Sample T-test

Z -test \Rightarrow population S.D given

(46)

t -test \Rightarrow population S.D not given.

We will use the same problem as we have taken before in Z -test, the only change is that this time the population S.D is not given.

Q) Population average $I.Q = 100$, $n=30$, $\bar{x} = 240$, $s = 20$. did the medication affect intelligence? $\alpha = 0.05$

\Rightarrow Given:- population mean (μ) = 100

sample mean (\bar{x}) = 110

sample size (n) = 30

sample standard deviation (s) = 20

degree of freedom (df) = $n-1 = 29$

$\alpha = 0.05$

Step 1: set up hypothesis (Two tailed)

$H_0: \mu = 100$ (medication has no effect)

$H_1: \mu \neq 100$ (medication affect $I.Q$)

Step 2: calculate the test statistic (t-score)

$$t = \frac{\bar{x} - \mu}{s/\sqrt{n}} = \frac{110 - 100}{20/\sqrt{30}} = \frac{10}{3.651} \approx 2.739$$

Step 3: Find the critical t-value

From the t-distribution table with:

$$\rightarrow df = 29$$

$$\rightarrow \alpha = 0.05 \text{ (two tailed)}$$

$$\text{critical } t \approx \pm 2.045$$

Step 4: compare,

- calculated $t = 2.739$

- critical $t = \pm 2.045$

since, $2.739 > 2.045$, we reject the null hypothesis.

Final conclusion

- 1) The medication has a statistically significant effect on IQ.
(47)
- 2) since the sample mean (110) > population mean (100),
 the medication likely improve intelligence.

CHI SQUARE TEST

The chi-square test is a statistical test used to compare observed data with expected data.

Formula

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

where:

O = observed frequency

E = Expected frequency.

Properties

- 1) It is a non-parametric test.

Non-parametric means

- It doesn't assume anything about the distribution of the data (like normal distribution).
- It is based on frequencies, not means or standard deviation.

So, it's perfect when your data is categorical - not continuous.

- 2) Chi-square test is performed on categorical variables, which can be:

Type

Nominal

Ordinal

Example

Gender (Male/Female), Yes/No, color

Education level (High school < Graduate < Postgrad)

- Even though ordinal data has some order, in chi-square we just count categories, not treat them as numeric values.

Summary

Feature

Type

works on

uses

Assumptions

Typical use case

chi-Square Test

(4B)

non-parametric

categorical data (nominal, ordinal)

Frequencies (not means / variance)

No assumption of normality

Test: independence or goodness-of-fit.

The objective

Q) In the 2000 Indian census, the age of individual in small town were found to be the following.

< 18	$18 - 35$	> 35
20%	30%	50%

In 2010, age of $n = 500$ individuals were sampled, below are the result

< 18	$18 - 35$	> 35
121	288	91

Using $\alpha = 0.05$, would you conclude the population has changed in the last 10 years.

Ans: Step 1: Define the hypothesis.

- Null hypothesis (H_0): The age distribution in 2010 is the same as in 2000
- Alternative hypothesis (H_1): The age distribution in 2010 is different from that in 2000.

Step 2: Calculate expected counts.

Multiply the 2000 proportions with the 2010 sample size ($n = 500$)

< 18	$18 - 35$	> 35
$0.20 \times 500 = 100$	$0.30 \times 500 = 150$	$0.5 \times 500 = 250$

Step 3: Apply chi-square test formula

$$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i}$$

(49)

O_i = observed freq. E_i = Expected freq.

$$\therefore \chi^2 = \frac{(121-100)^2}{100} + \frac{(288-150)^2}{150} + \frac{(91-250)^2}{25}$$

$$\chi^2 = 232.49$$

Step 4: Degree of freedom.

$$df = \text{Number of categories} - 1 = 3 - 1 = 2$$

Step 5: critical value at $\alpha = 0.05$ and $df = 2$
From chi-square distribution table

$$\chi^2_{\text{critical}} = 5.991$$

Step 6: Conclusion

Since,

$$\chi^2_{\text{calculated}} = 232.49 > \chi^2_{\text{critical}} = 5.991$$

we reject the null hypothesis

Hence, there is a strong evidence to suggest that the population age distribution has changed between 2000 and 2010.

Relation between confidence interval, significance value and P value

1) confidence interval = $1 - \alpha$ (significance value)

2) If $P\text{-value} < \text{significance level } \alpha$

→ reject the null hypothesis (H_0)

If $P\text{-value} > \alpha$

→ accept the null hypothesis (H_0)

Covariance

Covariance is a measure of how two variables change together.

(EQ)

Intuition

- If both variables increase together, the covariance is +ve.
- If one increases while the other decreases, the covariance is negative.
- If they don't seem to change together, the covariance is close to 0.

e.g:-

Study hours

2

4

6

8

Exam marks

50

60

70

80

+ve covariance

Formula

$$\text{Cov}(X, Y) \neq \frac{1}{n}$$

1) Population covariance formula

$$\boxed{\text{Cov}(X, Y) = \frac{1}{n} \sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}$$

↳ use this when we have the entire population.

2) Sample covariance formula

$$\boxed{\text{Cov}(X, Y) = \frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}$$

↳ use this when we have a sample from the population.

The question is now why divide by $(n-1)$. In the formula of sample covariance.

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Ans:- This is due to the Bessel's correction.

But what it is and how it is divided by $(n-1)$.

Population (N)

For mean

$$\mu = \frac{1}{N} \sum_{i=1}^N x_i$$

sample (n)

$$\bar{x} = \frac{1}{n} \sum_{i=1}^n x_i$$

For Variance

$$\sigma^2 = \frac{1}{N} \sum_{i=1}^N (x_i - \mu)^2$$

$$S^2 = \frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2$$

Suppose we have a data of ages in a population.

Ages 

When I randomly take a sample from this population and calculate the sample mean, it often turns out to be close to the population mean. The same happens with sample variance - it becomes closer to the true true value variance of the population, but only if we correct it properly.

However, if I just take the first few values (like the first 4), or a random slice, the sample mean and variance might be very different from the actual population.

To fix this issue, statisticians ran experiments:

They took many samples from the population and tried calculating variance by dividing by

- n
- $n-1$
- $n-2$

and so on

What they found was this:

when they divided the sum of squared differences by $n-1$, the average of the sample variances (52) factors all the samples come closer to the true population variance.

This is why we divide by $n-1$ to make the sample variance an unbiased estimator of the population variance.

This technique is called Bessel's correction.

Since covariance doesn't have fixed limit - its value depends on the scale of the variables.

For example, if our variable in kilograms and rupees, or meters and dollars, the covariance can become very large or very small, making it hard to interpret. So we use the Pearson correlation coefficient.

Pearson Correlation coefficient

The Pearson correlation coefficient (r) is a statistical measure that tells us how two variables are linearly related. i.e., whether they move together and how closely.

Formula:

$$r = \frac{\text{Cov}(X, Y)}{\sigma_x \times \sigma_y}$$

Where :

- $\text{Cov}(X, Y)$ = covariance of variables X and Y .
- σ_x = standard deviation of X .
- σ_y = standard deviation of Y .

Value of r lies between -1 and 1.

r value

+1

0

-1

Closer to 1 and -1

Closer to 0

meaning

Perfect positive correlation

(53)

No linear correlation.

Perfect negative correlation.

Strong relationship

Weak relationship.

Eg:- Student

x (hours studied)

y (Marks scored)

A	1	2
B	2	3
C	3	6
D	4	8
E	5	7

Step 1: Calculate means:

$$\bar{x} = \frac{1+2+3+4+5}{5} = 3$$

$$\bar{y} = \frac{2+3+6+8+7}{5} = \frac{26}{5} = 5.2$$

Step 2: Build the table

Student	x	y	$x - \bar{x}$	$y - \bar{y}$	$(x - \bar{x})(y - \bar{y})$	$(x - \bar{x})^2$	$(y - \bar{y})^2$
A	1	2	-2	-3.2	6.4	4	10.24
B	2	3	-1	-2.2	2.2	1	4.84
C	3	6	0	0.8	0	0	0.64
D	4	8	1	2.8	2.8	1	7.84
E	5	7	2	1.8	3.6	4	3.24

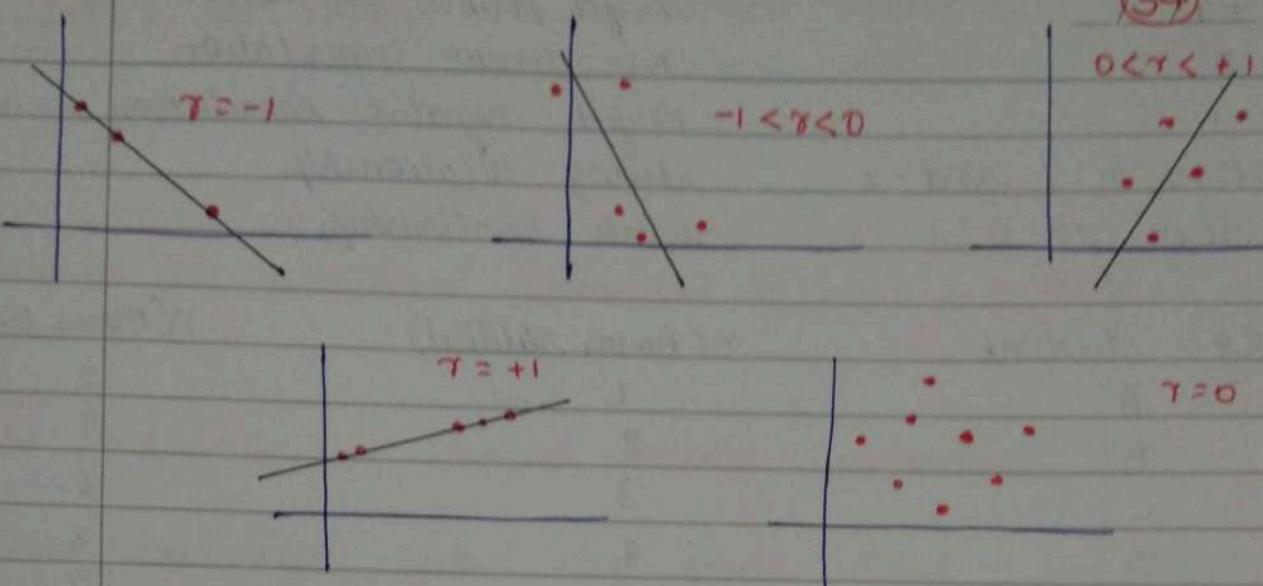
Step 3: Apply the Pearson correlation formula

$$r = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sqrt{\sum (x - \bar{x})^2 \cdot \sum (y - \bar{y})^2}}$$

$$r \approx 0.916$$

That's a very strong +ve correlation - almost perfect, but with small variations in data.

(54)



Spearman coefficient correlation

The Spearman's Rank correlation coefficient (denoted by ρ or γ_s) is a non-parametric measure of monotonic association between two variables - based on the rank values other than the raw data.

Key Points

- It doesn't assume a linear relationship like Pearson's correlation.
- It is used when data is ordinal, not normally distributed, or when you want to measure monotonic relationships.
- Works well even with outliers or non-linear relationships.

Formula

If there is no similar ranks

$$\gamma_s = 1 - \frac{6 \sum d_i^2}{n(n^2 - 1)}$$

where: d_i = diff. b/w the ranks of the two variable for each observation.

n = number of observations.

Example

Let say we have data for 5 students

(55)

Student	Math Rank(X)	English Rank(Y)
A	1	2
B	2	1
C	3	4
D	4	3
E	5	5

Now compute the difference in ranks:

Student	X	Y	$d = X - Y$	d^2
A	1	2	-1	1
B	2	1	1	1
C	3	4	-1	1
D	4	3	1	1
E	5	5	0	0

$$\sum d^2 = 1 + 1 + 1 + 1 + 0 = 4$$

Now apply the formula:

$$\gamma_s = 1 - \frac{6 \cdot 4}{5(5^2 - 1)} = 0.8$$

$\therefore \gamma_s = 0.8 \rightarrow$ strong +ve monotonic relationship
bw Math and English ranks.