Lecture 8

Normal Random Variables

Text: Chapter 4

STAT 8010 Statistical Methods I
February 3, 2020

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Notes

Agenda

1. Normal Density Curves
2. Standard Normal
3. Sums of Normal Random Variables

Normal Random Variables
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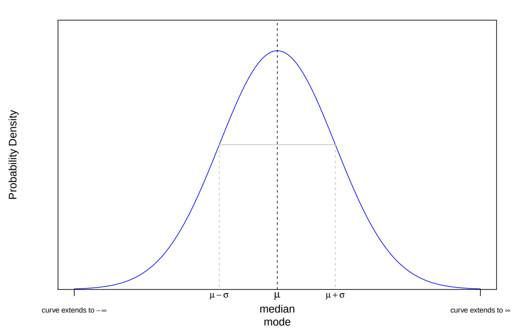
Normal Density Curves
Standard Normal
Sums of Normal Random Variables

Notes

Probability Density Curve for Normal Random Variable



Normal Random Variables
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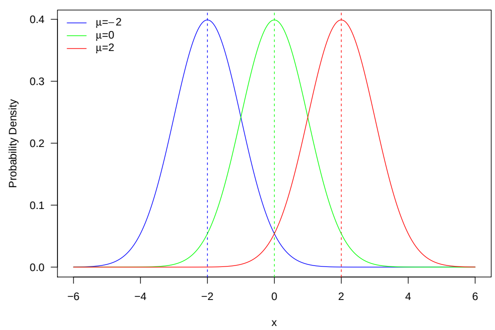
Notes

Normal Density Curves

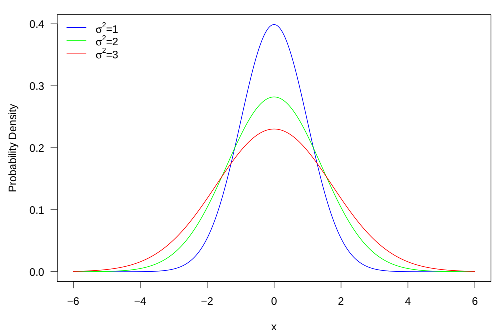
Different μ but same σ^2



Notes

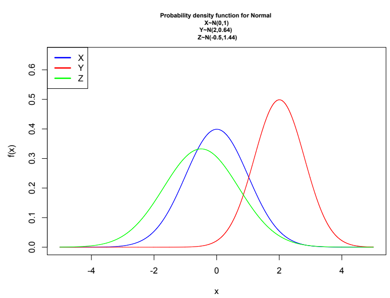
Normal Density Curves Cont'd

Same μ but different σ^2



Notes

Normal Density Curves



- The parameter μ determines the center of the distribution
- The parameter σ^2 determines the spread of the distribution
- Also called bell-shaped distribution

Notes

Characteristics of Normal Random Variables

Let X be a Normal r.v.

- The support for X: $(-\infty, \infty)$
- Parameters: μ : mean and σ^2 : variance
- The probability density function (pdf): $\frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{-(x-\mu)^2}{2\sigma^2}}$ for $-\infty < x < \infty$
- The cumulative distribution function (cdf): No explicit form, look at the value $\Phi(\frac{x-\mu}{\sigma})$ for $-\infty < x < \infty$ from standard normal table
- The expected value: $\mathbb{E}[X] = \mu$
- The variance: $Var(X) = \sigma^2$

Notes

Standard Normal $Z \sim N(\mu = 0, \sigma^2 = 1)$

- Normal random variable X with mean μ and standard deviation σ can convert to standard normal Z by the following :

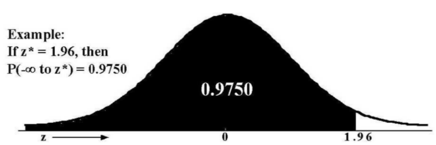
$$Z = \frac{X - \mu}{\sigma}$$

- The cdf of the standard normal, denoted by $\Phi(z)$, can be found from the standard normal table
- The probability $\mathbb{P}(a \leq X \leq b)$ where $X \sim N(\mu, \sigma^2)$ can be compute

$$\mathbb{P}(a \leq X \leq b) = \mathbb{P}(\frac{a-\mu}{\sigma} \leq Z \leq \frac{b-\mu}{\sigma})$$
$$= \Phi(\frac{b-\mu}{\sigma}) - \Phi(\frac{a-\mu}{\sigma})$$

Notes

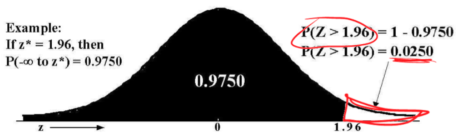
Standard Normal (Z) Table



z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	**0.9750**	0.9756	0.9761	0.9767

Notes

Standard Normal (Z) Table Cont'd



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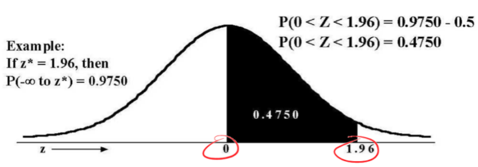

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Notes

Properties of Φ

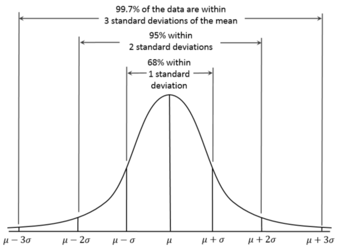
- $\Phi(0) = .50 \Rightarrow$ Mean and Median (50_{th} percentile) for standard normal are both 0
- $\Phi(-z) = 1 - \Phi(z)$
- $\mathbb{P}(Z > z) = 1 - \Phi(z) = \Phi(-z)$

Notes

The Empirical Rules

The Empirical Rules provide a quick way to approximate certain probabilities for the Normal Distribution as the following table:

Interval	Percentage with interval
$\mu \pm \sigma$	68%
$\mu \pm 2\sigma$	95%
$\mu \pm 3\sigma$	99.7%



Notes

Example

Let us examine Z. Find the following probabilities with respect to Z:

1. Z is at most -1.75
2. Z is between -2 and 2 inclusive
3. Z is less than .5

Notes

Example Cont'd

Solution.

1. $\mathbb{P}(Z \leq -1.75) = \Phi(-1.75) = .0401$
2. $\mathbb{P}(-2 \leq Z \leq 2) = \Phi(2) - \Phi(-2) = .9772 - .0228 = .9544$
3. $\mathbb{P}(Z < .5) = \Phi(.5) = .6915$

Notes

Example

Suppose a STAT-8020 exam score follows a normal distribution with mean 78 and variance 36. Let X to denote the exam score, answer the following questions:

1. What is the probability that a randomly chosen test taker got a score greater than 84?
2. Suppose the passing score for this exam is 75. What is the probability that a randomly chosen test taker got a score greater than 84 given that she/he pass the exam?
3. Using the empirical rule to find the 84_{th} percentile.

Notes

Example

Find the following percentile with respect to Z

1. 10_{th} percentile
2. 55_{th} percentile
3. 90_{th} percentile

Notes

Example Cont'd

Solution.

1. $Z_{10} = -1.28$
2. $Z_{55} = 0.13$
3. $Z_{90} = 1.28$

Notes

Example

Let X be Normal with a mean of 20 and a variance of 49. Find the following probabilities and percentile:

1. X is between 15 and 23
2. X is more than 30
3. X is more than 12 knowing it is less than 20
4. What is the value that is smaller than 20% of the distribution?

Notes

Example Cont'd

Solution.

1. $\mathbb{P}(15 \leq X \leq 23) = \Phi(\frac{15-20}{7}) - \Phi(\frac{23-20}{7}) = \Phi(0.43) - \Phi(-0.71) = .6664 - .2389 = .4275$
2. $\mathbb{P}(X > 30) = 1 - \mathbb{P}(X \leq 30) = 1 - \Phi(\frac{30-20}{7}) = 1 - .9236 = .0764$
3. $\mathbb{P}(X > 12 | X < 20) = \frac{\mathbb{P}(12 < X < 20)}{\mathbb{P}(X < 20)} = \frac{\Phi(0) - \Phi(-1.14)}{\Phi(0)} = .7458$
4. $Z_{80} = 0.84 \Rightarrow X_{80} = \mu + Z_{80} \times \sigma = 20 + 0.84 \times \sqrt{49} = 25.88$

Notes

Sums of Normal Random Variables

If X_i $1 \leq i \leq n$ are independent normal random variables with mean μ_i are variance σ_i^2, respectively.

- Let $S_n = \sum_{i=1}^{n} X_i$ then $S_n \sim N(\sum_{i=1}^{n} \mu_i, \sum_{i=1}^{n} \sigma_i^2)$
- This can be applied for any integer n

Notes

Example

Let X_1, X_2, and X_3 be mutually independent, Normal random variables. Let their means and standard deviations be $3k$ and k for $k = 1, 2,$ and 3 respectively. Find the following distributions:

1. $\sum_{i=1}^{3} X_i$
2. $X_1 + 2X_2 - 3X_3$
3. $X_1 + 5X_3$

Notes

Example Cont'd

Solution.

1. $\sum_{i=1}^{3} X_i \sim N(\mu = 3+6+9 = 15, \sigma^2 = 1^2+2^2+3^2 = 14)$
2. $X_1 + 2X_2 - 3X_3 \sim N(\mu = 3 + 12 - 27 = -12, \sigma^2 = 1^2 + 4 \times 2^2 + 9 \times 3^2 = 98)$
3. $X_1 + 5X_3 \sim N(\mu = 3+45 = 48, \sigma^2 = 1^2+25\times 3^2 = 226)$

Notes

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