Chapter 6 Some Continuous Probability Distributions:

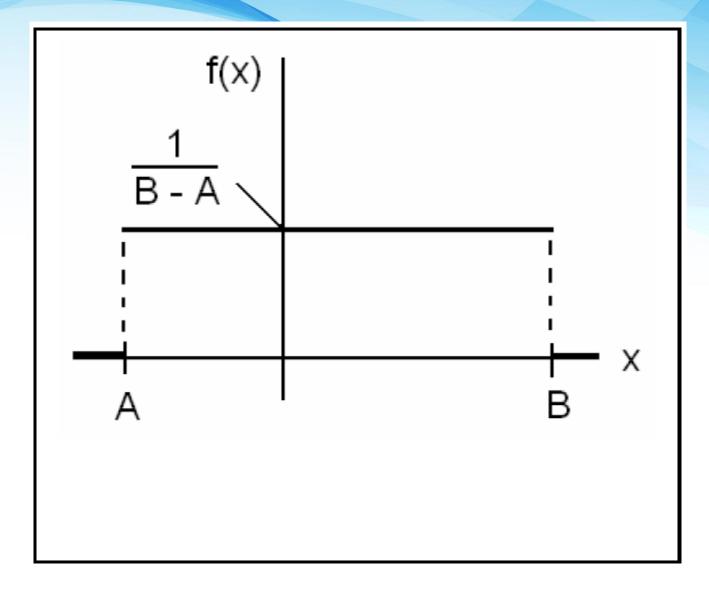
Continuous Uniform distribution

(Rectangular Distribution)

The probability density function of the continuous uniform random variable X on the interval [*A*, *B*] is given by:

$$f(x) = f(x; A, B) = \begin{cases} \frac{1}{B - A} ; A \le x \le B\\ 0 ; elsewhere \end{cases}$$

We write
$$X \sim Uniform(A,B)$$
.





The mean and the variance of the continuous uniform distribution on the interval [A, B] are:

$$\mu = \frac{A+B}{2}$$
$$\sigma^2 = \frac{(B-A)^2}{12}$$



- Suppose that, for a certain company, the conference time, X, has a uniform distribution on the interval [0,4] (hours).
- (a) What is the probability density function of X?(b) What is the probability that any conference lasts at least 3 hours?



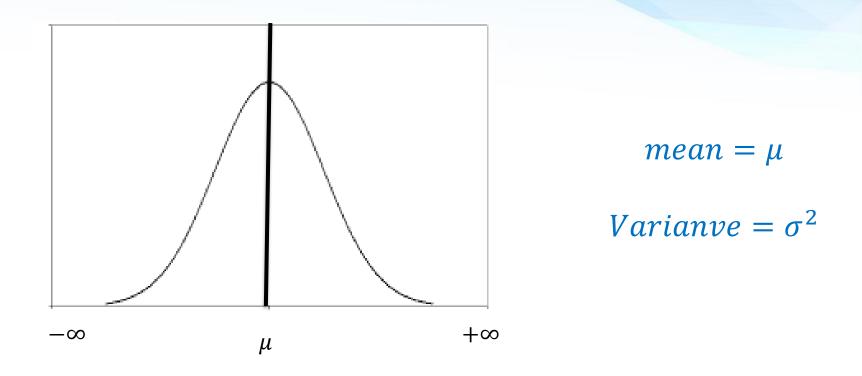
(a)
$$f(x) = f(x;0,4) = \begin{cases} \frac{1}{4} ; 0 \le x \le 4\\ 0 ; elsewhere \end{cases}$$

(b) P(X \ge 3) =
$$\int_{3}^{4} f(x) dx = \int_{3}^{4} \frac{1}{4} dx = \frac{1}{4}$$

Normal Distribution (Gaussian distribution)

- □ The normal distribution is one of the most important continuous distributions.
- Many measurable characteristics are normally or approximately normally distributed, such as, height and weight.
- The graph of the probability density function
 (pdf) of a normal distribution, called the normal
 curve, is a bell-shaped curve.

The normal distribution characteristics 1) $-\infty < X < \infty$ 2) The density function of *X*, *f*(*x*), has a bell-shaped curve



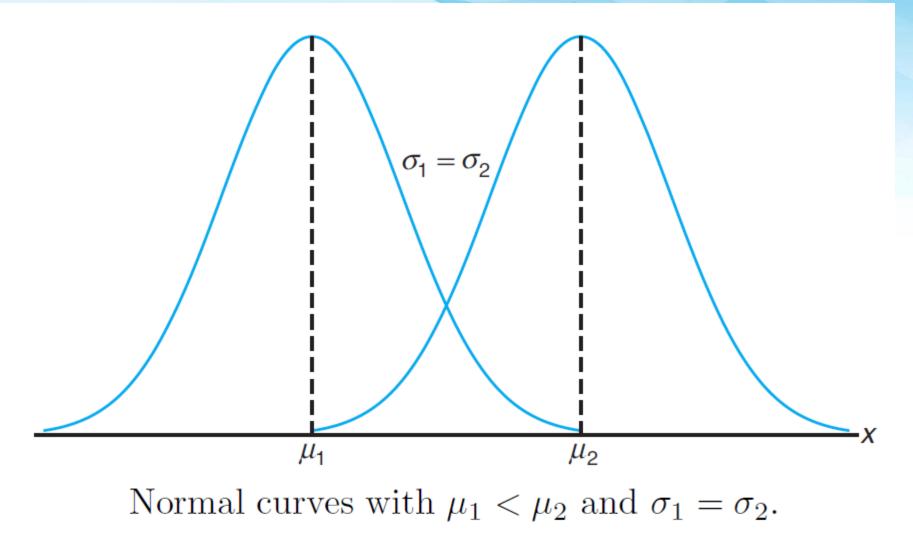
3) The highest point of the curve of f(x) at the mean μ The curve of f(x) is symmetric about the mean μ . μ =mean = mode = median

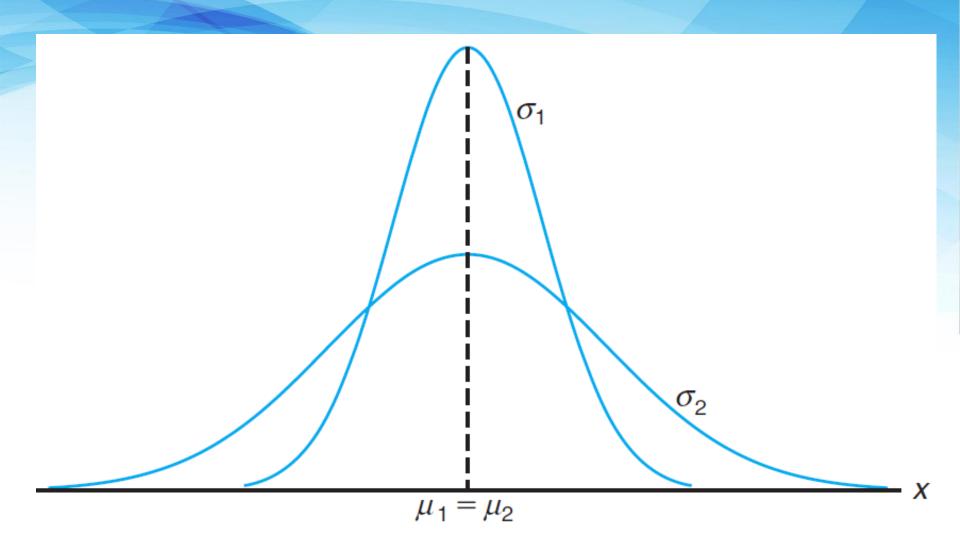
4) The normal distribution depends on two parameters: mean = μ and variance = σ^2

(5) If the r.v. *X* is normally distributed with mean μ and variance σ^2 , we write:

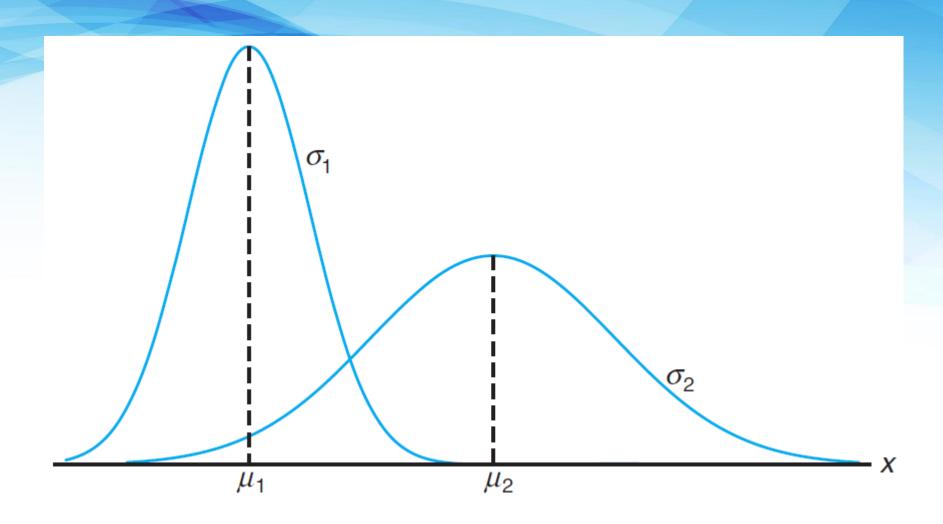
 $X \sim \text{Normal}(\mu, \sigma^2) \text{ or } X \sim \text{N}(\mu, \sigma^2)$

(6) The location of the normal distribution depends on μ The shape of the normal distribution depends on σ^2





Normal curves with $\mu_1 = \mu_2$ and $\sigma_1 < \sigma_2$.



Normal curves with $\mu_1 < \mu_2$ and $\sigma_1 < \sigma_2$.

The pdf of $X \sim Normal(\mu, \sigma)$ is given by:

$$f(x) = n(x; \mu, \sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} ; \begin{cases} -\infty < x < \infty \\ -\infty < \mu < \infty \\ \sigma > 0 \end{cases}$$

where $\pi = 3.14159...$ and e = 2.71828...

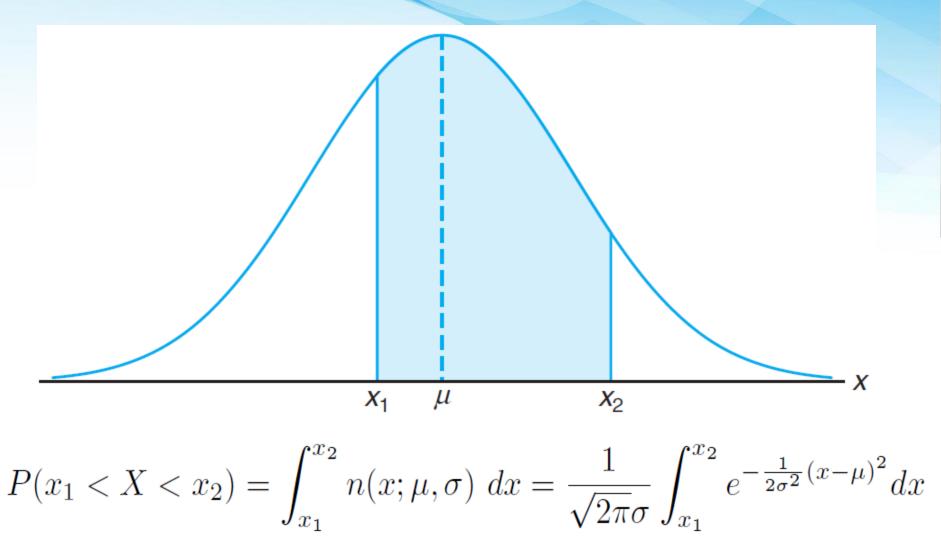
Some properties of the normal curve f(x)of $N(\mu, \sigma)$:

1. f(x) is symmetric about the mean μ .

2. f(x) has two points of inflection at $x = \mu \pm \sigma$.

- 3. The total area under the curve of f(x) = 1.
- 4. The highest point of the curve of f(x) at the mean μ .

Areas Under the Normal Curve



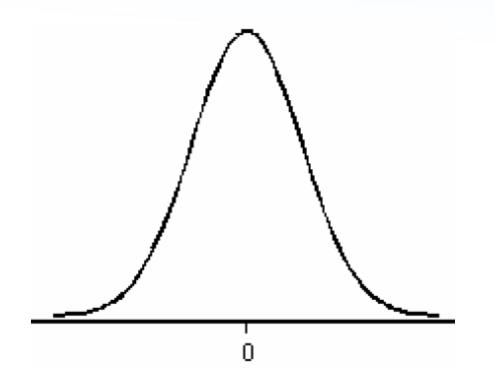
Areas Under the Normal Curve

The Standard Normal Distribution:

• The normal distribution with mean $\mu=0$ and variance $\sigma^2=1$ is called the standard normal distribution and is denoted by Normal(0,1) or N(0,1). If the random variable Z has the standard normal distribution, we write Z~Normal(0,1) or Z~N(0,1).

• The pdf of $Z \sim N(0,1)$ is given by:

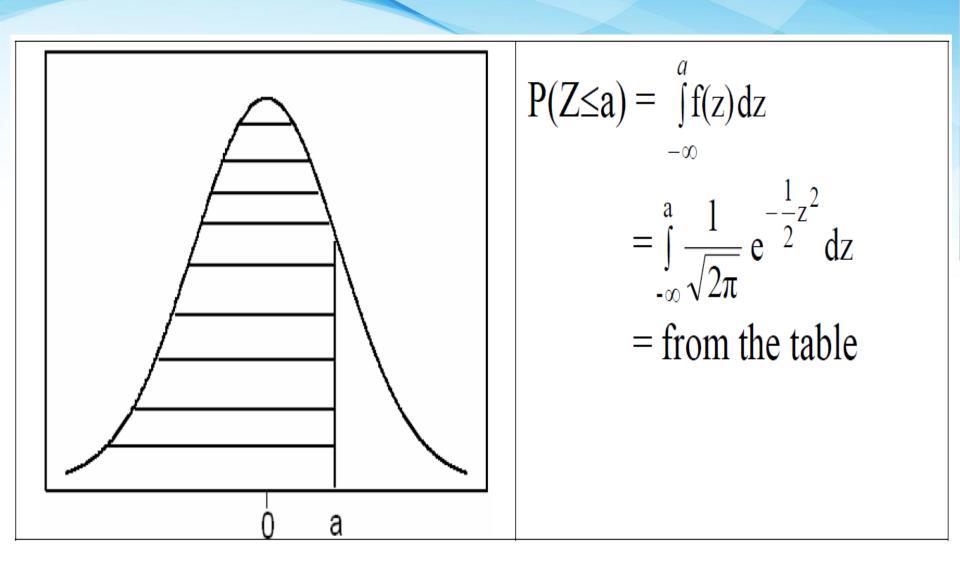
$$f(z) = n(z;0,1) = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}z^2}$$



• The standard normal distribution, Z~N(0,1), is very important because probabilities of any normal distribution can be calculated from the probabilities of the standard normal distribution.

• Probabilities of the standard normal distribution

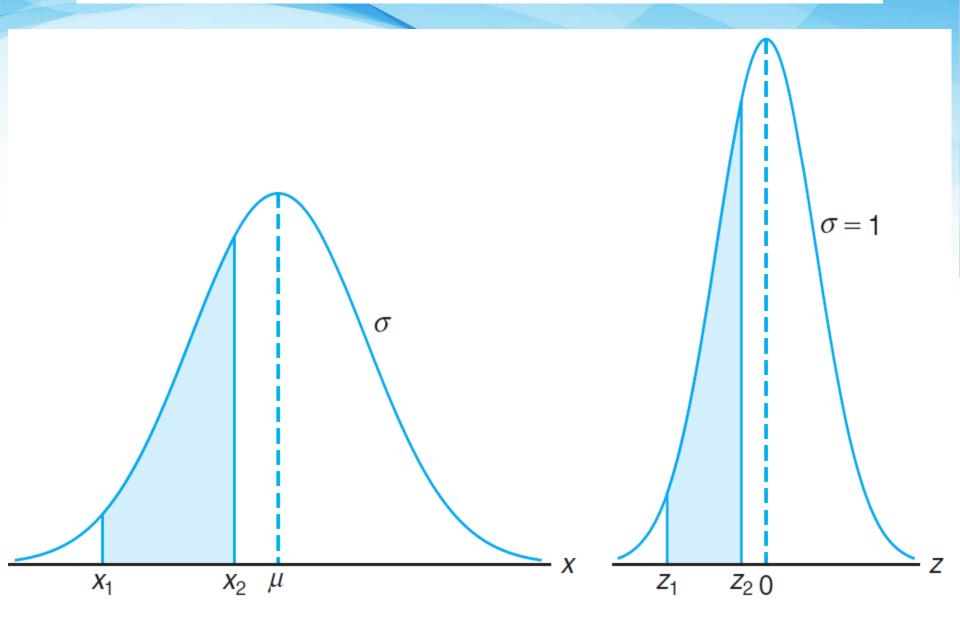
 $Z \sim N(0,1)$ of the form $P(Z \le a)$ are tabulated.



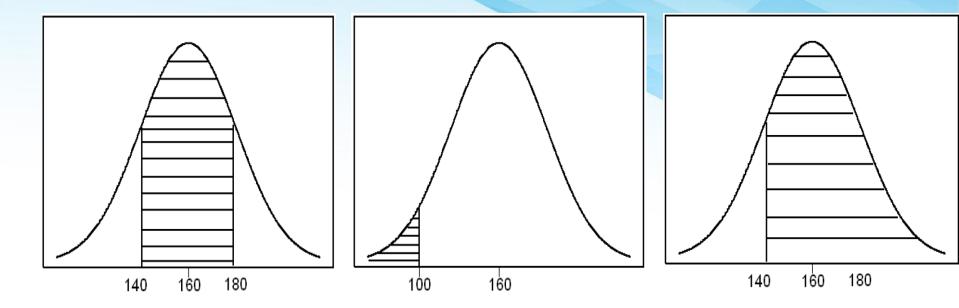
We can transfer any normal distribution
 X~N(μ,σ) to the standard normal distribution,
 Z~N(0,1) by using the following result.

Result: If X~N(μ,σ), then $Z = \frac{X - \mu}{\sigma} \sim N(0,1)$.

The original and transformed normal distributions.



(ii) Probability of an interval event is given by the area under the curve of f(x) and above that interval.



 $P(140 < X < 180) = \int_{140}^{180} f_X(x) dx \quad P(X < 100) = \int_{-\infty}^{100} f_X(x) dx \quad P(X > 140) = \int_{140}^{\infty} f_X(x) dx$ $area = P(a \le X \le b) \quad area = P(X \le a) \quad area = P(X \ge b)$ $= \int_{a}^{b} f(x) dx \quad = \int_{-\infty}^{a} f(x) dx \quad = \int_{b}^{\infty} f(x) dx$

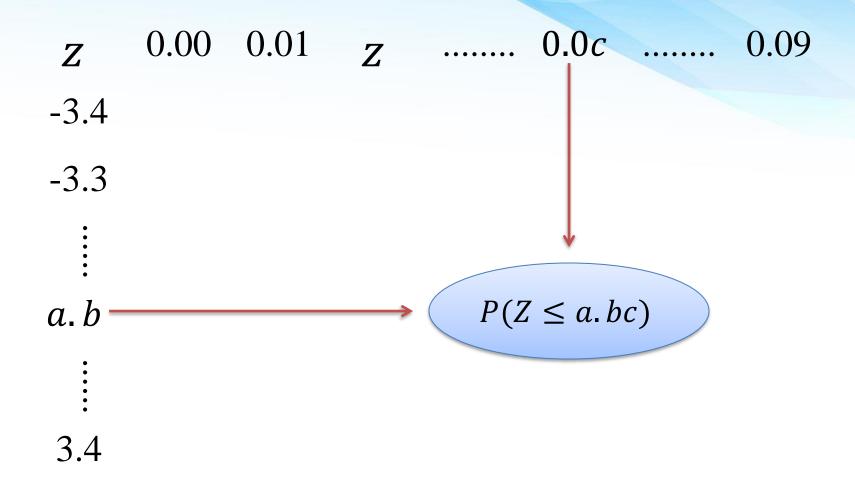
Note: Probabilities of Z~N(0,1):

If X is continuous random variable then:

(i)
$$P(X = x) = 0$$
 for any x
(ii) $P(X \le a) = P(X < a)$
(iii) $P(X \ge b) = P(X > b)$
(iv) $P(a \le X \le b) = P(a \le X < b) = P(a < X \le b) = P(a < X < b)$
(v) $P(X \le x) =$ cumulative probability
(vi) $P(X \ge a) = 1 - P(X < a) = 1 - P(X \le a)$
(vii) $P(a \le X \le b) = P(X \le b) - P(X \le a)$

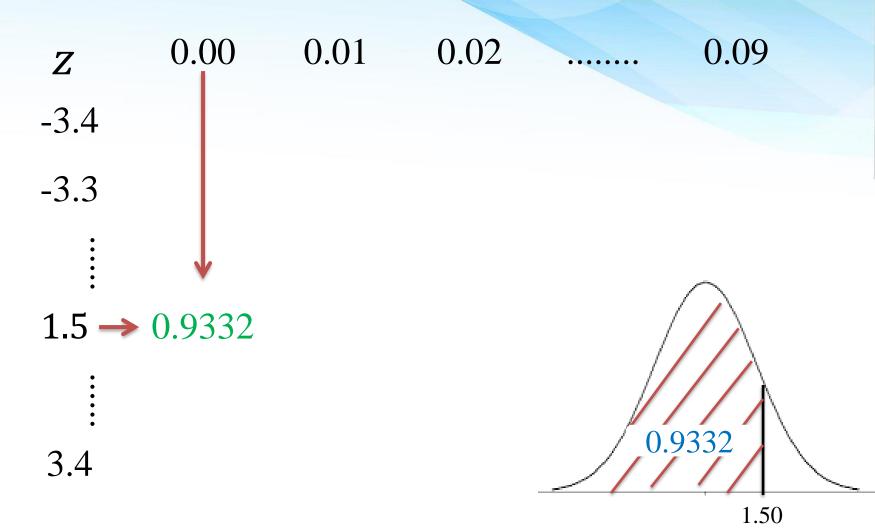
Finding $P(Z \le z)$ from the table

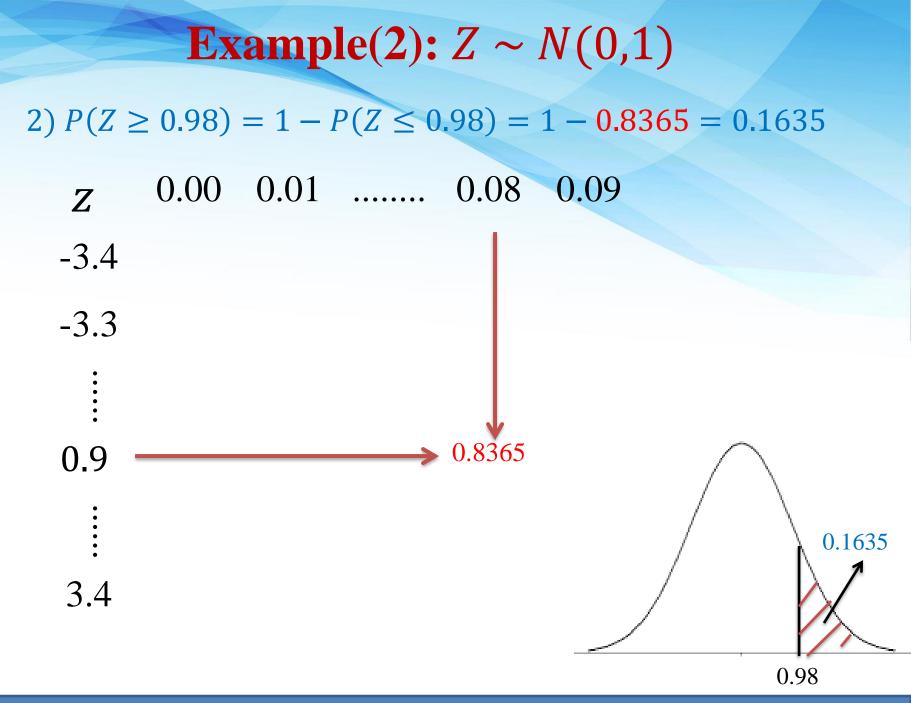
consider that the value of z is rounded to 2 decimal places as z = a.bc



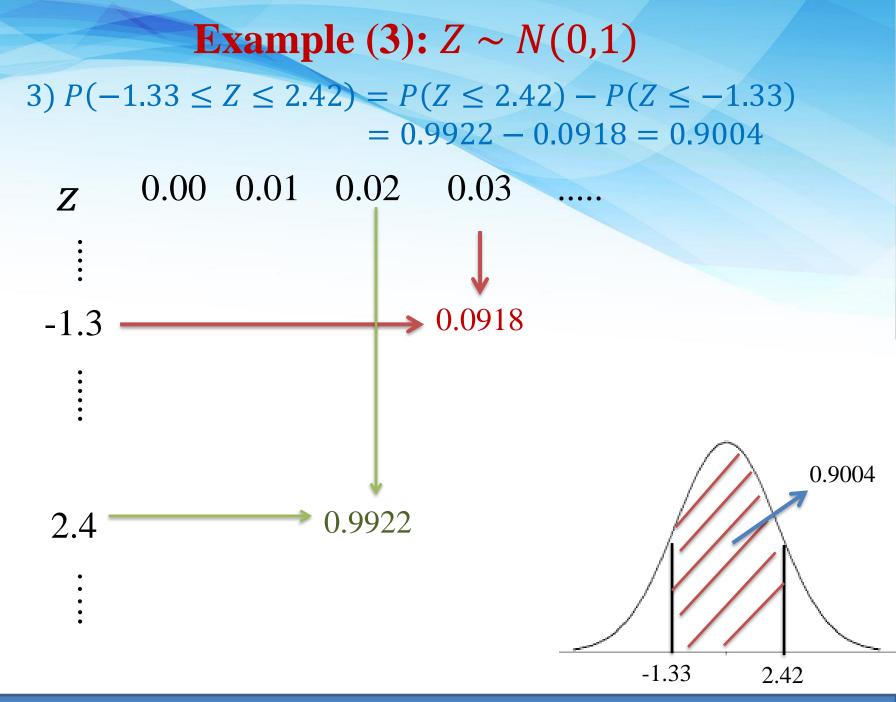
Example(1): $Z \sim N(0,1)$

1) $P(Z \le 1.50)$

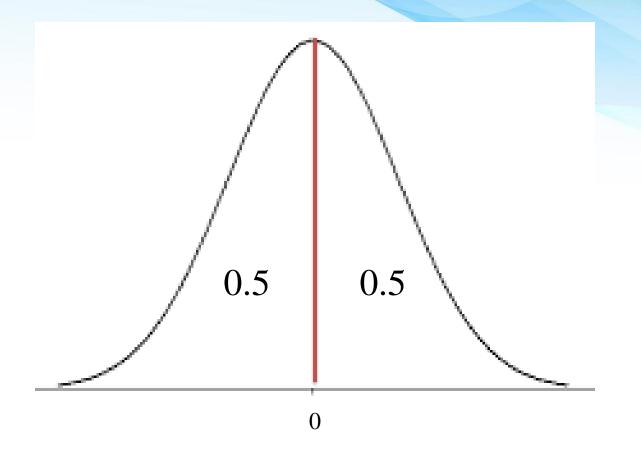




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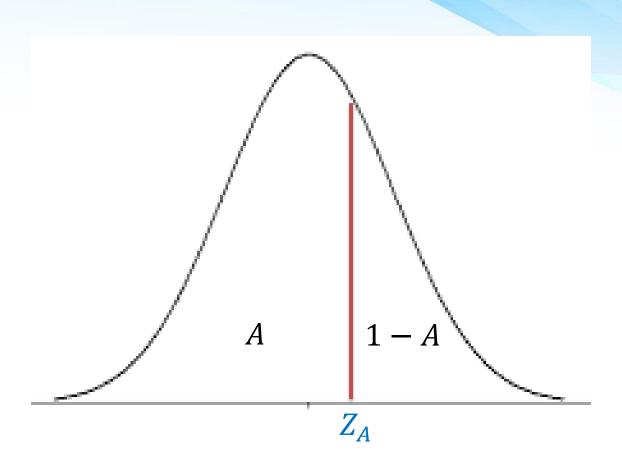


Example(4): $Z \sim N(0,1)$ 4) $P(Z \ge 0) = P(Z \le 0) = 0.5$





 $P(Z \le Z_A) = A$



Example: $Z \sim N(0,1)$ If $P(Z \le a) = 0.9505$

Ζ	•••	0.05	•••
•		\uparrow	
1.6	\leftarrow	0.9505	
:			

Then a = 1.65

Example: $Z \sim N(0,1)$ $Z_{0.90} = 1.285$

 $Z_{0.95} = 1.645$

 $Z_{0.975} = 1.96$

 $Z_{0.99} = 2.325$

Calculating Probabilities of Normal (μ, σ^2)

$$X \sim \text{Normal}(\mu, \sigma^2) \iff Z = \frac{X - \mu}{\sigma} \sim \text{Normal}(0, 1)$$
$$X \leq a \iff \frac{X - \mu}{\sigma} \leq \frac{a - \mu}{\sigma} \iff Z \leq \frac{a - \mu}{\sigma}$$

(i)
$$P(X \le a) = P\left(Z \le \frac{a-\mu}{\sigma}\right)$$

(ii) $P(X \ge a) = 1 - P(X \le a) = 1 - P\left(Z \le \frac{a-\mu}{\sigma}\right)$

(iii)

$$P(a \le X \le b) = P(X \le b) - P(X \le a) = P\left(Z \le \frac{b-\mu}{\sigma}\right) - P\left(Z \le \frac{a-\mu}{\sigma}\right)$$

(iv) $P(X = a) = 0$ for every a .

(V) $P(X \le \mu) = P(X \ge \mu) = 0.5$

Example:

Suppose that the hemoglobin level for healthy adults males has a normal distribution with mean μ =16 and variance σ^2 =0.81 (standard deviation σ =0.9).

(a) Find the probability that a randomly chosen healthy adult male has hemoglobin level less than 14.

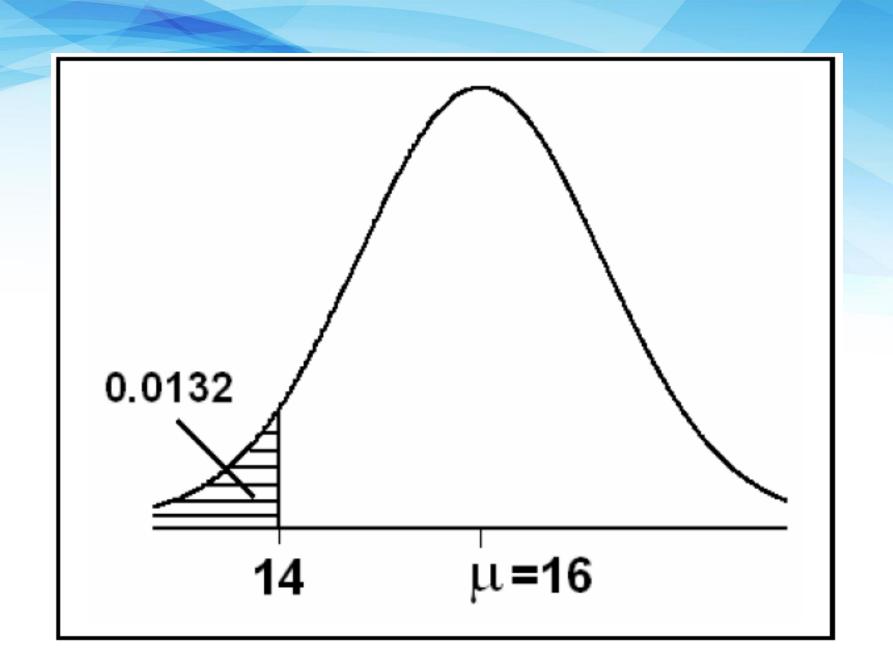
(b) What is the percentage of healthy adult males who have hemoglobin level less than 14?



(a)
$$P(X \le 14) = P\left(Z \le \frac{14-\mu}{\sigma}\right)$$

= $P\left(Z \le \frac{14-16}{0.9}\right) = P(Z \le -2.22) = 0.0132$

(b) The percentage of healthy adult males who have hemoglobin level less than 14 is $P(X \le 14) \times 100\% = 0.01320 \times 100\% = 1.32\%$ 1.32% of healthy adult males have hemoglobin level less than 14.



Example:

Suppose that the birth weight of Saudi babies has a normal distribution with mean μ =3.4 and standard deviation σ =0.35.

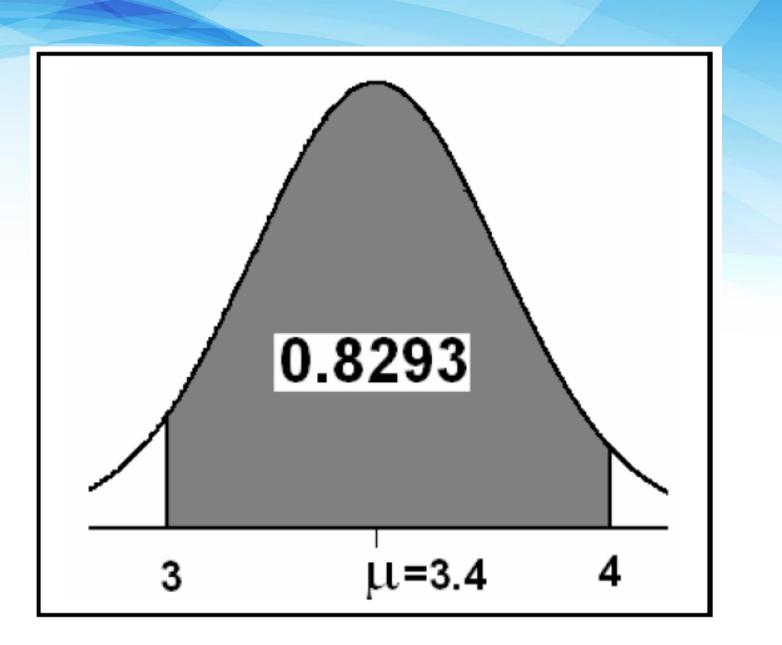
(a) Find the probability that a randomly chosen Saudi baby has a birth weight between 3.0 and 4.0 kg.

(b) What is the percentage of Saudi babies who have a birth weight between 3.0 and 4.0 kg?

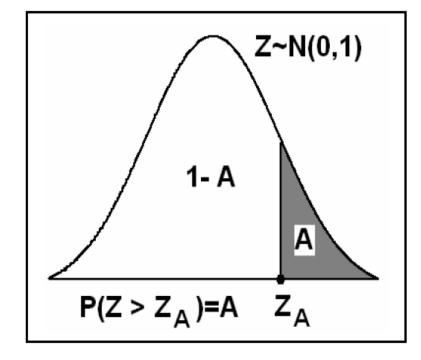
Solution:

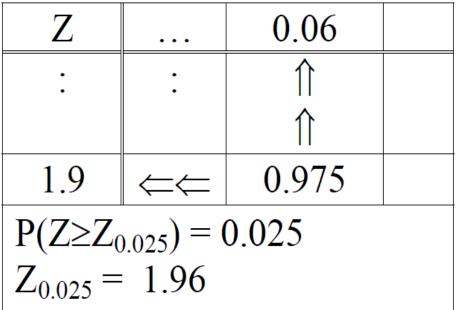
(a) $P(3.0 < X < 4.0) = P(X \le 4.0) - P(X \le 3.0)$ $= P\left(Z \le \frac{4.0 - \mu}{\sigma}\right) - P\left(Z \le \frac{3.0 - \mu}{\sigma}\right)$ $= P\left(Z \le \frac{4.0 - 3.4}{0.35}\right) - P\left(Z \le \frac{3.0 - 3.4}{0.35}\right)$ $= P(Z \le 1.71) - P(Z \le -1.14)$ = 0.9564 - 0.1271 = 0.8293

(**b**) 82.93% of Saudi babies have birth weight between 3.0 and 4.0 kg.



Notation: $P(Z \ge Z_A) = A$ **Result:** $Z_{A} = -Z_{1-A}$ **Example:** $Z \sim N(0,1)$ $P(Z \ge Z_{0.025}) = 0.025$ $P(Z \ge Z_{0.95}) = 0.95$ $P(Z \ge Z_{0.90}) = 0.90$ **Example:** $Z \sim N(0,1)$ $Z_{0.025} = 1.96$ $Z_{0.95} = -1.645$ $Z_{0.90} = -1.285$





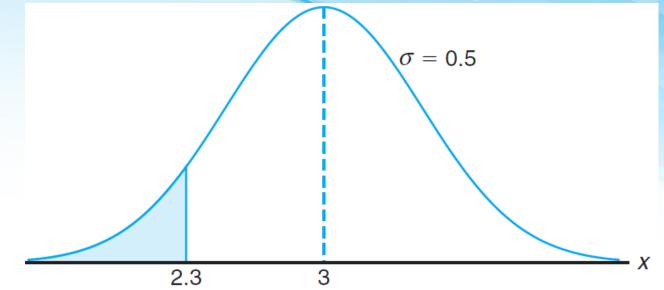
More examples see Ex: 6.2, 6.3, 6.4 and 6.5 on page 178

Applications of the Normal Distribution



A certain type of storage battery lasts, on average, 3.0 years with a standard deviation of 0.5 year. Assuming that battery life is normally distributed, find the probability that a given battery will last less than 2.3 years.





$$z = \frac{2.3 - 3}{0.5} = -1.4$$

$$P(X < 2.3) = P(Z < -1.4) = 0.0808.$$

Example

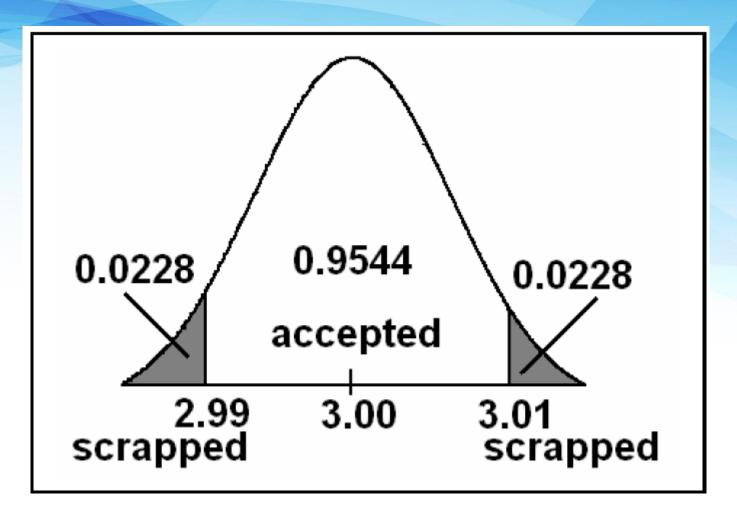
In an industrial process, the diameter of a ball bearing is an important component part. The buyer sets specifications on the diameter to be 3.00 ± 0.01 cm. The implication is that no part falling outside these specifications will be accepted. It is known that, in the process, the diameter of a ball bearing has a normal distribution with mean 3.00 cm and standard deviation 0.005 cm. On the average, how many manufactured ball bearings will be scrapped?



 $\mu = 3.00$ $\sigma = 0.005$ X=diameter $X \sim N(3.00, 0.005)$ The specification limits are: 3.00 ± 0.01 x_1 =Lower limit=3.00-0.01=2.99 x_2 =Upper limit=3.00+0.01=3.01

$$P(x_1 \le X \le x_2) = P(2.99 \le X \le 3.01) = P(X \le 3.01) - P(X \le 2.99)$$

= $P\left(Z \le \frac{3.01 - \mu}{\sigma}\right) - P\left(Z \le \frac{2.99 - \mu}{\sigma}\right)$
= $P\left(Z \le \frac{3.01 - 3.00}{0.005}\right) - P\left(Z \le \frac{2.99 - 3.00}{0.005}\right)$
= $P(Z \le 2.00) - P(Z \le -2.00)$
= $0.9772 - 0.0228$
= 0.9544



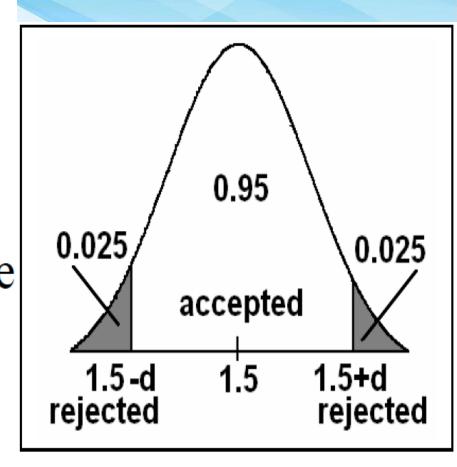
Therefore, on the average, 95.44% of manufactured ball bearings will be accepted and 4.56% will be scrapped.

Example

Gauges are used to reject all components where a certain dimension is not within the specifications $1.50 \pm d$. It is known that this measurement is normally distributed with mean 1.50 and standard deviation 0.20. Determine the value d such that the specifications cover 95% of the measurements.



 $\mu = 1.5$ $\sigma = 0.20$ X= measurement $X \sim N(1.5, 0.20)$ The specification limits are $1.5 \pm d$ x_1 =Lower limit=1.5-d x_2 =Upper limit=1.5+d



 $P(X \ge 1.5 + d) = 0.025 \iff P(X \le 1.5 + d) = 0.975$ $P(X \le 1.5 - d) = 0.025$ $P(X \le 1.5 - d) = 0.025$ $\implies P\left(\frac{X - \mu}{\sigma} \le \frac{(1.5 - d) - \mu}{\sigma}\right) = 0.025$

 $\Leftrightarrow P\left(Z \le \frac{(1.5 - d) - \mu}{\sigma}\right) = 0.025$ $\Leftrightarrow P\left(Z \le \frac{(1.5-d)-1.5}{0.20}\right) = 0.025$ $\Leftrightarrow P\left(Z \le \frac{-d}{0.20}\right) = 0.025$ $\Leftrightarrow \frac{-d}{0.20} = -1.96$ $\Leftrightarrow -d = (0.20)(-1.96)$ $\Leftrightarrow d=0.392$

Z
 ...
 0.06

 :
 :
 î

 -1.9
 :
 0.025

 P(Z <
$$\frac{-d}{0.20}$$
) = 0.025

 $\frac{-d}{0.20}$ = -1.96

 Note:
 $\frac{-d}{0.20}$ = Z_{0.025}

The specification limits are:

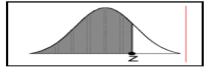
x_1 =Lower limit=1.5-d = 1.5 - 0.392 = 1.108

x_2 =Upper limit=1.5+d=1.5+0.392= 1.892

Therefore, 95% of the measurements fall

within the specifications (1.108, 1.892).

TABLE: Areas Under The Standard Normal Curve Z~Normal(0,1)



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	z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
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$\begin{array}{cccccccccccccccccccccccccccccccccccc$	-3.3	0.0005	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0003
$ \begin{array}{ccccccccccccccccccccccccccccccccccc$											
$\begin{array}{cccccccccccccccccccccccccccccccccccc$							0.0016				
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	-2.8	0.0026	0.0025	0.0024	0.0023	0.0023	0.0022	0.0021	0.0021	0.0020	0.0019
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	-2.7	0.0035			0.0032		0.0030	0.0029	0.0028		0.0026
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$\begin{array}{cccccccccccccccccccccccccccccccccccc$	-2.3	0.0107	0.0104	0.0102	0.0099	0.0096	0.0094	0.0091	0.0089	0.0087	0.0084
	-2.2	0.0139	0.0136	0.0132	0.0129	0.0125	0.0122	0.0119	0.0116	0.0113	0.0110
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$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$	-1.6	0.0548	0.0537	0.0526	0.0516	0.0505	0.0495	0.0485	0.0475	0.0465	0.0455
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$\begin{array}{cccccccccccccccccccccccccccccccccccc$	-1.0	0.1587	0.1562	0.1539	0.1515	0.1492	0.1469	0.1446	0.1423	0.1401	0.1379
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$\begin{array}{cccccccccccccccccccccccccccccccccccc$	-0.5	0.3085	0.3050	0.3015	0.2981	0.2946	0.2912	0.2877	0.2843	0.2810	0.2776
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	-0.4	0.3446	0.3409	0.3372	0.3336	0.3300	0.3264	0.3228	0.3192	0.3156	0.3121
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	-0.3	0.3821	0.3783	0.3745	0.3707	0.3669	0.3632	0.3594	0.3557	0.3520	0.3483
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