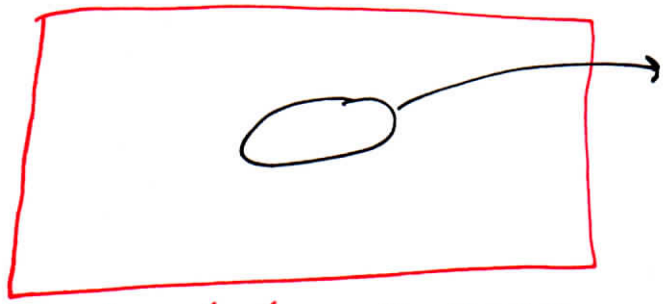
ENGINEERS STAT LECTURE NOTES | CHAPTER 6

* Basic Concepts:



Random Sample
Size: n

Population $N=12000$

X_i: Weekly food expenditure of a student at Bilkent University

$$y_i = \begin{cases} 1 & \text{if the student makes any sport} \\ 0 & \text{o.w.} \end{cases}$$

	Population Parameters (Unknown Constants)	Sample statistics (Known Variables)
MEAN	μ	$\bar{X} = \dfrac{\sum X_i}{n}$
VARIANCE	σ^2	$s^2 = \dfrac{\sum X_i^2 - \dfrac{(\sum X_i)^2}{n}}{n-1}$
standard deviation	σ	$s = \sqrt{s^2}$
PROPORTION	p	$\hat{p} = \dfrac{\sum y_i}{n} = \dfrac{T}{n}$

$T \sim \text{Binomial}(n; p)$

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SAMPLING DISTRIBUTIONS

Sample Mean: $\bar{X}$

* If X_i has a normal distribution with mean μ and variance σ^2, we know (from prob.) that Linear combinations of Normal Random Variables have also Normal Distribution. Then;

$$X_i \overset{i.i.d}{\sim} Normal(\mu; \sigma^2) \Rightarrow \bar{X} \sim Normal\left(\mu; \left(\frac{\sigma}{\sqrt{n}}\right)^2\right)$$

Then, sampling distribution of $\bar{X}$ is Normal with mean μ and Variance $\frac{\sigma^2}{n}$. It is easy to show that $E(\bar{X}) = \mu$ & $Var(\bar{X}) = \frac{\sigma^2}{n}$

(Remember $E(aX+bY+c) = aE(X) + bE(Y) + c$ and

$Var(aX+bY+c) = Var(aX+bY) = a^2 Var(X) + b^2 Var(Y)$

for X, Y independent Random Variables and a, b, c constants)

* If X_i has ANY distribution with mean μ and variance σ^2, then for large n (practically $n \geq 30$) $\bar{X}$ has again Normal distribution with mean μ and Variance $\frac{\sigma^2}{n}$. This is called "Central Limit Theorem"

$$X_i \overset{i.i.d}{\sim} \text{ANY DISTRIBUTION} \xrightarrow{\text{(Large } n)} \bar{X} \sim Normal\left(\mu; \left(\frac{\sigma}{\sqrt{n}}\right)^2\right)$$

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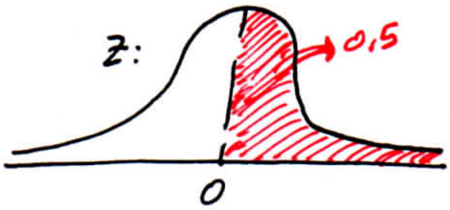
* Remember, we find Normal Probabilities from Z: Standard Normal distribution table.

For a single unit, we have $Z = \dfrac{X - \mu}{\sigma}$

Then, for sample mean, we have $Z = \dfrac{\bar{X} - \mu}{\sigma / \sqrt{n}}$

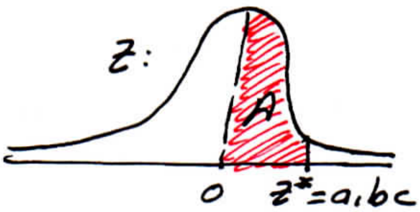
Note that $Z \sim \text{Normal}(\mu = 0 ; \sigma^2 = 1^2)$

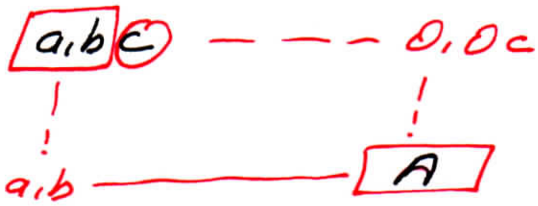
* Finding Probabilities from Z-table:



we have; (i) Total Area = 1
(ii) Half Area = 0,5
(iii) Symmetric areas are equal.

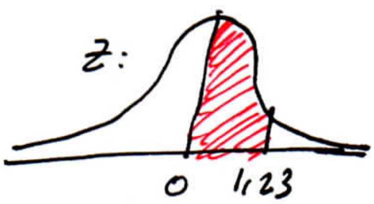
$P(-z_2 < Z < z_1) = P(z_1 < Z < z_2)$





$A = P(0 < Z < a,bc)$

(I) $P(0 < Z < 1{,}23) = ?$



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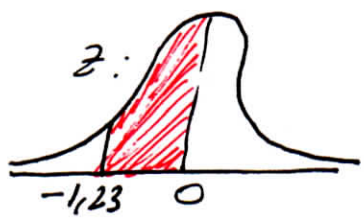

$P(0 < Z < 1{,}23) = 0{,}3907 = P(-1{,}23 < Z < 0)$

(II) (i) $P(1{,}23 < Z < 2{,}45) = ?$

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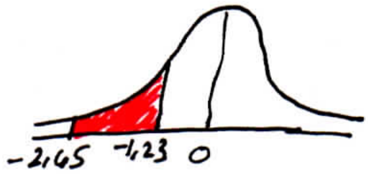


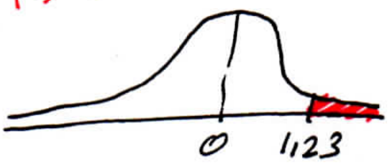
$P(1{,}23 < Z < 2{,}45) = 0{,}4929 - 0{,}3907 = 0{,}1022$
$= P(-2{,}45 < Z < 1{,}23)$

(ii) $P(-1{,}23 < Z < 2{,}45) = ?$

=

$P(-1{,}23 < Z < 2{,}45) = 0{,}4929 + 0{,}3907 = 0{,}8836$
$= P(-2{,}45 < Z < 1{,}23)$

(III) (i) $P(Z > 1{,}23) = ?$



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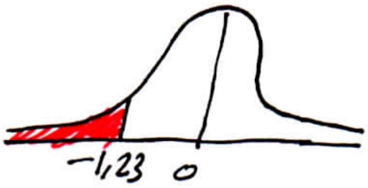
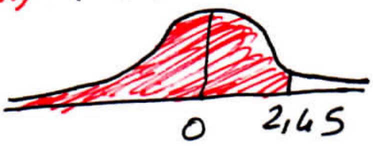


$P(Z > 1{,}23) = 0{,}5 - 0{,}3907 = 0{,}1093 = P(Z < -1{,}23)$

(ii) $P(Z < 2{,}45) = ?$



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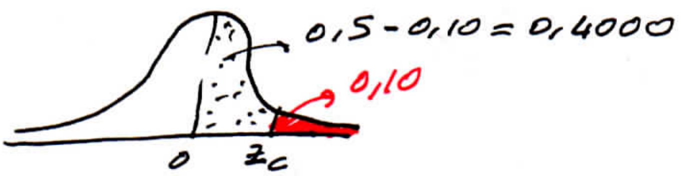
$P(Z < 2{,}45) = 0{,}5 + 0{,}4929 = 0{,}9929 = P(Z > -2{,}45)$

IV $P(Z > z_c) = 0{,}10 \Rightarrow z_c = ?$



$P(0 < Z < 1{,}28) = 0{,}3997 \Rightarrow z_c = 1{,}28$

6.9 Shear-strength measurements for spot welds of a certain type have been found to have a standard deviation of approximately 10 psi. If 100 test welds are to be measured, find the approximate probability that the sample means will be within 1 psi of the true population mean.

6.10 If shear-strength measurements have a standard deviation of 10 psi, how many test welds should be used in the sample if the sample mean is to be within 1 psi of the population mean with probability approximately 0.95?

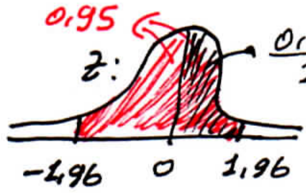
6.9) $X \sim Normal(\mu; \sigma^2 = 10^2)$ $n = 100$ (Even if X is NOT normally distributed, $n > 30$ and by CLT, $\bar{X} \sim Normal$)

$$P(\bar{X} \in (\mu - 1; \mu + 1)) = P(\mu - 1 < \bar{X} < \mu + 1)$$

$$= P\left(\frac{\mu - 1 - \mu}{\sigma/\sqrt{n}} < \underbrace{\frac{\bar{X} - \mu}{\sigma/\sqrt{n}}}_{= Z} < \frac{\mu + 1 - \mu}{\sigma/\sqrt{n}}\right) = P\left(-\frac{\sqrt{100}}{10} < Z < \frac{\sqrt{100}}{10}\right)$$

$$= P(-1 < Z < 1) = 2 \cdot 0{,}3413 = 0{,}6826$$

6.10) $P(\mu - 1 < \bar{X} < \mu + 1) = \cdots = P\left(-\frac{\sqrt{n}}{10} < Z < \frac{\sqrt{n}}{10}\right) = 0{,}95$



$\frac{0{,}95}{2} = 0{,}4750$

Then; $\frac{\sqrt{n}}{10} = 1{,}96$

$n = (19{,}6)^2 = 384{,}16$

$\boxed{n = 385}$ ← ROUND UP!

6.13 Resistors of a certain type have resistances that average 200 ohms with a standard deviation of 10 ohms. Twenty-five of these resistors are to be used in a circuit.

- **a** Find the probability that the average resistance of the 25 resistors is between 199 and 202 ohms.
- **b** Find the probability that the *total* resistance of the 25 resistors does not exceed 5,100 ohms. [*Hint:* Note that $P(\sum_{i=1}^{n} X_i > a) = P(n\bar{X} > a) = P(\bar{X} > a/n)$.]
- **c** What assumptions are necessary for the answers in (a) and (b) to be good approximations?

6.13) c) Assume $X \sim Normal(\mu = 200; \sigma^2 = 10^2)$

$\boxed{n = 25}$

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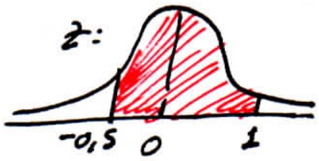
a) $P(199 < \bar{X} < 202) = P\left(\frac{199-200}{10/\sqrt{25}} < \underbrace{\frac{\bar{X}-\mu}{\sigma/\sqrt{n}}}_{=z} < \frac{202-200}{10/\sqrt{25}}\right)$

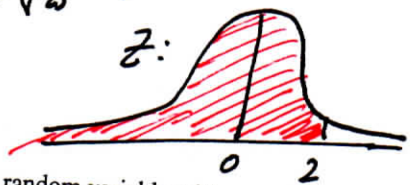
$= P(-0{,}5 < z < 1) = 0{,}1915 + 0{,}3413 = 0{,}5328$



b) $P(\sum X_i \le 5100) = P\left(\frac{\sum X_i}{n} \le \frac{5100}{25}\right) = P(\bar{X} \le 204)$

$= P\left(\frac{\bar{X}-\mu}{\sigma/\sqrt{n}} \le \frac{204-200}{10/\sqrt{25}}\right) = P(z \le 2) = 0{,}5 + 0{,}4772$

$= 0{,}9772$



6.17 The strength of a thread is a random variable with mean 0.5 pound and standard deviation 0.2 pound. Assume the strength of a rope is the sum of the strengths of the threads in the rope.

a Find the probability that a rope consisting of 100 threads will hold 45 pounds.

b How many threads are needed for a rope that will hold 50 pounds with 99% assurance?

6.17) X: strength of a thread

$\mu = 0{,}5;\ \sigma = 0{,}2;$

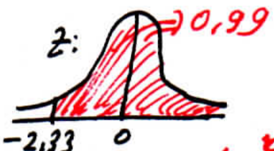
a) $P\left(\sum_{i=1}^{100} X_i > 45\right) = P\left(\frac{\sum X_i}{n} > \frac{45}{100}\right) = P(\bar{X} > 0{,}45)$

$= P\left(\frac{\bar{X}-\mu}{\sigma/\sqrt{n}} > \frac{0{,}45-0{,}50}{0{,}2/\sqrt{100}}\right) = P(z > -2{,}5) = 0{,}5 + 0{,}4938$

$= 0{,}9938$

b) $P\left(\sum_{i=1}^{n} X_i > 50\right) = P\left(\frac{\sum X_i}{n} > \frac{50}{n}\right) = P\left(\bar{X} > \frac{50}{n}\right) = P\left(\frac{\bar{X}-\mu}{\sigma/\sqrt{n}} > \frac{\frac{50}{n}-0{,}5}{0{,}2/\sqrt{n}}\right)$

$= P\left(z > \underbrace{\frac{50-0{,}5n}{0{,}2\sqrt{n}}}_{-2{,}33}\right) = 0{,}99$



$\frac{50-0{,}5n}{0{,}2\sqrt{n}} = -2{,}33$

$50 = 0{,}5n - 0{,}466\sqrt{n}$

by trying: $\boxed{n = 110}$

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6.18 Many bulk products, such as iron ore, coal, and raw sugar, are sampled for quality by a method that requires many small samples to be taken periodically as the material is moving along a conveyor belt. The small samples are then aggregated and mixed to form one composite sample. Let Y_i denote the volume of the ith small sample from a particular lot, and suppose $Y_1, \ldots, Y_n$ constitutes a random sample with each Y_i having mean μ and variance σ^2. The average volume of the samples μ can be set by adjusting the size of the sampling device. Suppose the variance of sampling volumes σ^2 is known to be approximately 4 for a particular situation (measurements are in cubic inches). It is required that the total volume of the composite sample exceed 200 cubic inches with probability approximately 0.95 when $n = 50$ small samples are selected. Find a setting for μ that will allow the sampling requirements to be satisfied.

6.18) $\sigma^2 = Var(y_i) = 4 \quad \mu = E(y_i) \quad n = 50$

$$P\left(\sum_{i=1}^{50} x_i > 200\right) = 0{,}95$$

$$P\left(\sum_{i=1}^{50} x_i > 200\right) = P\left(\frac{\sum x_i}{n} > \frac{200}{50}\right) = P(\bar{x} > 4)$$

$$= P\left(\frac{\bar{x} - \mu}{\sigma/\sqrt{n}} > \frac{4 - \mu}{2/\sqrt{50}}\right) = P\left(z > \underbrace{\frac{4-\mu}{0{,}2828}}_{= -1{,}645}\right) = 0{,}95$$

$4 - \mu = 0{,}2828 \cdot (-1{,}645)$

$\mu = 4 + 0{,}2828 \cdot 1{,}645$

$\boxed{\mu = 4{,}465}$

6.21 Suppose that $X_1, \ldots, X_{n1}$ and $Y_1, \ldots, Y_{n2}$ constitute independent random samples from populations with means μ_1 and μ_2 and variances σ_1^2 and σ_2^2, respectively. Then the Central Limit Theorem can be extended to show that $\overline{X} - \overline{Y}$ is approximately normally distributed for large n_1 and n_2, with mean $\mu_1 - \mu_2$ and variance $(\sigma_1^2/n_1 + \sigma_2^2/n_2)$.

Water flow through soils depends, among other things, on the porosity (volume proportion due to voids) of the soil. To compare two types of sandy soil, $n_1 = 50$ measurements are to be taken on the porosity of soil A, and $n_2 = 100$ measurements are to be taken on soil B. Assume that $\sigma_1^2 = 0.01$ and $\sigma_2^2 = 0.02$. Find the approximate probability that the difference between the sample means will be within 0.05 unit of the true difference between the population means, $\mu_1 - \mu_2$.

6.22 Refer to Exercise 6.21. Suppose samples are to be selected with $n_1 = n_2 = n$. Find the value of n that will allow the difference between the sample means to be within 0.04 unit of $\mu_1 - \mu_2$ with probability approximately 0.90.

6.21)

$$\frac{X_i}{n_1} \qquad \frac{y_i}{n_2}$$

$$E(X_i)=\mu_1 \qquad E(y_i)=\mu_2$$

$$Var(X_i)=\sigma_1^2 \qquad Var(y_i)=\sigma_2^2$$

$$(\bar{X}-\bar{y}) \sim Normal\left(\mu_1-\mu_2;\ \frac{\sigma_1^2}{n_1}+\frac{\sigma_2^2}{n_2}\right)$$

Soil A	Soil B
$n_1=50$	$n_2=100$
$\sigma_1^2=0{,}01$	$\sigma_2^2=0{,}02$

$$z=\frac{(\bar{x}-\bar{y})-(\mu_1-\mu_2)}{\sqrt{\frac{\sigma_1^2}{n_1}+\frac{\sigma_2^2}{n_2}}}$$

$$P(\mu_1-\mu_2-0{,}05<\bar{x}-\bar{y}<\mu_1-\mu_2+0{,}05)$$

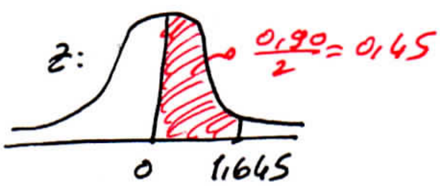
$$=P\left(\frac{(\mu_1-\mu_2-0{,}05)-(\mu_1-\mu_2)}{\sqrt{\frac{0{,}01}{50}+\frac{0{,}02}{100}}}<z<\frac{(\mu_1-\mu_2+0{,}05)-(\mu_1-\mu_2)}{\sqrt{\frac{0{,}01}{50}+\frac{0{,}02}{100}}}\right)$$

$$=P\left(-\frac{0{,}05}{0{,}02}<z<\frac{0{,}05}{0{,}02}\right)=P(-2{,}5<z<2{,}5)$$

$$=2\cdot 0{,}4938=0{,}9876$$

6.22)

$$P\left(\frac{-0{,}04}{\sqrt{\frac{0{,}01}{n}+\frac{0{,}02}{n}}}<z<\underbrace{\frac{0{,}04}{\sqrt{\frac{0{,}01}{n}+\frac{0{,}02}{n}}}}_{=1{,}645}\right)=0{,}90$$



$$\sqrt{\frac{0{,}01}{n}+\frac{0{,}02}{n}}=\frac{0{,}04}{1{,}645}$$

$$\sqrt{n}=\frac{1{,}645\cdot\sqrt{0{,}03}}{0{,}04}=7{,}123$$

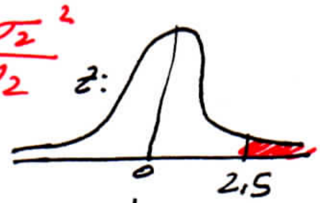
$$n=50{,}74 \Rightarrow \boxed{n=51}$$

6.23 An experiment is designed to test whether operator A or operator B gets the job of operating a new machine. Each operator is timed on 50 independent trials involving the performance of a certain task on the machine. If the sample means for the 50 trials differ by more than 1 second, the operator with the smaller mean gets the job. Otherwise, the experiment is considered to end in a tie. If the standard deviations of times for both operators are assumed to be 2 seconds, what is the probability that operator A gets the job even though both operators have equal ability?

6.23)

Operator A	Operator B
$n_1 = 50$	$n_2 = 50$
$\sigma_1 = 2$	$\sigma_2 = 2$
$\mu_1 = \mu$	$\mu_2 = \mu$

$$(\bar{X}_B - \bar{X}_A) \sim Normal\Big(\underbrace{0}_{=\mu-\mu} \; ; \; \underbrace{\frac{2^2}{50} + \frac{2^2}{50}}_{=\frac{\sigma_1^2}{n_1}+\frac{\sigma_2^2}{n_2}}\Big)$$



$$P(\bar{X}_B > \bar{X}_A + 1) = P(\bar{X}_B - \bar{X}_A > 1)$$

$$= P\left(\frac{(\bar{X}_B - \bar{X}_A) - 0}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}} > \frac{1}{\sqrt{\frac{2^2}{50}+\frac{2^2}{50}}}\right) = P(Z > 2{,}5) =$$

$$= 0{,}5 - 0{,}4938$$

$$= 0{,}0062$$

Sample Proportion: $\hat{p}$

* Remember; $y_i = \begin{cases} 1 & \text{if student makes sport} \\ 0 & \text{o.w.} \end{cases}$

Then, p: Probability of a randomly selected student to make sport.

$T = \sum_{i=1}^{n} y_i$: # of success among n trials

$T \sim Binomial(n; p)$

$\mu = E(T) = n \cdot p \;;\; \sigma^2 = Var(T) = n \cdot p \cdot (1-p)$

* The sample proportion is; $\hat{p} = \frac{T}{n}$.

Then; $\mu_{\hat{p}} = E(\hat{p}) = E\left(\frac{T}{n}\right) = \frac{1}{n} E(T) = \frac{1}{n} \cdot np = p$

$$\sigma_{\hat{p}}^2 = Var(\hat{p}) = Var\left(\frac{T}{n}\right) = \frac{1}{n^2} Var(T) = \frac{1}{n^2} \cdot n \cdot p \cdot (1-p)$$
$$= \frac{p \cdot (1-p)}{n}$$

If n is large enough; practically $p \pm 2\sigma_{\hat{p}}$ lies in the interval $(0,1)$, Normal approximation to Binomial distribution is applicable. Namely; Sampling distribution of $\hat{p}$ is;

$$\hat{p} \underset{approx.}{\sim} Normal\left(\mu_{\hat{p}} = p \,;\, \sigma_{\hat{p}}^2 = \frac{p(1-p)}{n}\right)$$

$$\text{So; } Z = \frac{\hat{p} - p}{\sqrt{\frac{p(1-p)}{n}}}$$

* Likewise, if number of success is under consideration, we have

$$T \underset{approx}{\sim} Normal\left(\mu = np \,;\, \sigma^2 = np(1-p)\right)$$

and $P(T \geq b) = P\left(Z > \frac{b - 0{,}5 - np}{\sqrt{np(1-p)}}\right)$ and

$$P(T \leq b) = P\left(Z < \frac{b + 0{,}5 - np}{\sqrt{np(1-p)}}\right)$$

Since T is discrete and Z is continuous, we have $\pm 0{,}5$.

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6.27 The quality of computer disks is measured by the number of missing pulses. For a certain brand of disk, 80% are generally found to contain no missing pulses. If 100 such disks are inspected, find the approximate probability that 15 or fewer contain missing pulses.

6.27) T: # of disks that contain missing pulses.

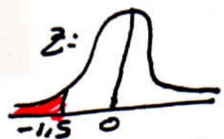
$$T \sim \text{Binomial}(n=100;\ p=\underbrace{0{,}20}_{=1-0{,}80})$$

$$P(T \leq 15) = P\left(\frac{T-np}{\sqrt{np(1-p)}} < \frac{15{,}5-100\cdot 0{,}20}{\sqrt{100\cdot 0{,}20\cdot 0{,}80}}\right)$$

$$= P(Z < -1{,}13) = 0{,}5 - 0{,}3708 = 0{,}1292$$

6.28 The capacitances of a certain type of capacitor are normally distributed with a mean of 53 μf (microfarads) and a standard deviation of 2 μf. If 64 such capacitors are to be used in an electronic system, approximate the probability that at least 12 of them will have capacitances below 50 μf.

6.28) $X \sim \text{Normal}(\mu = 53;\ \sigma^2 = 2^2)$



$$p = P(X < 50) = P\left(\frac{X-\mu}{\sigma} < \frac{50-53}{2}\right) = P(Z < -1{,}5)$$

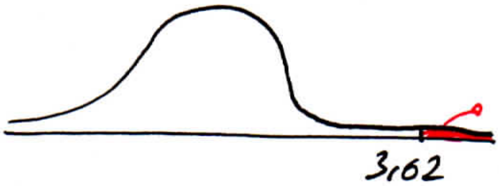
$$= 0{,}5 - 0{,}4332 = 0{,}0668$$

T: # of capacitors below ~~among~~ 50.

$$T \sim \text{Binomial}(n = 64;\ p = 0{,}0668)$$

$$P(T \geq 12) = P\left(\frac{T-np}{\sqrt{np(1-p)}} > \frac{11{,}5 - 64\cdot 0{,}0668}{\sqrt{64\cdot 0{,}0668\cdot(1-0{,}0668)}}\right)$$

$$= P(Z > 3{,}62) \cong 0{,}0000$$



can be ignored

$(P(Z > 3) = 0{,}0001)$

6.33 An auditor samples 100 of a firm's travel vouchers to check on how many of these vouchers are improperly documented. Find the approximate probability that more than 30% of the sampled vouchers will be found to be improperly documented if, in fact, only 20% of all the firm's vouchers are improperly documented.

6.33) $n = 100 \; ; \; p = 0,2$

$$\hat{p} \sim Normal\left(\mu_{\hat{p}} = 0,2 \; ; \; \sigma_{\hat{p}}^2 = \frac{0,2 \cdot 0,8}{100} = 0,0016\right)$$

$$\sigma_{\hat{p}} = 0,04$$

$$P(\hat{p} > 0,3) = P\left(\frac{\hat{p}-p}{\sigma_{\hat{p}}} > \frac{0,3-0,2}{0,04}\right) = P(Z > 2,5)$$

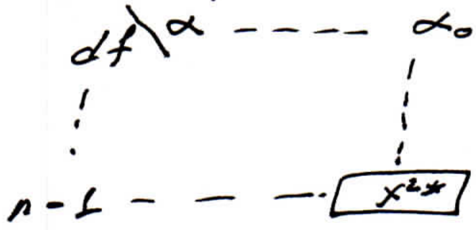
$$= 0,5 - 0,4938 = 0,0062$$

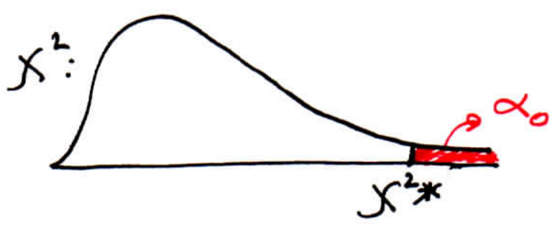
Sample Variance; S^2

* We used to find probabilities for $\bar{X}$ and $\hat{p}$ using $Z = \frac{\bar{X}-\mu}{\sigma/\sqrt{n}}$ or $Z = \frac{\hat{p}-p}{\sqrt{\frac{p(1-p)}{n}}}$. For S^2, we have a new distribution; $\chi^2 = \frac{(n-1) \cdot S^2}{\sigma^2}$.

* $n-1$ is degrees of freedom. χ^2 distribution does NOT have negative values and NOT symmetric. Moreover, the table gives χ^2 values, NOT probabilities.

we have;





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6.42 In constructing an aptitude test for a job, it is important to plan for a fairly large variance in test scores so the best applicants can be easily identified. For a certain test, scores are assumed to be normally distributed with a mean of 80 and a standard deviation of 10. A dozen applicants are to take the aptitude test. Find the approximate probability that the sample standard deviation of the scores for these applicants will exceed 15.

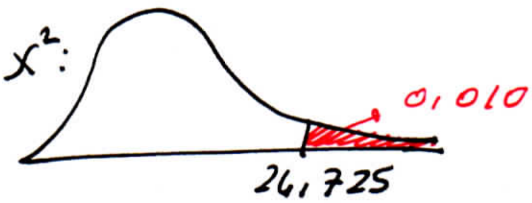
6.43 For an aptitude test for quality-control technicians in an electronics firm, history shows scores to be normally distributed with a variance of 225. If 20 applicants are to take the test, find an interval in which the sample variance of test scores should lie with probability 0.90.

6.42) $X \sim \text{Normal}(\mu = 80;\ \sigma^2 = 10^2)$ $n = 12$

$$P(s^2 > 15^2) = P\left(\frac{(n-1) \cdot s^2}{\sigma^2} > \frac{11 \cdot 15^2}{10^2}\right)$$

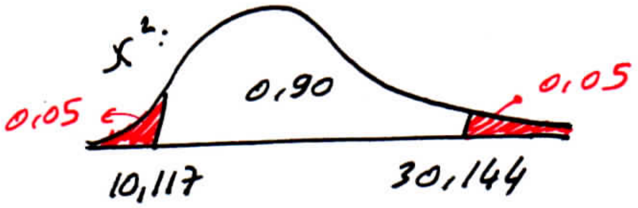
$$= P(\chi^2 > 24{,}75) \cong 0{,}010$$

$(df = 11)$



6.43) $X \sim \text{Normal}(\mu;\ \sigma^2 = 225)$ $n = 20$

$df = n - 1 = 19$



$$P(\underbrace{10{,}117 < \chi^2 < 30{,}144}) = 0{,}90$$

$$10{,}117 < \frac{(n-1) \cdot s^2}{\sigma^2} < 30{,}144$$

$$10{,}117 < \frac{19 s^2}{225} < 30{,}144$$

$$\frac{225}{19} \cdot 10{,}117 < s^2 < 30{,}144 \cdot \frac{225}{19}$$

$$P(119{,}81 < s^2 < 356{,}97) = 0{,}90$$

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* Let $U \sim \chi^2_{(n-1)}$ where n-1 stands for df.

we have, $E(U) = n-1$ and
$Var(U) = 2(n-1)$

Then, $E\left(\frac{(n-1)s^2}{\sigma^2}\right) = \frac{(n-1)}{\sigma^2} \cdot E(s^2) = n-1$

$E(s^2) = \sigma^2$ and

$Var\left(\frac{(n-1)s^2}{\sigma^2}\right) = \frac{(n-1)^2}{\sigma^4} Var(s^2) = 2 \cdot (n-1)$

$Var(s^2) = \frac{2\sigma^4}{n-1}$

* We use these results in

(i) Finding a lower bound using Tchebyscheff's theorem $P(\mu - k\sigma \leq X \leq \mu + k.\sigma) \geq 1 - \frac{1}{k^2}$

(ii) Unbiasedness property (Chapter 7) of s^2

Ex: For Ex. 6.43, find an interval in which at least 75% of sample variances should lie.

Ans: $\mu_{s^2} = \sigma^2$; $\sigma_{s^2}^2 = \frac{2\sigma^4}{n-1}$; $1 - \frac{1}{k^2} = 0,75$

$k = 2$

The interval is $\mu_s \pm 2 . \sigma_s$

$225 \pm 2 . \sqrt{\frac{2 . 225^4}{19}}$

Because s^2 cannot be negative

$(0 ; 33074,84)$

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