

Assignment-5

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<https://github.com/PrasannaLanka/Assignment5/blob/main/Assignment5/codes/Assignment5.tex>

PROBLEM UGC/MATH (2018 DEC-MATH SET-A)
Q.104

Let X_1, X_2, \dots be i.i.d. $N(0, 1)$ random variables. Let $S_n = X_1^2 + X_2^2 + \dots + X_n^2, \forall n \geq 1$. Which of the following statements are correct?

- (A) $\frac{S_n - n}{\sqrt{2}} \sim N(0, 1)$ for all $n \geq 1$
- (B) For all $\epsilon > 0, \Pr\left(\left|\frac{S_n}{n} - 1\right| > \epsilon\right) \rightarrow 0$ as $n \rightarrow \infty$
- (C) $\frac{S_n}{n} \rightarrow 1$ with probability 1
- (D) $\Pr(S_n \leq n + \sqrt{n}x) \rightarrow \Pr(Y \leq x) \forall x \in \mathbb{R}$, where $Y \sim N(0, 2)$

SOLUTION

Theorem 0.1 (Strong law of large numbers). Let X_1, X_2, \dots be i.i.d random variables with same expectation(μ) and finite variance(σ^2). Let $S_n = X_1 + X_2 + \dots + X_n$, Then as $n \rightarrow \infty$

$$\frac{S_n}{n} \xrightarrow{a.s} \mu, \quad (0.0.1)$$

almost surely.

Theorem 0.2 (Weak law of large numbers). Let X_1, X_2, \dots be i.i.d random variables with same expectation(μ) and finite variance(σ^2). Let $S_n = X_1 + X_2 + \dots + X_n$, Then as $n \rightarrow \infty$

$$\frac{S_n}{n} \xrightarrow{i.p} \mu, \quad (0.0.2)$$

in probability

Theorem 0.3 (Central limit theorem). The Central limit theorem states that the distribution of the sample approximates a normal distribution as the sample size becomes larger, given that all the samples are equal in size, regardless of the distribution of the individual samples.

Theorem 0.4 (chi-square distribution). If X_1, X_2, \dots are independent normally distributed random variables with mean 0 and variance 1. Then $S_n = \chi = X_1^2 + X_2^2 + \dots + X_n^2$ is chi-square distributed with n degrees of freedom.

$$E(\chi) = n \quad (0.0.3)$$

$$Var(\chi) = 2n \quad (0.0.4)$$

Definition 0.1 (Convergence in probability). A sequence of random variables $\{X_n\}_{n \in \mathbb{N}}$ is said to converge in probability (denoted by i.p) to X if

$$\lim_{n \rightarrow \infty} \Pr(|X_n - X| > \epsilon) = 0, \forall \epsilon > 0 \quad (0.0.5)$$

Definition 0.2 (Almost sure convergence). A sequence of random variables $\{X_n\}_{n \in \mathbb{N}}$ is said to converge almost surely or with probability 1 (denoted by a.s or w.p 1) to X if

$$\Pr(\omega | X_n(\omega) \rightarrow X(\omega)) = 1 \quad (0.0.6)$$

Given X_1, X_2, \dots follow normal distribution with mean 0 and variance 1.

$$f_{X_i}(x) = \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}}, i \in \{1, 2, \dots\} \quad (0.0.7)$$

(A) From theorem (0.4) and (0.0.3)

$$E\left(\frac{S_n - n}{\sqrt{2}}\right) = \frac{E(S_n) - n}{\sqrt{2}} \quad (0.0.8)$$

$$= \frac{E(\chi) - n}{\sqrt{2}} \quad (0.0.9)$$

$$= \frac{n - n}{\sqrt{2}} \quad (0.0.10)$$

$$= 0 \quad (0.0.11)$$

From theorem (0.4) and (0.0.4)

$$Var\left(\frac{S_n - n}{\sqrt{2}}\right) = Var\left(\frac{\sum_i (X_i^2 - 1)}{\sqrt{2}}\right) \quad (0.0.12)$$

$$= \frac{\sum_i Var(X_i^2 - 1)}{\sqrt{2}} \quad (0.0.13)$$

$$= \frac{Var(\sum_i (X_i^2))}{\sqrt{2}} \quad (0.0.14)$$

$$= \frac{Var(\chi)}{\sqrt{2}} \quad (0.0.15)$$

$$= \frac{2n}{\sqrt{2}} \quad (0.0.16)$$

$$= n\sqrt{2} \quad (0.0.17)$$

$$Var\left(\frac{S_n - n}{\sqrt{2}}\right) = n\sqrt{2} \quad (0.0.18)$$

Hence from theorem 0.1 as $n \rightarrow \infty$

$$\left(\frac{S_n - n}{\sqrt{2}}\right) \sim N(0, n\sqrt{2}) \quad (0.0.19)$$

Hence **Option A is false.**

(B) Given

$$S_n = X_1^2 + X_2^2 + \dots + X_n^2, \forall n \geq 1 \quad (0.0.20)$$

Assume that For all $\epsilon > 0, \Pr\left(\left|\frac{S_n}{n} - 2\right| > \epsilon\right) \rightarrow 0$ as $n \rightarrow \infty$ is true

Hence from theorem 0.2 we can write

$$\frac{S_n}{n} \xrightarrow{i.p} \frac{nE((X_i)^2)}{n} \quad (0.0.21)$$

$$\Rightarrow \frac{S_n}{n} \xrightarrow{i.p} 1 \quad (0.0.22)$$

in probability.

From definition 0.1 we can write,

$$\Rightarrow \Pr\left(\left|\frac{S_n}{n} - 1\right| > \epsilon\right) \rightarrow 0, \forall \epsilon > 0 \quad (0.0.23)$$

But this is contradiction to our assumption.

Hence **Option B is false .**

(C) Given

$$S_n = X_1^2 + X_2^2 + \dots + X_n^2, \forall n \geq 1 \quad (0.0.24)$$

Hence from theorem 0.1 we can write

$$\frac{S_n}{n} \xrightarrow{i.p} Var(X^2) \quad (0.0.25)$$

$$\Rightarrow \frac{S_n}{n} \xrightarrow{a.s} 1 \quad (0.0.26)$$

almost surely.

$$\Pr\left(\lim_{n \rightarrow \infty} \frac{S_n}{n} = 1\right) = 1 \quad (0.0.27)$$

From definition 0.2 and (0.0.27) we can write,

$$\frac{S_n}{n} \xrightarrow{w.p.1} 1 \quad (0.0.28)$$

with probability 1.

Hence **Option C is true.**

(D) Consider,

$$E\left(\frac{S_n - n}{\sqrt{n}}\right) = 0 \quad (0.0.29)$$

using (0.0.3).

$$Var\left(\frac{S_n - n}{\sqrt{n}}\right) = \frac{2n}{\sqrt{n}} \quad (0.0.30)$$

$$= 2\sqrt{n}. \quad (0.0.31)$$

using (0.0.4).

From theorem 0.3 we can write,

$$\left(\frac{S_n - n}{\sqrt{n}}\right) \sim N(0, 2\sqrt{n}) \quad (0.0.32)$$

$$\Pr\left(\frac{S_n - n}{\sqrt{n}} \leq x\right) = \Pr(S_n \leq n + \sqrt{nx}) \quad (0.0.33)$$

Hence using (0.0.32), **Option D is false.**