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Problem 3: Sums of a random number of random variables

(4/4 points)

Let $N, X_1, Y_1, X_2, Y_2, \dots$ be independent random variables. The random variable N takes positive integer values and has mean a and variance r . The random variables X_i are independent and identically distributed with mean b and variance s , and the random variables Y_i are independent and identically distributed with mean c and variance t . Let

$$A = \sum_{i=1}^N X_i \quad \text{and} \quad B = \sum_{i=1}^N Y_i.$$

1. Find $\text{cov}(A, B)$. Express your answer in terms of the given means and variances using standard notation .

$$\text{cov}(A, B) =$$

b*c*r



Answer: b*c*r

2. Find $\text{var}(A + B)$. Express your answer in terms of the given means and variances using standard notation .

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Exam 2

Exam 2 due Apr 20, 2016 at 23:59 UTC



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$$\text{var}(A + B) = a^2s + a^2t + b^2r + c^2r +$$

✓ Answer: $a^2(s+t) + r^2(b+c)^2$

Answer:

1. The covariance of A and B is given by $\text{cov}(A, B) = \mathbf{E}[AB] - \mathbf{E}[A]\mathbf{E}[B]$. Using the law of iterated expectations,

$$\begin{aligned} \mathbf{E}[AB] &= \mathbf{E}[\mathbf{E}[AB \mid N]] \\ &= \mathbf{E}[\mathbf{E}[(X_1 + X_2 + \cdots + X_N)(Y_1 + Y_2 + \cdots + Y_N) \mid N]] \\ &= \mathbf{E}[N^2 \mathbf{E}[X_1 Y_1 \mid N]] \\ &= \mathbf{E}[N^2 \mathbf{E}[X_1] \mathbf{E}[Y_1]] \\ &= bc \mathbf{E}[N^2] \\ &= bc(r + a^2), \end{aligned}$$

where the third equality holds because there are N^2 terms after expanding the product, each of which have the same expected value since the X_i 's and Y_i 's are both identically distributed. The fourth equality holds by independence.

Also using the law of iterated expectations,

$$\begin{aligned} \mathbf{E}[A] &= \mathbf{E}[\mathbf{E}[X_1 + X_2 + \cdots + X_N \mid N]] \\ &= \mathbf{E}[Nb] \\ &= ab, \\ \mathbf{E}[B] &= \mathbf{E}[\mathbf{E}[Y_1 + Y_2 + \cdots + Y_N \mid N]] \end{aligned}$$

$$= \mathbf{E}[Nc]$$

$$= ac.$$

Hence, the covariance of A and B is

$$\begin{aligned}\text{cov}(A, B) &= bc(r + a^2) - a^2bc \\ &= bcr.\end{aligned}$$

2. We are dealing with a sum of a random number of independent random variables.

Let us define $Z_i = X_i + Y_i$ so that $A + B = \sum_{i=1}^N Z_i$. Since the X_i 's are i.i.d. and the Y_i 's are also i.i.d., the Z_i 's are i.i.d. as well, with mean $b + c$ and variance $s + t$.

Using the formula for the variance of the sum of a random number of i.i.d. random variables, we have

$$\begin{aligned}\text{var}(A + B) &= \mathbf{E}[N]\text{var}(X_1 + Y_1) + \text{var}(N)(\mathbf{E}[X_1 + Y_1])^2 \\ &= a(s + t) + r(b + c)^2.\end{aligned}$$

Alternatively, we can also use the formula

$$\text{var}(A + B) = \text{var}(A) + \text{var}(B) + 2 \cdot \text{cov}(A, B).$$

We can calculate $\text{var}(A)$ and $\text{var}(B)$ in a similar manner as above and apply the result from part (1) for $\text{cov}(A, B)$.

You have used 2 of 3 submissions

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