

EXERCISE SHEET 4

The exercise enumeration aligns with the numbering system used in Chapter 4 in the book “Introduction to Probability” by David Anderson, Timo Seppäläinen, and Benedek Valko.

Exercises with ****** are harder and the solution is not provided. Discussions on these exercises is possible if there is time during the lectures or by asking an office hour.

1. EXERCISES

Ex. 3: Approximate the probability that out of 300 die rolls we get exactly 100 numbers that are multiples of 3.

Ex. 5: Liz is standing on the real number line at position 0. She rolls a die repeatedly. If the roll is 1 or 2, she takes one step to the right. If the roll is 3, 4, 5 or 6, she takes two steps to the right. Let X_n be Liz’s position after n rolls of the die.

- (a) Find $\lim_{n \rightarrow \infty} \mathbb{P}(X_n > 1.6n)$.
- (b) Find $\lim_{n \rightarrow \infty} \mathbb{P}(X_n > 1.7n)$.

Ex. 11: On the first 300 pages of a book, you notice that there are, on average, 6 typos per page. What is the probability there will be at least 4 typos on page 301? State clearly the assumptions you are making.

Ex. 12: Let $T \sim \text{Exp}(\lambda)$. Compute $\mathbb{E}[T^3]$.

Ex. 15: Suppose that a class of students is star-gazing on top of the local mathematics building from 11pm to 3am. Suppose further that meteors arrive (i.e. they are seen) according to a Poisson process with intensity $\lambda = 4$ per hour.

- (a) Find the probability that the students see more than 2 meteors in the first hour.
- (b) Find the probability that the students see zero meteors in the first hour, but at least 10 meteors in the final three hours (from midnight to 3am).
- (c) Given that there were 13 meteors seen all night, what is the probability that there were no meteors seen in the first hour?

Ex. 20: You flip a fair coin 10,000 times. Approximate the probability that the difference between the number of heads and number of tails is at most 100.

Ex. 23: Suppose that the distribution of the lifetime of a car battery, produced by a certain car company, is well approximated by a normal distribution with a mean of $1.2 \cdot 10^3$ hours and variance 10^4 . What is the approximate probability that a batch of 100 car batteries will contain at least 20 whose lifetimes are less than 1100 hours?

Ex. 28: For which values of p will the probability mass function of the $\text{Bin}(n, p)$ distribution have its maximum at n ?

Ex. 32: Recall that, if $X \sim \text{Poi}(\lambda)$ then $\mathbb{E}[(X)_n] = \lambda^n$ (see third problem of the additional exercises for the sheet n.3). Use this formula to compute $\mathbb{E}[X^3]$.

Ex. 35: Every morning Jack flips a fair coin ten times. He does this for an entire year. Let X denote the number of days when all the flips come out the same way (all heads or all tails).

- (a) Give the precise expression for the probability $\mathbb{P}(X > 1)$.
- (b) Apply either the normal or the Poisson approximation to give a simple estimate for $\mathbb{P}(X > 1)$. Explain your choice of approximation.

Ex. 36: How many randomly chosen guests should I invite to my party so that the probability of having a guest with the same birthday as mine is at least $\frac{2}{3}$?

Ex. 41: We roll a die 72 times. Approximate the probability of getting exactly 3 sixes with both the normal and the Poisson approximation and compare the results with the exact probability 0.000949681.

Ex. 44: Suppose that 50% of all watches produced by a certain factory are defective (the other 50% are fine). A store buys a box with 400 watches produced by this factory. Assume this is a random sample from the factory.

- (a) Write an expression for the exact probability that at least 215 of the 400 watches are defective.
- (b) Approximate the probability, using either the Poisson or normal approximation, whichever is appropriate, that at least 215 of the 400 watches are defective.

Ex. 49: Suppose that you own a store that sells a particular stove for \$1000. You purchase the stoves from the distributor for \$800 each. You believe that this stove has a lifetime which can be faithfully modeled as an exponential random variables with a parameter of $\lambda = 1/10$, where the units of time are years. You would like to offer the following extended warranty on this stove: if the stove breaks within r years, you will replace the stove completely (at a cost of \$800 to you). If the stove lasts longer than r years, the extended warranty pays nothing. Let $\$C$ be the cost you will charge the consumer for this extended warranty. For what pairs (C, r) will the expected profit you get from this warranty be zero? What do you think are reasonable choices for C and r ? Why?

Ex. 50: Suppose an alarm clock has been set to ring after T hours, where $T \sim \text{Exp}(1/3)$. Suppose further that your friend has been starting at the clock for exactly 7 hours and can confirm that it has not yet rung. At this point, your friend wants to know when the clock will finally ring. Calculate her conditional probability that she needs to wait at least 3 more hours, given that she has already waited 7 hours. More generally, calculate the conditional probability that she needs to wait at least x more hours, given that she has already waited 7 hours.

Ex. 52: Show that $\Gamma(r+1) = r\Gamma(r)$ for any $r > 0$. Deduce then that for any integer n , $\Gamma(n) = (n-1)!$.

Ex. 53: Let $X \sim \Gamma(r, \lambda)$. Find $\mathbb{E}[X]$ and $\text{Var}(X)$.

Ex. 54:** The point of this exercise is to check that it is immaterial whether the inequality is $<$ or \leq in the (weak) law of large numbers. Consider these two statements:

$$\forall \varepsilon > 0 \quad \lim_{n \rightarrow \infty} \mathbb{P} \left(\left| \frac{S_n}{n} - p \right| \leq \varepsilon \right) = 1, \quad (1)$$

and

$$\forall \varepsilon > 0 \quad \lim_{n \rightarrow \infty} \mathbb{P} \left(\left| \frac{S_n}{n} - p \right| < \varepsilon \right) = 1. \quad (2)$$

- (a) Show that (1) implies (2).
- (b) Show that (2) implies (1).

Ex. 56:** Suppose that $X \sim \text{Poi}(\lambda)$. Find the probability $\mathbb{P}(X \text{ is even})$. Your answer should not be written as an infinite series.