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Statistics: Homework 1

1.19 (a) Let X_1, X_2 and X_3 denote the computer owners that use Macintosh, Windows and Linux respectively and let V denote the event that the user's system is infected with the virus. We want to find $\mathbb{P}(X_2|V)$

$$\begin{aligned}\mathbb{P}(X_2|V) &= \frac{\mathbb{P}(V|X_2)\mathbb{P}(X_2)}{\sum_{i=1}^{3}\mathbb{P}(V|X_i)\mathbb{P}(X_i)} \\ &= \frac{(.82)(.5)}{(.65)(.3)+(.82)(.5)+(.5)(.2)} \\ &= 0.581560284\end{aligned}$$

(b) $\mathbb{P}(V) = (.65)(.3) + (.82)(.5) + (.5)(.2) = .705$

(c) Let A and B denote the event that the second person has a system that was also infected by a virus and the second person is known to have the same computer system as the first person. We observe that A and B are independent events as the probability of getting a virus on your computer system is the same regardless of whether the second person has the same computer system as the first person. Thus $\mathbb{P}(A|B) = \mathbb{P}(A) = \mathbb{P}(V) = .705$

2.4 (a)

$$F_X(x) := \begin{cases} \frac{1}{4}x & 0 < x < 1 \\ \frac{1}{4} & 1 \leq x \leq 3 \\ \frac{3}{8}x - \frac{7}{8} & 3 < x < 5 \\ 1 & x > 5 \end{cases}$$

(b)

$$\begin{aligned}\mathbb{P}(Y \leq y) &= \mathbb{P}(1/X \leq y) \\ &= \mathbb{P}(X \geq 1/y) \\ &= 1 - \mathbb{P}(X \leq 1/y)\end{aligned}$$

From (a):

$$F_Y(y) := \begin{cases} \frac{15}{8} - \frac{3}{8y} & 1/5 < y < 1/3 \\ \frac{3}{4} & 1/3 \leq y \leq 1 \\ 1 - \frac{1}{4y} & y > 1 \end{cases}$$

$$f_Y(y) := \begin{cases} \frac{3}{8y^2} & 1/5 < y < 1/3 \\ \frac{1}{4y^2} & y > 1 \\ 0 & \text{otherwise} \end{cases}$$

2.11 (a) We see that $\mathbb{P}(X = 1) = p = \mathbb{P}(Y = 0)$. Since the state space contains $\{H, T\}$, we have $1 - \mathbb{P}(X = 1, Y = 0) = 1 - p = \mathbb{P}(X = 0, Y = 1)$. But since

$$\mathbb{P}(X = 1)\mathbb{P}(Y = 0) = p^2 \neq p = \mathbb{P}(X = 1, Y = 0)$$

X and Y are dependent.

(b) By total law of probability,

$$\begin{aligned}\mathbb{P}(X=x) &= \sum_{n=x}^{\infty}\mathbb{P}(X=x|N=n)\cdot\mathbb{P}(N=n)\\ &= \sum_{n=x}^{\infty}\binom{n}{x}p^x(1-p)^{n-x}\cdot e^{-\lambda}\frac{\lambda^n}{n!}\\ &= e^{-\lambda}\frac{(\lambda p)^x}{x!}\sum_{n=x}^{\infty}\frac{[\lambda(1-p)]^{n-x}}{(n-x)!}\\ &= e^{-\lambda p}\frac{(\lambda p)^x}{x!}\end{aligned}$$

in a similar fashion, we have

$$\mathbb{P}(Y=y) = e^{-\lambda(1-p)}\frac{(\lambda(1-p))^y}{y!}$$

for the joint distribution of X and Y,

$$\begin{aligned}\mathbb{P}(X=x, Y=n-x) &= \mathbb{P}(X=x, Y=n-x|N=n)\cdot\mathbb{P}(N=n)\\ &= \binom{n}{x}p^x(1-p)^{n-x}\cdot e^{-\lambda}\frac{\lambda^n}{n!}\end{aligned}$$

now

$$\begin{aligned}\mathbb{P}(X=x)\cdot\mathbb{P}(Y=y) &= e^{-\lambda p}\frac{(\lambda p)^x}{x!}\cdot e^{-\lambda(1-p)}\frac{(\lambda(1-p))^y}{y!}\\ &= \binom{x+y}{x}p^x(1-p)^y e^{-\lambda}\frac{\lambda^{x+y}}{(x+y)!} = \mathbb{P}(X=x, Y=y)\end{aligned}$$

which shows that X and Y are independent.

3.4 Let Y_i denote the jump of the particle at the ith unit. Then $X_n = \sum_{i=1}^n Y_i$. The Y_i's are iid, with $\mathbb{E}(Y_i) = 1-2p$ and $\mathbb{V}(Y_i) = 1-(1-2p)^2 = 4p(1-p)$ for $i = 1, 2, \ldots, n$.

$$\begin{aligned}\mathbb{E}(X_n) &= \sum_{i=1}^{n}\mathbb{E}(Y_i) = n(1-2p)\\ \mathbb{V}(X_n) &= \sum_{i=1}^{n}\mathbb{V}(Y_i) = n\cdot 4p(1-p)\end{aligned}$$

4.3 Using Chebyshev's and Hoeffding's inequality we have

$$\begin{aligned}\mathbb{P}(|\overline{X}_n - p| > \epsilon) &\le \frac{1}{4n\epsilon^2}\\ \mathbb{P}(|\overline{X}_n - p| > \epsilon) &\le 2e^{-2n\epsilon^2}\end{aligned}$$

$$\lim_{n\to\infty}\frac{e^{-2n\epsilon^2}}{1/(4n\epsilon^2)} = 4\epsilon^2\lim_{n\to\infty}\frac{n}{e^{2n\epsilon^2}} \to 0 \text{ as } n\to\infty$$

thus $\frac{1}{4n\epsilon^2}$ grows faster than $e^{-2n\epsilon^2}$ for sufficiently large n.

5.7 (a)

$$\begin{aligned}\mathbb{P}(|X_n - 0| > \epsilon) = \mathbb{P}(X_n^2 > \epsilon^2) &\le \frac{\mathbb{E}(X_n^2)}{\epsilon^2} \text{ by Markov's inequality}\\ &= \left(\frac{1}{n}+\frac{1}{n^2}\right)\cdot\frac{1}{\epsilon^2} \to 0 \text{ as } n\to\infty\end{aligned}$$

(b) Let Y_n be as given in the question. Then we can show $Y_n \rightsquigarrow Y$ and $\mathbb{P}(Y = 0) = 1$ which implies $Y_n \xrightarrow{P} Y$. The cdf of Y, $F(t) = 1$ for all $t \geq 0$ and 0 otherwise.

$$F_n(t) = \mathbb{P}(Y_n \leq t) = \sum_{k=0}^{\lfloor \frac{t}{n} \rfloor} e^{-1/n} \frac{(1/n)^k}{k!}$$

$$\lim_{n\to\infty} F_n(t) = \lim_{n\to\infty} \sum_{k=0}^{\lfloor \frac{t}{n} \rfloor} e^{-1/n} \frac{(1/n)^k}{k!} = 1$$

therefore $Y_n \xrightarrow{P} 0$.