Final Review Sheet Answers

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The proofs/calculations of most exercises here are omitted. Again, refer to your notes if unsure; all of the theoretical results have been discussed in lecture notes or in the textbook.

1 Relationships Between Distributions

1. cX, where $X \sim$ Exp (λ), $c > 0$:

   Exp $(\frac{\lambda}{c})$

2. $X_1 + X_2 + X_3$, where the X_i's are i.i.d. Gamma $(1, \mu)$. What about $\frac{X_1}{X_1+X_2+X_3}$?

   $X_1 + X_2 + X_3 \sim$ Gamma $(3, \mu)$; $\frac{X_1}{X_1+X_2+X_3} \sim$ Beta (1,2). (For this one, think about T_1 and T_3 for a Poisson Process.)

3. $X^2 + Y^2$, where X, Y are independent standard Normal. What is $\sqrt{X^2 + Y^2}$?

   Exp $(\frac{1}{2})$; standard Rayleigh

4. $2X + 3Y$, where X, Y independent Normal (μ, σ^2). What if X, Y are bivariate normal with correlation $\rho = 0.6$?

   $2X + 3Y \sim \mathcal{N}(5\mu, 13\sigma^2)$ if $\rho = 0$; $2X + 3Y \sim \mathcal{N}(5\mu, (13 + 7.2)\sigma^2)$ if $\rho = 0.6$

5. Consider each of the following common discrete distributions: Poisson, Binomial, Geometric, and Hypergeometric. For which of these is the sum of two independent RVs a known distribution? Under what conditions?

   Excluding the degenerate cases (e.g., $p = 0$ or $p = 1$), this holds for the first 3 distributions. For Binomial, the p values must be the same, in which case the n's are added; for the Geometric the result is Negative Binomial provided the p values are the same.

2 Symmetry

1. Under some conditions, we can quickly recognize the expectation of a random variable X to be zero. What are they?

   The distribution/density of X must be symmetric about the origin, and $\mathbb{E}(|X|) < \infty$; i.e. the expectation must be defined.

2. Find the probability that the last ace in a standard, well-shuffled deck is at position 47 or greater.

   Using symmetry between the front and back of the deck, this answer is

$$\frac{\binom{4}{1}\binom{48}{6}}{\binom{52}{6}}$$

3. You and I each roll a fair n sided die. Without using a summation, find the probability your roll is strictly greater than mine.

   $P(X < Y) = P(X > Y)$, and $P(X < Y) + P(X > Y) + P(X = Y) = 1$. Therefore,

   $$P(X > Y) = \frac{1 - \frac{1}{n}}{2}$$

4. Let X, Y be independent $\mathcal{N}(0, \sigma^2)$ random variables. Without using Φ, find $P(X + 2Y > 0, X > 0)$. What is the reason behind this answer?

   Using the rotational symmetry of the joint distribution of (X, Y),

   $$P(X + 2Y > 0, X > 0) = \frac{\frac{\pi}{4} + \arctan(\frac{1}{2})}{2\pi}$$

5. Suppose we have 5 independent Uniform $[0, 1]$ variables. Prove that $U_{(2)} - U_{(1)}$ is equal in distribution to $U_{(1)}$. Recognize this as a named distribution, and state the parameters.

   Both variables should be Beta (1,5).

3 To Infinity, and Beyond

1. Let $X \sim$ Geom (p) on $\{1, 2, \ldots\}$. It is not easy to directly find $\mathbb{E}(X)$ using the formula $\sum_{x=1}^{\infty} xP(X = x)$. We have shown three alternate methods for finding this expectation; what are they?

   The three methods are (i) the tail sum formula for expectations of discrete RVs, (ii) using the MGF of a Geometric, and (iii) conditioning on the result of the first toss.

2. Two players simultaneously toss coins which land heads with probabilities p_1 and p_2 respectively. They continue until exactly one player's coin lands heads; that player is the winner. Show that the probability Player 1 wins is $\frac{p_1 q_2}{p_1 q_2 + q_1 p_2}$.

   Hint: write this out as a sequence of tosses. For the first player to win on the n^{th} toss, what has to happen?

3. Find $\mathbb{E}(X(X - 1))$ for $X \sim$ Pois (μ).

   Using the function rule, we observe that this value is μ^2.

4. Let Y have density $f_Y(y) = \frac{\lambda}{2} e^{-\lambda |y|}$, for $y \in \mathbb{R}$. With little computation, find $\mathbb{E}(|Y|)$ and $\mathbb{E}(Y)$.

   If we look at the graph of the density of Y, or through the change-of-variable formula, we observe that $|Y| \sim$ Exp (λ). Thus $\mathbb{E}(|Y|) = \frac{1}{\lambda}$, and $\mathbb{E}(Y) = 0$ by symmetry.

4 Could You Rephrase That?

1. Suppose there are $3n$ people in a room, divided into groups of 3. What is the chance that there is at least one group where two members share the same birthday?

   $$1 - \left(\frac{364 \cdot 363}{365^2}\right)^n$$

2. Continued from (a): Approximate this chance for large n.

   We use a Poisson approximation, with $p = P(\text{shared b-day in group}) = 2(\frac{1}{365}) - (\frac{1}{365})^2$ (using inclusion-exclusion rule). Then this probability from (a) is approximately $1 - e^{-np}$ for large n.

3. Let $X \sim$ Gamma (r, λ), where r is an integer. Use what we know about the Poisson process to obtain the CDF of X.

$$\begin{aligned}
P(X < t) &= P(N_t \geq r) \\
&= 1 - P(N_t < r) \\
&= 1 - \sum_{k=0}^{r-1} e^{\lambda t} \frac{(\lambda t)^k}{k!}
\end{aligned}$$

4. Let X be an arbitrary random variable with an invertible CDF F_X. What is the random variable formed by $F_X(X)$?

   Let $Z = F_X(X)$. Then,

$$\begin{aligned}
F_Z(z) &= P(Z \leq z) \\
&= P(F_X(X) \leq z) \\
&= P(F_X^{-1}(F_X(X)) \leq F_X^{-1}(z)) \\
&= P(X \leq F_X^{-1}(z)) \\
&= F_X(F_X^{-1}(z)) \\
&= z, \quad z \in [0, 1]
\end{aligned}$$

   We conclude that $Z \sim$ Unif (0,1).

5 Some Useful Results

1. Let $X \sim$ Pois (μ), $Y \sim$ Pois (λ), $X \perp Y$. What is the distribution of $X + Y$? (Hint: use the binomial theorem, $(x + y)^n = \sum_{k=0}^{n} \binom{n}{k} x^k y^{n-k}$.) $X + Y \sim$ Pois $(\mu + \lambda)$

2. Use Markov's Inequality to derive Chebyshev's Inequality. See pg. 191 – 192 in Pitman's *Probability*.

3. Let $X \sim$ Exp (λ_X), $Y \sim$ Exp (λ_Y). What is $P(X < Y)$? $\frac{\lambda_X}{\lambda_X + \lambda_Y}$

4. Find the distribution of $\min\{X_1, X_2, \ldots, X_n\}$, where the X_i's are independent Exp (λ) variables.

   Let M denote the minimum. Then $M \sim$ Exp $(n\lambda)$. Note this result generalizes to the case where the rates are all different; you simply add the rate parameters.

5. Suppose cars and trucks arrive at a bridge according to independent Poisson processes with rates λ_c and λ_r per minute respectively. Given that n vehicles arrive in t minutes, what is the distribution of $N_{c,t}$, the number of cars to arrive by time t?

   The easiest way to proceed here is using the conditional probability rule. We find that $N_{c,t} | N_t = n \sim$ Binom $(n, \frac{\lambda_c}{\lambda_c + \lambda_r})$.