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Probability and Statistics Interview Questions

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Counting, sample spaces and the axioms of probability

1. What is the difference between a permutation and a combination?

A permutation counts selections where order matters, a combination counts selections where order does not. Choosing r items from n gives $P(n,r) = n!/(n-r)!$ permutations and $C(n,r) = n!/(r!(n-r)!)$ combinations. Each combination corresponds to $r!$ permutations, which is why the combination count is smaller by that factor.

2. What is the difference between independent events and mutually exclusive events?

Independent events satisfy $P(A \cap B) = P(A)P(B)$: knowing one occurred does not change the chance of the other. Mutually exclusive events cannot occur together, so $P(A \cap B) = 0$. If both have non-zero probability, they cannot be both: mutually exclusive events are strongly dependent, since one occurring rules the other out.

3. How many distinct arrangements can be made from all the letters of the word BANANA?

There are 60 distinct arrangements. The six letters can be ordered in $6!$ ways, and dividing by $3!$ for the repeated A's and $2!$ for the repeated N's removes orderings that look the same.

WORKING

1. Total letters: 6, with A repeated 3 times, N repeated 2 times, B once.
2. Arrangements $= \dfrac{6!}{3!\,2!\,1!}$.
3. $= \dfrac{720}{6 \times 2} = 60.$

Conditional probability and Bayes' theorem

4. State Bayes' theorem and say what it is used for.

Bayes' theorem states $P(A \mid B) = \dfrac{P(B \mid A)\,P(A)}{P(B)}$. It reverses a conditioning: from the probability of the evidence given a cause to the probability of the cause given the evidence. The denominator $P(B)$ is usually found with the law of total probability over all possible causes.

5. Why can a positive result from a very accurate medical test still mean the person is probably healthy?

Because the prior (base rate) matters. If the disease is rare, healthy people far outnumber sick ones, so even a small false positive rate produces more false positives than true positives. Bayes' theorem combines the test accuracy with the prevalence, and a low prevalence pulls the posterior probability of disease down.

6. A disease affects 1% of a population. A test is positive for 95% of people who have the disease and for 5% of people who do not. A person tests positive. What is the probability that they have the disease?

The probability of disease given a positive test is about 16.1%. Sick people who test positive make up 0.95% of the population and healthy people who test positive make up 4.95%, so only $0.0095/0.059$ of positive results are true.

WORKING

1. $P(D) = 0.01$, $P(+ \mid D) = 0.95$, $P(+ \mid D^c) = 0.05$.
2. $P(+) = 0.01 \times 0.95 + 0.99 \times 0.05 = 0.0095 + 0.0495 = 0.059$.
3. $P(D \mid +) = \dfrac{0.0095}{0.059} \approx 0.161$.

7. What is the law of total probability?

If events $B_1, \ldots, B_k$ are mutually exclusive and together cover the whole sample space, then $P(A) = \sum_i P(A \mid B_i)\,P(B_i)$. It finds the overall chance of A by splitting the sample space into cases, taking the chance of A in each case and weighting it by how likely the case is.

Descriptive statistics

8. When is the median a better measure of centre than the mean?

The median is better when the data are skewed or contain outliers. The mean uses every value, so one extreme value can drag it far; the median depends only on the middle position and barely moves. For symmetric data without outliers the two are close, and the mean is then preferred because it uses all the information.

9. Why does the sample variance divide by $n - 1$ instead of n?

The deviations are measured from the sample mean, which sits closer to the data than the true mean does, so dividing by n underestimates the population variance on average. Dividing by $n - 1$ corrects this bias and makes s^2 an unbiased estimator. One degree of freedom is used up in estimating the mean.

10. What is the difference between zero correlation and independence?

Independent variables with finite variances always have zero covariance, but zero correlation does not imply independence. Correlation measures only linear association. For example, if X is uniform on $[-1, 1]$ and $Y = X^2$, then $\operatorname{Cov}(X, Y) = E[X^3] - E[X]E[X^2] = 0$, yet Y is completely determined by X.

Random variables

11. Does the expectation of a sum of random variables equal the sum of the expectations only when they are independent?

No. Linearity of expectation, $E[X + Y] = E[X] + E[Y]$, holds always, whether or not the variables are independent. Variance is different: $\operatorname{Var}(X + Y) = \operatorname{Var}(X) + \operatorname{Var}(Y) + 2\operatorname{Cov}(X, Y)$, which reduces to the plain sum only when the covariance is zero, for example under independence.

12. Why does adding a constant to a random variable not change its variance, while multiplying by a constant scales it by the square of that constant?

Variance measures spread about the mean. Adding b shifts every value and the mean by the same amount, so deviations are unchanged: $\operatorname{Var}(X + b) = \operatorname{Var}(X)$. Multiplying by a scales every deviation by a, and variance squares deviations, so $\operatorname{Var}(aX) = a^2 \operatorname{Var}(X)$.

13. What is the difference between Markov's inequality and Chebyshev's inequality?

Markov's inequality needs only a non-negative variable with a finite mean: $P(X \geq a) \leq E[X]/a$ for $a > 0$. Chebyshev's inequality uses the mean and a finite, non-zero variance of any variable: $P(|X - \mu| \geq k\sigma) \leq 1/k^2$ for $k > 0$. Both hold for every distribution meeting these conditions, are often loose, and Chebyshev follows from applying Markov to $(X - \mu)^2$.

Discrete distributions

14. A machine produces a defective item with probability 0.3, independently for each item. In a batch of 10 items, what is the probability that exactly 2 are defective?

The probability of exactly 2 defective items is about 0.2335. The number of defectives in 10 independent items is binomial with $n = 10$ and $p = 0.3$, so the probability is $\binom{10}{2}(0.3)^2(0.7)^8$.

WORKING

1. The number of defectives is binomial with $n = 10$, $p = 0.3$.
2. $P(X = 2) = \binom{10}{2}(0.3)^2(0.7)^8$.
3. $= 45 \times 0.09 \times 0.05765$.
4. ≈ 0.2335.

15. What is the difference between the binomial and geometric distributions?

Both come from repeated independent trials with success probability p. The binomial counts the successes in a fixed number n of trials, with mean np and variance $np(1 - p)$. The geometric counts the number of trials needed to get the first success, with mean $1/p$. In one the number of trials is fixed, in the other it is random.

16. What conditions must hold for a count of successes to follow a binomial distribution?

There must be a fixed number n of trials, each with only two outcomes, the same success probability p in every trial, and independent trials. If these fail, the model breaks: drawing without replacement from a small population makes each draw's success probability depend on the earlier draws, which gives a hypergeometric distribution instead.

Continuous random variables and the named distributions

17. For a continuous random variable, what does the density $f(x)$ represent, and can it exceed 1?

The density is not a probability: probabilities are areas under it, $P(a \leq X \leq b) = \int_a^b f(x)\,dx$, and any single point has probability zero. The density can exceed 1 where the values are tightly packed, for example a uniform variable on $[0, 0.5]$ has $f = 2$. Only the total area must equal 1.

18. Why is the exponential distribution called memoryless?

Because $P(X > s + t \mid X > s) = P(X > t)$: given that the wait has already lasted s, the remaining wait has the same distribution as a fresh one. This follows from the survival function $e^{-\lambda x}$, whose exponent splits into $e^{-\lambda s}e^{-\lambda t}$. It is the only continuous distribution with this property.

19. Exam marks are normally distributed with mean 70 and standard deviation 10. What fraction of

students score above 85? Use $\Phi(1.5) = 0.9332$.

About 6.68% of students score above 85. A mark of 85 lies $(85 - 70)/10 = 1.5$ standard deviations above the mean, so the fraction scoring above it is the upper tail area $1 - \Phi(1.5) = 0.0668$.

WORKING

1. Standardise: $z = (85 - 70)/10 = 1.5$.
2. $P(X > 85) = P(Z > 1.5)$.
3. $= 1 - \Phi(1.5) = 1 - 0.9332$.
4. $= 0.0668$.

20. Calls reach a help desk as a Poisson process at an average of 4 per hour. What is the probability that no call arrives in a 30 minute period?

The probability of no call in 30 minutes is about 0.1353. At 4 calls per hour the count in half an hour is Poisson with mean 2, and the chance of zero events is e^{-2}.

WORKING

1. Mean number of calls in 30 minutes: $\lambda = 4 \times 0.5 = 2$.
2. Poisson: $P(N = 0) = e^{-\lambda}\lambda^0/0!$.
3. $= e^{-2} \approx 0.1353$.

21. How do the chi-squared and t distributions arise from normal samples?

A chi-squared variable with k degrees of freedom is the sum of squares of k independent standard normal variables. A t variable with k degrees of freedom is $Z/\sqrt{V/k}$, where Z is standard normal and V is an independent chi-squared variable with k degrees of freedom. For a normal sample, $(n-1)s^2/\sigma^2$ is chi-squared and $(\bar{X} - \mu)/(s/\sqrt{n})$ is t, both with $n - 1$ degrees of freedom.

Central limit theorem and hypothesis tests

22. What does the central limit theorem say, and why is it useful?

For independent, identically distributed observations with mean μ and finite variance σ^2, the sample mean is approximately normal with mean μ and standard deviation $\sigma/\sqrt{n}$ when n is large, whatever the shape of the original distribution. This lets us build confidence intervals and tests using normal tables.

23. A sample of 36 readings has a mean of 50 kg. The population standard deviation is known to be 12 kg. What is the margin of error of a 95% confidence interval for the population mean? Use $z = 1.96$.

The margin of error is 3.92 kg, so the interval runs from 46.08 kg to 53.92 kg. The standard error is $12/\sqrt{36} = 2$ kg, and the margin is 1.96×2.

WORKING

1. Standard error $= \sigma/\sqrt{n} = 12/\sqrt{36} = 2$ kg.
2. Margin $= z \times \mathrm{SE}$.
3. $= 1.96 \times 2 = 3.92$ kg.

24. What does a p-value mean in a hypothesis test?

The p-value is the probability, assuming the null hypothesis is true, of getting a test statistic at least as extreme as the one observed. It is not the probability that the null hypothesis is true. A small p-value means the data would be unlikely under the null, so it counts as evidence against it.

25. What is the difference between a z-test and a t-test for a mean?

Use a z-test when the population standard deviation is known, or the sample is large. Use a t-test when it must be estimated by the sample standard deviation s, with $n - 1$ degrees of freedom. The t distribution has heavier tails to allow for the extra uncertainty, and it approaches the normal as n grows.

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