18.440: Lecture 38

Review: practice problems

Scott Sheffield

MIT

- Let X be a uniformly distributed random variable on $[-1, 1]$.

- Let X be a uniformly distributed random variable on $[-1, 1]$.
  - Compute the variance of X^2.

- Let X be a uniformly distributed random variable on $[-1, 1]$.
  - Compute the variance of X^2.
  - If $X_1, \ldots, X_n$ are independent copies of X, what is the probability density function for the smallest of the X_i

Order statistics — answers

-
$$\mathrm{Var}[X^2] = E[X^4] - (E[X^2])^2$$
$$= \int_{-1}^{1} \frac{1}{2} x^4 dx - \left(\int_{-1}^{1} \frac{1}{2} x^2 dx\right)^2 = \frac{1}{5} - \frac{1}{9} = \frac{4}{45}.$$

Order statistics — answers

▶

$$\text{Var}[X^2] = E[X^4] - (E[X^2])^2$$
$$= \int_{-1}^1 \frac{1}{2} x^4 dx - \left(\int_{-1}^1 \frac{1}{2} x^2 dx\right)^2 = \frac{1}{5} - \frac{1}{9} = \frac{4}{45}.$$

▶ Note that for $x \in [-1, 1]$ we have

$$P\{X > x\} = \int_x^1 \frac{1}{2} dx = \frac{1-x}{2}.$$

If $x \in [-1, 1]$, then

$$P\{\min\{X_1, \ldots, X_n\} > x\}$$
$$= P\{X_1 > x, X_2 > x, \ldots, X_n > x\} = \left(\frac{1-x}{2}\right)^n.$$

So the density function is

$$-\frac{\partial}{\partial x}\left(\frac{1-x}{2}\right)^n = \frac{n}{2}\left(\frac{1-x}{2}\right)^{n-1}.$$

Moment generating functions

- Suppose that X_i are independent copies of a random variable X. Let $M_X(t)$ be the moment generating function for X. Compute the moment generating function for the average $\sum_{i=1}^{n} X_i/n$ in terms of $M_X(t)$ and n.

- Write $Y = \sum_{i=1}^{n} X_i/n$. Then

$$M_Y(t) = E[e^{tY}] = E[e^{t \sum_{i=1}^{n} X_i/n}] = (M_X(t/n))^n.$$

Entropy

- ▶ Suppose X and Y are independent random variables, each equal to 1 with probability $1/3$ and equal to 2 with probability $2/3$.
    - ▶ Compute the entropy $H(X)$.

Entropy

- Suppose X and Y are independent random variables, each equal to 1 with probability $1/3$ and equal to 2 with probability $2/3$.
    - Compute the entropy $H(X)$.
    - Compute $H(X + Y)$.

Entropy

- Suppose X and Y are independent random variables, each equal to 1 with probability $1/3$ and equal to 2 with probability $2/3$.
  - Compute the entropy $H(X)$.
  - Compute $H(X + Y)$.
  - Which is larger, $H(X + Y)$ or $H(X, Y)$? Would the answer to this question be the same for any discrete random variables X and Y? Explain.

Entropy — answers

- $H(X) = \frac{1}{3}(-\log\frac{1}{3}) + \frac{2}{3}(-\log\frac{2}{3})$.

Entropy — answers

- $H(X) = \frac{1}{3}(-\log\frac{1}{3}) + \frac{2}{3}(-\log\frac{2}{3})$.
- $H(X + Y) = \frac{1}{9}(-\log\frac{1}{9}) + \frac{4}{9}(-\log\frac{4}{9}) + \frac{4}{9}(-\log\frac{4}{9})$

- $H(X) = \frac{1}{3}(-\log \frac{1}{3}) + \frac{2}{3}(-\log \frac{2}{3})$.
- $H(X + Y) = \frac{1}{9}(-\log \frac{1}{9}) + \frac{4}{9}(-\log \frac{4}{9}) + \frac{4}{9}(-\log \frac{4}{9})$
- $H(X, Y)$ is larger, and we have $H(X, Y) \geq H(X + Y)$ for any X and Y. To see why, write $a(x, y) = P\{X = x, Y = y\}$ and $b(x, y) = P\{X + Y = x + y\}$. Then $a(x, y) \leq b(x, y)$ for any x and y, so
  $H(X, Y) = E[-\log a(x, y)] \geq E[-\log b(x, y)] = H(X + Y)$.