

FINAL EXAM
ECEN 446 - Neural Networks
Information Theory, Inference, and Learning Algorithms

Joseph J. Boutros, 11 July 2021

Three Problems in Inference and Neural Networks (100 points)

Textbooks, lecture notes, scientific calculators are allowed. Laptops and tablets are only authorized for consulting class notes, for visiting ECEN 446 web page, and for running Jupyter-Notebook, Python 3, Pari/gp or WolframAlpha/Mathematica software. Cellphones and chat applications are forbidden, they should stay away from your desk. Total time duration is 120 minutes.

Part I - Information Theory (20 points)

We recall that, for a discrete random variable $X \in \mathcal{X} = \{x_1, x_2, \dots, x_M\}$, the entropy of X is defined as

$$\begin{aligned} H(X) &= - \sum_{x \in \mathcal{X}} \mathbb{P}(X = x) \log(\mathbb{P}(X = x)) \\ &= - \sum_{x \in \mathcal{X}} p_X(x) \log(p_X(x)) = - \sum_{i=1}^M p_i \log(p_i), \end{aligned} \quad (1)$$

where $p_X(x)$ is the probability mass function of X and $p_i = \mathbb{P}(X = x_i) = p_X(x_i)$, $i = 1 \dots M$. Here, the integer M could be finite or infinite (to be replaced by ∞), e.g. if X is Poisson. For continuous random variables, we recall the similar definition of differential entropy

$$h(X) = - \int_{-\infty}^{\infty} p_X(x) \log(p_X(x)) dx, \quad (2)$$

where $p_X(x)$ is the probability density function of X , $X \in \mathbb{R}$.

(a) Let $X_1 \sim \text{Bernoulli}(p_1)$ and $X_2 \sim \text{Bernoulli}(p_2)$, X_1 and X_2 independent. Define $S = X_1 + X_2$, where the sum is modulo 2. Find the expression of the entropy of S as a function of p_1 and p_2 .

Hint: Determine $\mathbb{P}(S = 0)$ and $\mathbb{P}(S = 1)$.

(b) Compute $H(S)$ for $p_1 = 1/2$ and any p_2 . Compute $H(S)$ for $p_1 = p_2 = 1/4$. Does the entropy increase after modulo 2 addition?

Hint: Compare $H(S)$ to $H(X_1)$.

(c) Now $S = X_1 + X_2$ where $+$ is the standard addition in \mathbb{R} . The two random variables are not independent, their joint distribution is given by the following table

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**Wei Wang, Jiasong Mu, Xin Liu, Zhenyu
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