

**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  $\infty$ ), 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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