

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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Table of Contents Neural Networks Final Exam

1. Understanding the eBook Neural Networks Final Exam
 - The Rise of Digital Reading Neural Networks Final Exam
 - Advantages of eBooks Over Traditional Books
2. Identifying Neural Networks Final Exam
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Neural Networks Final Exam
 - User-Friendly Interface
4. Exploring eBook Recommendations from Neural Networks Final Exam

- Personalized Recommendations
 - Neural Networks Final Exam User Reviews and Ratings
 - Neural Networks Final Exam and Bestseller Lists
5. Accessing Neural Networks Final Exam Free and Paid eBooks
 - Neural Networks Final Exam Public Domain eBooks
 - Neural Networks Final Exam eBook Subscription Services
 - Neural Networks Final Exam Budget-Friendly Options
 6. Navigating Neural Networks Final Exam eBook Formats
 - ePub, PDF, MOBI, and More
 - Neural Networks Final Exam Compatibility with Devices
 - Neural Networks Final Exam Enhanced eBook Features
 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Neural Networks Final Exam
 - Highlighting and Note-Taking Neural Networks Final Exam
 - Interactive Elements Neural Networks Final Exam
 8. Staying Engaged with Neural Networks Final Exam
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Neural Networks Final Exam
 9. Balancing eBooks and Physical Books Neural Networks Final Exam
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Neural Networks Final Exam
 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
 11. Cultivating a Reading Routine Neural Networks Final Exam
 - Setting Reading Goals Neural Networks Final Exam
 - Carving Out Dedicated Reading Time
 12. Sourcing Reliable Information of Neural Networks Final Exam

- Fact-Checking eBook Content of Neural Networks Final Exam
 - Distinguishing Credible Sources
13. Promoting Lifelong Learning
- Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
14. Embracing eBook Trends
- Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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