CSE 446: Final Exam

Please WAIT to open the exam until you are instructed to begin. You can write your name on this page.

Please write your name and ID on your notes page (if you have one). We will collect this with your exam.

Please take out your student ID and leave it on the corner of your desk, as we will come around and check them while you work on the exam.

Instructions: This exam consists of a set of True/False and multiple choice questions.

Write your name and ID number in the provided spaces on every page of the exam.

For each question, clearly indicate your answer by filling in the letter associated with your choice.

If you need to change an answer, please very clearly indicate what your final answer is. Responses where we cannot determine the selected option will be marked as incorrect.

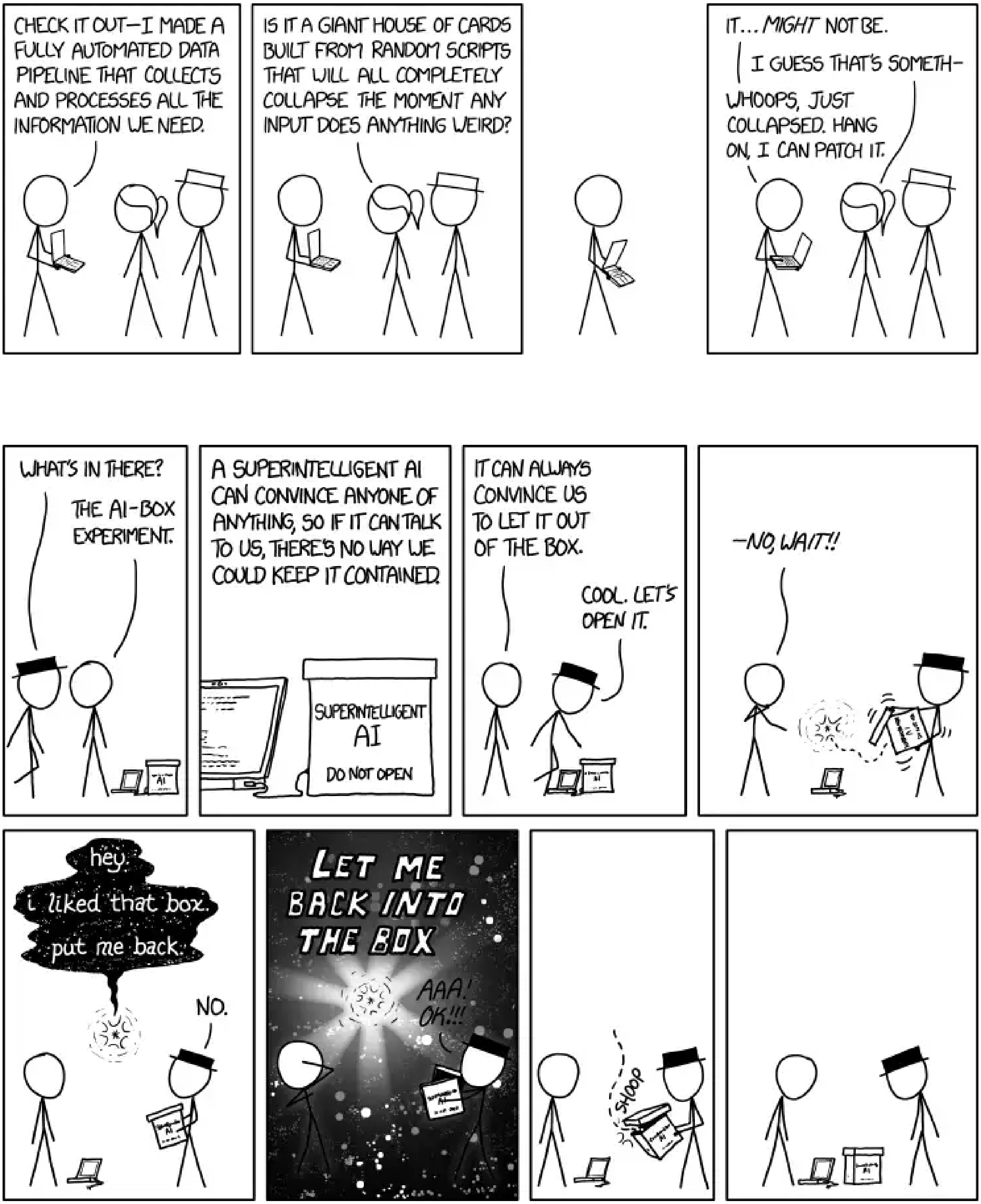


Figure 1: These images are included only to cover the back of this page. They have no relation to the exam.

Consider the following matrix X with four data points in $\mathbb{R}^2$. We would like to use PCA to find a rank-1 linear representation of these data.

$$X = \begin{bmatrix} 4 & 1 \\ 5 & 4 \\ 1 & 2 \\ 1 & 0 \end{bmatrix}$$

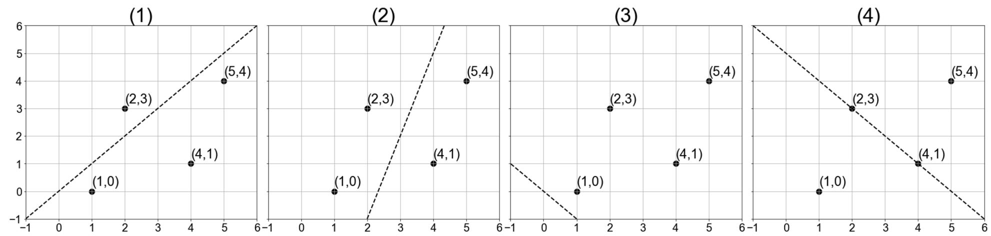


Figure 2: These plots depict data points from the four-sample dataset X.

(1) Which line in Figure 2 represents the direction of the first principal component of $X - \mu$, where $X \in \mathbb{R}^{n \times d}$ the vector $\mu \in \mathbb{R}^d$ is the featurewise mean of X?

(A) Plot 1

(B) Plot 2

(C) Plot 3

(D) Plot 4

(2) Which of the following statements about kernels is **false**?

(A) Kernel feature vectors $\phi(x_i)$ can be infinite-dimensional

(B) Kernels methods scale well to large datasets because the size of the kernel matrix does not depend on the size of the dataset

(C) Kernel matrices store the results of inner products of the data's features computed in a higher-dimensional space

(D) Kernels allow otherwise linear models to find non-linear decision boundaries

(3) Suppose you have a logistic regression model for spam detection, using a dataset with a binary outcome that indicates whether an email is spam (1) or not spam (0). The predictor variables x_1, x_2, and x_3 are boolean values (0 or 1) that indicate whether the email contains the words "free", "order", and "homework", respectively. The model has four parameters: weights w_1, w_2, w_3, and offset b. You find that emails containing the words "free" and "order" have a higher probability of being spam, while emails containing the word "homework" have a lower probability of being spam. Given this information, which of the following signs is most likely for the weights w_1, w_2, and w_3?

(A) All positive

(B) All negative

(C) w_1 and w_2 are positive, w_3 is negative

(D) w_1 and w_2 are negative, w_3 is positive

(4) True/False: Solving the k-means objective is an unsupervised learning problem.

(A) True

(B) False

(5) Which of the following is typical for decision trees trained to have 0 training error?

(A) High bias, low variance

(B) High bias, high variance

(C) Low bias, high variance

(D) Low bias, low variance

(6) When is PCA ineffective?

(A) When data has an orthogonal underlying structure.

(B) When the data's underlying low-dimensional structure is non-linear.

(C) When the data is standardized.

(D) When data visualisation is needed.

(7) The kernel matrix K is **not**

(A) Symmetric

(B) Square

(C) Positive semi-definite (defined as $x^T Kx > 0$ for every nonzero column vector x; a necessary condition for this is that K has nonnegative eigenvalues).

(D) Elementwise positive

(8) True/False: Ridge regression's optimal parameters $\hat{w} = (X^T X + \lambda I)^{-1} X^T y$ are a linear combination of the data points x_i in X.

(A) True

(B) False

(9) True/False: Solving the k-means objective with Lloyd's algorithm (shown in lecture) will always converge to the global optimum of the k-means objective.

(A) True

(B) False

(10) When might it be appropriate to use ridge regression instead of (unregularized) least square regression?

(A) When the data is linearly separable.

(B) When the number of predictor variables is very large relative to the number of observations ($d > n$).

(C) When there are categorical or one-hot features in the input dataset.

(D) When the data is not standardized.

(11) True/False: For PCA, the objective function can equivalently be thought of as (1) variance-maximization or (2) reconstruction error-minimization.

(A) True

(B) False

(12) Which of the following activation functions can be used in the **output** layer of a neural network if we wish to predict the probabilities of k classes $\hat{p} = (p_1, p_2, ..., p_k)$ such that sum of $\hat{p}$ over all k equals to 1? (Assume $k \geq 2$.)

(A) Tanh

(B) Leaky ReLU

(C) Sigmoid

(D) Softmax

(13) True/False: For decision tree algorithms, small perturbation in the training data can result in large differences in the resulting classifiers.

(A) True

(B) False

(14) True/False: The unfairness with respect to race of a model trained on a dataset can be completely resolved by removing race as a feature.

(A) True

(B) False

(15) For the following code snippet on the bootstrap algorithm, determine whether it is correct or select the function that is possibly buggy.

```
import random

def sample(data):
    sample = random.sample(data, len(data)) # samples len(data) elements without replacement
    return sample

def mean(numbers):
    return sum(numbers) / len(numbers)

def bootstrap(data, num_samples):
    samples = [sample(data) for _ in range(num_samples)]
    sample_means = [mean(sample) for sample in samples]
    return sample_means

data = [1, 2, 3, 4, 5]
bootstrap_means = bootstrap(data, 10)
```

(A) Code is correct.

(B) `sample` function is buggy.

(C) `mean` function is buggy.

(D) `bootstrap` function is buggy (assuming `sample` function and `mean` function is correct).

(16) True/False: The bootstrap method can be applied to other statistics, not just variance.

(A) True

(B) False

(17) True/False: The cluster centers that are calculated during each iteration of Lloyd's algorithm are always actual data points.

(A) True

(B) False

(18) What kind of method can be used to tune models and hyperparameter selection so as to optimize the bias-variance tradeoff?

(A) Bootstrap.

(B) k-means.

(C) Cross validation.

(D) All of the above.

(19) True/False: The expected error on unseen samples is at least the irreducible error.

(A) True

(B) False

(20) Which of the following methods would not help when a model suffers from high bias?

(A) Add more input features.

(B) Standardizing the data (to have mean 0, variance 1).

(C) Decrease regularization.

(D) Increase the complexity of the hypothesis class.

(21) Which of the following would be the most appropriate loss function to use when training a neural network on a multi-class classification problem?

(A) Mean Absolute Error

(B) Mean Squared Error

(C) Cross Entropy

(D) Hinge loss

(22) Which of the following does not increase the complexity of a neural network?

(A) Adding more layers

(B) Increasing the hidden layer size

(C) Reducing the strength of the regularizer

(D) Reducing the learning rate

(23) Which of the following is **NOT** an advantage of SVMs?

(A) SVMs can guarantee that the solution is a global minimum.

(B) SVMs can be used for both linearly-separable and non-linearly-separable data.

(C) The SVM objective can be solved in closed form.

(D) SVMs can be combined with the kernel trick to learn feature mappings.

(24) Which of the following would be the most appropriate model for an image classification problem?

(A) Neural network with fully-connected layers

(B) Neural network with convolutional layers

(C) Kernel SVM

(D) Random forest

(25) Assume you train a neural network with SGD with a batch size of 10 on a dataset consisting of 500 samples. How many cumulative backward passes will your neural network perform on any given epoch?

(A) 5000

(B) 500

(C) 50

(D) 10

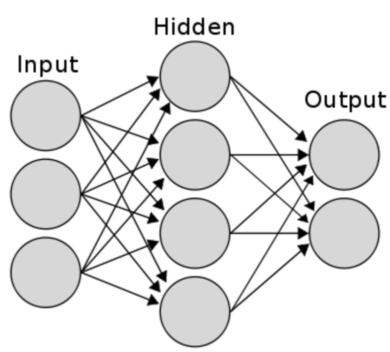


Figure 3: This figure depicts a 2-layer neural network.

(26) Assuming the neural network in figure 3 has no bias parameters, how many trainable parameters does it have?

(A) 9

(B) 20

(C) 24

(D) 29

(27) Which of the following is NOT a potential benefit of using ridge regression?

(A) It can reduce the variance of the model.

(B) It can improve the interpretability of the model.

(C) It can help to reduce overfitting.

(28) How many parameters do we need to learn a mixture of two Gaussian distributions with N samples in $\mathbb{R}^1$?

(A) 2

(B) 4

(C) $N \times 2$

(D) N

(29) Which of the following statements is true about the bootstrap method?

(A) The bootstrap estimator for prediction error offers better generalization than cross-validation.

(B) A bootstrap sample can be obtained from the empirical distribution of the data.

(C) All of the above.

(D) None of the above.

(30) What does the generalization error of an SVM measure?

(A) How far the hyperplane is from the support vectors.

(B) How accurately the SVM can predict outcomes for unseen data.

(C) The threshold amount of error in an SVM.

(D) The complexity of the decision boundary.

(31) True/False: Support vectors are the data points that lie closest to the decision boundary.

(A) True.

(B) False.

(32) Which of the following is a potential advantage of using Lasso regression over unregularized linear regression?

(A) It can decrease the bias of the model.

(B) It will always be more computationally efficient to train.

(C) It always produces the best results (in terms of test error).

(D) It can make the model more interpretable.

(33) Consider a neural network with L layers. How many forward passes through the entire network are needed in a run of the backpropagation algorithm?

(A) L

(B) L^2

(C) 1

(D) 2

(34) Suppose you have trained an SVM with a quadratic kernel. After training the SVM, you correctly infer that your SVM model is underfitting. Which of the following option should you consider for (re)training this SVM next time to address the underfitting?

(A) Increase the number of training data points.

(B) Decrease the number of training data points.

(C) Increase the degree of the kernel used (e.g., fit an SVM with a cubic kernel instead).

(D) Decrease the degree of a kernel used (e..g, fit a linear SVM instead).

(35) Consider a fully connected layer with input size M, an offset, and output size N. What is the total number of parameters of this layer?

(A) $M + N$

(B) $M^2 \times N$

(C) $(M + 1) \times N$

(D) $M^2 \times N^2$

(36) You have a batch of size N 512 x 512 RGB images as your input. The input tensor your neural network has the shape (N, 3, 512, 512). You pass your input through a convolutional layer like below:

```
Conv2D(in_channels=3, out_channels=32, kernel_size=9, stride=1, padding=1)
```

What is the shape of your output tensor?

(A) (N, 32, 512, 512)

(B) (N, 32, 506, 506)

(C) (N, 32, 505, 505)

(D) (N, 32, 253, 253)

(37) Which of the following sets is NOT convex?

(A) $\{\mathbf{x} \in \mathbb{R}^2 \mid ||\mathbf{x}||_2 < 1\}$

(B) $\{(x, y) \in \mathbb{R}^2 \mid |x| > y\}$

(C) $\{(x, y) \in \mathbb{R}^2 \mid x < y^2\}$

(D) $\{\mathbf{x} \in \mathbb{R}^3 \mid \mathbf{x} \cdot \langle 1, 2, 3\rangle \geq 0\}$

(38) What is the correct order of a training step of a neural network?

(A) compute loss $\rightarrow$ forward pass $\rightarrow$ backward pass

(B) backward pass $\rightarrow$ compute loss $\rightarrow$ forward pass

(C) forward pass $\rightarrow$ compute loss $\rightarrow$ backward pass

(D) backward pass $\rightarrow$ forward pass $\rightarrow$ compute loss

(39) Which of the following is true for random forest algorithm?

(A) Random forests generally have low bias and low variance.

(B) The trees for the random forest are only trained on a subset of the training data.

(C) Random forests can be used for both classification and regression

(D) All of the above.

(40) Which of the following functions is convex on the given interval?

(A) $y = -|x|$ on $[0, 2]$

(B) $y = x^3$ on $[-1, 1]$

(C) $y = \max(-x^2, -x)$ on $[0, 2]$

(D) $y = \cos(x)$ on $[0, \pi]$.

(41) How does lasso regression differ from ridge regression?

(A) Lasso regression adds a penalty term to the regression equation, while ridge regression does not.

(B) Lasso regression can achieve feature selection (by setting feature weights to exactly zero), while ridge regression can not.

(C) Lasso regression is a type of unregularized linear regression, while ridge regression is regularized.

(D) Lasso regression is a type of regularized linear regression, while ridge regression is unregularized.

(42) In which of the following situations would it be appropriate to use logistic regression?

(A) Predicting whether a credit card transaction is fraudulent based on some attributes.

(B) Predicting the number of cars that will pass through a particular intersection during rush hour.

(C) Predicting the annual income of a person based on their education and employment history.

(D) Predicting the price of a stock based on historical data.

(43) Which of the following statements about principal component analysis (PCA) is **false**?

(A) All principal components are always orthogonal to each other.

(B) Before using PCA, it's important to preprocess data by demeaning the data matrix.

(C) The first q principal components are the first q eigenvectors of the demeaned data matrix

(D) PCA produces a linear transformation of the data.

(44) Which of the following is NOT a convex optimization problem?

(A) Logistic regression

(B) neural network training

(C) Gaussian kernel SVM

(D) minimizing least squares with polynomial features

(45) Which of the following facts can lead to misleading correlational statistics in criminal justice datasets?

(A) Different *reported* crime rates across different neighborhoods.

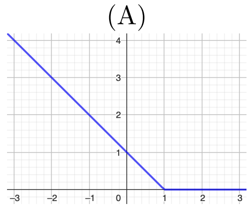
(B) Different wrongful arrest rates across different demographic groups.

(C) Difference in local laws, i.e., different laws regarding indoor and outdoor drug sales in Seattle

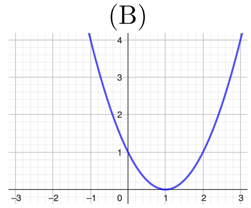
(D) All of the above.

(46) Which of the following functions is the logistic loss for label $y = +1$?

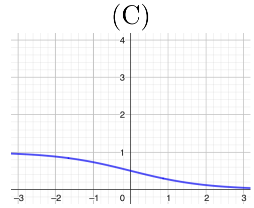
(A)



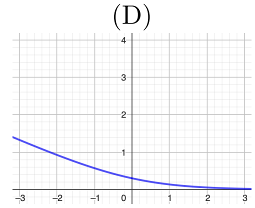
(B)



(C)



(D)



(47) Which of the following methods would **not** help when a model suffers from high variance?

(A) Reduce training data.

(B) Decrease model size.

(C) Increase the amount of regularization.

(D) Perform feature selection.

(48) In linear regression, the loss function is $L(\alpha) = ||y - K\alpha||_2^2 + \lambda\alpha^T K\alpha$, where the kernel matrix K is given by $K_{ij} = \langle\phi(x_i), \phi(x_j)\rangle$ for a kernel map ϕ, inner product $\langle\cdot,\cdot\rangle$, and data samples $x_i, x_j \in \mathbb{R}^d$. What is the closed form solution for $\hat{\alpha}$ that minimizes $L(\alpha)$?

(A) $(K^T K + \lambda I)^{-1} K^T y$

(B) $(K + \lambda I)^{-1} y$

(C) $K^T (K + \lambda I)^{-1} y$

(D) $(K + \lambda I)^{-1} K^T y$

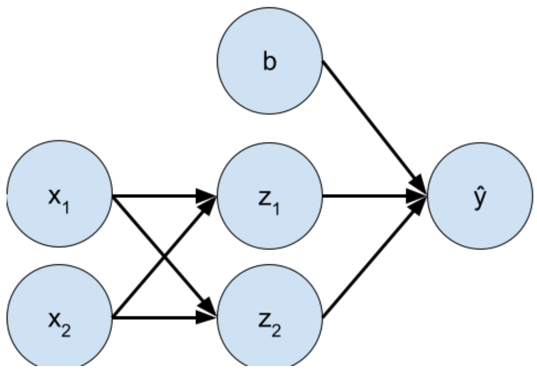


Figure 4: Use this figure to answer the following two questions.

(49) Consider the following equations:

$$z_1(x_1, x_2) = (x_1)^2 + 4x_2 \tag{1}$$
$$z_2(x_1, x_2) = (x_1 + x_2)^2 \tag{2}$$
$$\hat{y}(z_1, z_2, b) = b + z_1 \cdot z_2 \tag{3}$$

which can be combined to form the network shown in Figure 4 What is the formula for $\frac{\partial \hat{y}}{\partial x_1}$?

(A) $4x_1$

(B) $2(x_1 + x_2) + 2z_1 x_2$

(C) $2z_1 x_1 + 2z_2(x_1 + 2x_2)$

(D) $2z_2 x_1 + 2z_1(x_1 + x_2)$

(50) If $x_1 = 2$ and $x_2 = -1$, then what is the value of $\frac{\partial \hat{y}}{\partial x_2}$?

(A) 0

(B) 4

(C) 2

(D) 1

(51) When reviewing the grade for an assignment in CSE 446, TAs found out those grades follows a gamma distribution. The probability density function $f(x)$ for the gamma distribution with parameters k and θ is

$$f(x;\, k, \theta) \;=\; \frac{1}{\Gamma(k)\theta^k} x^{k-1} e^{-\frac{x}{\theta}}\ , \qquad \Gamma(x) = (x-1)!\ .$$

What is the Maximum Likelihood Estimator (MLE) for the parameter θ in terms of the number of students n, the student grades $x_1, \ldots, x_n$, and the parameter k?

(A) $\frac{1}{kn} \sum_{i=1}^{n} x_i$

(B) $\frac{n}{(k-1)!} \sum_{i=1}^{n} x_i e^{-\frac{x_i}{k}}$

(C) $\ln(\frac{1}{n} \sum_{i=1}^{n} x_i) - n(k-1)!$

(D) $\frac{ln(k)-(k-1)!}{\frac{1}{k}}$

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