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## Learning From Data

Caltech

<http://work.caltech.edu/telecourse>

Self-paced version

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### Online Homework # 2

*All questions have multiple-choice answers ([a], [b], [c], ...). You can collaborate with others, but do not discuss the selected or excluded choices in the answers. You can consult books and notes, but not homework solutions. Your solutions should be based on your own work. Definitions and notation follow the lectures.*

#### Note about the homeworks

- The goal of the homeworks is to facilitate a deeper understanding of the course material. The questions are not designed to be puzzles with catchy answers. They are meant to make you roll your sleeves, face uncertainties, and approach the problem from different angles.
- The problems range from easy to hard, and from theoretical to practical. Some problems require running a full experiment to arrive at the answer.
- The answer may not be obvious or numerically close to one of the choices, but one (and only one) choice will be correct if you follow the exact instructions in each problem. You are encouraged to explore the problem further by experimenting with variations of these instructions, for the learning benefit.
- You are also encouraged to take part in the forum

<http://book.caltech.edu/bookforum>

where there are many threads about each homework. We hope that you will contribute to the discussion as well. Please follow the forum guidelines for posting answers (see the “BEFORE posting answers” announcement at the top there).

## Hoeffding Inequality

Run a computer simulation for flipping 1,000 virtual fair coins. Flip each coin independently 10 times. Focus on 3 coins as follows:  $c_1$  is the first coin flipped,  $c_{\text{rand}}$  is a coin chosen randomly from the 1,000, and  $c_{\text{min}}$  is the coin which had the minimum frequency of heads (pick the earlier one in case of a tie). Let  $\nu_1$ ,  $\nu_{\text{rand}}$ , and  $\nu_{\text{min}}$  be the fraction of heads obtained for the 3 respective coins out of the 10 tosses. Run the experiment 100,000 times in order to reduce variability in your results (note that  $c_{\text{rand}}$  and  $c_{\text{min}}$  will change from run to run) and compute average values for the  $\nu$ 's.

1.  $\nu_{\text{min}}$  is closest to:

[a] 0

[b] 0.01

[c] 0.1

[d] 0.5

[e] 0.67

2. Which coin or coins satisfy Hoeffding's Inequality?

[a]  $c_1$  only

[b]  $c_{\text{rand}}$  only

[c]  $c_{\text{min}}$  only

[d]  $c_1$  and  $c_{\text{rand}}$

[e]  $c_{\text{min}}$  and  $c_{\text{rand}}$

## Error and Noise

Consider the bin model for a hypothesis  $h$  that makes an error with probability  $\mu$  in approximating a deterministic target function  $f$  (both  $h$  and  $f$  are binary functions). If we use the same  $h$  to approximate a noisy version of  $f$  given by:

$$P(y \mid \mathbf{x}) = \begin{cases} \lambda & y = f(x) \\ 1 - \lambda & y \neq f(x) \end{cases}$$

3. What is the probability of error that  $h$  makes in approximating  $y$ ? *Hint: Two wrongs can make a right!*

- [a]  $\mu$
- [b]  $\lambda$
- [c]  $1-\mu$
- [d]  $(1-\lambda) * \mu + \lambda * (1-\mu)$
- [e]  $(1-\lambda) * (1-\mu) + \lambda * \mu$

4. At what value of  $\lambda$  will the performance of  $h$  be independent of  $\mu$ ?

- [a] 0
- [b] 0.5 uv + (1-u)(1-v) = 2uv - u + 1 - v. To be independent of u, we can put 2uv - u as 0 giving v as 0.5. Thus if the noise is so much that y is purely random, then \mu is irrelevant.
- [c]  $1/\sqrt{2}$
- [d] 1
- [e] No values of  $\lambda$

## Linear Regression

In this problem, we will explore how Linear Regression for classification works. As with the Perceptron Learning Algorithm in Homework 1, you will create your own target function  $f$  and data set  $\mathcal{D}$ . Take  $d = 2$  so you can visualize the problem, and assume  $\mathcal{X} = [-1, 1] \times [-1, 1]$  with uniform probability of picking each  $\mathbf{x} \in \mathcal{X}$ . In each run, choose a random line in the plane as your target function  $f$  (do this by taking two random, uniformly distributed points in  $[-1, 1] \times [-1, 1]$  and taking the line passing through them), where one side of the line maps to +1 and the other maps to -1. Choose the inputs  $\mathbf{x}_n$  of the data set as random points (uniformly in  $\mathcal{X}$ ), and evaluate the target function on each  $\mathbf{x}_n$  to get the corresponding output  $y_n$ .

5. Take  $N = 100$ . Use Linear Regression to find  $g$  and evaluate  $E_{\text{in}}$ , the fraction of in-sample points which got classified incorrectly. Repeat the experiment 1000 times and take the average. Which of the following values is closest to the average  $E_{\text{in}}$ ? (*closest* is the option that makes the expression |your answer - given option| closest to 0. Use this definition of *closest* here and throughout)

- [a] 0
- [b] 0.001
- [c] 0.01

- [d] 0.1  
[e] 0.5
6. Now, generate 1000 fresh points and use them to estimate the out-of-sample error  $E_{\text{out}}$  of  $g$  that you got in Problem 5 (number of out-of-sample points misclassified / total number of out-of-sample points). Again, run the experiment 1000 times and take the average. Which value is closest to the average  $E_{\text{out}}$ ?
- [a] 0  
[b] 0.001  
[c] 0.01  
[d] 0.1  
[e] 0.5
7. Now, take  $N = 10$ . After finding the weights using Linear Regression, use them as a vector of initial weights for the Perceptron Learning Algorithm. Run PLA until it converges to a final vector of weights that completely separates all the in-sample points. Among the choices below, what is the closest value to the average number of iterations (over 1000 runs) that PLA takes to converge? (When implementing PLA, have the algorithm choose a point randomly from the set of misclassified points at each iteration)
- [a] 1  
[b] 15  
[c] 300  
[d] 5000  
[e] 10000

### Nonlinear Transformation

Consider the target function:

$$f(x_1, x_2) = \text{sign}(x_1^2 + x_2^2 - 0.6)$$

Generate a training set of  $N = 1000$  points on  $\mathcal{X} = [-1, 1] \times [-1, 1]$  with uniform probability of picking each  $\mathbf{x} \in \mathcal{X}$ . Generate simulated noise by flipping the sign of the output in a random 10% subset of the generated training set.

8. Carry out Linear Regression without transformation, i.e., with feature vector:

$$(1, x_1, x_2),$$

to find the weight  $\mathbf{w}$ . What is the closest value to the classification in-sample error ( $E_{\text{in}}$ )? Run the experiment 1000 times and take the average  $E_{\text{in}}$  in order to reduce variation in your results.

- [a] 0
- [b] 0.1
- [c] 0.3
- [d] 0.5
- [e] 0.8

Now, transform the training data into the following nonlinear feature vector:

$$(1, x_1, x_2, x_1x_2, x_1^2, x_2^2)$$

Find the vector  $\tilde{\mathbf{w}}$  that corresponds to the solution of Linear Regression.

9. Which of the following hypotheses is closest to the one you find using Linear Regression on the transformed input? Closest here means agrees the most with your hypothesis (has the most probability of agreeing on a randomly selected point).

- [a]  $g(x_1, x_2) = \text{sign}(-1 - 0.05x_1 + 0.08x_2 + 0.13x_1x_2 + 1.5x_1^2 + 1.5x_2^2)$
- [b]  $g(x_1, x_2) = \text{sign}(-1 - 0.05x_1 + 0.08x_2 + 0.13x_1x_2 + 1.5x_1^2 + 15x_2^2)$
- [c]  $g(x_1, x_2) = \text{sign}(-1 - 0.05x_1 + 0.08x_2 + 0.13x_1x_2 + 15x_1^2 + 1.5x_2^2)$
- [d]  $g(x_1, x_2) = \text{sign}(-1 - 1.5x_1 + 0.08x_2 + 0.13x_1x_2 + 0.05x_1^2 + 0.05x_2^2)$
- [e]  $g(x_1, x_2) = \text{sign}(-1 - 0.05x_1 + 0.08x_2 + 1.5x_1x_2 + 0.15x_1^2 + 0.15x_2^2)$

10. What is the closest value to the classification out-of-sample error  $E_{\text{out}}$  of your hypothesis? (Estimate it by generating a new set of 1000 points and adding noise as before. Average over 1000 runs to reduce the variation in your results).

- [a] 0
- [b] 0.1
- [c] 0.3
- [d] 0.5
- [e] 0.8