

# Problem Set 1

CS 7301

Due: 9/10/2017 by 11:59pm

Note: all answers should be accompanied by explanations for full credit. All code used as part of your solutions should be included for partial credit. Late homeworks will not be accepted.

## Warm-Up: Subgradients & More (12 pts)

1. Compute a subgradient at the specified points for each of the following convex functions.
  - (a)  $f(x) = \max\{\frac{1}{2}x^2, |x|\}$  at  $x = 0$  and  $x = -2$ .
  - (b)  $g(x) = \max\{\exp(x), 10x\}$  at  $x = 2$  and  $x = -1$ .
2. Recall that a function  $f : \mathbb{R}^n \rightarrow \mathbb{R}$  is convex if for all  $x, y \in \mathbb{R}^n$  and  $\lambda \in [0, 1]$ ,  $\lambda f(x) + (1 - \lambda)f(y) \geq f(\lambda x + (1 - \lambda)y)$ . Using this definition, show that  $f(x) = \max\{ax + b, cx + d\}$  is a convex function for  $x \in \mathbb{R}$  and any choice of constants  $a, b, c, d \in \mathbb{R}$ . Be sure to clearly explain your argument.

## Problem 1: Perceptron Learning (30 pts)

Consider the data set (perceptron.data) attached to this homework. This data file consists of  $n$  data elements of the form  $(x_1^{(i)}, x_2^{(i)}, x_3^{(i)}, x_4^{(i)}, y_i)$  where  $x_1^{(i)}, \dots, x_4^{(i)} \in \mathbb{R}$  define a data point in  $\mathbb{R}^4$  and  $y_i \in \{-1, 1\}$  is the corresponding label. In class, we saw how to use the perceptron algorithm to minimize the following objective.

$$\sum_{i=1}^n \max\{0, -y_i \cdot (w^T x^{(i)} + b)\}$$

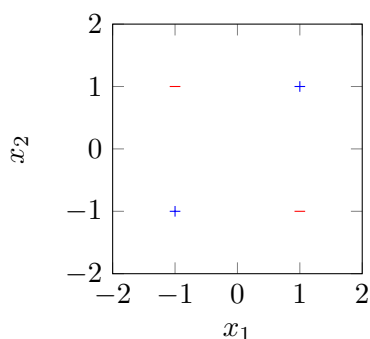
In this problem, you are to implement the perceptron algorithm using two different gradient descent strategies (you can use any programming language that you would like - your code will not be used for grading purposes). For each strategy below, report the number of iterations that it takes to find a perfect classifier for the data, the values of  $w$  and  $b$  for the first three iterations, and the final weights and bias. Each descent procedure should start from the initial point

$$w^0 = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad b^0 = 0.$$

1. Standard gradient descent with the step size  $\gamma_t = 1$  for each iteration.
2. Stochastic gradient descent where exactly one component of the sum is chosen to approximate the gradient at each iteration. Instead of picking a random component at each iteration, you should iterate through the data set starting with the first element, then the second, and so on until the  $n^{th}$  element, at which point you should start back at the beginning again. Again, use the step size  $\gamma_t = 1$ .
3. How does the rate of convergence change as you change the step size? Provide some example step sizes to back up your statements.
4. What is the smallest, in terms of number of data points, two-dimensional data set containing both class labels on which the algorithm, with step size one, fails to converge? Use this example to explain why the method may fail to converge more generally.

## Problem 2: Separability & Feature Vectors (8 pts)

1. Consider the following data set.



Under which of the following feature vectors is the data linearly separable? For full credit, you must justify your answer by either providing a linear separator or explaining why such a separator does not exist.

- |  |   |
|--|---|
| (a) $\phi(x_1, x_2) = \begin{bmatrix} x_1 + x_2 \\ x_1 - x_2 \end{bmatrix}$    | (c) $\phi(x_1, x_2) = \begin{bmatrix} \exp(x_1) \\ \exp(x_2) \end{bmatrix}$     |
| (b) $\phi(x_1, x_2) = \begin{bmatrix} x_1^2 \\ x_2^2 \\ x_1 x_2 \end{bmatrix}$ | (d) $\phi(x_1, x_2) = \begin{bmatrix} x_1 \cdot \sin(x_2) \\ x_1 \end{bmatrix}$ |

## Problem 3: Support Vector Machines, By Hand! (25 pts)

In class, we saw how to formulate SVMs as a quadratic optimization problem that can be solved with standard algorithmic techniques (e.g., `quadprog()` in MATLAB). However, when all of the data points are support vectors, the optimization problem can often be solved by hand. For this problem, you should use the SVM formulation without slack variables.

$x_1$	$x_2$	$y$
0	0	1
-1	-1	-1
2	-2	-1
-1	1	1

1. Which of the above data points must be support vectors? Explain why.
2. Find the linear SVM classifier, by hand, for the above data points. Give a precise setting of the weights and bias. You must show your work to receive credit for this problem. Simply providing the weights and bias will not earn any points.
3. What is the size of the margin?

### Problem 4: Support Vector Machines, By Computer! (25 pts)

For this problem, consider the data set (mystery.data) attached to this homework that, like Problem 2, contains four numeric attributes per row and the fifth entry is the class variable (either + or -).

1. Find a perfect classifier for this data set using support vector machines. Your solution should explain the optimization problem that you solved and provide the learned parameters, the optimal margin, and the support vectors.