# Problem Set 5

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Problem Sets due Jul 26, 2022 23:00 PKT Completed

Problems 1-4 correspond to "Unconstrained optimization I"

## Problem 1

1/1 point (graded)

Let $F$ be a function from $\mathbb{R}^d$ to $\mathbb{R}$. Which of the following is the most accurate description of the derivative $\nabla F$?

- ○ It is a real number.
- ○ It is a $d$-dimensional vector.
- ○ For any point $u \in \mathbb{R}^d$, the derivative at that point, $\nabla F(u)$, is a real number.
- ◉ For any point $u \in \mathbb{R}^d$, the derivative at that point, $\nabla F(u)$, is a $d$-dimensional vector.

✓

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## Problem 2

6/6 points (graded)

Consider the following loss function on vectors $w \in \mathbb{R}^3$:

$$L(w) = w_1^2 - 2w_1w_2 + w_2^2 + 2w_3^2 + 3.$$

a) Compute $\nabla L(w)$. Match each of its coordinates to the following list:

Option 1: $4w_3$

Option 2: $2w_1 - 2w_2$

Option 3: $-2w_1 + 2w_2$

What is $dL/dw_1$? (Just answer 1,2,or 3)

2 ✓

2

$dL/dw_2 =$

3 ✓

3

$dL/dw_3 =$

1 ✓

1

b) What is the minimum value of $L(w)$?

3

3

c) Is there is a unique solution $w$ at which this minimum is realized?

no

d) Suppose we use gradient descent to minimize this function, and that the current estimate is $w = (1, 2, 3)$. If the step size is $\eta = 0.5$, what is the next estimate?

- ○ $w = (1, 1, 0)$
- ○ $w = (-1, 0, 1)$
- ◉ $w = (2, 1, -3)$
- ○ $w = (0, -1, -1.5)$

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## Problem 3

1/1 point (graded)

We are given a set of data points $x^{(1)}, \ldots, x^{(n)} \in \mathbb{R}^d$, and we want to find a single point $z \in \mathbb{R}^d$ that minimizes the loss function

$$L(z) = \sum_{i=1}^{n} \|x^{(i)} - z\|^2.$$

Use calculus to determine $z$, in terms of the $x^{(i)}$. ($Hint:$ It might help to just start by looking at one particular coordinate.) Then select which of the following correctly describes the solution.

- ○ The sum of the $x^{(i)}$ vectors
- ◉ The average of the $x^{(i)}$ vectors
- ○ The average of the $x^{(i)}$ vectors, times a constant $c \neq 1$
- ○ Zero, regardless of what the $x^{(i)}$ vectors are

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## Problem 4

Problem 4

2/2 points (graded)

Given a set of data points $x^{(1)}, \ldots, x^{(n)} \in \mathbb{R}^d$, we want to find the vector $w \in \mathbb{R}^d$ that minimizes this loss function:

$$L(w) = \sum_{i=1}^{n} (w \cdot x^{(i)}) + \frac{1}{2} c \|w\|^2.$$

Here $c > 0$ is some constant.

a) Let $s$ denote the sum of the data points, that is, $s = \sum_{i=1}^{n} x^{(i)}$. Express $\nabla L(w)$ in terms of $s$, $c$, and $w$.

- ○ $\nabla L(w) = s + w$
- ◉ $\nabla L(w) = s + cw$
- ○ $\nabla L(w) = cw$
- ○ $\nabla L(w) = s/c + w$

✓

**Answer**

Correct: The derivative is $\nabla L(w) = \sum_i x^{(i)} + cw = s + cw$

b) What value of $w$ minimizes $L(w)$? Give the answer in terms of $s$ and $c$.

- ◉ $w = -\frac{s}{c}$
- ○ $w = cs$
- ○ $w = \frac{s}{4c}$
- ○ $w = -\frac{s}{2c}$

✓

**Answer**

Correct: This results from setting $\nabla L(w) = 0$.

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Problems 5-7 correspond to "Convexity I"

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## Problem 5

7/7 points (graded)

For each of the following functions of one variable, say whether it is **convex**, **concave**, **both**, or **neither**.

a) $f(x) = x^2$

convex ✓

**Answer**
Correct: $f''(x) = 2$

b) $f(x) = -x^2$

concave

**Answer**
Correct: $f''(x) = -2$

c) $f(x) = x^2 - 2x + 1$

convex

**Answer**
Correct: $f''(x) = 2$

d) $f(x) = x$

both

**Answer**
Correct: $f''(x) = 0$

e) $f(x) = x^3$

neither

**Answer**
Correct: $f''(x) = 6x$, which is sometimes positive, sometimes negative.

f) $f(x) = x^4$

convex

**Answer**
Correct: $f''(x) = 12x^2$

g) $f(x) = \ln x$

concave

**Answer**
Correct: $f''(x) = -1/x^2$

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## Problem 6

1/1 point (graded)
Consider the function $f : \mathbb{R}^3 \to \mathbb{R}$ given by

$$f(x_1, x_2, x_3) = x_1^2 + x_2^2 - x_3^2 - 4x_1x_2 + 6x_2x_3.$$

Compute and select the matrix of second derivatives (the Hessian) $H(x)$.

- $\begin{pmatrix} 1 & -2 & 0 \\ -2 & 1 & 3 \\ 0 & 3 & -1 \end{pmatrix}$

- $\begin{pmatrix} 2 & -4 & 0 \end{pmatrix}$

$$\begin{pmatrix} & & \\ -4 & 2 & 6 \\ 0 & 6 & 0 \end{pmatrix}$$

- (selected) $\begin{pmatrix} 2 & -4 & 0 \\ -4 & 2 & 6 \\ 0 & 6 & -2 \end{pmatrix}$
- $\begin{pmatrix} 1 & -4 & 0 \\ 0 & 2 & 6 \\ 0 & 0 & -2 \end{pmatrix}$

✔

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## Problem 7

1/1 point (graded)

For some fixed vector $u \in \mathbb{R}^d$, define the function $F : \mathbb{R}^d \to \mathbb{R}$ by

$$F(x) = e^{u \cdot x}.$$

Which of the following is the Hessian $H(x)$?

- (selected) $e^{(u \cdot x)} u u^T$
- $e^{(u \cdot x)} I$ (here $I$ is the $d \times d$ identity matrix)
- $e^{(u \cdot x)} \|u\|^2$
- $e^{(u \cdot x)} (u \cdot x)^2$

✔

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Problems 8-11 correspond to "Positive semidefinite matrices"

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## Problem 8

1/1 point (graded)

Is the matrix $M = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$ positive semidefinite?

- Yes, because every entry in the matrix is $\geq 0$
- No, because not every entry is $> 0$

Yes, because $u^T Mu \geq 0$ for all vectors $u$

No, because there is a vector $u$ for which $u^T Mu < 0$

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## Problem 9

1/1 point (graded)

Is the matrix $M = \begin{pmatrix} 1 & -1 \\ -1 & 1 \end{pmatrix}$ positive semidefinite?

No, because not every entry is $\geq 0$

Yes, because $u^T Mu \geq 0$ for all vectors $u$

No, because there is a vector $u$ for which $u^T Mu < 0$

No, because there is a vector $u$ for which $u^T Mu = 0$

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## Problem 10

1/1 point (graded)

For a fixed set of vectors $v^{(1)}, \ldots, v^{(n)} \in \mathbb{R}^d$, let $M$ be the $n \times n$ matrix of all pairwise dot products: that is, $M_{ij} = v^{(i)} \cdot v^{(j)}$. Do you see why $M$ is positive semidefinite? Think about it a little bit, and then choose one of the following options (you'll get marked as correct whichever you choose).

Yes, the entire argument is clear to me.

That sounds right, but I can't fully construct the argument.

I don't get it.

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## Problem 11

1/1 point (graded)

Suppose $M$ and $N$ are positive semidefinite matrices of the same size. Which of the following matrices are *necessarily* positive semidefinite? Select all that apply.

- [x] $M + N$
- [ ] $M - N$

- [x] $2M$
- [x] $(1/2)\,M$
- [x] $M^T NM$

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Problems 12-13 correspond to "Convexity II"

## Problem 12

2/2 points (graded)

For some fixed vector $u \in \mathbb{R}^d$, define

$$F(x) = \|x - u\|^2.$$

We wish to determine whether $F(x)$ is a convex function of $x$.

a) The Hessian matrix $H(x)$ is of the form $cI$, where $I$ is the $d \times d$ identity matrix and $c$ is some constant. What is $c$?

2

$2$

b) Is $F(x)$ a convex function?

- (●) Yes
- ( ) No
- ( ) It depends on the specific vector $u$

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## Problem 13

3/3 points (graded)

Let $p = (p_1, p_2, \ldots, p_m)$ be a probability distribution over $m$ possible outcomes. The *entropy* of $p$ is a measure of how much randomness there is in the outcome. It is defined as

$$F(p) = -\sum_{i=1}^{m} p_i \ln p_i,$$

where $\ln$ denotes natural logarithm. We wish to ascertain whether $F(p)$ is a convex function of $p$. As usual, we begin by computing the Hessian.

a) Consider the specific point $p = (1/m, 1/m, \ldots, 1/m)$. What is the $(1,1)$ entry of the Hessian at this point? Your answer should be a function of $m$.

-m

b) Continuing, what is the $(1,2)$ entry of the Hessian at this specific point?

0

$0$

c) Is the function $F(p)$ $\mathtt{convex}$, $\mathtt{concave}$, $\mathtt{both}$, or $\mathtt{neither}$?

concave

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