2024 Autumn
Intro-to-Machine Learning
Homework 1

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Release Date: 2024/09/24 15:00

Homework 1

- Deadline: 23:59, Oct. 8th (Tue), 2024
- **Coding** (60%): Implement linear regression by **only** using ***numpy*.**
  - Submit your code in executable python files (.py).
  - Report the outcome and parameters by screenshots to the questions.
- **Handwritten Questions** (40%): Answer questions about linear regression.
  - Answer the questions in the report.
  - You **must use the template** and in **digital-typed** (**no handwritten scan**)
  - In English

Links

- Questions and Report template
- Sample code / Dataset

Coding Environment

- Recommnedation: Python 3.9 or higher
- Tips
  - We recommend you to use **virtual environments** when implementing your homework assignments.
  - Here are some popular virtual environment management tools
    - Poetry
    - Conda
    - Virtualenv

Numpy

- High efficient vector and matrix operations
- Numpy Tutorial: [Link]

element-wise multiply

```
a = np.array([1, 2, 3])
b = np.array([4, 5, 6])
for i in range(a.shape[0]):
    a[i] *= b[i]
print(a)
# a = [ 4 10 18]
```

```
a = np.array([1, 2, 3])
b = np.array([4, 5, 6])
a *= b
print(a)
# a = [ 4 10 18]
```

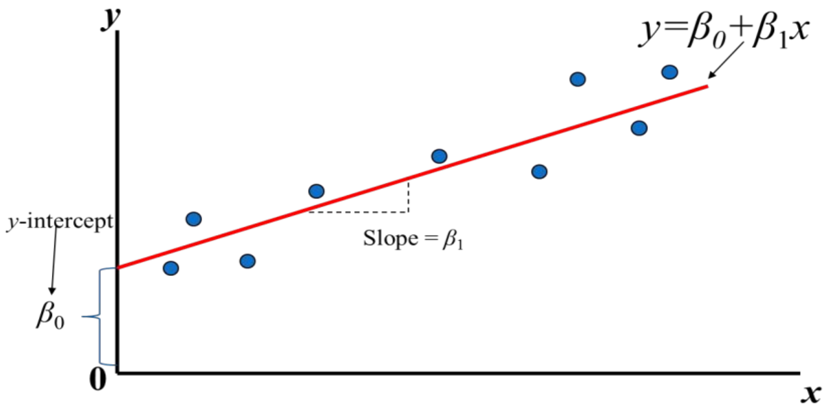
squre root

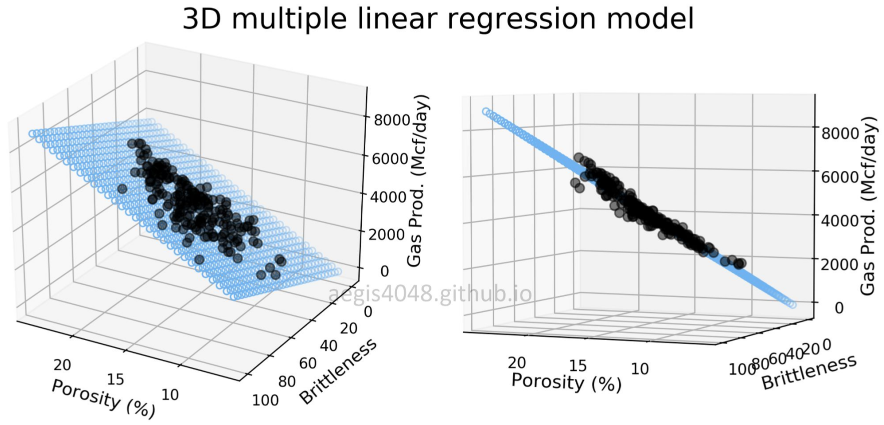
```
import math
a = np.array([1, 4, 9])
for i in range(a.shape[0]):
    a[i] = math.sqrt(a[i])
print(a)
# a = [1 2 3]
```

```
a = np.array([1, 4, 9])
a = np.sqrt(a)
print(a)
# a = [1 2 3]
```

Linear Regression

- Find the the slope (weights) and the intercept of given data





https://aegis4048.github.io/mutiple_linear_regression_and_visualization_in_python

How to find β0 and β1?

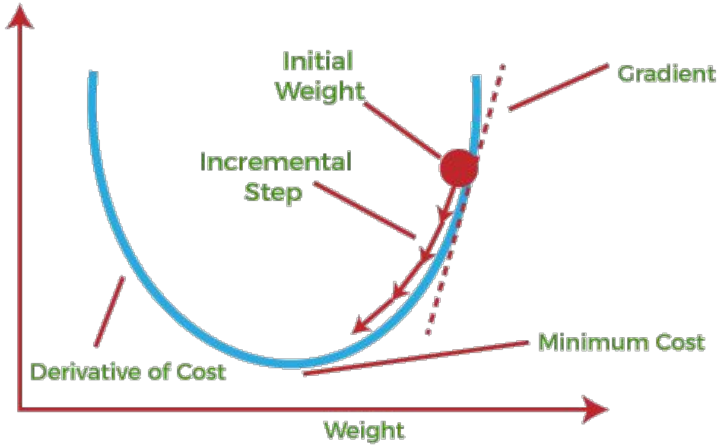
- Implement the closed-form solution (*Question 1-1*)

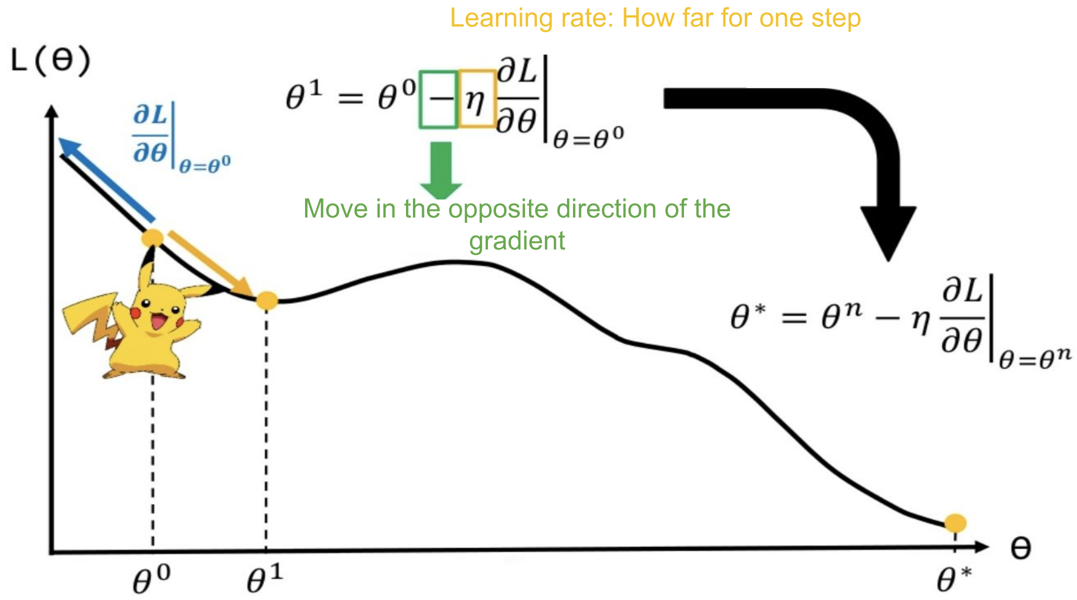
$$\hat{\beta} = (X^T.X)^{-1}X^T.Y$$

- How about a huge dataset?
  - high dimensional data
  - huge amount of data

How to find β0 and β1?

- Gradient Descent (*Question1-2 ~ Question1-4*)

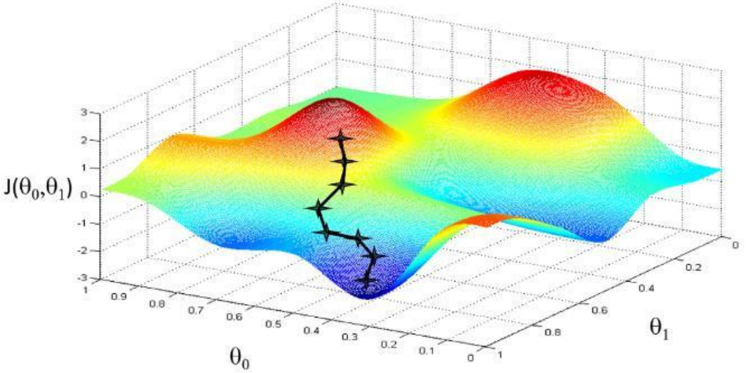




To better understand GD, see https://www.youtube.com/watch?v=yKKNr-QKz2Q

Gradient Descent

- x-axis and y-axis: the value of weights
- z-axis: the value of loss of the corresponding weights
- Goal: Find the weights that minimize the loss value



https://www.linkedin.com/pulse/gradient-descent-visualization-python-ibrahim-sobh/

Dataset and Environment

- Student Performance Dataset
- Features
  - Hour Studied
  - Previous Score
  - Sleep Hours
  - Sample Question Papers Practiced
- Target
  - Performance Index (higher means better performance)

- Required packages: `numpy`, `pandas`, `matplotlib`, `loguru`, `flake8`, `pytest`

Linear Regression – Closed-form Solution (10%)

- Requirements
  - Implement Linear Regression by **closed-form** solution.
- Grading Criteria
  - (10%) Show the weights and intercepts of your linear model.
- Tips
  - There is only one answer.
  - You can check your answer by yourself using third-party libraries (such as scikit-learn).

Linear Regression – Gradient Descent (40%)

- Requirements
  - Update your weights and intercept by using **gradient descent**
    - you can implement mini-batch gradient descent or stochastic gradient descent if you want.
  - Use MSE (Mean Square Error) as your loss function.

$$\mathrm{MSE} = \frac{1}{N}\sum_{i=1}^{N}(y_i - \hat{y}_i)^2$$

  - Tune the **learning rate** and **epoch** hyper-parameters (and **batch size** if you implement mini-batch gradient descent) to make your testing MSE loss as close as the closed-form solution.

Linear Regression – Gradient Descent (40%)

- Grading Criteria
  - (10%) Show the hyperparameters of your setting. Also, show the weights and intercepts of your fitted model.
  - (10%) Plot the learning curve. (x-axis=epoch, y-axis=training loss)
  - (20%) Show your MSE.cf, MSE.gd, and error rate between your closed-form solution and the gradient descent solution.
    - error rate: | (gradient_descent_loss - closed_form_loss) / closed_form_loss | * 100

Points	**error rate, given both of the MSE of close-form and MSE of gradient descent < 20**
20	**< 0.5%**
15	**< 1%**
10	**< 3%**
5	**< 5%**
0	**>= 5%**

Linear Regression – Gradient Descent

- Tips
  - Finding suitable hyper-parameters may cost you some time. Be patient!

Code Output

- Do not modify the main function architecture heavily.
- Your code output will look like this

```
2024-03-14 23:13:57.944 | INFO     | __main__:main:77 - LR_CF.weights=
```

```
2024-03-14 23:54:18.052 | INFO     | __main__:main:84 - LR_GD.weights=
```

```
2024-03-14 23:54:18.055 | INFO     | __main__:main:93 - Prediction difference:
2024-03-14 23:54:18.055 | INFO     | __main__:main:98 - mse_cf=      , mse_gd=      . Difference: 0.027%
```

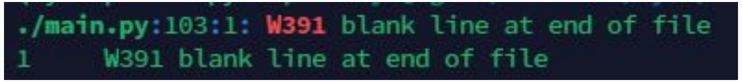
Python Coding Style Guide Reference

1. PEP8
2. Google Python Style

Additional Requirements (10%)

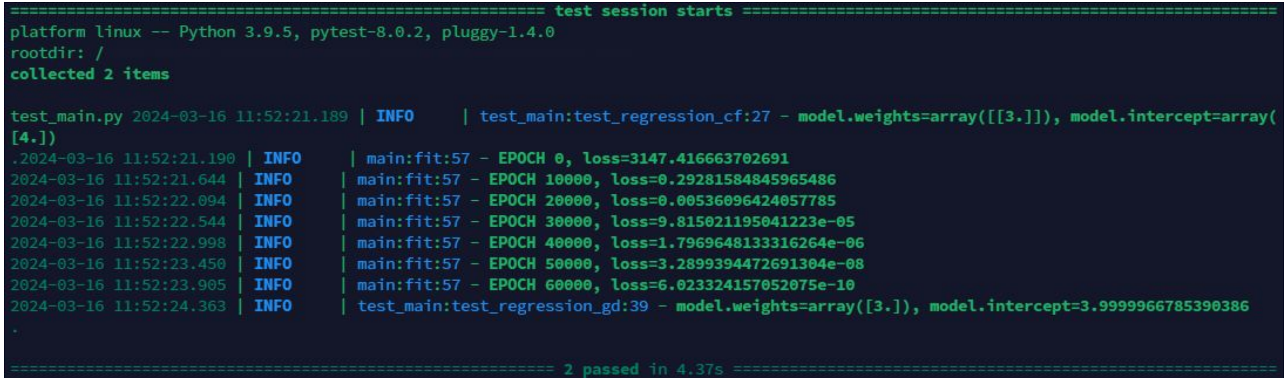
Code Check and Verification: **Lint** the code and show the **PyTest** results (10%)

- Code linting: `$ flake8 main.py`
    - -2pt per warning / error



```
./main.py:103:1: W391 blank line at end of file
1       W391 blank line at end of file
```

- Run PyTest: `$ pytest ./test_main.py -s`
    - -5pt per failed case



```
============================== test session starts ==============================
platform linux -- Python 3.9.5, pytest-8.0.2, pluggy-1.4.0
rootdir: /
collected 2 items

test_main.py 2024-03-16 11:52:21.189 | INFO     | test_main:test_regression_cf:27 - model.weights=array([[3.]]), model.intercept=array(
[4.])
.2024-03-16 11:52:21.190 | INFO     | main:fit:57 - EPOCH 0, loss=3147.416663702691
2024-03-16 11:52:21.644 | INFO     | main:fit:57 - EPOCH 10000, loss=0.29281584845965486
2024-03-16 11:52:22.094 | INFO     | main:fit:57 - EPOCH 20000, loss=0.005360964240577785
2024-03-16 11:52:22.544 | INFO     | main:fit:57 - EPOCH 30000, loss=9.815021195041223e-05
2024-03-16 11:52:22.998 | INFO     | main:fit:57 - EPOCH 40000, loss=1.7969648133316264e-06
2024-03-16 11:52:23.450 | INFO     | main:fit:57 - EPOCH 50000, loss=3.2899394472691304e-08
2024-03-16 11:52:23.905 | INFO     | main:fit:57 - EPOCH 60000, loss=6.023324157052075e-10
2024-03-16 11:52:24.363 | INFO     | test_main:test_regression_gd:39 - model.weights=array([3.]), model.intercept=3.9999966785390386
.

============================== 2 passed in 4.37s ==============================
```

Handwritten Questions (40%)

2-1 (10%) How does the presence of outliers affect the performance of a linear regression model? How should outliers be handled? List <u>at least two</u> methods.

2-2 (15%) How do different values of learning rate (too large, too small…) affect the convergence of optimization? Please <u>explain in detail</u>.

2-3 (15%) What is the prior, likelihood, and posterior in Bayesian linear regression. (Explain the concept in detail rather than writing out the mathematical formula.) **What is the difference between Maximum Likelihood Estimation (MLE) and Maximum A Posteriori Estimation (MAP)?** (Analyze the assumptions and the results.)

Report

- Please follow the report template format. (-5pts if not use the template)
- Link

Submission

- Compress your **code** and **report** into a **.zip file** and submit it to E3.
- Report should be written in English. (-5 pts if not English)
- <STUDENT ID>_HW1.zip
  - main.py
  - setup.cfg
  - test_main.py
  - <STUDENT ID>_HW1.**pdf** (NO .doc, .docx or others format)

- Don't put the data (e.g. train.csv / test.csv) into submission file

Other rules

- **Late Policy**: A penalty of **20 points** per additional late day. (-20pt / delayed.day)
    - For example, If you get 90 points but delay for two days, your will get only 50 points!

- **No Plagiarism**: You should complete the assignment by yourself. Students engaged in plagiarism will be penalized heavily. Super serious penalty.
    - e.g. -100pt for the assignment or failed this course, etc
    - Report to academic integrity office

AI-Assistant

- Not recommended but no forbidden
- Copy-and-Paste answers from the AI-Assiant will be seen as Plagiarism
    - However, you can have your own answer first then rephrase it by AI-Assiant.
- Some questions might be parts of final exam, make sure you understand the concept

FAQs

- Why can't my gradient descent model converge?
  - Make sure you calculate the gradients correctly.
  - Use smaller learning rate.
- Can I use deep learning frameworks such as TensorFlow, PyTorch or other library such as math?
  - **No!** In HW1, you are request using only Numpy to implement linear regression and gradien descent. You can use matplotlib to plot the results.

- If you have other questions, ask on **E3 forum** first! We will reply as soon as possible.

Have Fun!