COMP5541: Machine Learning and Data Analytics

Assignment

PolyU Summer 2025

Submission Deadline: 23:59, June 29, 2025.

Important Notes.

- This is an *individual* assessment. So, please don't share your solutions with others, while discussing general ideas or approaches is fine. Please indicate the contributions of your classmates or the use of generative AI tools (e.g., ChatGPT) in your solution. Any cheating or copying detected will result in a zero score, and all parties involved will be reported to the department.
- In this assignment, only Python and Pytorch are allowed to answer the programming questions.
- Please submit the compressed folder (in zip or rar) with all your answers. Please also name the folder with your student ID, such as "21123456D.zip" or "21123456D.rar".
- In the compressed folder, please create a subfolder for each question below. For example, for Question 1, please create a folder named "Q1" to put your answers. **For non-coding questions**, please put your answers and detailed problem-solving steps into a report and save it in PDF format (to avoid messy formulas). You are allowed to submit a scanned copy of your handwritten answers. **For coding questions**, if you are using Google Colab, please download and submit your code in ".ipynb" format. As we don't have the time to re-run all the code, please make sure your running outputs are available in your submitted ".ipynb" file. To be safe, please also provide screenshots of running outputs and all visualization results in your report for easier marking of your assignment. If your codes are developed in other platforms beyond Google Colab, please provide your code as well as a readme.txt or a readme.doc file to explain how to run the code.

- The code should be well commented for easy reading, and indicate clearly in the comments which part is for which sub-question (if any). It is for the case that the implementation is imperfect (with bugs) and we need to somehow find scores from the code to see if your model or algorithm is implemented in a correct way.
- The compressed folder should be submitted to the *blackboard*.[1] The full mark is 100' and the submission entry is: Assessments/Individual Assignment.
- You are highly encouraged to start early for the assignment as training neural networks will take a long time to finish. No late submission is allowed, and the late submission will be subjected to a 20-mark deduction for every single day of delay. Don't forget to double check if the submission is saved successfully before leaving. Multiple submissions are allowed, and we will only mark the latest version.
- **GPU Resources**: The Google Colab provides free GPUs that are sufficient to accomplish this assignment. If you want to access extra GPU resources to explore new ideas, you may consider the paid cloud computing resources provided by AutoDL[2], Lambda[3], Amazon Web Services (AWS)[4], Microsoft Azure.
- Last but not least, best of luck for this assignment! :)

Question 1. [**Forward and Backward Process of Neural Network**] As illustrated in Figure 1, given a neural network with the following architecture:

- The input layer has 3 neurons.
- The hidden layer has 4 neurons with weights $\mathbf{W}_1$.
- The output layer has 3 neurons with weights $\mathbf{W}_2$.

The `ReLU()` and `softmax()` activation functions are used for the hidden layer and the output layer, respectively. The `cross-entropy` loss function $\mathscr{L}_{CE}$ is used for the output. With the given weights and inputs, please calculate the gradients of the loss with respect to $\mathbf{W}_1$ and $\mathbf{W}_2$ using the backpropagation algorithm.

$$\text{ReLU}(x) = \max(0, x) = \begin{cases} x, & \text{if } x > 0 \\ 0, & \text{otherwise} \end{cases}$$

[1] `learn.polyu.edu.hk`
[2] https://www.autodl.com/home/
[3] https://lambdalabs.com/
[4] https://aws.amazon.com/cn/

$$\text{softmax}(\mathbf{z})_i = \hat{y}_i = \frac{e^{z_i}}{\sum_{j=1}^{n} e^{z_j}}, \quad \text{for } i = 1, 2, \ldots, n$$

Given:

- Input $\mathbf{x} = \begin{bmatrix} 0.5 & -1.0 & 2 \end{bmatrix}^T$
- Label $\mathbf{y} = \begin{bmatrix} 1 & 1 & 0 \end{bmatrix}^T$
- Weights $\mathbf{W_1}$ and $\mathbf{W_2}$:

$$\mathbf{W_1} = \begin{bmatrix} 0.2 & -0.3 & 0.4 \\ 0.1 & 0.2 & -0.5 \\ -0.3 & 0.1 & 0.2 \\ 0.4 & -0.1 & 0.3 \end{bmatrix}$$

$$\mathbf{W_2} = \begin{bmatrix} 0.1 & 0.2 & -0.1 & 0.1 \\ -0.2 & 0.3 & 0.1 & -0.3 \\ 0.2 & -0.1 & 0.3 & 0.2 \end{bmatrix}$$

(a) [**Non-coding Question**] Perform the forward process of the neural network and compute the hidden representation $\mathbf{h}$ and output prediction $\hat{\mathbf{y}}$. You are required to provide detailed derivations in your solution, and please write your answers in vector/matrix notation. Moreover, you are required to retain 3 significant digits. (10')

[Hint]: $\mathbf{h} = \text{ReLU}(\mathbf{W_1 x})$, $\hat{\mathbf{y}} = \text{softmax}(\mathbf{W_2 h})$

(b) [**Non-coding Question**] Apply the backpropagation algorithm to derive the gradients $\frac{\partial \mathscr{L}_{CE}}{\partial \mathbf{W_2}}$ and $\frac{\partial \mathscr{L}_{CE}}{\partial \mathbf{W_1}}$. You are required to provide detailed derivations in your solution, and please write your answers in vector/matrix notation. Moreover, you are required to retain 3 significant digits. (20')

[Hint]: $\mathscr{L}_{CE} = (\mathbf{y}, \hat{\mathbf{y}}) = -\sum_{i=1}^{n} y_i \ln(\hat{y}_i)$

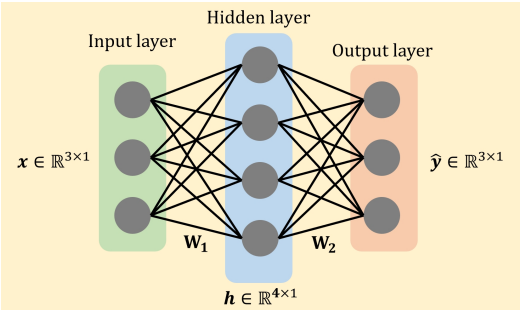

Figure 1: Illustration of the network architecture used in Question 1.

Question 2. [**Convolution Neural Networks**] We have learned the convolutional neural network (CNN) during the lecture. In this question, we will apply CNNs to classify images from the CIFAR-10 dataset[5]. The CIFAR-10 dataset consists of 60,000 32×32 colour images in 10 classes, with 6,000 images per class. There are 50,000 training images and 10,000 test images. Some image samples from this dataset are provided in Figure 2. We provide you the start-up code and you are required to modify them to accomplish the following tasks.

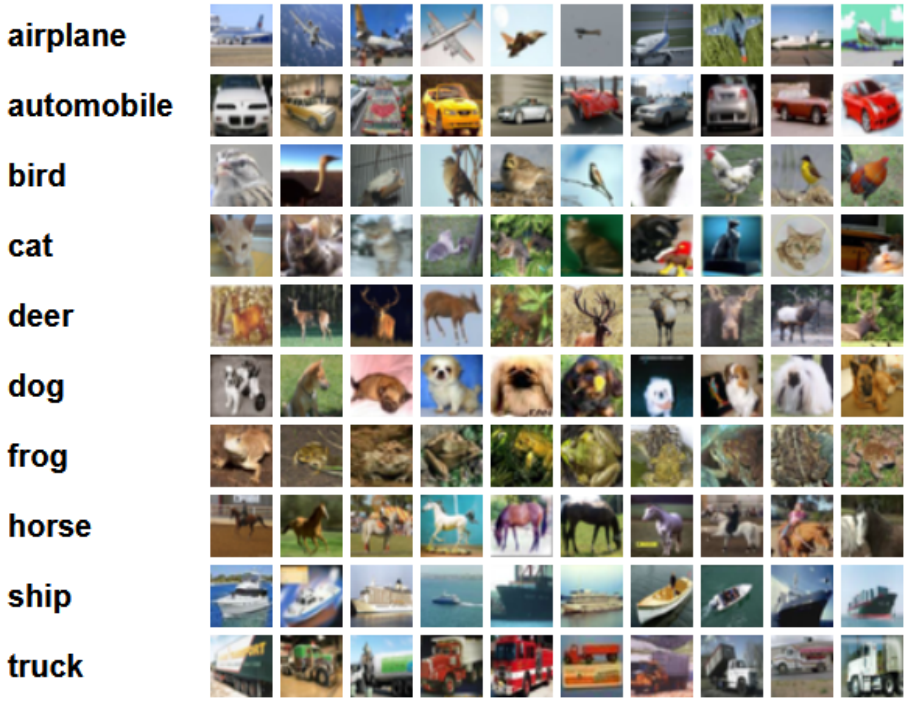

Figure 2: Illustration of the image samples in the CIFAR-10 dataset.

(a) [**Coding Question**] In the start-up code, we have trained the AlexNet architecture to classify CIFAR-10 images. Here, you are required to implement and train two more advanced CNN architectures on this dataset, including **VGGNet and ResNet**. Note that you are free to choose the particular network architecture variant. For each network architecture, you are required to train **40 epochs**. Please record your training statistics (i.e., train loss, test loss, train accuracy, and test accuracy), and plot them into different figures (one for each network architecture). Please state and analyze your observations. (10')

(b) [**Coding Question**] We have learned many advanced optimization algorithms in Lecture 3. Here, you are required to apply **RMSProp and Adam** algorithms to train the AlexNet on CIFAR-10. Please record your training statistics

[5]https://www.cs.toronto.edu/ kriz/cifar.html

and the learning curves as in part (a). Please state and analyze your observations. (10')

(c) [**Coding Question**] In this part, you are required to explore new methods to improve the model performance reported in part (a) and (b). For example, you may consider using different learning rate schedulers, more advanced network architectures, data augmentation methods, different batch size, etc. Please state **two effective methods** you have tried and analyze your observations. (10')

Question 3. [**Transfer Learning**] In this question, we will explore the transfer learning method to further improve our model classification performance on the CIFAR-10 dataset. Particularly, we will use ImageNet pre-trained models provided by Pytorch Model Zoo[6]. The start-up code are provided in Blackboard and you are required to modify them to accomplish the following tasks.

a) [**Coding Question**] In this part, you are required to fine-tune ImageNet pre-trained AlexNet models on the CIFAR-10 dataset with a different amount of training data, i.e., 10%, 20%, and 50% randomly selected training data. Please report the test results and compare the results with the setting that the same model is trained from scratch with the same amount of data. Please analyze how does the transfer learning method helps with a different amount of training data. (15')

[**Hint**]: The torchvision package provides the AlexNet, VGG, ResNet18 and other commonly used models. It also provides the pre-trained model weights.

b) [**Coding Question**] In this part, you are required to fine-tune ImageNet pre-trained models on the CIFAR-10 dataset, e.g., Resnet18 and VGG16. Please state two models you have tried and analyze your observations. (15')

c) [**Coding Question**] Following the exercise in part b), we encourage you to explore fine-tuning only a portion of the network layers to see how it affects the test results (e.g., learning speed and classification accuracy). Please state what you have tried and analyze your observations. (10')

Consultation Feel free to contact TAs if you have questions regarding this assignment:

[**Question 1**] Please contact Ms. Yujing Zhang (24068516r@connect.polyu.hk)

[**Questions 2&3**] Please contact Ms. Zhu WANG (juliazhu.wang@connect.polyu.hk)

Survey Please state how many hours you have spent on this assignment, and feel free to let us know if you have any other concerns or recommendations. Your constructive feedback is highly appreciated!

[6]Please copy the full link to access: https://docs.pytorch.org/serve/model_zoo.html