Homework Assignment 4
Machine Learning for Bioinformatics,
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1 Convolutional Neural Networks

Say you have an input image whose shape is 128 × 128. You are deciding on the hyperparameters for a Convolutional Neural Network.

1.1

Compute the output activation volume dimensions and number of parameters of the first Convolutional layer. You can write the activation shapes in the format (H, W, C) where H, W, and C are the height, width, and channel dimensions, respectively. The layer has a stride of 1, a filter size of 5 × 5, input padding of 2, and 16 filters.

1.2

Say you create a CNN made of identical modules, each of which consists of: a Convolutional layer, a Max-Pooling layer, and an activation layer. All Pooling layers will have a stride of 2 and a width/height of 2. We define the Convolutional layer to have stride 1, filter size 5 × 5, input padding of 2, and 16 filters. Compute the output activation volume dimensions after passing the input through the entire network, as well as the number of parameters in the entire network.

1.3

Say you want to solve a 10-class classification problem given the input. To do so, you decide to add a Fully-Connected layer after your three Conv-Pool-ReLU modules. Compute the number of parameters in the entire network.

2 Generative Adversarial Network (GAN)

2.1

Compare VAE and GAN models and state the advantages and limitations of each.

2.2

Assuming the use of the same dataset and a relatively complete training process, does one of these models generally have better quality images than the other? Please explain your answer with reasoning and if necessary, mathematical proof.

2.3

You are training on a GAN to generate images. However, you are only able to curate a small number of images. You decide that image augmentation might be a good idea to improve GAN training. You try using three common augmentation techniques: adding blur to the image, changing the color of pixels and flipping the left-right axis of the image. Which of these do you think might be a good idea to help the Generator output better octopus images and why?

2.4

One of the common problems in GAN networks is Mode Collapse. Explain this phenomenon in detail and describe possible solutions to overcome this problem.

3 Autoencoders

We have been given 1000 gene expression profile data including healthy and esophageal cancer samples. The goal is to design a model that can distinguish healthy from cancerous samples. For this purpose, we first divided the data into 800 training data and 200 test data.
Each gene expression profile consists of a 20,000-long vector of numbers between 0 and 15. We have designed a seven-layer autoencoder, which has 20,000 neurons in the first and seventh layers, 2000 neurons in the second and sixth layers, 200 neurons in the third and fifth layers, and 20 neurons in the fourth layer. For simplicity, we have assumed that the connections between each layer and the next layer are fully connected and the activation function of all neurons is sigmoid. We have also set the cost function as Mean Squared Error.

3.1

We have trained the network for 100 epochs, but we see that the cost function does not drop at all. What is the main problem?

3.2

After solving the above problem, we train the network again for 100 epochs. We can see that on the test data, MSE is less than 0.1. Has this network worked well? If you are not sure, what do you control?

3.3

After learning the network, we realize that with every small change in the input, the value of several neurons of the middle layer (Latent) changes. What do you do to solve this problem? Provide a formula if possible.

3.4

If we finally succeed in learning the network in such a way that it is able to reconstruct the data from 20 neurons of the middle layer with a very small error rate, what characteristic in the input data do you think helped you the most in this success?

4 Beam Search Encoding

In the context of sequence generation tasks, such as machine translation or text generation, encoding plays a crucial role in capturing the input sequence information.

4.1

Discuss the importance of encoding in the Beam Search algorithm.

4.2

Explain how the encoding step is incorporated into the overall process of Beam Search and its impact on the generated sequences.

4.3

Additionally, describe how the encoding step affects the generated sequences in terms of quality, fluency, and relevance to the input. Discuss the trade-off between encoding complexity and the performance of the Beam Search algorithm. Finally, propose one technique that can be used to enhance the encoding step and improve the performance of the Beam Search algorithm.

5 Vanishing Gradient in RNN

5.1

Why does vanishing gradient occur in RNNs? What are some techniques for addressing it in RNNs? Explain about one of them.

5.2

How does using GRUs or LSTMs help address the vanishing gradient problem?

5.3

Consider that you have an RNN with a single neuron and a sigmoid activation function.

$$h_m \;=\; \sigma(\theta h_{m-1} \;+\; x_m)$$

Draw the schematic diagram of the described network and prove that for $|\theta| < 1$, the following equation holds:

$$\lim_{k \to \infty} \quad \frac{\partial h_{m+k}}{\partial h_m} \;=\; 0$$