**Assignment 9**

**Due Thursday, April 17th before midnight (California time)**

In this assignment, you will build and train a generative model on chest X-ray image data. You will also explore and analyze the learned latent space.

## Provided Data

You will work with chest X-ray image data in this assignment:

- **xray_images.npz**: Images of chest X-rays.

## Part 1: Data Visualization [1 pts]

1. Download the data. Load and standardize the images using min-max normalization. Use an **80%-20% split** of the data for training and testing in this assignment.
2. Use visualization to explore the images. What differences do you notice between the images?

## Part 2: Generative Variational Autoencoder [2 pts]

- Train a convolutional variational autoencoder to learn a low-dimensional representation of the data.
- Use three different latent space sizes: 4, 16, and 32 (i.e., build separate models).
- Use two a two-term loss function:
    - *Reconstruction loss*: Binary Cross Entropy between each pixel of the input and reconstructed images.
    - *Kullback-Leibler (KL) loss*: KL divergence between the latent distribution and a standard normal distribution.
- Train the model for at least 100 epochs (adjust as needed for optimal results).
- Report the training and testing history plots.

*Hints:*

- Use a symmetric encoder-decoder architecture.
- Use Conv2D with stride=2 for each encoder layer, and Conv2DTranspose with stride=2 for each decoder layer
- Do not use activation functions in the input, latent, or output layers.

## Part 3: Visualize Reconstruction and PCA/t-SNE [2 pts]

- For each model from Part 2:

    - Visualize the original image vs. reconstructed image for 10 images from the test dataset.
    - Randomly sample 1000 images from the training dataset and encode each one into its latent vector.
    - Cluster the vectors (K-means clustering) and visualize images from a few of the clusters.
    - Perform PCA and t-SNE on these latent vectors and make plots visualizing the distribution of the images for the first two dimensions, coloring points by cluster.
- Discuss:
    - What do you notice about the reconstruction performance between the different models? Why are there differences?
    - Do you notice differences in images between different clusters? Is the latent space organized differently between models?
    - Are the PCA or t-SNE plots different between models? Why or why not?

## Part 4: Cluster and interpolate [2 pts]

- For each model trained in Part 2:
    - Encode the images with lowest and highest PCA1 values.
    - Interpolate between these two latent vectors, computing the latent vectors for seven evenly spaced points in between.
    - Decode and visualize each of these vectors, labeling the interpolation value (between 0 and 1) of each. Include the original and reconstructed images in the visualization.
    - Repeat this process for PCA2, t-SNE1, t-SNE2, and one of the dimensions from the latent space.
- Discuss:
    - Do you notice any interesting image features or patterns that seem to be described by any of these interpolation dimensions?
    - Are there any notable difference between them?
    - Describe the differences between each model.

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