DS552/CS552- Generative AI - Assignment 3

I. Theory Questions

A. Why is the KL Divergence term important in the VAE loss function?

The KL Divergence term in the Variational Autoencoder (VAE) loss function acts as a regularizer that ensures the learned latent distribution remains close to a prior distribution, typically a standard normal distribution, N(0,1). This prevents overfitting to the training data and encourages smooth and meaningful latent space representations, improving generalization and interpolation ability.

B. How does the reparameterization trick enable backpropagation through the stochastic layers of a VAE?

The reparameterization trick enables backpropagation through stochastic layers by rewriting the sampling process in a differentiable way. Instead of directly sampling $z \sim N(\mu,\sigma 2)$, we express it as:

$$Z = \mu + \sigma \cdot \epsilon, \text{ where } \epsilon \sim N(0,1)$$

Since ϵ is drawn from a fixed standard normal distribution, it does not depend on learnable parameters (μ and σ), allowing gradients to propagate through μ and σ during backpropagation.

C. Why does a VAE use a probabilistic latent space instead of a fixed latent space?

A VAE uses a probabilistic latent space to ensure smooth and continuous latent representations, allowing for better interpolation and generalization. Unlike traditional autoencoders, which learn fixed latent representations, VAEs model uncertainty by encoding inputs as distributions, which helps in generating diverse and coherent samples when decoding.

D. What role does KL Divergence play in ensuring a smooth latent space?

KL Divergence ensures that the learned latent space does not collapse into a disjoint or sparse representation. By minimizing the KL divergence between the approximate posterior $q(z|x)$ and the prior $p(z)$, the VAE encourages similar inputs to be mapped to nearby points in latent space, creating a structured, continuous, and interpolatable representation.