Assignment 4a: Implementing deep generative models in PyTorch

Goal: Implement a VAE and a GAN in PyTorch and analyze them.

Submission: The assignment consists of two parts: implementation and analysis. You are supposed to present results for both parts in the following manner:

1. Upload your code.
2. Prepare a report with an analysis of results obtained at home.

The code and the report must be uploaded due to the deadline to Canvas.
UPLOAD A **SINGLE FILE** (a zip file) containing your code and the report. Name your file as follows: [vunetid]_[assignment number].

Introduction

In this assignment, we are going to implement a Variational Auto-Encoder (VAE) and Generative Adversarial Network (GAN). A VAE is a likelihood-based deep generative model that consists of a stochastic encoder (a variational posterior over latent variables), and a stochastic decoder, and a marginal distribution over latent variables. A GAN models an implicit distribution (i.e., it does not assume any form of the likelihood function) using a generator (a neural network for generating), and a discriminator (a neural network that mimics the likelihood function).
The goal of this assignment is twofold:

1. Implement a VAE and a GAN.
2. Analyze them and compare them.

Since this assignment is an advanced one, please think of appropriate architectures.

Part 1: Descriptions of a VAE and a GAN

Please describe both models in the report:

1. Write objective functions for VAEs and GANs. Use standard normal prior p(z) for VAE.
2. Derive VAE objective with the Normalizing Flow as a prior. What are the advantages of such model formulation?
3. Please write down components of VAEs and GANs, and explain their roles.

4. Please pay attention to the adversarial loss. Please explain which loss you are going to use.

Part 2: Implementation

Implement a VAE and a GAN in PyTorch

1. Write a code in Python using PyTorch for:
    a. VAE + standard Gaussian prior
    b. VAE + flow-based prior (RealNVP)
    c. GAN
2. Please think of appropriate architectures (e.g., architectures that do not take too long to be trained).
3. Please use the ADAM optimizer.
4. Please implement the FID score using the pre-trained Inception V3 network from torchvision. Since there is no baseline pre-trained Inception V3 network for MNIST, please resize MNIST images (1x28x28) to appropriate sizes (3x32x32).
5. As you know from the lecture, one of the advantages of VAE is that it allows us to approximate the likelihood. Implement a Negative Log Likelihood estimator for VAE. Use Importance Sampling to get the approximation (also referred to as IWAE, see appendix A in this paper).
6. Please use the following datasets:
    a. MNIST
    b. SVHN: http://ufldl.stanford.edu/housenumbers/ (torchvision: link)

REMARKS:

- Please do not try to achieve state-of-the-art scores, but still, ensure that the models generate reasonable images.
- Please focus rather on reasonable architectures that you can learn on your machine.
- Please try to keep the number of weights in a VAE and a GAN to be comparable.
- You can use Pytorch Model Summary to calculate the number of weights (and summaries) in your models (https://pypi.org/project/pytorch-model-summary/).

Part 3: Analysis

Learn the VAE and the GAN using the ADAM optimizer and analyze their performance:

1. Analyze learning curves during training. If you use separate validation data (NOT test!), please analyze learning curves on it as well.
   At the end of training (e.g., after a fixed number of epochs), calculate the test FID scores for the VAE and the GAN.
2. Sample from the VAE and the GAN. Analyze and compare samples.
3. Sample two points in the latent space and linearly interpolate between them. Then, for 10 points between the two original points, generate images. Analyze and compare the interpolations.
4. Perform 2 and 3 on MNIST and SVHN.

Remarks:

- In order to monitor the progress during training, it is beneficial to observe generations' quality every 10 or so epochs.

Grading (10pt)

- Proper implementation of a VAE + standard Gaussian prior: 1pt
- Proper implementation of a VAE + RealNVP-based prior: 1.5pt
- Proper implementation of a GAN: 1.5pt
- Analysis on MNIST: 3pt
- Analysis on SVHN: 3pt