Introduction to Deep Learning
Assignment 2:
Generative models and sequence modelling

November 2024

Task 1: Generative Models

The goal of this task is to learn training and using generative models for image-related tasks. You are provided with a Jupyter notebook that illustrates how you would build, train and use Variational Autoencoders (VAEs) and Generative Adversarial Networks (GANs). You can download the dataset that was used in the notebook here. Your main goal in this task will be to find your own image dataset, preprocess it and retrain these networks, and use the models to generate novel content.

State of the art generative models can create an endless stream of photorealistic images of whatever data they are trained on (e.g. *StyleGAN2* - image below, now text-conditioned diffusion models like DALL-E, Midjourney, etc.). However, such enormous neural nets are very expensive and difficult to train, therefore it is better to start out small and understand the working principles behind simpler generative architectures.

Figure 1: *Output of StyleGAN2.*

Your tasks are as follows:

1. Go through the provided notebook and try to understand how the generative models are built using Keras. To start with you are provided with a convolutional autoencoder (CAE) architecture which contains the two main building blocks - the encoder and decoder. The Variational autoencoder (VAE) is built in a very similar way, but includes a sampling layer that gives this model its generative capabilities. The generator and discriminator in the GAN model are also build using these similar building blocks, however they are arranged differently and use a very different loss function.

2. Generally, training generative models is a tricky process, especially when your dataset includes a very diverse set of samples. That is why datasets of faces are often used to showcase the power of generative models as they are usually very uniform (people facing the camera at a similar distance and angle). However there are definitely many other interesting and viable datasets, use cases and applications.

Your task is to find a new image dataset of your choice online and use the code provided in the notebook to retrain your generative models (both VAE and GAN). You should provide a link to the data that you used in the report along with its description.

3. To properly train the models you will probably need to rescale your data to be close to the size of the example dataset (64x64x3). Since all of the neural networks in the notebook are build using functions *build_conv_net()* and *build_deconv_net()* you can also adjust the convolutional architectures if you desire - both to more closely match the scaling of your data and reduce/increase the complexity of your models.
4. Once your models are trained, their latent spaces capture the distribution of the data that they were trained on. You can use randomly generated vectors as input to the decoder components of these models to generate novel images (the decoder in case of VAE, generator in case of GAN). Each vector represents a point in this latent space and since it is continuous, you can generate various interesting visualizations. Your task is to create one of these visualizations by linearly interpolating between two random points in the latent space and seeing how the output of your network changes.
5. In your report provide a detailed description of the working principles of these generative models and emphasize the differences between them. You should also include the modified notebook with your visualisations when submitting the assignment.

Task 2: Sequence modelling with recurrent neural networks

The goal of this task is to learn how to use encoder-decoder recurrent models. Specifically, we will be dealing with a sequence-to-sequence problem and trying to develop a neural network that can learn the principles behind simple arithmetic operations.

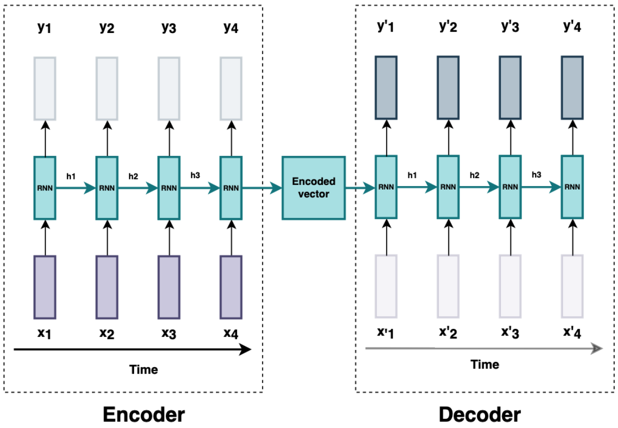

Figure 2: *An illustration of an encoder-decoder recurrent network model.*

Description: Let us suppose that we want to develop a neural network that learns how to add or subtract two integers that are at most two digits long. For example, given input strings of 5 characters: **‘81+24’** or **’41-89’** that consist of 2 two-digit long integers and an operand between them, the network should return a sequence of 3 characters: **‘105 ’** or **’-48 ’** that represent the result of their respective queries. Additionally, we want to build a model that generalizes well - if the network can extract the underlying principles behind the ’+’ and ’-’ operands and associated operations, it should not need too many training examples to generate valid answers to unseen queries. To represent such queries we need 13 unique characters: 10 for digits (0-9), 2 for the ’+’ and ’-’ operands and one for whitespaces ’ ’ used as padding.

The example above describes a text-to-text sequence mapping scenario. However, we can also use different modalities of data to represent our queries or answers. For that purpose, the MNIST handwritten digit dataset is going to be used again, however in a slightly different format. We can create an alternative image representation of our text queries described in the first paragraph by stacking multiple MNIST samples as follows:

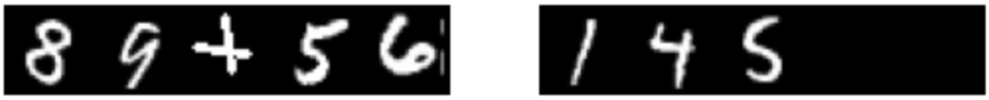

Figure 3: *Converting text query '89+56' and its answer '145' to sequences of images using randomly selected samples from the MNIST dataset. The images are stacked along the time axis, resulting in two tensors of size [5, 28, 28] that are then sequentially fed into the recurrent models.*

We can then use these text and image queries/answers as our training data/labels and create different variations of mappings between text and images - e.g. using text input to predict image output or vice versa. You are provided with a Jupyter notebook that contains functions for creating the image and text datasets along with sample *Keras* code for building a text-to-text RNN model.

Your tasks are as follows:

1. Analyze the code for generating numerical and image queries and their respective answers from MNIST data. Inspect the provided text-to-text RNN model and try to understand the dimensionality of the inputs and output tensors as well as how they are encoded/decoded (one-hot format).
2. In the text-to-text scenario, we are not interested in "memorizing" the whole addition/subtraction table (about 20,000 strings in total); instead, we want the network to learn some general principles behind these arithmetic operations. Therefore you should try multiple different splits for your training and test sets (50% train - 50% test; 25% train - 75% test, 10% train, 90% test etc.) and evaluate the accuracy and generalization capability of your models. Compare the outputs of your trained networks to the true labels, and find out what kind of mistakes your models make on the misclassified samples. Visualize these differences and try to explain them.

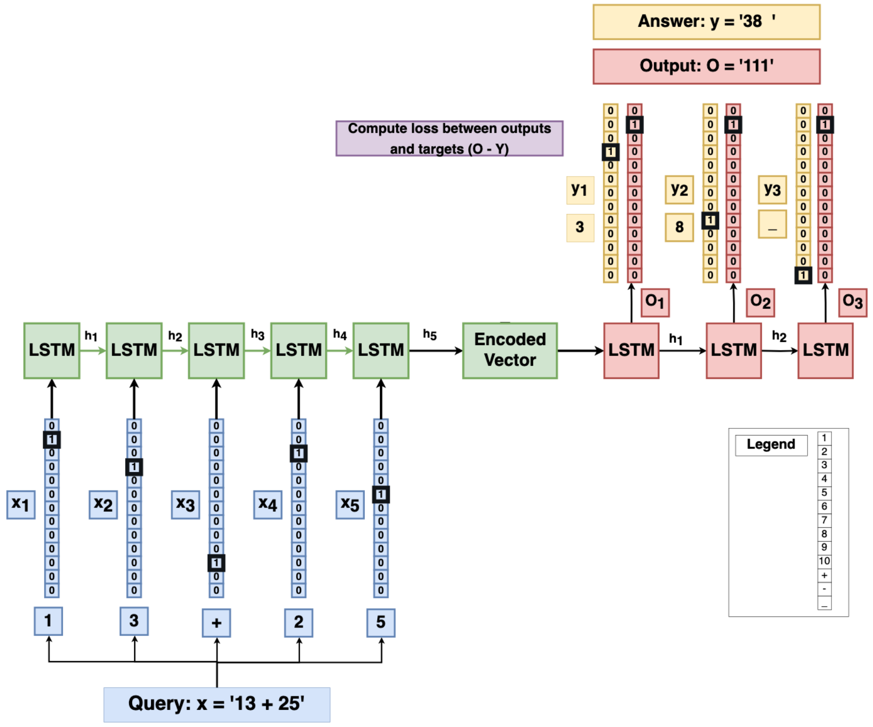

Figure 4: *LSTM Model visualisation using the arithmetic queries as an example for inputs/outputs.*

3. Create an image-to-text RNN model: given a sequence of MNIST images that represent a query of an arithmetic operation, your model should return the answer in text format. Once you have trained your model, evaluate its accuracy and compare it to the text-to-text model.
4. Build a text-to-image RNN model: given a text query, your network should generate a sequence of images that represent the correct answer. In this case, it is harder to evaluate the performance of your

model qualitatively. However, you should provide examples of the output generated by your model in the report. What can you say about the appearance of these generated images?

- *Optional: train a separate supervised model for evaluating the generated images of your text-to-image model.*

5. Try adding additional LSTM layers to your encoder networks and see how the performance of your models changes. Try to explain these performance differences in the context of the mistakes that your network was making before. *Tip: you should add a flag* ***"return_sequences=True"*** *to the first recurrent layer of your network.*

Deliverables: your submission should consist of a report in *pdf* format (at most 10 pages) and neatly organized code (Jupyter notebooks) so that we could reproduce your results. You also need to submit .py files of all the notebooks (by converting *.ipynb* to *.py*). You can find more information about report writing on Brightspace → Assignments section.

Deadline: Look up Brightspace..