A Comparison of Deep Learning Architectures for the 3D Generation Data

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There is a need to identify the best artificial images for each use case faced with several Deep Learning architectures for generating them. Twelve models with different hyperparameters were created to compare several networks with the generative architectures Autoencoder, Variational Autoencoder, and Generative Adversarial Networks in the 3D MNIST dataset. After training, the models were compared with loss functions to assess the difference between the original and artificial data, so that greater complexity did not translate into better performance, indicating the Autoencoder models as the best cost-benefit.

Keywords: Generative Networks. 3D Data. Comparison. Machine Learning.

Introduction

Computer vision has been providing many projects developed in image generation, with deep learning technologies (DL) showing advances for the generation of data in 2D, making use of architectures already relevant in the area [1]. On the other hand, the 3D segment is often in the background, maybe because of the high complexity concerning 2D or the computational power needed to process this data [2].

The need for automated 3D data generation comes from the difficulty of creating three-dimensional representations manually, requiring too much time and research to build the items that will be portrayed [3].

The 3D MNIST dataset was used, which has 12,000 images in three dimensions [4]. The data was adapted from MNIST, which has numbers from 0 to 9 handwritten in a 2D representation [5].

The article aims to compare the Autoencoder, Variational Autoencoder (VAE), and Generative Adversarial Networks (GANs) architectures regarding several evaluation metrics to present the performance of each architecture for representing 3D data [6-8].

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Autoencoder

The Autoencoder (AU) architecture is composed of two smaller networks that seek to compress the input into a latent representation, a version Where only the essence of its structure remains. In the first network, the encoder, the original data is reduced to a one-dimensional vector h, where its characteristics are categorized by increasing importance, between 0 and 1, to be discarded or preserved. In the next step, the decoder network receives the vectorized structure and performs the inverse process, returning the data to its original size and aspect, but with only the essence of its structure [9].

$$Loss = -Log\ P(x|x') \quad (1)$$

To check the quality of the representation created by the network, the loss function observed in Equation 1 is used, where -log P compares the original input x with its latent representation x'. The loss in an autoencoder should be as small as possible, but it will hardly be zero. Considering that one of the main characteristics of the AU architecture is to learn the essentials and return data with reduced dimensionality, a loss of value 0 implies a faithful reproduction of the image, which in turn denotes low learning of its main components, essentially creating a network that returns your input without a concrete benefit [10].

Variational Autoencoder

The Variational Autoencoder (VAE) is an architecture composed of the union of two networks, an encoder, which maps the inputs and compresses them from the input to the latent space; and the decoder, which maps the data from the latent space to perform its decompression. The difference between VAE and Autoencoder architectures is the guarantee of properties in the latent space to allow the generation of new data. The latent space is the compressed data: its reproduction with lower dimensionality. Broadly, the VAE requires the standard Gaussian distribution anterior to the latent space. Thus, the VAE tends to maximize Equation 2 [11].

$$P(z) = N(z|0, I) \quad (2)$$

To solve it, the VAE needs to deal with defining the information that will be represented by the latent variable z and how to deal with the integral over z. The latent variable can be understood as the choice of a character to be generated by the model before assigning a value to any specific pixel, that is, the model will produce configurations for the generation of the character. The z settings tend to produce a character that resembles the initial die. Furthermore, the interpretation of dimensional samples can be extracted from a simple distribution, being it N (0, I), where I is an identity matrix [11]. That said, the model parameters are trained to minimize the reconstruction error between the reconstructed and the initial data, making use of the Loss function KL divergence, acting as a regularization term, to calculate this divergence.

Generative Adversarial Networks

Generative Adversarial Networks (GAN), are generative architectures based on Deep Learning, in which an adversarial training process takes place between two networks: A Generative model G that is based on the original distribution of data to generate a new sample, and a Discriminative model D that estimates the probability a data sample coming either from the original data distribution or from the sample generated by the Generative model G. This training occurs until the Discriminator becomes unable to discern between the original and generated data [8].

GANs are often used in the Computer Vision field to perform various tasks involving images. They can be used to generate higher resolution versions of images and create sketches, paintings, and others. During the training stage of this architecture, with the data generated by the Generator model, the Discriminator model has the role of correctly classifying between real and generated data. In consideration of the above, the final function of value V (G, D) is based on Equation 3, which involves the minimization of the Discriminator's error and the maximum precision of the Generator when creating the images [8].

$$\min_G \max_D V(D, G) = Ex \sim Pdata(x) [Log\ D(x)] + Ez \sim Pz(z) [Log\ (1 - D(G(Z)))] \quad (3)$$

Recurrent Neural Networks

The Recurrent Neural Network (RNN) is an artificial neural network, used for sequential data or time series. The RNN, unlike traditional neural networks, can remember previous information from the feedback, allowing the information to persist [12]. To decide, the network considers its current input and what it learned from the previous input. It has a "memory", which stores the information of the calculations performed, enriching the expressive power of the model by capturing causal and contextual information [13]. That said, RNN manages to reduce the complexity of parameters, in addition to adjusting the weights through backpropagation and descending gradient processes, facilitating the learning process.

As there were advances in the development of RNNs, other architectures were created from it, such as Long-Short Term Memory (LSTM) [13] and Gated Recurrent Unit (GRU) [14].

Convolutional Neural Network

The Convolutional Neural Network (CNN) is a neural network widely used in problems dealing with image data, such as pixels. Important applicability of CNN is the extraction or detection of image contents when the input propagates through deeper layers [15]. During the convolution process applied to images, weights are assigned to certain sets of pixels that can indicate lines, curves, and eventually, complex patterns, where higher weights denote greater importance of that set of pixels for the current task. In addition, there are other types of convolutional neural network architectures, such as the Fully Convolutional Network (FCN), a kind of convolutional neural network, which contains only convolutional layers, not having "Dense" layers.

Multilayer Perceptron

The Multilayer Perceptron, or MLP, is a simple artificial neural network with several interconnected neurons that present a non-linear mapping between an input vector and an output vector [16]. Efficiently, MLPs backpropagate the network's error, based on that error, the weights of previous layers are recalculated starting from the last layer up to the first.

Materials and Methods

The approach chosen for this work was the comparative between practical experiments of several generative networks with different activation functions, number of layers, and number of neurons per layer. This exploratory, empirical, quantitative, and qualitative research seeks to identify the advantages of each architecture, ranging from the network training time to the quality of the data generated at the end of the process. The work was divided into 3 stages:

(1) search,
(2) generation,
(3) evaluation and synthesis.

In stage (1), a literature review was carried out where relevant works on the AU, VAE, and GAN architectures were identified, to verify the validity of the proposed comparison. During (2) a single base model was created for each architecture, subsequently, the bases were adapted into 4 models, divided into FCN, CNN with MLP, LSTM, and GRU, amounting to 12 models. In stage (3), the results of the models were grouped in tabular form, comparing the differences between the original image and that generated through the loss metrics Binary Cross-Entropy and Mean Squared Error (MSE), described in Equations 4 and 5, generating a Table per metric, with both divided between architectures and their respective networks [17].

$$H(X) = -[\theta \log 2\, \theta + (1 - \theta) \log 2(1 - \theta)] \quad (4)$$

$$\frac{1}{N} \sum_{j=1}^{D} (\theta_j - \theta_j)^2 \quad (5)$$

Results and Discussion

The Autoencoder FCN model presented the best results for Binary Cross-Entropy, with a total loss of 0.1304 concerning the original data, followed by the Autoencoder models GRU, LSTM, and CNN with MLP, respectively, with the latter having the same loss value as the VAE model with the same architecture (Table 1).

For the MSE metric, Table 2 demonstrates a similar hierarchy, with FCN, GRU, and LSTM Autoencoder models having the smallest difference between the original and generated data, followed by the VAE CNN with MLP. Comparing the two Tables, it becomes noticeable that GANs obtained the worst performance for both metrics in all proposed architectures. To match the performance of GANs, it would be necessary to increase the time and computational power expressively, leading to the conclusion that this model should be preferentially used when there is a high processing capacity.

Table 1. Loss binary cross-entropy.

	CNN+MLP	FCN	LSTM	GRU
AU	0.2249	0.1304	0.1626	0.1495
VAE	0.2249	0.2946	0.2283	0.2272
GAN	5.5372	6.3513	12.9795	5.9794

Table 2. Metric MSE.

	CNN+MLP	FCN	LSTM	GRU
AU	0.0760	0.0110	0.0535	0.0156
VAE	0.0749	0.0888	0.0765	0.0733
GAN	0.9264	0.9139	0.8890	0.8449

Conclusion

This study aimed to evaluate the AU, VAE, and GAN architectures in their ability to reproduce three-dimensional data using the MNIST 3D dataset as a basis. Using the Mean Squared Error and Binary Cross-Entropy metrics, it was possible to observe that the AU-based models obtained representations closer to the original data, furthermore, these models required a lower tuning of hyperparameters and training time, obtaining high cost-effectiveness in comparison to other architectures. In parallel, the VAE architectures obtained results close to the original data, with the LSTM and CNN models being comparable to the quality of the AUs. As for the GAN constructions, in addition to having a longer training, the resulting images and the metrics evaluated had poor quality.

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