Generative Adversarial Networks: The Most Interesting Idea in the Last Ten Years of Machine Learning

***Dr. Siyamalan Manivannan** explores the evolution of machine learning and the potential challenges in the future*

Assume that I produce fake currencies, and you are a police officer trying to detect whether the currencies given by me are real or fake. Initially, as I am not an expert in producing currencies, the currencies I produce look far different from the real ones. Hence, you can easily catch me. However, as my main aim is to fool you, over time I will improve my skills in producing currencies which are indistinguishable from the real ones. Simultaneously, you also improve your skills in distinguishing fake currencies from the real ones. So over time, both our skills get better and better. This explains the basic idea of Generative Adversarial Networks (GANs).

GAN was introduced by Ian Goodfellow and his team in 2014 [1] . According to Yann LeCun (in 2016), the Chief AI Scientist of Facebook AI Research, "GAN is the most interesting idea in the last 10 years of machine learning".

Generative vs. Discriminative Models - GAN, as the name implies, is a generative model based on deep neural nets. In machine learning, two categories of models are used, and they are: discriminative and generative. Discriminative models focus on defining the boundary between different categories of data- .When a new data is given, a discriminative model predicts its category. Examples of discriminative models include Support Vector Machines and Nearest Neighbor classifier. Generative models have the ability to generate new data and can be categorized into Explicit Density Models and Implicit Density Models. Explicit density models (e.g., Maximum Likelihood Estimation) focus on learning the underlining distribution of the input data samples by defining an explicit density function. Once this function is learned, a new data can be generated by sampling from this learned distribution. Instead, the implicit density model learns the model without explicitly specifying the density function. GAN is an implicit generative model [3]

The Adversarial Learning Process of GAN

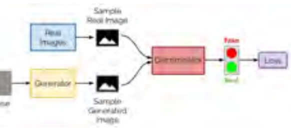

Figure 1: *The structure of a GAN: The generator generates an image (fake one). The discriminator tries to identify whether the given image is a real or fake one.*

Unlike other generative models, GAN contains a generator (analogous to myself in the previous story) and a discriminator (you, the police officer), and they are trained in an adversarial manner. The generator is responsible for generating new data (from a noise vector as the input), and the discriminator, on the other hand, is a classifier, and its task is to determine whether the given data is a real or fake one (Figure 1). Adversarial learning plays the most important role in GAN, and it is regarded as the min-max optimization process. Here, the generator wants to deceive the discriminator; therefore, it tries to maximize the discriminator's loss by generating data that resemble the real ones. On the other hand, the discriminator tries to minimize its loss by correctly classifying the data generated by the generator as "fake".

Because of the idea of adversarial learning and the excellent performance of generating new data, GAN received much attention since it was proposed, and it became one of the hottest research topics in Deep Learning. Various types of GANs were proposed since its introduction. For example, Deep Convolutio-

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nal GAN (DCGAN) uses convolutional neural networks with GANs to make GANs more stable and to produce high-quality images, Conditional GAN (DGAN) uses auxiliary information such as class labels when training and generating new data.

Applications - GAN has a wide range of applications in various fields including computer vision, computer graphics, and medical imaging. The following are a subset of them.

1. Data augmentation: GAN can be used to generate new data, and therefore, can be used as a data augmentation method for training deep models.

2. Image-to-image translation: This includes generating coloured images from sketches, converting painting to photos, black and white images to colour, day-time images into night-time images, and vice versa.

3. Image inpainting: Damaged photographs can be automatically corrected with GANs without human intervention.

4. Image super-resolution: Better high-resolution images (better than using interpolation techniques) can be obtained from their low-resolution version.

5. Text-to-image synthesis: Images can also be generated from text descriptions. E.g., if the input is "A white bird with a black crown and yellow beak" GAN will generate images accordingly.

Challenges with Training a GAN - Although GANs provide lots of cool applications, training a GAN is not easy. There are mainly two problems often encountered when training GANs. The first one is the problem with vanishing gradients, particularly, when the discriminator is too good compared to the generator, the generator won't get updated as the discriminator won't give much information (gradients will be close to zero) to the generator to update. Hence, the generator won't show much progress in learning. The second problem is mode collapsing, where the generator fails to produce diverse samples. There are possible solutions explored to overcome these problems, which includes mini-batch discrimination and one-side label smoothing [2].

References

1. *Ian J. Goodfellow et al., Generative Adversarial Nets. NIPS, 2014*

2. *Tim Salimans et al., Improved Techniques for Training GANs, NIPS, 2016*

3. *Jie Gui et al., A Review on Generative Adversarial Networks: Algorithms, Theory, and Applications, CoRR abs /2001.06937, 2020*

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