Digital twin technology: An evaluation

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Digital Twin Technology

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Contents

1.1 Introduction: background

- The Internet is believed to be a new wheel that brings a radical change in our society. Vast amount of data are collected every second from IoT devices to predict the future of tomorrow.
- Fig.1.1 illustrates the distribution consisting of innovators followed by early adopters to laggards. IoT technology lies between innovators and early adopters. In the future, IoT will be the backbone of life and businesses.

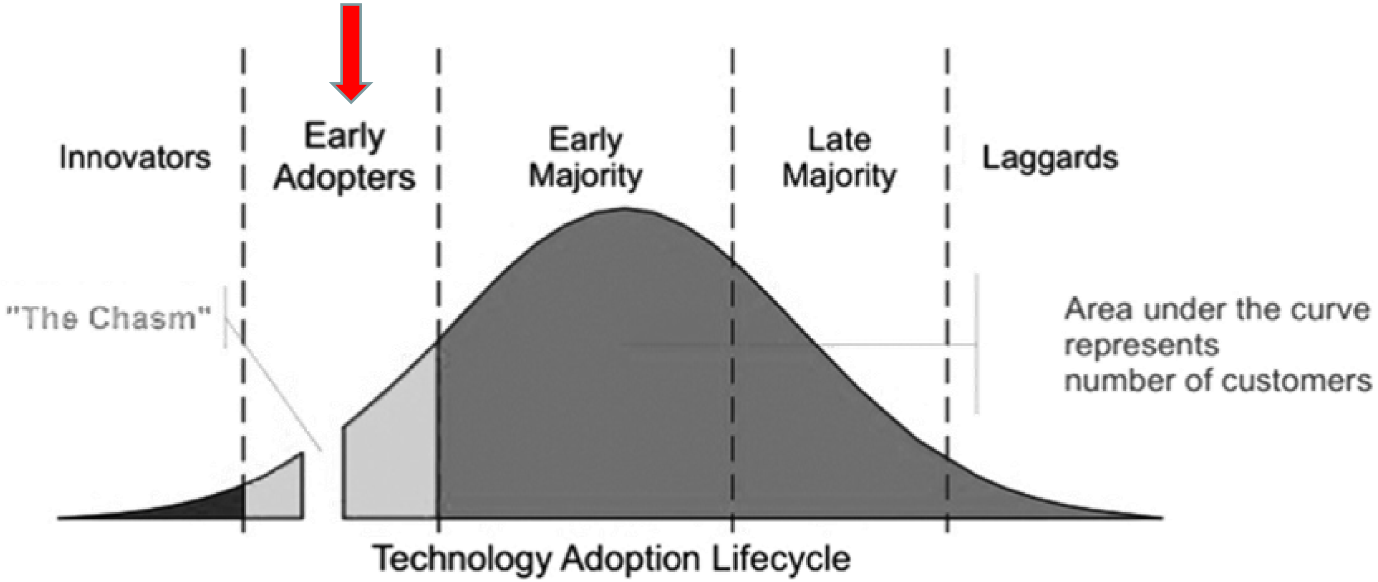

Fig. 1 Technology adoption curve

1.1 Introduction: background

- IoT is believed to be in the second wave of the digital revolution, first being computers and internet. Smartphones have put enormous computing power for communication and digital applications in the hands of the user.
- We generate more than 2.5 Quintillion bytes of data each day, and the rate of data generation is only increasing with time.
- With IoT, big data, and machine learning in place, data collection will take the next steps to understand patterns or real-time conditions of bridges, roadways, buildings, or super-efficient tracking systems.
- Big data and machine learning play an important role in solving complex problems that used to be impossible earlier. The combination of IoT and machine learning will change education, business, personal life, and politics.
- There are several challenges such as privacy in IoT where cyberattacks threaten the identity and confidential knowledge of citizens, government and business applications.
- The applications, technologies, and security of IoT products that deal with massive data are important areas of discussion.

1.2 Digital twin technology

- IoT data for machine learning is collected using two different methods, stream and accumulated. Stream data is captured or generated in small intervals, whereas accumulated data is sent in a storage system for analysis, storage, or prediction.
- Response time in many applications must be in real-time or near real-time hence, accumulated data is not useful in such circumstances.
- For example, a self-driving car system cannot rely on accumulated data. It has to be based on streaming prediction, which can respond in few milliseconds to a few seconds.
- IoT streaming data for machine learning is deployed based on high-performance cloud computers, data parallelism and incremental processing framework.
- Data parallelism is performed by dividing extensive dataset into smaller datasets, on which analytics can be performed simultaneously.
- In incremental processing, a small batch of data is fetched and processed in a computational pipeline as quickly as possible.

1.2 Digital twin technology

- Deep learning is a subset of machine learning, consisting of supervised and unsupervised algorithms to train systems.
- These algorithms are further categorized in specific architectures, and all such architectures consist of multiple layers.
- Each layer is responsible for producing a nonlinear response based on the input from the previous layer. Deep learning systems closely resemble the human brain to solve complex problems.
- Deep Learning models are categorized into generative, discriminative, and hybrid. Discriminative models are usually based on supervised learning. Generative models are based on unsupervised learning. In contrast, hybrid models are the best of both worlds, discriminative and generative.
- Deep Learning architectures include many architectures such as convolutional neural networks (CNNs), recurrent neural networks (RNNs), long short-term memory (LTSM), autoencoders (AEs), variational autoencoders (VAEs), generative adversarial network (GANs), and restricted Boltzmann machine (RBMs).

1.3 Digital twin technology using convolutional neural networks with IoT

- CNN are well known for processing pixel data and performs well with image recognition.
- Hidden layers are a combination of convolution layers and are fully connected end layers. The convolutional layer is at the core of a CNN.
- The benefit of CNN in IoT is that many IoT devices use cameras as a sensor to sense the environment around them.

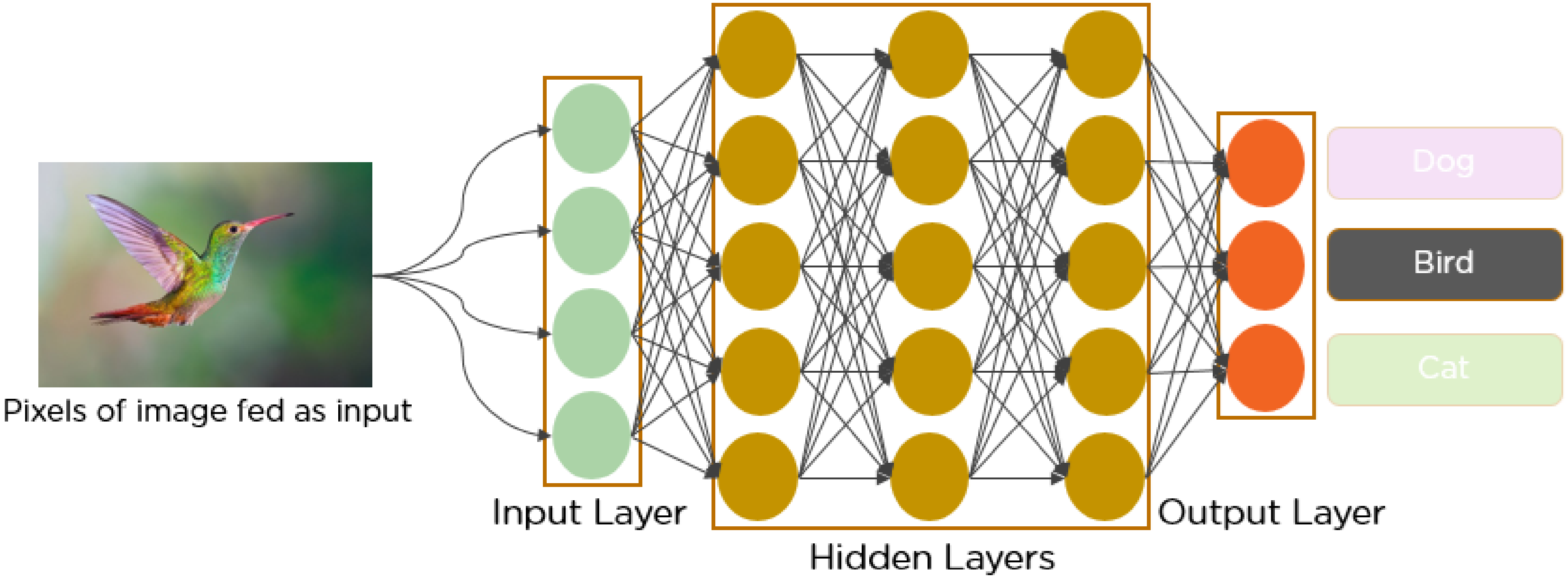

Fig. 2 Convolutional Neural Networks

Image source: https://www.analyticsvidhya.com/blog/2021/05/convolutional-neural-networks-cnn/

1.4 Digital twin technology using recurrent neural networks with IoT

- RNN works well with real-time streaming data analytics in many major devices depends upon RNN.
- RNN use Backpropagation Through Time to train the network. RNN is used in those applications where individual samples are not enough, but sequences of inputs play a vital role.
- Energy demand prediction for smart home in smart grid framework and intrusion detection is one of the products based on RNN with IoT.

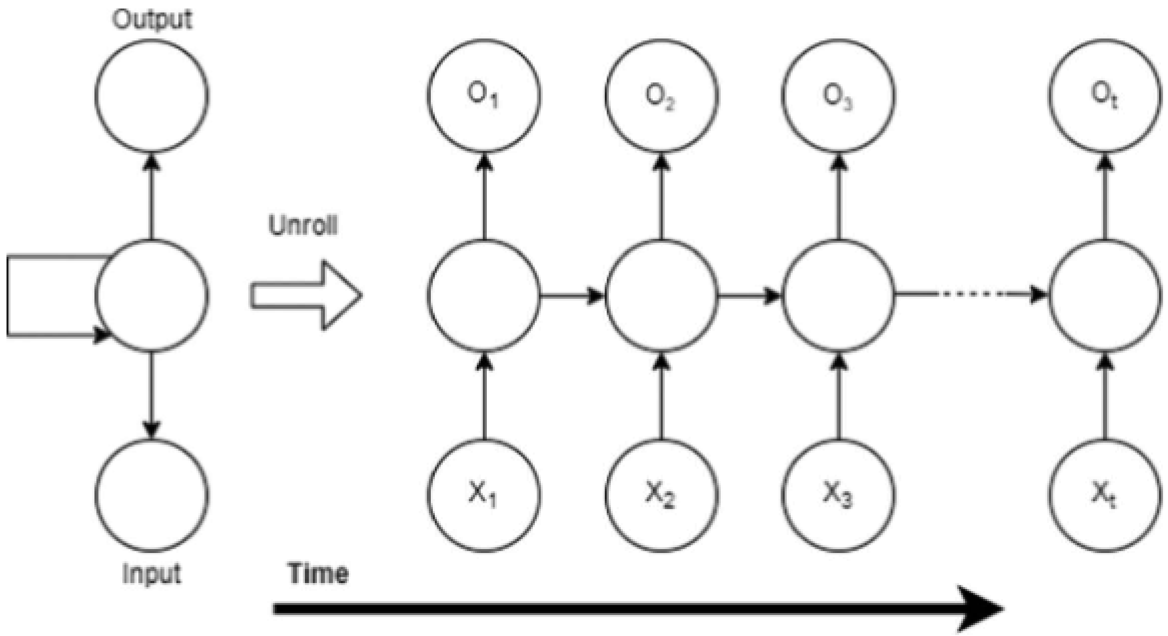

Fig. 3 Recurrent Neural Networks

1.5 Digital twin technology using long short-term memory with IoT

- Long short-term memory (LSTM) is an extension of RNN.
- The weakness with RNN is that it simply store the previous data in their “short-term memory”. Once the memory in it runs out, it simply deletes the longest retained information and replaces it with new data.
- The LSTM model attempts to escape this problem by retaining selected information in long-term memory. This long-term memory is stored in the Cell State. In addition, there is also the hidden state, like in normal neural networks where short-term information from the previous calculation steps are stored.
- Applications such as human activity recognition in sports, disaster prediction on environmental monitoring, are some of such applications that use this concept.

1.6 Digital twin technology using autoencoders and variational autoencoders with IoT

- Autoencoders (AEs) have an input layer and an output layer which are connected thought multiple hidden layers that can vary from one to tens. AEs are also known to have a same number of input and output layers as shown in Figure 4.
- VAE uses a fast-training process by using backpropagation; this model is usually used for semi-supervised learning.
- VAE is mostly used in security systems, failure detection for smart city and IoT cyber security.

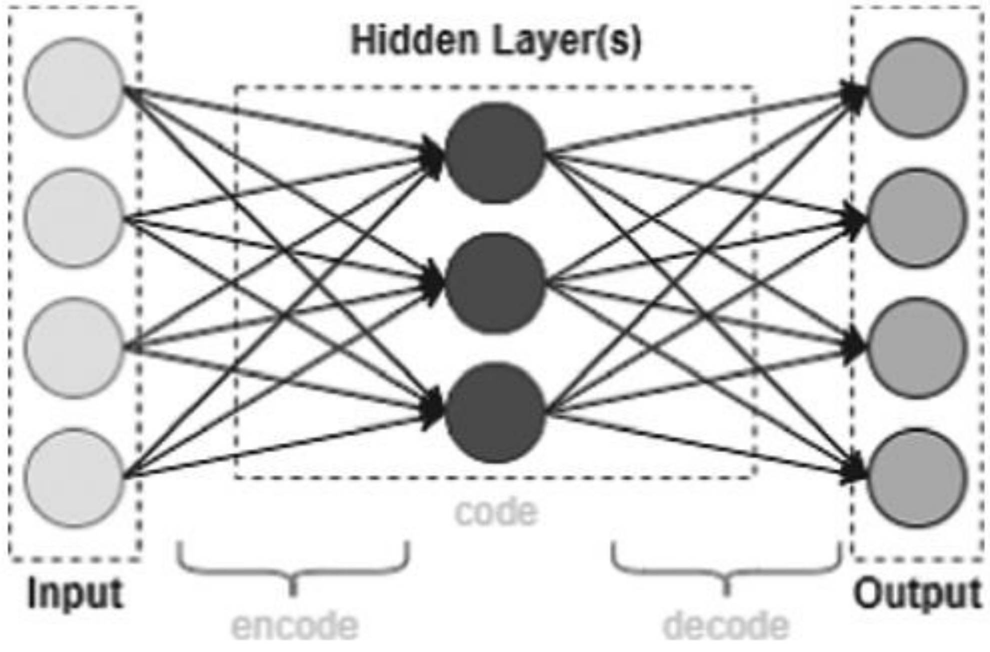

Fig. 4 Autoencoder network architecture

1.6 Digital twin technology using generative adversarial networks with IoT

- GAN consists of two neural networks, namely, generative and discriminative networks, as shown in Figure 5.
- The generative network is responsible for generating new data using the available dataset after it learns data distribution.
- At the same time, discriminative networks try to differentiate between real and fake data.
- The generative network works against a discriminative network to try to deceive it, while discriminative networks try to tell the difference between fake and real.
- GANs have been applied to many applications, including image generation, video prediction, and 3D object generation

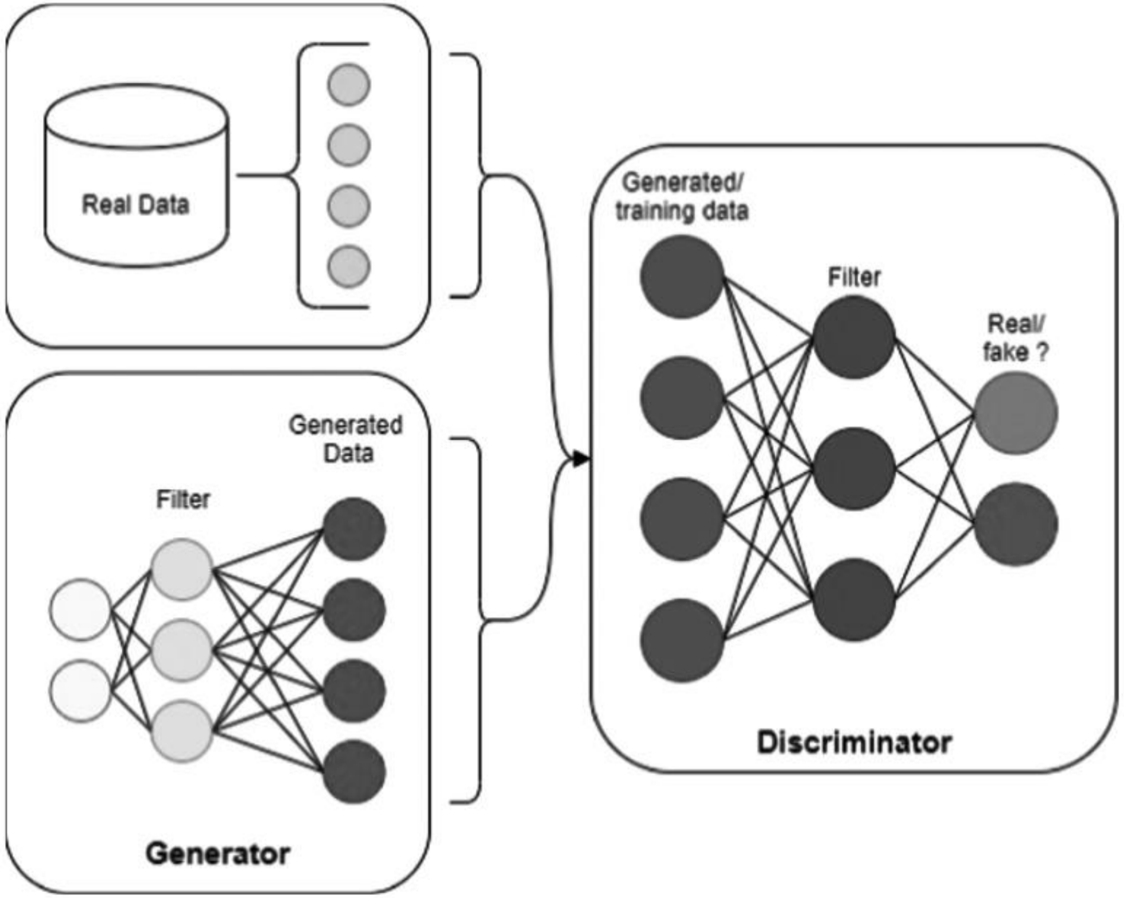

Fig. 5 Generative adversarial network architecture

1.6 Digital twin technology using restricted boltzmann machine with IoT

- Restricted Boltzmann machines (RBMs) are used in classification, collaborative filtering, feature learning, and topic modeling.
- RBM, as shown in Figure 6, is a two-layer model, where one is the visible layer, which we know as input, and the other is the hidden layer responsible for latent variables.
- RBM is used to understand what causes an event to happen.
- In IoT, RBMs are used in multiple verticals, from energy consumption prediction, traffic congestion prediction, posture analysis, to indoor localization.

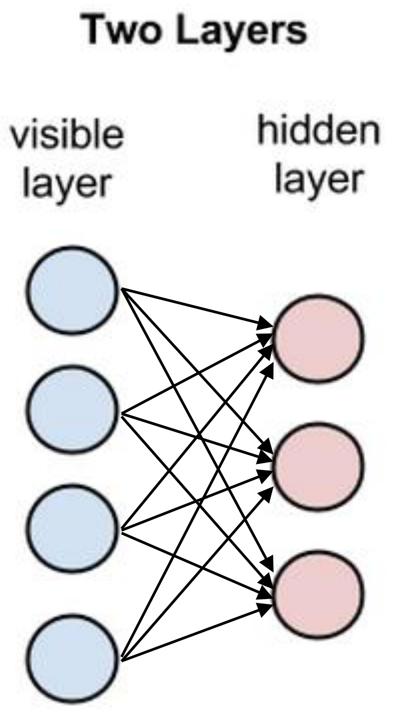

Fig. 6 Restricted Boltzmann machine

Image source: http://wiki.pathmind.com/restricted-boltzmann-machine

Thank you

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