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Research and application of deep learning in Metaverse

Keting Ren

School of Computing and Communications, Lancaster university, Lancaster, LA1 4YW, UK

renk2@lancaster.ac.uk

Abstract. The Metaverse, an immersive and interactive virtual environment, has garnered significant attention and presents numerous opportunities for technological advancements. The incorporation of artificial intelligence (AI) within the Metaverse can lead to transformative changes across various industries and applications. This paper delves into AI's role in the Metaverse, specifically focusing on deep learning and reinforcement learning techniques to address challenges faced by different applications with in- sufficient data. An overview of AI within the Metaverse is provided, along with an exploration of the connection between the Metaverse and the Digital Twin concept. The establishment of the Metaverse environment and AI- driven activities are examined, emphasizing their applications in virtual environments and interactions. Moreover, innovative deep learning training directions leveraging the Metaverse for various applications are proposed, including autonomous vehicles, surgical medical robots, nuclear decommissioning robots, and industrial design and experimentation. Finally, the paper summarizes and looks forward to the full text.

Keywords: deep learning, metaverse, digital twin.

1. Introduction

Virtual worlds represent continuous online computer-generated settings where multiple users at distant physical locations can engage in real-time interactions for work or entertainment purposes. These virtual worlds form a subset of virtual reality applications, which is a broader term referring to computer-generated representations of three-dimensional objects or environments that enable seemingly authentic, direct, or physical user interactions. In 2008, the National Academy While the main focus of the NAE Grand Challenges Committee is the United States, its members possess diverse international backgrounds, including a British member and multiple American members with substantial connections to institutions in Latin America, Africa, and Asia. Furthermore, a 2006 Chinese government report called "Outline of Medium- and Science and Technology Development Plan," as well as a 2007 Japanese report titled "Innovation 2025," both identify virtual reality as a priority technology for future development. Therefore, there is international support for advancing virtual reality applications [1].

In addition, in order to study the Metaverse, it is necessary to understand the differences between it and augmented reality. The main differences between Metaverse and augmented reality are described below:

Augmented Reality (AR): Which is a technology that overlays digital content onto the user's view of the physical world, enhancing their perception. Unlike virtual reality, which creates an entirely virtual experience, AR combines digital elements with the user's actual surroundings.

Metaverse: The Metaverse is a collective virtual shared space, resulting from the merging of digitally enhanced physical reality and a persistent virtual environment. As it develops, the Metaverse will facilitate online interactions that are more multidimensional than what current technology allows. Users of virtual worlds can not only view digital content but also become immersed in a space where the digital and physical realms blend.

Figure 1 illustrates the architectural features of the Metaverse [2].

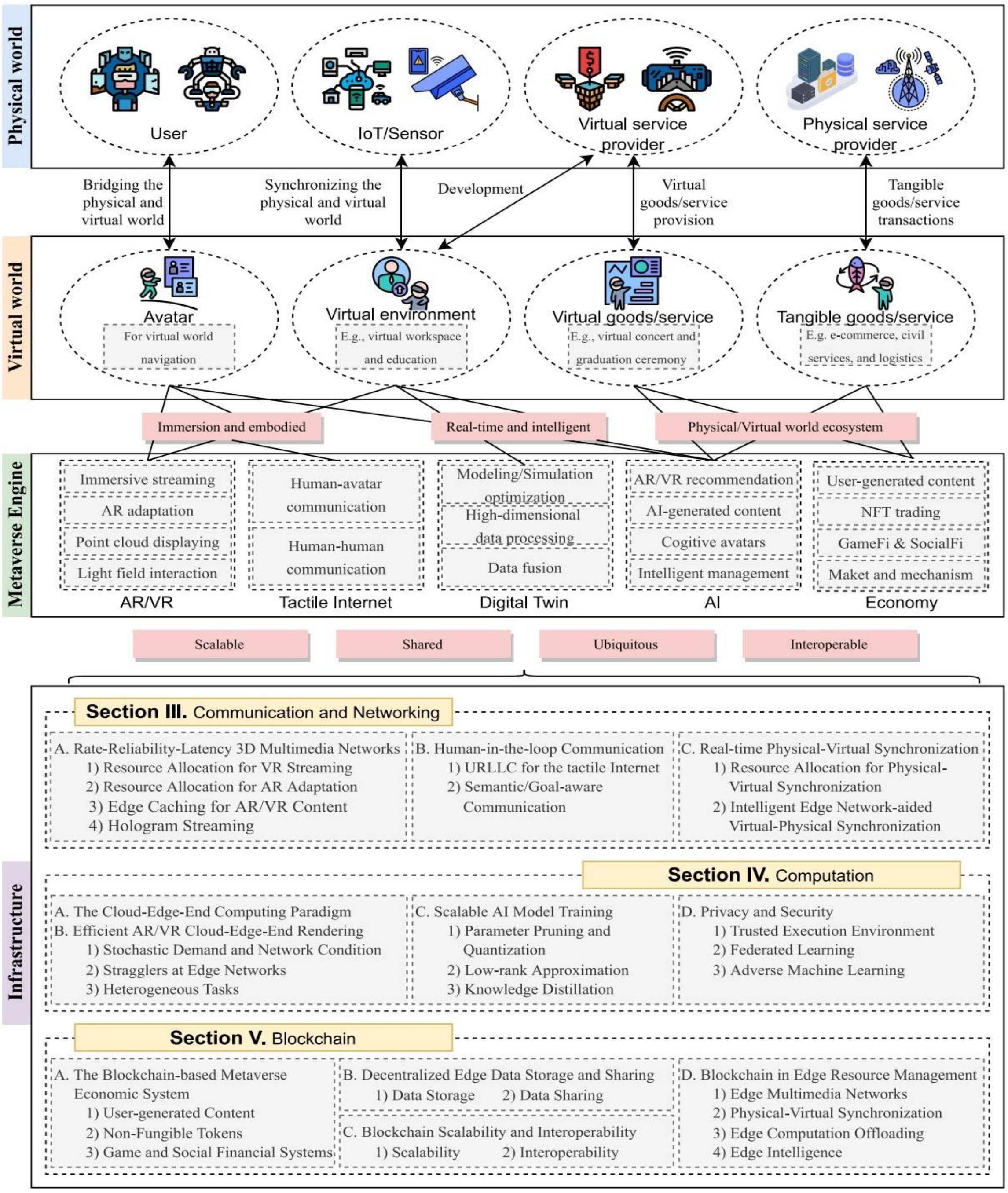

Figure 1. The Metaverse architecture features.

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And a metaspace platform can include several layers (see Figure 2) [3], which are represented below.

Infrastructure Components: 5G and 6G net- works, WiFi, cloud computing, data centers, central processing units, and GPUs.

Human-machine interface: mobile, smart watches, smart glasses, wearables, head- mounted displays, gestures, voice and electrode bundles.

Spatial computing: 3D rendering engines, virtual reality (VR), augmented reality (AR), extended reality (XR), geospatial visualization, and simultaneous task management.

Creator economies: design instruments, asset marketplaces, online commerce, and production processes.

Discovery: advertising networks, digital store-fronts, social recommendations, rankings, virtual personas, and conversational agents.

Experience: gaming, social interactions, competitive gaming, retail experiences, celebrations, events, educational activities, and professional tasks.

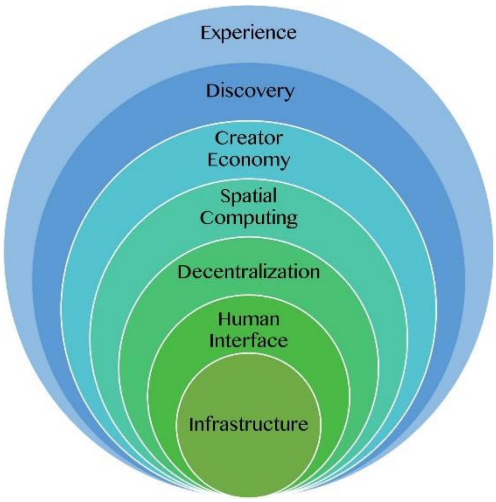

Figure 2. Metaverse structure.

2. AI in Metaverse

The Metaverse offers an immersive experience that leverages extended reality technology, digital twin technology to create real-world replicas, and blockchain technology for an efficient system. This integration seamlessly connects the virtual and real worlds within economic and identity systems, empowering users to contribute and modify the world around them.

In addition, the typical characteristics of the Metaverse itself are bound to require training on a large amount of data, and only artificial intelligence can control this huge amount of data. Therefore, how to train artificial intelligence in the Metaverse with appropriate methods has become a problem worth studying.

The development speed of artificial intelligence, especially cognitive intelligence, will directly affect the development rhythm of the "Metaverse" [4]. As an emerging concept, the Metaverse has not yet been clearly defined. But some typical features are widely recognized, such as definable digital avatar, multi-modal perception immersion, ultra-low latency, multi-dimensional and diverse virtual world, access anytime and anywhere, complete economic system, and complete civilization system. These basic characteristics of the Metaverse will form super-large-scale data, consume super-large-scale computing power, use ultra-high-bandwidth networks, ubiquitous multi-modal access devices, natural and smooth human-computer interaction. These characteristics bring the changes of the Metaverse will inevitably require more intelligent algorithms to process, to meet the needs of the construction of the Metaverse and the growth of users, especially the human-machine intelligent interaction ability that affects the user's perception and the processing of super-large data sets that affect the Metaverse governance model. The strength of each aspect is the key control point for when the Metaverse can be realized, and breakthroughs in these aspects depend on the development of cognitive intelligence. The pace of development of artificial intelligence, particularly cognitive intelligence, will therefore have a direct impact on the pace of development of the Metaverse. Figure 3 depicts the Metaverse's computer vision capabilities, which include scene comprehension, object identification, and the recognition of human actions and activities. This figure highlights the importance of deep learning and AI in analyzing various visual elements within the Metaverse. By utilizing state-of-the-art algorithms and techniques for scene understanding, it is possible to create realistic and immersive environments. Object detection plays a crucial role in enabling dynamic interactions between virtual objects and users, leading to richer experiences in the Metaverse. Additionally, the recognition of human actions and activities allows for more seamless integration of users' physical movements into the virtual world, further enhancing the overall user experience. The combination of these key aspects in the Metaverse can facilitate a wide range of applications, from entertainment to professional use, by leveraging advanced computer vision and artificial intelligence techniques.

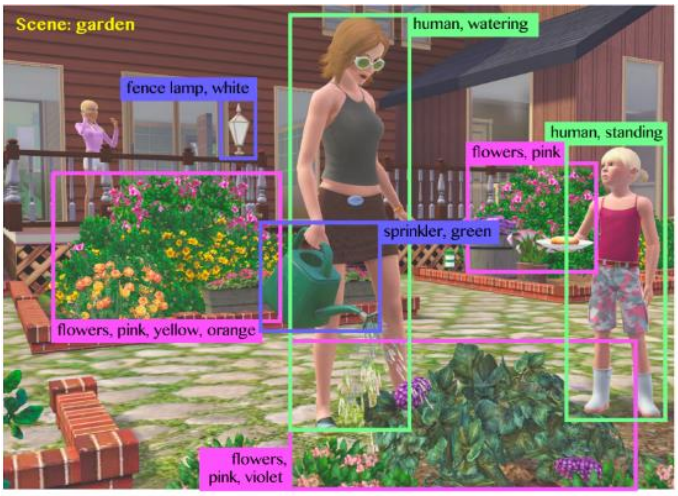

Figure 3. Computer vision within the Metaverse encompasses scene understanding, object detection, and the recognition of human actions and activities.

3. The Metaverse and the digital twin

In the current Metaverse boom, when touching on research about the Metaverse, the first thing that should be explored and focused on is not the Metaverse, which is currently difficult to breed, but the core key industrial technologies associated with the Metaverse, i.e. the industrial chain technologies that will build and support the future Metaverse being built.

According to the author of the book "Avalanche", that is, the famous American science fiction writer, Neil Stephenson's understanding of the Metaverse: everything in the Metaverse is virtual. Then the Metaverse does not need to be called the Metaverse, it is just a virtual reality, that is, VR technology can be realized, even AR is not needed [5].

This is not a Metaverse in the true sense. The Metaverse in the true sense is a multi-layered virtual reality hybrid world where the virtual and real physical worlds are interconnected, communicated, and interacted. So in the face of such a mixed virtual reality world, digital twin technology has become the key technology for realization and the core technology for building the virtualization of the real physical world.

The so-called digital twin is to digitise the physical world and build a twin of the physical world. In this digital twin, it is possible to interconnect, interoperate and interact with the physical world, and it is possible to control and influence some operations in the physical world through the virtual world built by the digital twin, or to rely on the physical world. Real-time changes affect and change the virtual world of the digital twin. It can therefore be argued that without the digital twin technology, the

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Metaverse that could be studied today would only be a science fiction statement. At the heart of the Metaverse, to achieve an overlay of the virtual and physical worlds, lies the digital twin technology. Therefore, before talking about the Metaverse, it is necessary to focus first on digital twin technology, a digital twin that actually creates a twin of the physical world [6].

Figure 4 depicts a data-driven Digital Twin (DT) framework for intelligent healthcare systems, which employs Machine Learning (ML) to process raw data from Internet of Medical Things (IoMT) devices. This framework highlights the importance of leveraging ML algorithms and techniques to analyze the vast amounts of data generated by IoMT devices. In the context of intelligent healthcare systems, the integration of Digital Twins allows for the creation of accurate and realistic virtual representations of both patients and medical equipment, enabling more efficient diagnostics and treatment planning. By utilizing ML to process and analyze the raw data from IoMT devices, the DT framework can effectively facilitate real-time monitoring, data-driven decision making, and personalized healthcare solutions. This combination of advanced technologies enables healthcare professionals to provide better care and optimize patient outcomes in the rapidly evolving landscape of digital healthcare.

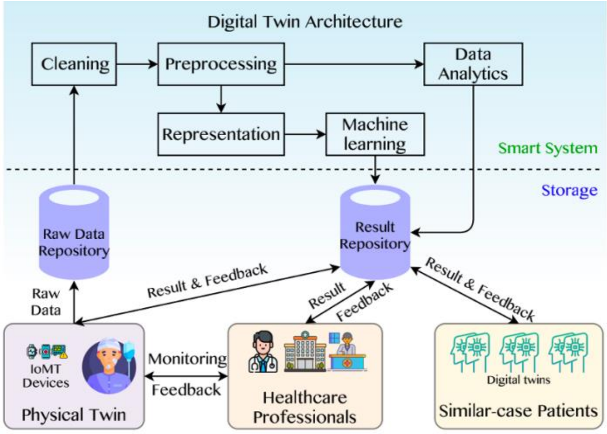

Figure 4. A data-driven decision tree (DT) approach for smart healthcare systems, utilizing machine learning (ML) to analyze unprocessed information from the Internet of Medical Things (IoMT) devices.

4. Challenges and opportunities in the Metaverse

4.1. Challenges in the Metaverse

In order to realize the Metaverse's potential, several challenges must be addressed. Some of the key challenges include the following:

Security and Privacy: Protecting users' personal information and ensuring the security of their digital assets are critical. Blockchain technology can help in achieving decentralized and secure data storage, but it needs further development and integration with the Metaverse infrastructure.

Scalability and Interoperability: The Metaverse must accommodate a vast number of users, digital assets, and transactions occurring concurrently [7]. Scalability is a significant concern that requires advancements in network infrastructure, computational resources, and communication protocols. Additionally, seamless interoperability between different platforms and digital assets is essential for the Metaverse's success.

Digital Asset Ownership and Intellectual Property Rights: Establishing a clear framework for digital asset ownership and intellectual property rights is necessary. This framework should protect the rights of content creators and users while also promoting collaboration and innovation within the Metaverse [8].

4.2. Opportunities in the Metaverse

Despite the challenges, the Metaverse presents numerous opportunities across various industries and fields:

Education and Training: The Metaverse can revolutionize education by providing immersive and interactive learning environments, facilitating remote collaboration, and offering personalized learning experiences [9].

Entertainment and Social Interaction: The Metaverse offers new forms of entertainment, such as virtual concerts and gaming experiences, as well as new ways for users to socialize and form communities across geographical boundaries [10].

Commerce and Business: The Metaverse enables new business models, such as virtual marketplaces and digital asset trading, while also providing a platform for businesses to collaborate, innovate, and reach new customers.

Healthcare: The Metaverse, when combined with digital twin technology and IoMT devices, can revolutionize healthcare systems by creating a data-driven, intelligent, and interconnected ecosystem, as discussed in the previous section.

4.3. Overview of Metaverse platforms and technologies

Table 1 provides a summary of the main Metaverse platforms and the technologies they employ. These platforms represent some of the key players in the development of the Metaverse and demonstrate the diverse range of applications and opportunities that the Metaverse can offer.

Table 1. Application of Artificial Intelligence in the Metaverse Overview.

Categories	Introduction	Machine Learning Algorithms	Application Scenarios
Digital Settings	Three-dimensional visual processing	DRL	Acquiring skills in indoor wayfinding, identifying actions, detecting occurrences, and more.
	Collaborative Learning	Configuration-dependent servers	Applications of Augmented Reality
	Reducing the execution latencies and shortcomings of AR	Centralized federated learning within the mobile edge computing realm	Co-operative studies
	Employing vast datasets and ML techniques for the development of intelligent urban environments.	Deep reinforcement learning with semi-supervision	Smart city services
AI-based Object	Avatar face identification	Markov Random Area	Face identification
	Tracking and detection	Multi-level with CNN three branches	Tracking multiple people
	Training for NPC	RL	RL-DOT

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Table 1. (continued).

	OpenAI Five	The LSTM and Distributed learning framework	Dota2
	Intelligent behavioral avatars	Bayesian network diagram based on RL	Game tracking for playback
	Interactive learning-based incarnation control	National action	Animated and controlled avatars
	Interaction between human and machine	RL	Avatar Mobility
Interactive virtual reality	Controllers trained in the virtual world can be made to be transferred to the physical world.	LSTM and Mixture Density Network	Training in robotics for digital twins for human-machine interaction

As technology advances and the Metaverse becomes more mature, these opportunities will continue to expand and evolve, shaping various aspects of our lives and driving innovation across industries.

4.4. Exploring the Metaverse for AI training in diverse applications

In this survey, research focusing on exploiting the metaverse for deep learning in various novel applications is discussed, with the aim of enriching training data for challenging applications that lack sufficient data, as shown in Figure 5.

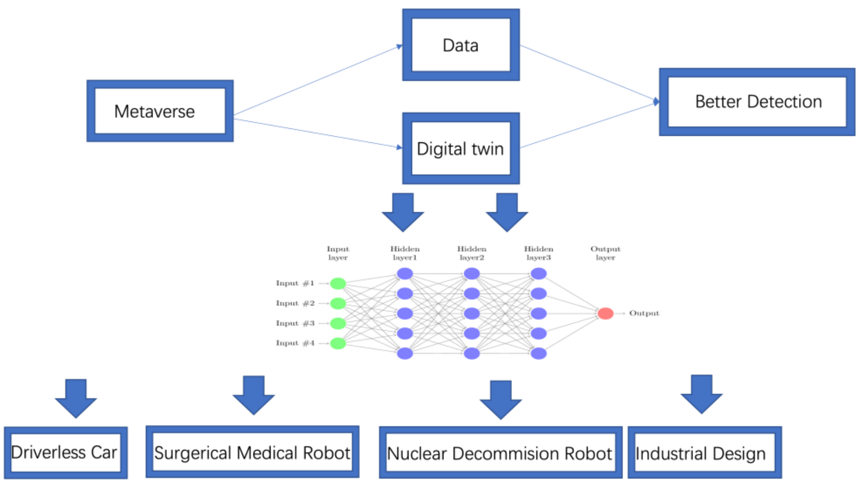

Figure 5. Metaverse DNN structure.

The novelty of the research covered in this survey primarily resides in the following aspects:

The development of efficient methods to enable DNNs to learn more effectively within the metaverse;

The application of new training frameworks to different DNNs, such as CNNs, LSTMs, AEs, GANs, and particularly Graph CNNs (for 3D Graphics)

The implementation of learning frameworks in various applications, including nuclear decommissioning robots, medical surgical robots, nano robots, drones, driverless vehicles, and more.

Specifically, metaverse-based deep learning for data-scarce applications is explored, such as:

Driverless Car:

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Autonomous driving requires a significant amount of road data for training. To ensure the safety of autonomous driving, a set of autonomous driving systems needs at least 18 billion kilometers of road tests [6]. The metaverse enables the virtualization of a "high imitation" Earth for road testing of autonomous driving. After designing and assembling a self-driving car in the metaverse, it can be placed in the "high imitation" Earth for various testing scenarios, quickly obtaining a large amount of road data, enabling the development of a commercialized autonomous driving system.

Surgical Medical Robot:

The healthcare technology industry is continuously developing due to innovations in the medical field. Technologies such as AR, VR, AI, and minimally invasive surgery are used to enhance patient outcomes [11]. Nonetheless, obstacles persist, including the development and interaction with tangible objects and surgical interfaces in digitally-generated environments, as well as handling intricate signals [12].

Nuclear Decommissioning Robot:

The decommissioning of nuclear power facilities is a major task for the foreseeable future, as more reactors have been closed globally than opened in recent years [13]. Nuclear Decommissioning Robots will be used to handle various applications in the nuclear-decommissioning industry, such as waste treatment and sorting, downsizing, box packaging, capping, wiping, and general housekeeping.

Industrial Design and Experimentation:

The industrial application of the metaverse, led by NVIDIA's Omniverse, enables engineers to simulate robots, cars, factories, and more in a shared virtual space. Individuals and groups can integrate essential design resources, materials, and tasks for cooperative work and refinement

5. Conclusion

The Metaverse has shown the potential to transform the way we live in the future. In order to create a realistic and practical metaverse, there is still a need to push the frontiers of several fundamental technologies, including perception, computation, reconstruction, collaboration and interaction. While significant progress has been made in these technologies over the past decade, there is still a long way to go to achieve more accurate perception, efficient computation, reconstruction of reality, ubiquitous collaboration and easy interaction. Over the past decade, artificial intelligence has shown significant value to these technologies, particularly with the emerging development of deep learning. In this survey, several representative efforts in AI and underlying meta-technologies are reviewed, outlining some of the algorithms that might be used in the Metaverse. While some of these are still far from practical application, it is expected that future developments in AI and related fields will greatly facilitate scientific research and commercial applications of the Metaverse, bringing it to all people and making the world a better place.

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