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A Hierarchical Model Description of the “Metaverse” and Next-Generation Internet (Postprint)

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Abstract

In 2021, the concept of “metaverse” attracted widespread global attention. While extant literature on the metaverse predominantly offers theoretical interpretations, research on practical industry experience remains relatively scarce. This paper employs a hierarchical modeling approach to delineate the architecture of next-generation internet platforms exemplified by the “metaverse.” Building upon this foundation, and drawing upon survey interviews with industry practitioners and researchers from leading enterprises including Tencent, NVIDIA, and Epic Games, as well as relevant textual materials, this study conducts a comparative analysis of the distribution of dominant firms within the metaverse industry, thereby identifying the vulnerabilities in China’s metaverse industry and technological capabilities.

Full Text

A Layered Model Description of the “Metaverse” and Next-Generation Internet

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Abstract: In 2021, the concept of “Metaverse” garnered widespread global attention. While existing literature predominantly offers theoretical interpretations, practical industry experiences remain relatively underexplored. This paper employs a layered modeling approach to describe the architecture of next-generation internet platforms exemplified by the Metaverse. Based on this framework and drawing from interviews with industry professionals and researchers from companies such as Tencent, NVIDIA, and Epic Games, along with relevant documentation, we conduct a comparative analysis of dominant

enterprises in the Metaverse industry, identifying key weaknesses in China's Metaverse industry and technology.

Keywords: Metaverse; network layered model; industrial layout; next-generation internet; spatial information technology

1. Common Characteristics of the Metaverse and Next-Generation Internet

1.1 The Metaverse and Related Concepts 1.1.1 The Metaverse

The term “Metaverse,” coined by American science fiction author Neal Stephenson in his 1992 novel *Snow Crash*, envisioned a persistent virtual world parallel to and interacting with physical reality, where people live through digital avatars. In contemporary terms, the Metaverse represents a new form of internet application and social morphology that integrates multiple emerging technologies, blending virtual and physical worlds in economic, social, and identity systems while enabling every user to produce and edit content. Through highly realistic three-dimensional internet spaces, it facilitates broader information and data exchange among users, platforms, and between users themselves. Its three-dimensional architecture can accommodate and generate far more information than the flat architectures of Web 1.0 and Web 2.0, with its upper limit approaching that of the real world.

1.1.2 3D Internet

The 3D Internet, also called three-dimensional internet, represents an evolutionary stage. The “one-dimensional internet” of Web 1.0 was primarily about information retrieval and reading, with users passively consuming information from portals and other PC-based platforms. The “two-dimensional internet” of Web 2.0 transformed users into content creators and co-builders of platforms, enabling bidirectional information flow between users and platforms. The 3D Internet emerges as the next phase, characterized by immersive, high-fidelity digital environments.

1.1.4 Omniverse

Omniverse is NVIDIA's Metaverse concept. In its narrow sense, it refers to an open platform for 3D design collaboration and digital twin simulation, aiming to integrate graphics, AI, simulation, and scalable computing into a foundational infrastructure connecting digital worlds. Through Omniverse, artists, designers, and creators can collaboratively produce high-fidelity 3D assets and scenes using their preferred design applications. Broadly, by extensively connecting and building physically accurate digital twins, Omniverse ultimately aims to construct scalable, real-time digital world simulations—from object scale to planetary scale—with high fidelity and physical accuracy.

2. Common Characteristics of Next-Generation Internet

The Metaverse broadly describes numerous types of future digital worlds that share fundamental foundations in presentation, experience, and connectivity. These essential commonalities include:

2.1.1 Realism

All next-generation internet platform concepts build upon high-fidelity three-dimensional technology that achieves physical-level accuracy—faithfully replicating the shape, volume, color, and other characteristics of physical objects, from dust particles to planets. This encompasses both highly realistic natural environments and simulated human societies.

2.1.2 Synchronization

Digital spaces maintain continuous connectivity with the real world, enabling high synchronization and real-time updates. This means most changes in the physical world (ultimately all changes) will be reflected in the digital world, and changes driven by user interactions in the digital world will eventually manifest in reality. This synchronization applies to both natural environments and human activities, including political and economic processes.

2.1.3 Creation

Achieving high-fidelity, physically accurate, scalable, real-time digital world simulation is extremely difficult. The creation and transformation of massive digital assets require participation from all users, particularly low-barrier involvement in building high-fidelity digital worlds. This includes both conscious UGC creation activities through which users obtain economic benefits, and unconscious creation through interaction data, such as digital trajectory information generated when users drive vehicles in digital environments.

2.2 Layered Model Description Method

Layered modeling is a fundamental approach in computer network design, employed by virtually all modern computer networks. This method decomposes overall network functionality into distinct layers based on information/data flow processes. Equivalent layers across different systems use identical protocols, while adjacent layers within the same system exchange information through interfaces. This approach offers significant advantages: each layer implements relatively independent functions, breaking complex problems into manageable “sub-problems” that reduce design complexity. Since 1974, when IBM introduced the first network architecture (Systems Network Architecture, SNA), nearly all network architectures have adopted layered models. In 1981, the International Organization for Standardization (ISO) proposed the Open Systems Interconnection reference model (OSI/RM), which systematically defines network layers and their functions without specifying implementation details or hardware composition.

The Metaverse, as a next-generation internet platform, represents the product of high-bandwidth transmission capabilities, massive information generation, and ultra-high computing power. Its functionality depends heavily on effective information flow between different layers, making layered models applicable for describing and analyzing its architecture.

[Figure 2: see original paper] Layered Model Description of Next-Generation Internet

2.2.1 Infrastructure Layer The infrastructure layer comprises fundamental hardware and software—the “land” and “air” of the Metaverse. Key components include: (1) **Cloud computing and storage**, which serves as the digital world’s brain where all environments and changes are realized. Edge computing may be retained at connection hubs like AR glasses to better capture real-world environmental changes for transmission to the cloud. (2) **Rendering technology**, the algorithmic foundation for abstracting real-world materials into curves or polygons and generating final images. While the Metaverse requires multiple computing technologies, rendering is uniquely critical—it builds the digital world interface. Without it, high-bandwidth transmission and powerful computing cannot deliver user experiences. Trends include cloud rendering and real-time rendering, essential for immediate reflection of user interactions and real-world changes. (3) **High-bandwidth communication**, ensuring transmission between endpoints and cloud to enable virtual-physical world synchronization. Next-generation internet requirements may exceed 5G’s capabilities (hundreds of Mbps), potentially requiring Gbps-level transmission. (4) **Spatial information technology**, including geographic information systems and positioning, enabling mapping between digital and physical worlds. Digital environments derive from real-world spatial data collected via GIS and remote sensing technologies. Post-construction, real-world changes require spatial information perception, including high-precision positioning for human/avatar movement. Future XR hardware will inevitably integrate positioning chips. (5) **Artificial intelligence**, applied across all layers from cloud computing to spatial information. For the Metaverse, AI performs specialized tasks such as creating AI-driven digital humans to serve as workers and assistants, enabling better human experiences in digital worlds.

Overall, the Metaverse represents a real-time 3D world based on massive computing, with three critical technologies: computing (including rendering), transmission, and perception.

2.2.2 Tools Layer The tools layer primarily generates digital world assets and drives world operations, including: (1) **3D rendering engines** that lower barriers for digital scene production and editing through accessible, “everyone-can-participate” approaches. (2) **3D scanning** to detect and analyze real-world object geometry and appearance data (color, surface albedo, etc.) for 3D reconstruction and digital model creation. (3) **AIGC (AI-Generated Content)**,

the primary method for asset generation within the Metaverse using artificial intelligence. (4) **Low-code platforms**, enabling rapid application development with minimal or no coding through visual programming and drag-and-drop interfaces. (5) **Procedural generation**, automatically creating digital content and assets or driving world changes based on algorithms and rules. (6) **AI vision**, using image recognition and semantic segmentation to generate digital content from visual data and perceive operations in both real and digital worlds.

While creators/operators provide underlying carriers and tools, these tools will ultimately exhibit UGC characteristics—for example, expert programmers optimizing “house-building tools” for other users, who can then sell these improved tools for profit.

2.2.3 Assets Layer The assets layer comprises 沉淀 assets within the Metaverse and platforms for sharing them, similar to platforms like ArtStation or online literature sites. In practice, tools often include built-in asset libraries. Asset creators are the Metaverse’s first users, generating content based on hobbies or interests. This user-generated content constitutes the Metaverse itself—for instance, a user creating a digital replica of their physical home and modifying their neighborhood environment according to established rules. As user bases expand and barriers lower, the world accumulates increasingly rich digital assets from users (though much may be digital noise), enabling easier reuse and further creation.

Currently, no independent strong enterprises have emerged in the assets layer; instead, it exists as part of tools or application layers, such as asset tools with powerful built-in libraries or platforms that accumulate substantial digital assets.

2.2.4 Application Layer The application layer encompasses Metaverse social activities and related functions—essentially the “society” of the Metaverse. This includes: (1) **3D interactive content**, comprising immediate changes from user activities in real or virtual worlds, matching application scenarios and programs, and encompassing digital world human activity patterns and institutions (laws, ethics, social operations, economic activities). This generates the Metaverse’s primary content, activities, and assets, constructing the vibrant digital world at micro levels. (2) **3D linear content**, representing changes independent of user interaction or occurring only after cumulative interaction, analogous to natural laws and macro-scale changes in the real world. (3) **2D internet content**, where Web 1.0 and Web 2.0 content enters the Metaverse, partially in 3D or remaining 2D. However, as the Metaverse evolves, most non-convertible 2D assets will become obsolete or lose significance.

3. Industry Distribution Analysis Based on Layered Model

Using the layered model to describe Metaverse architecture enables various analyses. This paper applies it to analyze the distribution of dominant Chinese and

foreign (internet/IT) enterprises across the Metaverse industry chain.

[Figure 3: see original paper] Distribution of Dominant Enterprises in Next-Generation Internet as Described by Layered Model

3.1 Chinese Enterprises’ Advantages in the Metaverse Industry Chinese enterprises primarily concentrate at two ends of the Metaverse industry: infrastructure and applications. In infrastructure, China possesses advantages in high-bandwidth communication and cloud computing, driven by Huawei’s strong 5G technology and market position, as well as rapid digitalization and massive user scale. Companies like Alibaba, Tencent, and Baidu have world-leading cloud computing and storage capabilities. In applications, Chinese gaming companies demonstrate particular strength. Platforms like ROBLOX and Minecraft are widely recognized as the digital forms closest to the Metaverse, and gaming represents the pioneering application of real-time rendering and cloud computing with experience in digital world socialization and management. Tencent and NetEase hold leading positions in the global gaming industry, while other major internet companies and content platforms are actively entering gaming. However, China remains in development for underlying hardware supporting cloud computing (CPUs, GPUs) and faces clear constraints from foreign enterprises.

3.2 Chinese Enterprises’ Disadvantages in the Metaverse Industry Chinese enterprises show significant gaps in the “tools layer” of Metaverse industry layout, manifesting in two areas. First, rendering technology—the “foundation of the Metaverse” —lags considerably, evidenced by the absence of dominant engine tools. Foreign engines like Unity 3D and Unreal Engine continuously lower barriers while building open ecosystems, similar to Windows and Android, making it difficult for global users to switch to domestic alternatives. Domestic engines from companies like Tencent remain in transition from code-based to visual interfaces, still requiring professional expertise. Second, other tool software is missing. China currently lacks widely-used content creation software comparable to Adobe suites or macOS design/video applications. Industry experts estimate China’s overall strength in the tools layer at less than 5%, with a clear generational gap.

3.3 Trends in Foreign Metaverse Industry Distribution From a global perspective, the Metaverse industry exhibits a clear “full industry chain” trend, producing super-enterprises like NVIDIA and Epic Games that span from infrastructure to application layers. NVIDIA, the inventor of GPU and a leading graphics card manufacturer, has extended from hardware to content creation based on GPU computing power and ecosystem. Omniverse is a content production platform perfectly matched to NVIDIA GPU technology, including highly compatible engine tools and building massive asset libraries through asset generation tools. Unlike Intel and AMD in the Web 2.0 era, which collaborated with software companies rather than extending vertically, NVIDIA may be the

first desktop computing company with strong capabilities in both hardware and software.

Similarly, Epic Games, originally a game developer using its Unreal Engine, announced in 2015 that Unreal Engine would be freely available with only a 5% royalty fee after certain revenue thresholds. This immediately drove global adoption across gaming and expanded its application to digital cities, factories, film, and smart vehicles. Epic Games continuously advances Unreal Engine's accessibility through optimized visual editing interfaces. Its game *Fortnite* also demonstrates strong Metaverse characteristics. Through acquisitions and holdings, Epic Games has built comprehensive tools and application layer capabilities, such as its 2015 acquisition of Quixel, a film and game asset tool manufacturer.

Next-generation internet involves more than technology alone. Analyzing its architecture clarifies characteristics, functions, and trends. The distribution of competitive enterprises across the Metaverse industry chain reflects current national positions in the next-generation internet race. China's analysis reveals clear weaknesses, particularly in digital asset generation software tools. Chinese enterprises with competitive edges in 5G, cloud computing, and gaming should extend into other industry chain segments, especially through open ecosystems, to expand coverage and adapt to the Metaverse's full-industry-chain trend.

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