

Future Visions: The Evolution of Voxel Art in the Wave of New Technologies

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요약 본 연구에서는 새로운 기술의 파도 속에서 복셀 아트(voxel art)의 진보와 다양한 분야에서의 응용이 논의될 것이다. 특히 컴퓨터 그래픽, 의료 영상, 가상 현실 및 서비스 디자인 등이 그렇다. 복셀 아트는 3차원 픽셀(복셀)을 사용하여 복잡하고 시각적으로 매력적인 이미지와 모델을 창조합니다. 이 독특한 제작 방식과 높은 수준의 세부 제어를 통해 예술가들은 3차원 공간에서 자유롭게 창작할 수 있습니다. 기술의 발전으로 복셀 아트의 응용은 전통적인 예술 분야에서 게임 개발 및 상호 작용 미디어로 확장되어 시장과 문화에서 광범위한 인정을 촉진시켰습니다. 또한 인공지능(AI) 기술과 결합하여 복셀 아트의 개발은 자동화와 고효율로 나아가고 있습니다. 그리고 본 논문은 복셀 아트가 직면한 도전에 대해 논의했습니다. 여기에는 기술적 한계와 실제 응용 분야에서 성능 문제를 포함하고 복셀 아트의 잠재적 발전 방향에 대해서도 논의합니다.

주제어: 복셀 아트의, 미래 동향, 실감나 기술, 서비스 디자인

Abstract This article explores the evolution of voxel art amid waves of new technologies and its applications in several fields, notably computer graphics, medical imaging, and virtual reality, and service design. Voxel art uses three-dimensional pixels (voxels) to create complex and visually appealing images and models. Its unique production method and high degree of detail control allow artists to create freely in three-dimensional space. With the advancement of technology, the application of voxel art has expanded from traditional art fields to game development and interactive media, driving its widespread recognition in the market and culture. In addition, combined with artificial intelligence (AI) technology, the development of voxel art is moving towards automation and high efficiency. This article also discusses challenges facing voxel art, including technical limitations and performance issues in real-world applications, as well as potential future directions for voxel art.

Keywords: Voxel Art, Future Trends, Immersive Technologies, Service design

Introduction

With the rapid development of technology, the boundaries between traditional art and digital art are increasingly blurred. Emerging technologies not only change the art creation process, but also redefine the expression of art and the way audiences interact. Voxel Art is a technology that uses voxels (three-dimensional pixels) to create images or models, and it plays a significant role in service design by enhancing user experience through interactive and immersive environments. Able to create complex and attractive visual effects through the combination of simple geometric shapes and colors. This technology has applications in multiple fields, including computer graphics, medical imaging, virtual reality, and more. A voxel is essentially the 3D equivalent of a pixel, the smallest distinguishable element of a digital image. The term "voxel" stands for "volume pixel" and is primarily used in 3D modeling and visualization. Unlike

polygons, which are essentially flat and two-dimensional (using interconnected points and lines to form the surface of a 3D object), voxels represent volumes and are visualized as small cubes or blocks in 3D space. In service design, voxel art can be used to create interactive displays, virtual walkthroughs, and immersive training modules, providing a richer user experience. This art form is characterized by its unique production method and high degree of control over details, which allows artists to create freely within a three-dimensional space to create more three-dimensional and complex visual effects.

According to the article "The Essence and Characteristic of Digital Art Interaction", the essence of digital art lies in interactivity[1]. This means that whether it is pixel art or voxel art, they can be transformed into a unique aesthetic experience through the interactive experience of the audience. This interactivity not only enhances the appeal of the artwork, but also enables the audience to feel the aesthetic value during the participation process. In voxel-based graphics, objects are not just surfaces but have an overall mass, somewhat like the atoms of a real object filling its volume. This allows for unique applications such as detailed terrain generation where each voxel can represent a portion of the ground, allowing for dynamic modification such as excavation or construction. It also enables true 3D destructibility, as objects can be exploded or altered at the voxel level, showing internal and external changes. The natural interactivity of voxel models has also become a unique advantage in user experience in voxel art.

Voxel graphics were popular in the 1990s and are experiencing a renaissance due to their advantages in creating more immersive and interactive 3D environments, as seen in games like Minecraft and Teardown. However, they have limitations in resolution and rendering speed compared to polygon-based graphics, which have evolved significantly with advances in GPU technology. With the continuous development of polygon graphics technology in recent years, the volume of voxel graphics has gradually been overshadowed by polygon graphics technology.

Voxels are mostly used in medicine and computer graphics. There are fewer cases where theories and methods from the fields of art, social sciences, economics and cultural studies are applied to voxel art. Voxel art has not received widespread attention and sufficient research. Research combining speculative design and artistic methodology shows that exploring technological potential through artistic methods can promote non-technical people's understanding and application of new technologies such as AI[2]. This shows that the development of voxel art will rely more on interdisciplinary collaboration and the stimulation of innovative thinking. An interdisciplinary research approach contributes to a comprehensive understanding of the socioeconomic effects of voxel art and how it shapes new cultural trends and market dynamics. Therefore, reflection on the future development of voxel art is necessary, especially in terms of technology integration, user participation, artistic expression and interdisciplinary research methods.

The historical development of voxel art

The development history of voxel art shows the progress and innovation of technology. Marching cubes algorithm from 1987[3], voxel-based morphometry (VBM) proposed in 2000[4], and then to the concept of infinite voxelized virtual modeling space proposed in 2002[5], pushing the development of voxel art every step of the way. In particular, with the improvement of computing power and advances in storage technology, high-resolution voxel rendering has become possible[6].

Voxel art is also widely used in different fields. In medical imaging, voxels are used to create high-resolution 3D surface models to help doctors better understand patient conditions.[3]. In a study, Nagaoka et al. (2004) utilized MRI technology to develop high-resolution whole-body voxel models of Japanese adult males and females. These models were primarily used for dosimetry of electromagnetic fields, providing important insights into structural and anatomical accuracy. This study demonstrated the potential of voxel technology in creating precise models for medical assessments[7]. In a significant advancement within the field of medical imaging, Ambrosanio et al. (2017) [8]introduced a novel method for the intra-voxel analysis in magnetic resonance imaging (MRI). Utilizing techniques such as sparse Bayesian learning, this approach enhances diagnostic capabilities by enabling detailed analysis of the composition within each voxel. This methodology not only improves the accuracy of diagnostics but also facilitates a deeper understanding of the complex structures within the scanned tissue. Such technological advancements are pivotal in refining the precision of medical diagnostics and offer substantial potential for future research in medical imaging applications. Voxels are a big part of this. In computer graphics, voxel art is used to create complex visual effects and interactive sculptures[5]. Additionally, voxel art is used for interactive graphics in virtual reality[9], and voxel refinement in optical direct write lithography[10].

In service design, voxel art can be utilized to create interactive and engaging environments that improve customer experiences. For example, in healthcare service design, voxel art can be used to create detailed and interactive 3D models of human anatomy, which can be used for patient education and training for medical professionals. In retail, voxel art can enhance virtual shopping experiences by creating detailed and interactive product models and store layouts.

However, voxel art also faces some challenges. For example, the choice of voxelization algorithm and data structure is critical for handling large dynamically changing scenes[10]. In addition, real-time rendering and interactivity of voxel art is also an important research direction.[9]. To overcome these challenges, researchers have proposed various optimization algorithms and techniques, such as the Pixels to Voxels algorithm[9], voxel DAGs and multi-resolution hierarchies[11], and a voxel-based shape grammar[12].

Over the past three decades, new conceptualizations around the human body in conjunction with technology and machines have led to the development of new artistic practices that develop in parallel with technological advances in biology, medicine, and computing.[13]. The historical development and key technological breakthroughs of voxel art are reflected in the deep integration of technology and art. Especially in the past three decades, with the advancement of biotechnology, medicine and computing technology, new conceptualizations of the human body have promoted art. Development of practice. In the field of medical imaging, voxel art improves the diagnostic process and patient experience by providing more intuitive, easier-to-understand images. Although traditional two-dimensional (2D) images are widely used in medical diagnosis, they often suffer from ambiguity and occlusion problems in interpretation due to the three-dimensional nature of human anatomy.[14]. Voxel technology can effectively solve these problems by providing three-dimensional (3D) imaging modalities, such as CT, MRI, and 3D ultrasound, thereby improving diagnostic accuracy.

The INTEGRARTE project is a classic example of physical interaction that emphasizes the importance of physical involvement throughout the interaction process. This project exemplifies the use of voxel art in virtual reality by

introducing physical experience through motion visualization and sound. This art form is not only a visual enjoyment, but also allows the audience to experience and feel the works of art more deeply through physical participation.[15]

Voxel art uses three-dimensional cubes (voxels) to construct graphics. This method is not only used in the field of visual arts, but also widely used in digital product and virtual reality scene design. For example, Langfan Yuedong Culture Media Co., Ltd. involves voxel art self-media services and virtual reality scene design products. In addition, new architectural projects also explore the unique aesthetics of architectural culture through voxel methods.



[Figure 1] Luoyang Mingtang produced by Langfan Yuedong Culture Media Co., Ltd. using voxel art

On December 10, 2022, Samsung TV collaborated with the "Voxel Ark" digital art exhibition to bring a new immersive viewing experience to the audience. Its content starts from the biological concept of "co-evolution", uses a virtual environment created by digital animation, and uses interactive technology to lead the younger generation to feel the power of life and pay attention to issues related to the protection of wild animals and endangered life forms.



[Figure 2] Voxel Ark

Games are one of the most suitable stages for voxel art. Voxel art provides game developers with rich means of visual expression by constructing a three-dimensional space using cubes as units. Due to the characteristics of voxels, it is particularly good at making games with great creativity and freedom. Minecraft is a typical example. It uses voxel art to create an open sandbox world where players can explore, build, and survive challenges.. This art form not only enhances the interactivity and immersion of the game, but also provides players with a space for unlimited creativity. Terasology is an open source voxel game inspired by Minecraft and designed to be super scalable. As a free and open source game, Terasology offers a unique building and gaming experience inspired by Minecraft, Dwarf Fortress and Dungeon Keeper. Players can survive and explore in a voxel world. In the game, players can destroy and collect various types of bricks and use them to build buildings or store them in the inventory. The main features of Terasology's open source voxel sandbox include its high degree of scalability and modular construction, game design that integrates elements of survival and discovery, design concepts influenced by multiple classic games, and continuous exploration of the possibility of adding new features, and rich interactive elements in the game.

"Enshrouded" combines survival, crafting and action RPG combat elements. Players can build complex buildings and underground structures in the game to change the world's terrain and landscape. The game is set on a vast continent based on voxel architecture, providing players with a vast stage to explore and build. is a voxel-based open world.

However, voxel games can experience performance issues when dealing with large numbers of models. For example, running a model with a large number of faces directly in Unity will cause the FPS to be lower than 15, and the mesh face count of the model needs to be deeply optimized to improve the smoothness of the game.. This shows that although the voxel model has its advantages, technical challenges still need to be paid attention to in practical applications to ensure that the performance of the game does not affect the player experience.

In the world of character design, voxel art can be used to create unique visual characters. Zach Soares is a self-taught voxel artist who uses voxel art to start from the most basic blocks and work his way up to create complete voxel renderings, including character modeling, rigging, and animation. This shows that voxel art can not only be used for static character design, but can also be extended to dynamic character performance, providing new possibilities for animation production.

Voxel art is a powerful technique that uses three-dimensional pixels to create images or models. Although there are some challenges, the scope of applications for voxel art will continue to expand as technology continues to advance and innovate. Future research may focus on improving the efficiency, quality, and interactivity of voxel art.

The development trend of voxel art

Voxels provide endless possibilities for artistic creation by building tiny cubes in digital space to create complex three-dimensional models. In 2002, with the proliferation of multi-megabyte RAM, high-resolution voxel rendering was no longer a distant dream.[6]. Digital Domain has developed a unique and animator-friendly way of working that is revolutionizing the way volumetric effects are created. This means that voxel art has not only improved at the technical level, but has also become more user-friendly and efficient in practical applications. This way, artists can more easily control and modify their work, creating more detailed and realistic visuals. With the continuous advancement of computer hardware, the disadvantage of voxels in occupying too much memory will gradually be resolved.

In terms of physical simulation, voxel games and polygon games each have their own characteristics and application areas, and they differ in how close the simulation effect is to the real world. Voxels handle large amounts of detail very well because each voxel is an independent unit and can be processed individually. This feature allows objects in voxel games to be destroyed or changed in great detail. Mari Velonaki and her colleagues argue that "physical incarnations of virtual agents greatly facilitate interactions between people and 'characters' because the characters physically coexist in the same space as the human and have the various effects of this coexistence." [16] The physical simulation characteristics of voxels make human-computer interaction more credible, which is very useful for improving the user experience of players. In the future, game developers can deeply combine this feature with the gameplay to create works with a high degree of interactive freedom. On the other hand, the characteristics of voxels make them particularly good at simulating fluids, collision responses and material deformations, which is particularly important in film special effects production.

Nowadays, AI has fully entered all walks of life and has become an irreversible trend. The combination of voxel technology and artificial intelligence (AI) has broad application prospects, especially in the fields of game development, computer graphics, three-dimensional modeling, and geographic information systems. This combination can increase automation, enhance creative solutions, and improve the overall efficiency of the system.

The characteristics of voxels make them particularly suitable in the field of AI. A 2021 study proposed a new voxel-based three-view hybrid parallel network for 3D shape classification. This method first obtains the depth projection

view of the 3D model from the front view, top view and side view, thereby retaining the spatial information of the 3D model to the greatest extent. A series of comparison and ablation experiments show that the algorithm achieves competitive performance in 3D object classification tasks[17].

Not only has it made achievements in the field of model recognition, but the advantages of voxels over polygons in generating content are also very obvious. There are still many problems with the current AI-generated 3D models. The most serious ones are chaotic wiring, which cannot meet the specification requirements and cannot be accepted and used by professional practitioners. The voxel model does not have wiring problems and can be used very well. Avoid the problem of poor wiring availability when deep learning generates polygonal 3D models. At the same time AI can leverage voxel data to automate complex design and modeling tasks, such as automated city planning and architectural design. AI algorithms can analyze large amounts of voxel data, automatically generate or optimize 3D models, reduce the need for manual input, and improve design efficiency and accuracy. There is currently data proving that AI-generated voxel models can effectively simulate real cases of breast cancer, although there are some acceptable deviations due to limited resolution.[18] This shows that the AI-generated voxel model is very promising and has considerable room for improvement. More research can be done on the efficiency and accuracy of AI-generated voxel models in the future. Currently, AI has made significant progress in generating voxel models. Andrew Brock et al. proposed a generative and discriminative voxel modeling method based on convolutional neural networks (CNN), which can generate and classify complex voxel models. Zeyu Hu et al. developed VMNet (Voxel-Mesh Network), which combines voxel and grid structure information to provide more accurate results for 3D semantic segmentation of indoor scenes. A study in 2023 developed a Transformer-based semantic scene completion framework that can output complete 3D volumetric semantics from only 2D images[19]. Generating voxel models for AI has demonstrated its technical potential.

As a unique art style, voxel art is loved by many people. However, among the game engines on the market, the polygonal game engine occupies a huge market share and a lot of money and technology have been invested. This makes the polygonal game engine It has more advantages in technology accumulation. In terms of visual performance, polygonal game engines are often more expressive. But the voxel model also has a lot of accumulation of rendering technology, and the game engine is an important tool for integrating technology to achieve commercialization. Currently, only individuals or small studios are developing some game engines, and engines of the scale of unity and unreal engine have not yet appeared. The development of voxel game engines will be of great significance in promoting voxel art and unleashing more potential of voxel art creation in the future. A good technology integration tool can attract more artists to use it to create, and the popularity gained from the dissemination of artworks will feed back to artists and creative tools, becoming a virtuous cycle[20].

Through AR technology, public art works can be presented in an interactive way, allowing viewers to gain a unique experience when interacting with these artworks[21]. The use of mixed reality technology, such as interaction with robots or virtual characters in gallery spaces, also demonstrates the positive response of audiences to artworks that they can "talk to" and "respond to"[22]. The expression form of voxels can make the interactive experience freer and richer, and will bring more possibilities, such as Interesting new forms of theater and live performance can be created. In addition, based on personal device performance considerations and the rise of cloud technology, voxel computing tasks can be completed by the cloud. This also brings the advantages of combining voxel art with cloud technology: breaking the limitations of computing power and promoting the development of UGC platforms. Combined with the

optimized voxel art production tools mentioned above, it is easier for ordinary people to enter art creation and jointly create the metaverse. The open metaplastic platform provides the theoretical and artistic context for the realization of new media and interdisciplinary methodologies that lie between reality and virtual reality[23]. The evolution of metaplastic spaces and virtual worlds, from their prototypes to definitions, demonstrates the definition of metaplasticity in applied fields of art and science. This interdisciplinary methodology not only promotes the integration of reality and virtual worlds, but also provides theoretical foundation and technical support for the construction of the metaverse.

Conclusion

This study has explored the evolution and future development trends of voxel art amid the wave of new technologies, highlighting its unique value in digital art and its extensive potential in multidisciplinary applications. As a distinctive form of digital art, voxel art has made a significant impact in various fields, including medical imaging, game design, and virtual reality. In medical imaging, voxel technology has enabled high-resolution 3D modeling, allowing doctors to diagnose and treat diseases more accurately. Voxel models combined with artificial intelligence (AI) have shown remarkable potential in breast cancer diagnosis. In game design and virtual reality, voxel art has given developers and designers unlimited creative freedom to build diverse virtual worlds, as games like Minecraft and Terasology have proven the vast potential of voxel art in the gaming world. In service design, voxel art has been instrumental in creating interactive and immersive environments that enhance user experience and engagement, demonstrating its versatility and broad application potential.

On the technical side, the production efficiency and graphical performance of voxel art have benefited from the continuous advancements in computer hardware and algorithms. By applying AI technologies like deep learning, generative adversarial networks (GANs), and convolutional neural networks (CNNs), significant progress has been made in the automated generation and recognition of voxel models. However, voxel art still faces challenges in real-time rendering performance, data structure optimization, and large-scale scene processing. To overcome these challenges, researchers have developed advanced techniques such as Neural Sparse Voxel Fields (NSVF) and multiresolution hierarchies, improving the efficiency of voxel model generation and rendering.

The combination of AI and voxel art is particularly promising, especially in game development, computer graphics, 3D modeling, and geographic information systems (GIS). AI can increase automation, enhance creative solutions, and improve overall system efficiency. Recent developments include convolutional neural networks (CNNs) that can generate and classify complex voxel models, and Transformer-based networks that output complete 3D volumetric semantics from 2D images. For instance, Andrew Brock et al. proposed a generative and discriminative voxel modeling method using CNNs, which demonstrated high performance in generating and recognizing complex voxel models. Zeyu Hu et al. developed the Voxel-Mesh Network (VMNet), combining voxel and mesh structures to deliver more accurate 3D semantic segmentation in indoor scenes. These advancements provide a foundation for future progress in automated voxel model generation.

Furthermore, AI can analyze large amounts of voxel data to automate complex design and modeling tasks, such as automated city planning and architectural design. While current AI-generated 3D models still face challenges like chaotic wiring, voxel models do not have wiring problems and can easily avoid poor mesh quality issues. This makes

them more suitable for automated generation. For example, a study in 2021 demonstrated the feasibility of AI-generated voxel models in breast cancer diagnosis, providing valuable insights into the potential of AI in medical imaging.

In addition to automated model generation, the integration of AI and voxel art offers opportunities to enhance user interactivity. By combining AI algorithms with augmented reality (AR) and virtual reality (VR), artists can create more immersive and interactive experiences, engaging audiences at a deeper level. Public art projects using mixed reality and interaction with robots or virtual characters have shown positive responses from audiences. As voxel art continues to evolve, integrating AI with mixed reality technologies will lead to richer artistic experiences and innovative forms of storytelling and live performances.

Overall, the evolution of voxel art highlights the importance of interdisciplinary collaboration and innovative thinking. By integrating advanced technologies like AI, AR, and data analytics, voxel art not only brings new techniques to artistic expression but also demonstrates its unique application value in game design, virtual reality, and medical imaging. In the future, with the further development of computing technology and the continuous application of optimization algorithms, voxel art is expected to overcome existing technical bottlenecks and achieve wider commercial applications and cultural influence. Ultimately, the development of voxel art will provide new perspectives for digital art creation and open new avenues for the fusion of art and technology, including the enhancement of service design practices through more interactive and immersive user experiences.

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