

Real-Time Rendering: A Comprehensive Review of Techniques and Application Domains

Goldi Soni

Assistant Professor
Amity University Raipur
gsoni@rpr.amity.edu

Madhudeep Singh

A801052224089, B. Tech CSE
Amity University Raipur
meenasinghkshatri@gmail.com

Shraddha Dansena

A80105224085, B. Tech CSE
Amity University Raipur
shraddhadansena9a948@gmail.com

Abstract

Real-time rendering is one of the core technologies in computer graphics which allows for visualization on a display device by producing images at a fast rate. This paper reviews five key research papers which have played an essential role in advancing rendering technology. The selected articles provide insights into the current classification of various rendering techniques ranging from basic classifications of rendering methods up to GPU acceleration and ray-tracing techniques currently utilized in game developing, VR, and simulations. Rendering techniques considered in these papers include geometric rendering, image-based rendering, global illumination, shadow mapping and real-time ray tracing techniques. Advances in the field of hardware, especially graphics processing units, and dedicated graphic systems allow implementing complex shading and lighting models that improve realism. Some of these improvements are described in this paper. Other topics related to rendering techniques covered in this work include optimization techniques, combination of techniques, and integration of artificial

intelligence based techniques. Based on comparative analysis, this study indicates that currently, hybrid rendering techniques that combine rasterization and ray tracing techniques are the most promising areas. Several problems associated with rendering techniques are described in this study. Finally, some possible directions of further research are highlighted.

Keywords—Real-time rendering, ray tracing, global illumination, GPU computing, Computer Graphics

I. Introduction

Real-time rendering implies rapid generation of images enabling various forms of interactions, including video games, simulations, virtual realities, etc. In contrast to offline rendering used for movie production and requiring hours to render a single image, real-time requires much faster operation measured in milliseconds. It is therefore

obvious that the performance optimization is essential in case of real-time rendering.

The history of real-time rendering goes back to simple wireframed images and shading methods. However, with the improvement of computer graphics hardware and introduction of dedicated GPUs (Graphics Processing Units), contemporary systems are capable of creating extremely realistic images applying techniques of global illumination, ray tracing, etc.

II. Literature Review

The field of real-time rendering witnessed a remarkable evolution in the last twenty years, owing largely to improvements in graphic hardware, new algorithms, and the increasing need for sophisticated interactive systems. The initial stage of research in this field was dedicated to studying various categories of rendering techniques, differentiating geometry-based from image-based approaches and showing the drawbacks and benefits of both. At the first stages, it became clear that none of these technologies could be used in their pure form, whereas hybrid solutions proved to be the most efficient ones.

Next developments concentrated mainly on further improvement of rasterization-based renderers, which dominated the market at that time. New technologies such as shadow mapping, screen space ambient occlusion, and spherical harmonics allowed achieving much better lighting and shading effects in video games. In addition, various techniques aimed at optimizing complex scenes were created, such as LOD and impostors for outdoor scenes. Moreover, new approaches were tried out, such

A number of various ways have been proposed to achieve faster and better rendering of images. Those methods could be considered as geometry based, image-based rendering algorithms, or combinations of these two approaches. Recently, the use of machine learning and dedicated hardware was introduced into rendering systems.

In this literature review five relevant studies devoted to real-time rendering will be discussed.

as introducing principles of control engineering into the system of renderer to achieve stability when working with frame rate.

One of the most important breakthroughs in the development of real-time rendering happened when real-time ray tracing began to be used in interactive systems. At the initial stage of development, this technique appeared to be very complicated for implementation, however, due to advanced algorithms and accelerated computation with specialized hardware, real-time ray tracing has become possible now. Currently, researchers have confirmed that real-time ray tracing makes interactive applications look much better but requires considerable resources. Hybrid ray tracing and rasterization became a norm in the industry.

The issue of global illumination is of particular importance for modern research into real-time rendering. Several techniques such as reflective shadow maps, voxel-based lighting, illumination probes, and virtual clusters of point light have been introduced in order to

enhance the performance of real-time lighting. It appears that in practice, each of them has some limitations, therefore all the above-listed techniques are used together. Recent development allowed achieving realistic lighting even in very big dynamic open world environments.

Firstly, the advent of VR/AR imposed constraints such as tight latency requirements and high frame rates. Research in the field paid particular attention to developing foveated rendering algorithms based on human vision mechanisms and interaction models that allow to achieve efficient rendering pipelines optimized according to the behavior pattern of users. Maintaining low latency was identified as the crucial factor for providing comfortable user experience, whereas optimized rendering pipelines could significantly improve performance. Apart from their entertainment use cases, VR/AR devices were found to be useful in healthcare, education, and industry training.

Various domain-specific applications have stimulated development of rendering in many ways. For instance, in the sphere of medical visualization, real-time rendering techniques allow to explore the volumetric data interactively and increase the effectiveness of diagnostic processes and preparation for surgery. In architectural visualization, game engines have become popular tools for producing interactive walkthroughs that look photorealistic and provide valuable feedback to designers and communicate designs to clients.

Machine learning and artificial intelligence have recently gained popularity among researchers working in real-time rendering. For example, neural networks are employed to perform tasks such as generating levels of detail, denoising images, radiance caching, and

optimizing rendering. Such techniques as neural radiance caching and reservoir sampling have proven their ability to significantly accelerate rendering process and handle up to a million of light sources in real time. Deep learning has also proven itself as an effective tool that allows to adjust rendering parameters automatically depending on hardware limitations.

Interactive path tracing and volumetric rendering have been recently developed successfully, narrowing down the quality gap between real-time and offline rendering even further. Using hardware acceleration and smart sampling methods, researchers achieved impressive results in simulating complex phenomena such as cloud simulation, fire and smoke simulations, and medical data visualization. The contributions of various industries such as those made by major tech corporations and game engine developers were instrumental in promoting advances in real-time rendering.

Thus, one can note the following trends in the development of real-time rendering techniques: the shift from rasterization to hybrid rendering approach, convergence of real-time and offline rendering quality, increased application of AI-driven methods, and the growing importance of problem-oriented optimization. The current trends imply some unresolved problems and challenges that need more research and development, e.g., achieving dynamic global illumination or dealing with complex materials and large-scale scenes.

Conclusion

In summary, real-time rendering has become a very interdisciplinary process combining computer graphics, artificial intelligence,

hardware, and even human perception. Today’s rendering engines employ an arsenal of technologies in order to find an optimal tradeoff between realism and performance. In the future, research will probably concentrate

on more tightly coupling AI, developing universal rendering architectures, and improving hardware/software co-design, thus delivering more realistic and efficient real-time graphics.

III. Comparison of Past Publishers

S. No.	Title of Paper	Year	Proposed Objective	Methodology	Conclusion/Result
1.	A Survey and Classification of Real Time Rendering Methods	2000	To classify and analyse different rendering techniques	Literature survey and taxonomy development	Established framework separating geometry-based and image-based rendering
2.	Advances in Real Time Rendering in 3D Graphics and Games	2009	To present the state of the-art rendering techniques used in games	Practical implementations and performance comparisons	Improved techniques for shadows, lighting, and ambient occlusion
3.	Physically Based Rendering: From Theory to Implementation	2016	To simulate realistic light transport in rendering systems	Mathematical modelling and rendering algorithms	Achieved more realistic lighting and material simulation on
4.	Real-Time Global Illumination Techniques	2018	To enable dynamic lighting in interactive scenes	Approximation algorithms and GPU optimisation on	Improved realism with manageable computation cost

5.	Real-Time Ray Tracing Using GPU Hardware	2020	To integrate ray tracing in real-time graphics	Hardware acceleration on and hybrid rendering pipeline	Enabled real-time reflections, shadows, and global illumination
----	--	------	--	--	---

IV. Conclusion

From the analysis of the selected five research articles, it is evident that tremendous development has been witnessed in the area of real-time rendering technology. Initially, the primary objective of the research works was to classify the various forms of rendering algorithms and their respective merits and demerits. However, as time progressed, more attention was devoted to practical applications and optimization of the algorithms.

The use of GPU computing technology has been instrumental in developing sophisticated algorithms like global illumination and ray tracing in real-time. Hybrid rendering methods that combine rasterization and ray tracing have proved to be an optimal choice for striking the right balance between performance and realism.

As computer technology continues to advance, it is possible that the quality of real-time rendering will come close to that of offline rendering.

V. Future Scope

Various areas of interest for future research on real-time rendering are:

1. The use of AI and neural rendering approaches.
2. The implementation of efficient global illumination algorithms in real-time rendering.
3. The improvement of low-power device compatibility in real-time ray tracing.
4. The enhancement of rendering techniques for use in virtual/augmented reality systems.
5. The implementation of machine learning for noise filtering in real-time rendering.
6. The creation of more energy-efficient GPUs.
7. The application of cloud-based rendering techniques.

REFERENCES

1. Matusik, W., Buehler, C., Raskar, R., Gortler, S.J., and McMillan, L. (2000). "A Survey and Classification of Real Time Rendering Methods:' MERL Technical Report TR2000-09.
2. Tatarchuk, N., Barczak, J., and Bilodeau, B. (2009). "Advances in Real-Time Rendering in 3D Graphics and Games 1:1 ACM SIGGRAPH 2009 Course Notes.
3. Lluch, J., Camahort, E., and Viv6, R. (2004). "Interactive Rendering of Outdoor Scenes: Real Time Visualisation of Trees and Plants:' Computers & Graphics, 28(4), 573-585.
4. Wong, K.W. and Wang, R. (2012). "Real-Time Rendering: Computer Graphics with Control Engineering:' CRC Press, Taylor & Francis Group.
5. Wald, I., Kollig, T., Benthin, C., Keller, A., and Slusallek, P. (2004). "Real me Ray Tracing for Current and Future Games:' Proceedings of Eurographics Symposium on Rendering.
6. McGuire, M., Shirley, P., Wyman, C., and Pharr, M. (2018). "Introduction to RealTime Ray Tracing:' SIGGRAPH 2018 Course.
7. Bha a, S., Jamwal, D., Zutshi, O., and Kachhwaha, H. (2025). "Ray Tracing: Impact on the Gaming Environment:' In: Rathore, V.S., Piuri, V., Babo, R., Karthik, S. (eds) Universal Threats in Expert Applications and Solutions. UNI-TEAS 2025. Lecture Notes in Networks and Systems, vol 1452. Springer, Singapore.
8. Intel Corporation on Graphics Team (2022). "Intel Arc Graphics Developer Guide for Real-Time Ray Tracing in Games:' Intel Developer Documentation.
9. Lambriu, N., Paun, F., and Zamfir, C.G. (2021). "Comparative Analysis of RealTime Global Illumination Techniques in Current Game Engines:' IEEE Access, 9, 125158125183.
10. Herholz, S., Elek, O., Vorba, J., and Krivanek, J. (2017). "A Real-Time Global Illumination Approach for High Resolution Reflected Shadow Maps in Open World Scenes:' Journal of Computer Graphics Techniques, 6(3)
11. Prutkin, R., Kaplanyan, A.S., and Dachsbacher, C. (2012). "Reflective Shadow Map Clustering for Real-Time Global Illumination Proceedings of Pacific Graphics.
12. Kaplanyan, A. and Dachsbacher, C. (2010). "High-Quality Global Illumina on Rendering Using Rasterization:' GPU Gems 2, Chapter 38, NVIDIA Developer.
13. Majercik, Z., Marrs, A., Spjut, J., and McGuire, M. (2021). "Scaling Probe-Based Real-Time Dynamic Global Illumination for Production:' Journal of Computer Graphics Techniques, 10(2).

14. Cipresso, P., Giglioli, I.A.C., Raya, M.A., and Riva, G. (2018). "The Past, Present, and Future of Virtual and Augmented Reality Research: A Network and Cluster Analysis of the Literature." *Frontiers in Psychology*, 9, 2086.
15. Albert, R., Patney, A., Luebke, D., and Kim, J. (2017). "Latency Requirements for Foveated Rendering in Virtual Reality." *ACM Transactions on Applied Perception*, 14(4), Article 25.
16. Leong, T.L., Saun, T.J., Mailey, B., and Vorstenbosch, J. (2021). "Virtual and Augmented Reality for Biomedical Applications." *Cell Stem Cell*, 28(8), 1476-1481.
17. Rokhsaritalemi, S., Sadeghi-Niaraki, A., and Choi, S.M. (2020). "Augmented and Virtual Reality Evolution and Future Tendency." *Applied Sciences*, 10(1), 322.
18. Takikawa, T., Litalien, J., Yin, K., Kreis, K., Loop, C., Nowrouzezahrai, D., Jacobson, A., McGuire, M., and Fidler, S. (2021). "Neural Geometric Level of Detail: Real-time Rendering with Implicit 3D Shapes." *IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR)*, 11358-11367.
19. Li, X., Zhang, Y., and Wang, H. (2024). "Exploration and Real-time Rendering Optimization Path Using Deep Learning Methods." *Proceedings of the 2024 5th International Conference on Computer Science and Management Technology*, 629634.
20. Chen, J., Liu, M., and Zhang, Q. (2024). "Research on Real-time Graphics Rendering and Interaction Optimization Strategies in Virtual Reality." *Applied Mathematics and Nonlinear Sciences*, 9(1), 1-22.
21. Hahn, N.A. (2013). "Integrating Interleaved Sampling into Reflective Shadow Maps and Splatting Indirect Illumination." *DigiPen Institute of Technology Master's Thesis*.
22. Villegas, J. (2016). "Deferred Voxel Shading for Real Time Global Illumination." *Personal Research Publication*.
23. Tatarchuk, N., Tchou, C., and Kaplanyan, A. (2023). "Advances in Real-Time Rendering in Games." *ACM SIGGRAPH 2023 Course Notes*.
24. Hofmann, N., Hasselgren, J., Clarberg, P., and Munkberg, J. (2021). "Interactive Path Tracing and Reconstruction of Sparse Volumes." *Proceedings of the ACM on Computer Graphics and Interactive Techniques*, 4(1), Article 8.
25. NVIDIA Graphics Research Team (2020). "Real-Time Ray Tracing Realized: RTX Brings the Future of Graphics to Millions." *NVIDIA Technical Blog*.
26. Epic Games Documenta on Team (2023). "What is Real-Time Ray

Tracing?" Unreal Engine
Documentation.

27. Various Medical Imaging Researchers (2019-2023). "Real-Time Rendering in Medical Visualisation: Survey of Techniques and Applications." Compilation of medical imaging literature.
28. Various Architecture and Design Researchers (2018-2024). "Architectural Visualisation on with Real Time Rendering: Industry Survey." Compilation of architectural visualization literature.
29. Bitterli, B., Wyman, C., Pharr, M., Shirley, P., Lefohn, A., and Clarberg, P. (2020). "Spatiotemporal Reservoir Resampling for Real-Time Ray Tracing with Dynamic Direct Lighting: • ACM Transactions on Graphics (SIGGRAPH), 39(4), Article 148.
30. Muller, T., Rousselle, F., Novak, J., and Keller, A. (2021). "Neural Importance Sampling:• ACM Transactions on Graphics (SIGGRAPH), 40(3), Article