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RENDERING

FREELY AVAILABLE ON THE INTERNET

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http://sglab.kaist.ac.kr/~sungeui/render

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Preface

Rendering is a way of visualizing various 3D models in 2D images or videos. It is one of fundamental tools in the field of computer graphics. Thanks to its ubiquitous demand, it is not only used for applications in computer graphics, but also widely used for many other fields.

There have been tremendous progress on rendering techniques. One of epitomes for rendering techniques is games, where we can see real-time, yet high-quality rendering images. These real-time techniques are commonly based on the concept of rasterization, which is the main theme of Part I of this book. Another successful application of computer graphics is movie. Unlike games, the movie production accommodates much longer computational time for higher rendering quality. Ray tracing based rendering techniques, therefore, are utilized more frequently for movies. These ray tracing techniques are mainly discussed in Part II.

These techniques have been developed for many decades. For example, the concept of ray tracing was introduced to the field of computer graphics at 1980. Since rendering techniques have been studied for a long period of time, it is very hard to catch up all the major concepts, unless properly guided. Also, new concepts and techniques have been constantly proposed.

Many graphics books are available, but only a few rendering books are available. Furthermore, most of them focuses either one of two main rendering techniques, rasterization and ray tracing, in an advanced manner. Given this situation, I decided to treat both of them, while covering most fundamental concepts of those techniques. I will also cover advanced topics as I have more time, built on top of those basic concepts.

In order to save time of writing this book and better explain concepts, I re-used many existing materials (e.g., images) of lecture slides and papers. For each of them, I mentioned its source, but here I'd like to point out that I borrowed many images from lecture slides used in a Computer Graphics course given at University of North Carolina at Chapel Hill for Part I and lecture slides of Prof. Kavita

Bala for Part II. Also, the latex template of this book is based on the Tufte's design style and is based on the Apache license.

Finally, many students of CS380, CS480, CS580 offered at KAIST posed many interesting questions that are the basis of many Q&A parts of this book. Also, many of them gave useful comments on different parts of this book.

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1 Introduction

Rendering is one of the fundamental techniques in computer graphics, visualization, and many other related fields. Since the rendering technique has been widely used in many different applications, its perceived meaning can vary a lot depending on people using it.

For users and developers for games, rendering techniques should be interactive and can support many interesting visual effects (e.g., magic fire). In terms of the performance, the rendering part used in games should take less than 10 ms, since the whole frame takes 33 ms assuming 30 frames per second, and other parts (e.g., game logics and network) can take 10 ms to 20 ms. As a result, rendering methods adopted in such games should be extremely fast[1].

[1] Games requires real-time rendering techniques spending only 10 ms for each frame

For viewers, artist, and developers for movies, rendering techniques should be photo-realistic and provide even artistic controls on effects that they want to express. In many movies (e.g., Jurassic Park), we see scenes captured from real cameras and mixed together with computer generated effects and virtual objects. Rendering methods for these movies should be indistinguishable between real and virtual scenes. As a result, these techniques are usually based on physics and simulations of light and material interactions. Furthermore, artists and directors making such movies are not satisfied with such realistic looking results[2]. They want to convey particular emotion and mood on computer generated effects. We thus need techniques accommodating such user inputs.

[2] Rendering used for movies needs to provide realistic results, while supporting various artistic directions

As you can see, there are such a wide variety of rendering applications with different characteristics. Therefore, a single rendering method satisfying all those characteristics and requirements is hard to be developed. As a result, many different rendering and visualization methods have been developed. Instead of covering them in detail in this book, we would like to cover main techniques and their variations.

1.1 *Rendering Techniques*

At a high level, there are two main, but different rendering techniques: rasterization and ray tracing.

There are two main rendering techniques: rasterization and ray tracing

Rasterization is to traverse triangles of a model and project triangles to the frame buffer. Rasterzation is classified as an object driven rendering method and has been widely accelerated by various hardwares (e.g., GPUs) because of its simplicity. Thanks to the simplicity and the hardware acceleration, rasterization based rendering methods can show an interactive rendering performance even for massive models consisting of more than hundreds of millions of triangles [3]. Thanks to these features, rasterization techniques are available in OpenGL and DirectX, graphics APIs, and adopted in many games through game engines (e.g., Unity).

[3] Sung-Eui Yoon, Brian Salomon, Russell Gayle, and Dinesh Manocha. Quick-VDR: Interactive View-dependent Rendering of Massive Models. In *IEEE Visualization*, pages 131–138, 2004

Ray tracing, however, generates rays per each pixel and finds triangles that intersect with these rays by traversing an acceleration hierarchy. Ray tracing is classified as a view-driven rendering method and requires random access on meshes and hierarchies. Therefore, it requires much complex control logics and caches and in turn has been showing much (e.g., two orders of magnitude) slower performance than that of rasterization based methods.

Although ray tracing shows much slower performance than rasterization, it can naturally support physically-correct rendering because its algorithm follows the physical intersections between lights and materials. Therefore, it has been widely used in offline applications (e.g., movies) that require high-quality rendering results. On the other hand, rasterization has been widely used for interactive applications such as games.

While there are such stereotypical usages of rasterization and ray tracing, these techniques are still under active, yet steady development, and are thus improved in many different directions. For example, many games want to interactively support realistic rendering effects that ray tracing has been able to support in the domain of rasterization. Furthermore, some of recent applications such as Poketmon Go, an AR (augmented reality) application, needs to seamlessly integrate camera-captured scenes and computer generated effects. To realize this, ray tracing and rasterization techniques are used together to achieve both the performance and quality[4].

[4] Ray tracing and rasterization are used together for achieving the fast performance and high quality.

Relationship with other fields. Computer graphics commonly assumes that virtual scenes are represented by various types of models such as triangles for the scene geometry and BRDF for material appearance (Fig. 1.1). The main output of various computer graphics methods is an image or a series of images known as video. Com-

Figure 1.1: An overall structure of computer graphics. Images are adopted from Google image search.

mon methods for computer graphics include rendering, a type of simulation for light and material interactions, and many other types of simulations such as cloth, fire, character simulations. Computer vision commonly starts with images and attempts to extract models (e.g., geometry and BRDF), and image processing deals with images for denoising or many other image improvement. One of well known image processing tools is Photoshop from Adobe.

These different approaches have been developed and matured in its own fields (e.g., computer graphics and vision). Recently, these techniques developed from different fields are mixed together to create novel applications and approaches. As a result, their boundaries become rather blurred in these days.

Applications of computer graphics. Numerous applications of computer graphics exist. A lot of them are in the entertainment business for making games and movies (Fig. 1.2). Some movies are generated totally based on computer graphics, or some scenes of movies have various special effects. They also get renewed attentions with other related technology advances such as introduction of 3D TV to consumer markets and head mounted display (HMD) for virtual reality (VR) and augmented reality (AR).

In addition to various entertainment applications, various product designs and analysis such as computer-aided design (CAD) uses computer graphics. Also, medical and scientific visualization is a big part of computer graphics. Finally, information visualization that associates various geometric meaning to complex data (e.g., graphs) are getting bigger and bigger.

Organization of the book. Rendering has been studied in various aspects covering optics and novel applications. As a result, we focus on the following two parts in this book.

Figure 1.2: Applications of computer graphics. From the top left, image cuts of startcraft, toy story, a CT image of mouse skull, a weather visualization from LLNL, and a double eagle oil tanker for CAD.

1. **Rasterization.** Rasterization is an efficient rendering technique that mainly works in an image space that can be easily accelerated in GPUs. This approach is discussed in Part I.

2. **Ray tracing.** Ray tracing is a common approach of simulating the physical interaction between the light and materials. It is therefore widely used for providing physically-based rendering. This is discussed in Part II.

1.2 *Related Materials*

Rendering techniques have been studied for several decades, and excellent books are available. We list some of them here:

- Fundamentals of Computer Graphics, by Peter Shirley et al. [5]. This book covers various fundamental topics of computer graphics.
- Physically based rendering by Pharr et al. [6].. This book also covers a wide variety of topics of physical-based rendering. It also provides source codes for all the concepts discussed in the book. If you want to have hands-on experience on physics-based rendering, this book provides both theoretical concepts and practical programming tools.
- Advanced Global illumination, by Dutre et al. [7]. This book covers physics-based rendering techniques.
- Realistic ray tracing, by Shirley et al. [8]. While this book is rather old, it covers various concepts and detailed information of ray tracing, which is one of main ingredients of building physics-based rendering.

[5] Peter Shirley and Steve Marschner. *Fundamentals of Computer Graphics*. A. K. Peters, Ltd., 3rd edition, 2009

[6] Matt Pharr and Greg Humphreys. *Physically Based Rendering: From Theory to Implementation 2nd*. Morgan Kaufmann Publishers Inc., 2010a

[7] Philip Dutre, Kavita Bala, and Philippe Bekaert. *Advanced Global Illumination*. AK Peters, 2006

[8] Peter Shirley and R. Keith Morley. *Realistic Ray Tracing*. AK Peters, second edition, 2003

Google Scholar

Computer Graphics

Publication	h5-index	h5-median
1. ACM Transactions on Graphics (TOG)	71	104
2. IEEE Transactions on Visualization and Computer Graphics	58	78
3. Computer Graphics Forum	46	61
4. Computers & Graphics	28	43
5. The Visual Computer	24	37
6. IEEE Symposium on Visual Analytics Science and Technology	23	39
7. IEEE Pacific Visualization Symposium	21	34
8. IEEE Computer Graphics and Applications	21	31
9. ACM SIGGRAPH/Eurographics Symposium on Computer Animation	21	30
10. Symposium on Interactive 3D Graphics (SI3D)	20	32
11. Computer Aided Geometric Design	17	23
12. International Conference on 3D Web Technology	16	20
13. Graphical Models	15	23
14. arXiv Graphics (cs.GR)	15	22
15. Eurographics	15	21

Figure 1.3: This shows a list of graphics related conferences and journals according to Google Scholar at 2016. Note that many conferences papers in computer graphics are published at journals, and thus journals (e.g., ACM Trans. on Graphics) are ranked higher than well-known conferences (e.g., SIGGRAPH).

These books cover fundamental concepts of rendering, but lacks recent developments. If you want to follow those recent techniques, you can find recent papers through the following:

- Google scholar. You can find recent technical papers from various search engines. Especially, Google scholar is useful, since it also identifies papers that refer to a particular paper. By looking this information, you can find prior and future works given a particular paper.

- Graphics conferences and journals. Novel ideas are generated in every where. One can easily learn those novel ideas by looking at recent papers published at graphics conferences and journals. One of well-known of them is ACM SIGGRAPH, whose papers are published at a journal called ACM Trans. on Graphics (ToG). Google Scholar also provides a list of influential conferences and journals with their ranking (Fig. 1.3).

1.3 *Common Q & A*

Do we need an excellent artistic sense to study computer graphics or to become an technical expert in this field? Not really. Of course, it is always better to have a good artistic sense to work on visual data processing. However, if some jobs require such a high standard of artistic senses, those jobs may be for artistic designers, not for engineers. In my opinion, it is more important to have better engineering backgrounds (e.g., mathematical backgrounds and algorithm developments) and problem-solving skills. For example, I don't have any sense of art, but I work on computer graphics!

I have found that something like tea pot and bunny models are widely used in many papers and technical videos. Why? You made a good observation. Some of models including the Utah teapot and Stanford bunny have been created earlier as research results or research benchmarks. Then, these models are distributed to other researchers for their follow-on research. That's why these models are widely used in many papers.