Jon Peddie

Ray Tracing: A Tool for All

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Foreword I

Shaded rendering has been one of the central topics of computer graphics research since the 1960s. Over the following decades, researchers have developed rendering techniques that evolved step-by-step from smooth shading to realistic reflections and ultimately to a level of realism that allows us to ignore the fact that the rendered images are not real.

Back in the early 1980s, Jon Peddie and I met for breakfast one weekend morning to discuss ways to commercialize realistic rendering. At the time, the idea seemed far-fetched. Today, it has become commonplace and it has found applications we had not imagined.

Making use of realistic rendering, whether for Hollywood special effects, video games, or redecorating your living room still requires an understanding of what it is and how it works. Papers, journals, books, and courses dive into the topic and open up the world of rendering to the average programmer. But what if you are not a programmer? Today, most of us want to use the technology without programming it from scratch. Regardless, a sophisticated graphics system requires some understanding of the technology in order to get the most use from it. That's where Jon Peddie's text comes into play.

Somewhere between the ten thousand foot overview and the vast collection of GPU code hiding beneath the surface is a level of explanation and understanding that provides a prospective user with enough background to get started. This book covers that range in detail, but in a manner that can be understood without reviewing graduate-level mathematics. It does a particularly good job of identifying both hardware and software resources to enable a beginning practitioner to get up and running.

To me personally, the most compelling sections of the book are the ones that fall into the category labeled "I didn't know that!" The number of contributors and the diversity of approaches that have brought realistic rendering to its current state are remarkable. Rather than attempting to condense this all into a summary, Jon has opted for completeness and has given the reader a full view of the topic.

In essence, this book is a story. It explains the technology, the applications, and the products, while also providing a history. You, the reader, don't need to spend 40 years writing and reviewing technical papers on rendering and ray tracing. Just read the book.

Chapel Hill, North Carolina Turner Whitted

Foreword II

Ray tracing is a topic that has inspired many engineers, artists, and storytellers. For some, it is a computer graphics course; for others, it is a degree; and for many—an entire career.

I count myself as one of those people so inspired. One day strolling through the engineering library, I browsed through a book entitled simply "Introduction to Ray Tracing." It instantly captured my imagination. The images were strikingly beautiful (compared to the state of the art the time), the math was approachable, and it only took a few hours to produce a single image! I soon learned that I was not alone—that other students and researchers were exploring the frontiers "photorealism," or the idea that a computer-generated image could be indistinguishable from a photograph.

For me, this inspiration launched a career. I am now a Vice President at Nvidia where I lead a team of dedicated engineers who are striving to make ray tracing fast enough to be used in real-time computer graphics. The goal is to bring the techniques that have brought advancements in visual effects and animation to gaming and design. Many in the industry share that goal.

It was this role that introduced me to Jon Peddie and his vast sphere of influence. I quickly learned that he travels the world in pursuit of technology, especially computer graphics, and ray tracing in particular. He is always learning, asking questions, probing technology, and getting all sides of a story. Along with Kathleen Maher, Jon integrates this information into some of the most influential reports in the computer graphics industry, including TechWatch and the JPR Workstation report. In addition, Jon gives countless lectures, serves on advisory boards, and has been recognized by ACM and CAAD for his efforts.

That is why I was intrigued when he told me of his plan to write a book on ray tracing. Many technical books have covered this topic in great depth, and Jon mentions many of them herein. However, "Ray Tracing: A Tool for All" brings an entirely fresh perspective to the topic. While he covers the technology and business in great depth, it is approachable by technical and non-technical readers alike.

Ray tracing has roots in medieval times, but received first attention for computer graphics via a paper by Turner Whitted at SIGGRAPH 1979. Ray tracing operates by simulating the physics of light as particles that interact with various surfaces, using very few simplifying assumptions. Because the human visual system is highly attuned to lighting in the physical world, subtle details can make the difference between an object looking "realistic" and "fake." Ray tracing can capture these effects, such as global illumination, soft shadows and accurate materials. Consequently, ray tracing is nearly ubiquitous in computer animation and visual effects industry. It is also rapidly becoming the standard in product design, marketing, and even real-time gaming.

A ray tracing program can be simple enough to fit on a business card, but turning it into a fully functional system (or renderer) results in very large sophisticated software. The results can be undeniably beautiful, and this book highlights many of these examples.

What Jon has done is take all of this technical excitement—the passions of inventors, the curiosity of a student or researcher, the creativity of the artists—and mapped it to the ecosystem and companies in the modern world. He covers the businesses around ray tracing, the interplay between the technology and the companies, and he speculates on what the future will bring to the industry. True to Jon's reputation, the book is filled with facts, data, and unique insight. It discusses the history, the workflows, the research papers, the hardware, the start-ups, and the primary technical challenges being tackled in the industry today.

Behind the technology and businesses, the primary goal of computer graphics is to use a visual I illusion to tell a story. Whether used for entertainment, a product introduction, or to gain insight—ray tracing has found application in a broad set of industries. Jon outlines these applications and ecosystems in a clear manner.

I learned a lot from reading "Ray Tracing: A Tool for All." It collects the under-documented aspects of computer graphics and paints a portrait that blends both technology and business. I expect that it will help inspire even more people to join in the quest of photorealistic rendering.

Dr. Steven G. Parker
Vice President
Professional Graphics, Nvidia
Chapel Hill, North Carolina

Acknowledgements

How could anyone write a book like this without having too many friends? I've met so many people over the years, starting with Turner Whited in 1979, who have made incredible discoveries and inventions. And then, demonstrating their extraordinary grace and charity, they took the time to edit (and mostly correct) the material I sent to them—I am truly blessed.

I know I'm missing someone or two in this list, and to you, should you read this, I am truly sorry—call me, I'll make amends.

My benefactors and mentors—the folks who really know what ray tracing is about, this book really would not exist without these people.

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Chapter 1
Preface

Abstract The goal of this book is to explain the many methods of rendering a digital image in a computer and what is ray tracing. Ray tracing is one part of the continuum of rendering solutions on the path to a perfect photorealistic image. Ray tracing has several cousins with a similar name such as Path Tracing and ray casting, which sometimes get used interchangeably; that is not correct and can be confusing. One of the objectives of this book is to establish clear delineation between those other technologies whose only common element is a word, but not the technology, algorithm, or result. Ray tracing holds the promise of providing us with the most cost-effective photorealistic images possible. The process has been criticized for being such an enormous consumer of computer resources, but new developments in hardware and algorithms are changing that and making real-time ray tracing not only possible but practical.

The ambition of artists, film producers, product designers, and engineers has been to simulate an image of a scene, a story, a product or a building before it was ever actually constructed. Architects have built scale models of buildings, as have car designers to convey the ideas they are trying to express. Film and game producers and directors have used storyboards to try and convey the sense of the movie or the game. And advertisers want to create perfect renditions of their product in the best possible light. In addition, product and machinery designers want to find the weaknesses in a design before it is ever built. Likewise, movie directors want to see what the final imager will look like before the arduous task of postproduction or to create a whole new world that does not actually exist. And marketers want to show potential customers what a product will look like to stimulate demand for it. At the same time, all these desires are also used for testing ideas. Should a character in a movie have green skin, have long hair or no hair? Will the light reflect from the windows of the proposed building blind its neighbors, or perhaps cast such a shadow the neighbors will never see sunlight again? The testing of such ideas is called virtual prototyping in manufacturing and pre-viz (previsualization) in the movie and TV industry.

J. Peddie, *Ray Tracing: A Tool for All*,
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All of those people, who are in various stages of the pipeline to bring the consumer or customer the final product need photorealistic images to tell their story, sell their project or sell their product. And they need those images, or video, in a cost-effective and timely manner. Ray tracing can, and does do that, and as things go faster, ray tracing will be called on more, by more people to do it more often.

There are two concepts presented in this book about visual perception. One is the concept of a pipeline: proposal and presentation to sell the idea, design of the proposed thing, manufacturing of the thing, and marketing of it. That last stage, marketing of it, often runs in parallel with the manufacturing stage, so the prospective customer is ready and hopefully anxious to see of getting the thing. Think of how far in advance movie previews are now, or how far in advance a skyscraper or bridge design is from the time it is built.

The other concept objective of the book is to explain that as good as ray tracing is, and it is not the end point. It is but one step on the path to computer-generated images that are so realistic, or fantastic that one can't distinguish them from the real or the imagined thing. The human visual system and supporting senses are the most amazing detectors in the universe and can detect in a fraction of a section the slightest mistake, this is sometimes referred to as the uncanny valley, but it goes beyond that. Photorealistic, physically accurate ray-traced images are almost perfect, and yet, a trained eye can still spot the discrepancies, so we will continue down the continuum in pursuit of the perfect image (Fig. 1.1).

Fig. 1.1 Saya. *Source* Teruyuki and Yuki Ishikawa

Teruyuki and Yuki Ishikawa are a husband-and-wife team of freelance 3D computer graphics artists from Tokyo. One of their recent creations is a character named Saya, and she is the star in the movie they are self-producing. According to the artists, the hardest part was achieving the moist, soft, and translucent skin of girls this age. However, the hair is not (yet) up to their expectations.

Every non-diagram image in this book is a ray-traced image, and it was difficult to not just fill the book with beautiful illustrations.

This book will provide insight for technologists, marketing and management people, educators, academics, and the public who are interested in photorealistic concepts, history, and practice, and the visual and sensory science behind the improvements in advanced display systems. From the explanation of the concepts of rendering issues, through the detailing of visual display and informational access systems, this book provides the reader an understanding of the issues related to defining, building, and using (with respect to our senses), our perception of what is represented, and ultimately, how we assimilate and react to this information.

The following chapters get a little technical but do not delve into the esoteric and abstract mathematics of ray-tracing algorithms. This is not a math book.

Finally, there is a discussion on some of the suppliers, take note—there are too many, over 70, to list and discuss them all. However, so many of the suppliers have such fantastic software with such clever tricks they simply had to be included. My apologies to those left out and to the customers and fans of those left out.

Ray tracing will touch all parts of our lives, our society, and if it is done right, we will never be aware of it, the images will be so perfect, so natural we won't even think about them. In the case of fantasy, the images will be so beautiful we will fall in love with them or scared out of our shoes. If fantasy images are so scary that we suspend disbelief about how the image was constructed and instead see it as a magical and scary monster, the artists can pat each other on the back and go have a beer.

Studying ray tracing is like spiraling down a Mandelbrot that reveals progressively ever-finer recursive detail. Down and down I go into the never-ending rabbit hole, finding one thing, only to learn about three others and on and on it goes—*Jon Peddie.*

1.1 About the Cover

The cover image is of the World Trade Center in New Your city and was created by Ferran Traité born in Spain and now located and living in New Jersey.

In 2018, I took a picture of the World Trade Center building, and the two of them are shown together in Fig. 1.2.

For many readers, if I hadn't pointed out that the image on the left was computer generated, it would have been assumed to be a photograph.

Fig. 1.2 Rendered and photograph of the World Trade Center

1.2 Terminology and Definitions

I have tried to avoid technobabble and geek-talk, and (hopefully) all acronyms are explained the first time they are used. There is an extensive glossary in the appendix which I encourage you to refer to if you encounter a word that is not familiar or ambiguous to you. One of the difficulties of writing a book on a technical subject is to make it as easy as possible for any reader, but not so laborious in explanations it would bore a more sophisticated or technical reader. I'll let you decide how well I did.

One of the most commonly used words, which is not a technical term but used as a modifier for technical descriptions is mapping or mapped.

Mapped A term that is used often in computer graphics, which loosely means to be fitted to something. One maps to a spatial distribution of (something). A texture map is a 2D image of something, bricks, or wood paneling for example.