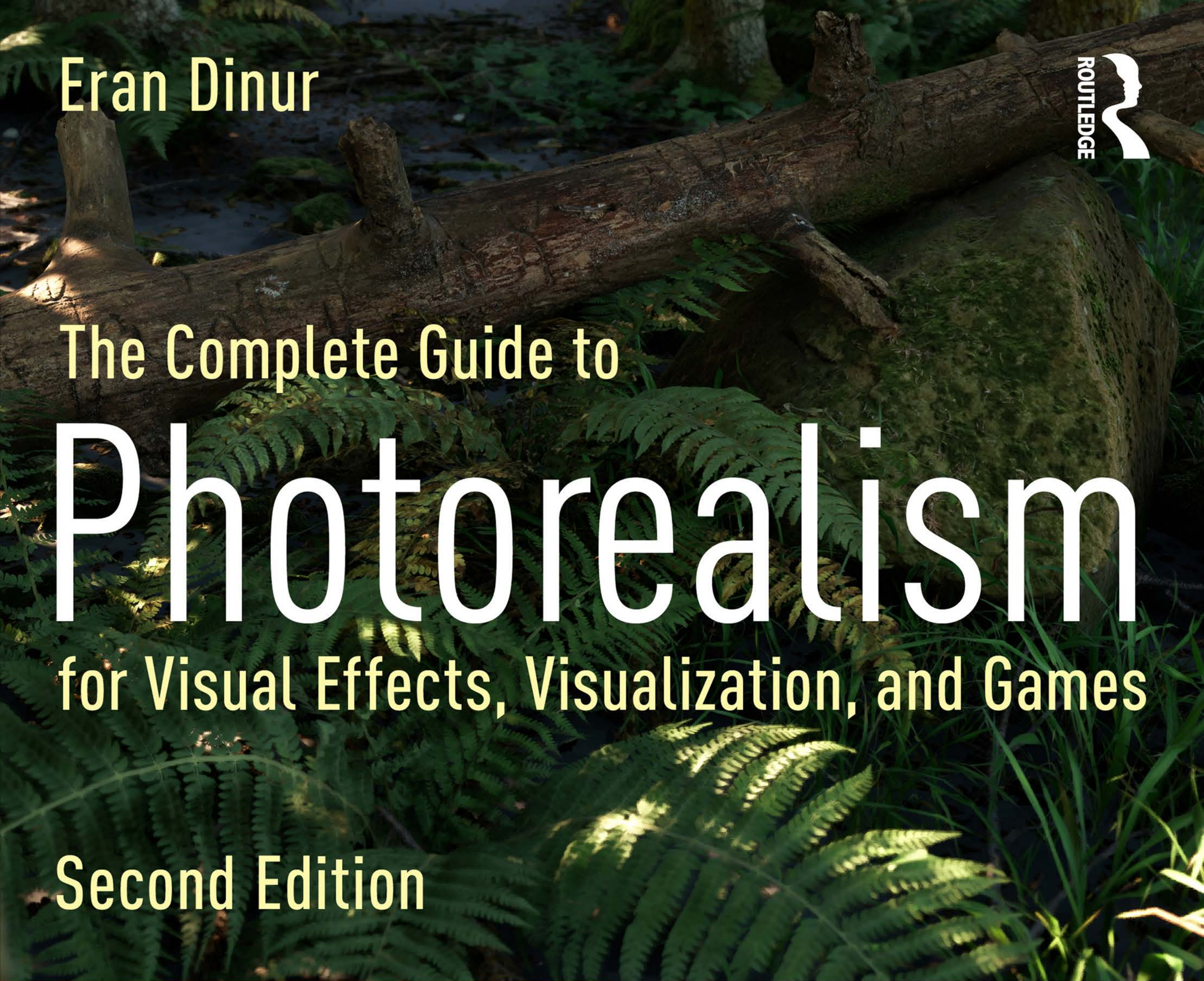
Eran Dinur



The Complete Guide to Photorealism for Visual Effects, Visualization, and Games

Second Edition

A Focal Press Book

The Complete Guide to Photorealism for Visual Effects, Visualization, and Games

This new edition offers the most up-to-date and comprehensive guide to accomplishing and perfecting a photorealistic look in digital content across visual effects, architectural and product visualization, and games.

Emmy award-winning VFX supervisor Eran Dinur offers readers a deeper understanding of the complex interplay of light, surfaces, atmospherics, and optical effects, and then discusses techniques to achieve this complexity in the digital realm, covering 3D, 2D, and generative AI methodologies. In addition, the book features artwork, case studies, and interviews with leading artists in the fields of VFX, visualization, and games. Exploring color, integration, light and surface behavior, atmospherics, shading, texturing, physically-based rendering, procedural modeling, compositing, matte painting, lens/camera effects, and much more, Dinur offers a compelling, elegant guide to achieving photorealism in digital media and creating imagery that is seamless from real footage. In this second edition, the book explores generative AI as a tool for producing photoreal content. It focuses on various workflows and techniques for controlling the generative process and guiding AI models toward the desired results.

The book's broad perspective makes this detailed guide suitable for VFX, visualization, and game artists and students, as well as directors, architects, designers, and anyone who strives to achieve convincing, believable visuals in digital media.

Eran Dinur is an Emmy and VES award-winning VFX supervisor, artist, and author of *The Filmmaker's Guide to Visual Effects* (2024). His film and TV work includes *Marty Supreme*, *The Trial of the Chicago 7*, *Hereditary*, *The Greatest Showman*, *Uncut Gems*, *The Wolf of Wall Street*, *Boardwalk Empire*, *Star Trek*, and *Iron Man*. He is an adjunct professor at the School of Visual Arts and the author of several popular VFX courses at fxphd.com.

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for Visual Effects, Visualization, and Games

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Eran Dinur

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PREFACE TO THE SECOND EDITION

In the few years since the release of this book's first edition, generative AI swept the digital visual world in a storm. New developments happen at a dizzying speed. Yesterday's hype is today's old news as AI companies constantly tout their latest model as they vie for attention (and subscribers). VFX, design, and visualization studios find themselves in a mad dash to keep up with the rushing current, and artists feel the pressure to continuously learn and adapt. Add to this the lack of clarity around copyrights and ethics, and the overhanging concerns about the unpredictable changes in our industries. It's the Wild West out there, and it's as exciting as it is intimidating.

For this edition, I wrote an entirely new chapter on generative AI. I chose to concentrate only on aspects that are relevant to this book – namely, generative AI as a tool for producing photoreal visual content. It is a powerful tool, no doubt, but it lacks the sort of precise control and predictability that 3D and 2D artists are accustomed to. In this new chapter, I look at the various techniques that artists can employ to guide AI generation toward the desired results, from prompt syntax and inpainting, to ControlNet models and IP adapters. I decided to focus on Stable Diffusion's open-source world because it is readily available to everyone and offers a remarkable level of flexibility in designing custom workflows. And, in keeping with the goals of this book, I strived to explain the "why" and not just the "how".

Of course, traditional 3D and 2D are still the core of this book, and for this edition, I updated and revised various sections to reflect the latest changes. I also added new case studies that cover topics such as realistic plastic shaders, photoreal nature in architectural visualizations, PBR lighting techniques, hybrid 2D/3D matte painting and more. Finally, this edition is filled with new and inspiring photoreal artwork by VFX, visualization and games artists, using 3D, 2D, and gen AI techniques. I find it particularly exciting to showcase such a diverse group of artists from around the world.

ACKNOWLEDGMENTS

Writing this book was a true journey for me, and I would like to thank all the people who supported me along the way, and shared their expertise, insight, and talent.

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To my amazing family – how can I ever thank you enough? Karin, my partner in life, and my children. Ayala and Yotam, thank you for your patience, wisdom, and understanding. I love you all so much!

I dedicate this book to the memory of my parents.

Introduction

Photorealism is a vital component in digital visual media: in visual effects, seamless integration with live-action footage is crucial for telling a believable visual story, and photorealism lies at the core of all successful VFX magic. In architectural and product visualization, photoreal CG renders are now the norm, and often replace photography in advertisements, presentations, and catalogs. Photorealism in video games is constantly evolving along real-time rendering technologies, with new games consistently raising the bar. The dramatic rise of generative AI opens up a completely new frontier for photorealistic visuals.

Yet despite the technological advancements and the wealth and quality of tools available to digital artists, achieving photorealism in digital media remains a complex, challenging, and often elusive goal. Numerous factors come into play, and these factors stretch across different crafts, from modeling, texturing, and shading, to lighting, matte painting, and compositing. Think about creating photoreal content, and numerous questions come to mind: how do you generate imagery that is indistinguishable from real photographs? How do you successfully emulate light and its interactions with surfaces? How much detail is needed to make digital visual content convincingly real? How to avoid the dreaded "CG look"? How to achieve realistic daylight and atmospheric depth? How to get the best out of physically-based renderers? What are BRDF shaders? How can render passes help in compositing? How to control generative AI and guide it toward the desired results? And so on, and so on.

This book provides a comprehensive guide to achieving photorealism in digital media. It approaches the subject through a broad perspective that spans various crafts and caters to digital artists working in a variety of fields. The key to photorealism lies in plain sight: it is everywhere around us. To produce convincingly realistic digital imagery, artists must expand their knowledge beyond the specific software tools and techniques of their craft and study the real world: the way light interacts with different materials; how Rayleigh and Mie scattering in the atmosphere transform the light of the sun; the way dirt and grime form on surfaces; the differences between human vision and cameras; the complex structure of plants; how the aperture of a lens affects defocus; or the different characteristics of metallic and dielectric surfaces (to mention just a few of the subjects discussed here).

In writing this book, I set myself two goals: the first is to provide an in-depth study of real-world light, the physical interaction of light and surfaces, material properties, atmosphere, depth, and cameras. These topics are vital for digital artists, yet much of the available information about them is explained in hardcore scientific jargon and through complex equations. In this book, I approach

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these subjects from an artist's point of view – focusing on their visual (rather than mathematical) aspects.

The second goal is to address the tools and techniques that digital artists can use to visually emulate reality and produce photoreal content. This includes CG approaches (path tracing, BRDF shaders, PBR texturing, procedural modeling, etc.), 2D workflows (seamless integration, extraction techniques, working with color, render passes, etc.), and generative AI techniques (inpainting, ControlNet, prompt syntax, IP adapters, etc.). In most cases, I have intentionally avoided software-specific discussions, knowing that readers rely on a wide variety of different applications and tools. So, whether you use Maya or Unreal Engine, V-ray or Redshift, Substance Painter or Mari, After Effects or Nuke, ComfyUI or InvokeAI, this book provides the general knowledge that can complement software-specific books, courses, or tutorials.

2003 by Cornelius Dämmrich. Created in Cinema 4D.

A note about Animation

I am of course completely aware of the importance of animation in the context of realism. Clearly, even the most photoreal modeling, texturing, shading, and lighting cannot salvage a poorly animated character, a lack of a proper sense of weight and inertia, or bad timing and gesturing. But the subject of animation is too vast to be covered in this book in any meaningful way, and it stands independent from other subjects discussed here. Moreover, there are already many excellent books devoted to animation and motion capture. Therefore, this book remains focused on the visual rather than kinetic characteristics of realism (with only a few minor exceptions in discussing motion blur and lens flares). In other words, this book is about how things **look**, and not about how things **move.**

A Quick Overview of the Book

The book is divided into four parts: **Part 1** (Core Concepts) addresses fundamental aspects of photorealism and color; **Part 2** (The Real World) is an artist-friendly exploration of the physical characteristics of light, materials, the atmosphere, and lenses; **Part 3** (The CG World) examines photoreal CG topics in reverse order, starting from rendering and lighting, then shading, texturing, and modeling; **Part 4** (The 2D World) is dedicated to the 2D aspects of photoreal content in compositing, matte painting, image manipulation, and generative AI.

Here is a short description of each chapter:

Chapter 1: Reality and Photorealism

A discussion of the fundamental aspects of photorealism, such as the difference between human vision and photography, detail and imperfections in simulated reality, the uncanny valley and more.

Chapter 2: Photorealism in Digital Media

This chapter compares the different roles, methodologies, aesthetics and challenges of photorealism in three main categories: visual effects, games, and visualizations.

Chapter 3: Color

Understanding color is crucial for achieving photorealism – and this chapter offers a methodological look at essential color subjects like color perception, additive color theory and operations, black and white levels, and dynamic range.

Chapter 4: Light Essentials

The fundamental physical properties of light are explained here from a visual perspective. Subjects covered include the particle/wave duality, photons and the electromagnetic spectrum, light decay, and direct/indirect light.

Chapter 5: Light Interaction

What happens to photons when they hit an obstacle? This chapter explores the principal light/surface interactions: diffuse and specular reflection, absorption and transmission.

Chapter 6: Daylight

Daylight is explained by studying the interaction of sunlight with atmospheric elements and the effect of Rayleigh and Mie scattering. This chapter also covers the principles of aerial perspective.

Chapter 7: Nighttime and Artificial Lighting

An overview of common emitters and fixtures, luminance and temperature measurements, and natural nighttime light.

Chapter 8: Shadows

Analysis of shadows: softness and color, nested and overlapping shadows, contact, and proximity shadows.

Chapter 9: Basic Material Properties

This chapter expands the subject light-surface interaction by examining material properties like diffuse/specular balance, large and small-scale roughness, the Fresnel effect, and the difference between metallic and dielectric materials.

Chapter 10: Lens and Camera Characteristics

This chapter provides a discussion of depth of field, Bokeh, lens distortion, chromatic aberrations, lens flares, lens blooms, motion blur, and grain.

Chapter 11: Rendering and Lighting

A brief overview of rendering and global illumination methods followed by a close look at path tracing and physically-based rendering. This chapter also focuses on various CG lighting tools like area lights and image-based lighting and discusses effective lighting practices for varying scenarios.

Chapter 12: Shading

This chapter starts with a glance at the evolution of shader technologies, then moves on to the various attributes of BRDF and how they contribute to photoreal renders. Additional shaders like hair/fur and volumetric are also discussed.

Chapter 13: Texturing

This chapter offers an overview of the PBR texturing workflow and discusses best practices and techniques for image-based and procedural textures.

Chapter 14: Modeling

The focus in this chapter is on aspects of modeling that relate to photorealism, like modeling for light and procedural generation of complex natural elements such as plants and terrains.

Chapter 15: Integrating 2D Elements

This chapter provides a thorough examination of different techniques for 2D integration and edge treatment, such as color matching, edge keying, matte-less extractions, and motion blur reconstruction.

Chapter 16: Integrating CG Elements

An overview of lighting and utility render passes and their use for improving the integration and realism of rendered elements, followed by additional techniques for "sweetening" the CG look.

Chapter 17: Lighting in 2D

This chapter examines different techniques of using color to modify the lighting, create atmospheric depth, shadows, and reflections in 2D.

Chapter 18: Lens and Camera Effects

In this chapter we look at tools and techniques for simulating lens and camera effects like depth of field, distortion, chromatic aberrations, and grain.

Chapter 19: Photorealism with Generative AI

The immense potential of generative AI for photoreal content creation is often outweighed by the lack of precise control and predictable output. In this chapter we explore various techniques and tools for guiding and controlling Stable Diffusion models, like ControlNet models, Inpainting, effective prompt syntax, and more.

Epilogue

A few words about the future of photorealism.

PART 1

CORE CONCEPTS

Scandinavian All White Interior by Javier Wainstein.

Chapter 1

Reality and Photorealism

Human Vision and Cameras

What is the definition of photorealism? Here is a common one: "If it looks like a photo, it is photoreal". This is a short, clear, and straight-forward answer, but it raises two essential questions: first, what does a photo "look like"? And second, why "look like a photo"? Why not just "look real"? Let me start by addressing the second question. The reality we see through our own eyes cannot be recorded and played back. We have no way (not yet, at least) to connect a person's brain to a monitor and see the world through that person's eyes. Everything we see on a screen or a monitor that we consider real (as opposed to animation, cartoons, or motion graphics) must first be captured by a camera. From the earliest printed photos of the 19th century to today's phones and tablets, the only way we can watch "transported reality" (any reality that's different from what we see around us) is through the mediating assistance of a camera. Our perception of reality in movies, videos and still photography is very tightly tied to a "photographic look", because essentially, it is the only look we have ever seen on a screen. Therefore, if we wish to create convincingly realistic digital content, we need to emulate the characteristics of photography and cinematography, rather than the way we see the world with our own eyes. This leads to the first question: what does a photo look like? In other words, if we could literally hook up a person's brain to a monitor and compare that person's vision to the camera's, would they look different? And in which ways?

This is of course a tricky question, exactly because we cannot perform this hypothetical comparison. If we think of "seeing" as a single process, then viewing photographs (or movies) is a double process: we are seeing through our own eyes reality that was "seen" (captured) by the camera. Take, for example, focus. Just like a camera, our eyes can dynamically shift focus. But we cannot possibly "view" our vision's out-of-focus areas. On the other hand, a photo on paper or on screen allows us to view areas that are in or out of focus equally well. So, while human defocus forever lies at the periphery of our vision, photographic defocus is an observable, meaningful part of the picture and a crucial artistic and narrative aspect of photography and cinematography. This is but one example that shows why, without the ability to observe our vision in the same way we observe footage, the comparison is somewhat flawed. Yet despite these limitations, it is still worth exploring, if only for the purpose of identifying those specific characteristics of photography that are distinctly different from human vision. Understanding those characteristics is crucial to making our digital content "look like a photo".

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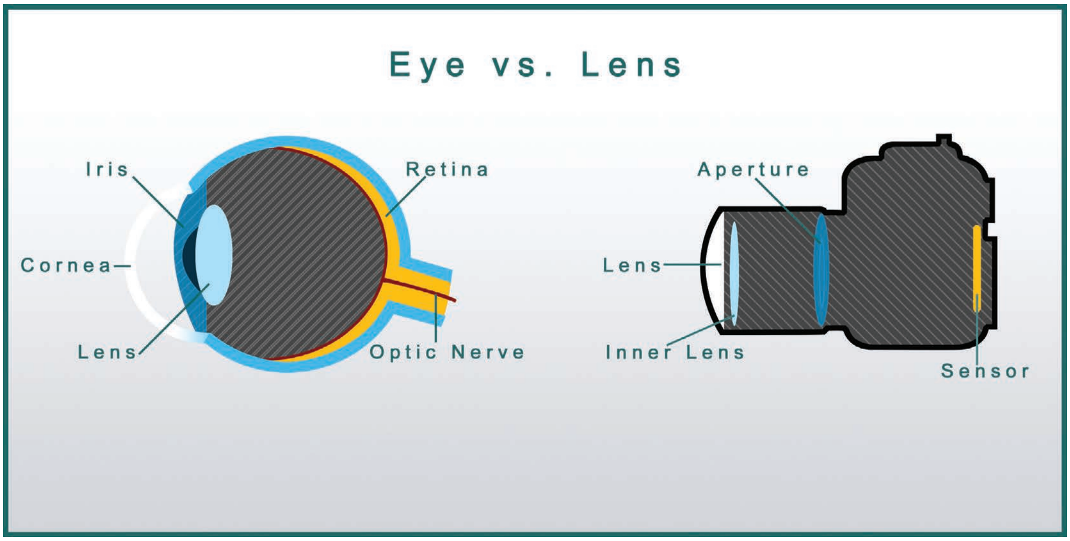
The Similarities

On a superficial level (and without digging too deep into anatomy or optometry) our eyes operate very much like a camera. The cornea and lens form the optical assembly that is the biological equivalent of a camera lens. The cornea acts like the static outer glass, while the inner lens is flexible and controllable to allow focus changes (much like the inner glass in a camera lens, which moves back and forth when the focus is adjusted). Our iris functions as the diaphragm, and controls the size of the opening (the aperture) through which light comes in. The purpose is the same as in a camera: to restrict the amount of light that reaches the retina in a brightly lit environment and let more light in when the environment is dark. Although the retina is structurally different from a camera sensor (it is curved, and its receptive cells are not evenly distributed along its surface) it still performs a similar task, sensing different light frequencies and intensities, and passing that information through the optic nerve to the brain. However, despite the initial similarities, there are some critical differences between cameras and human vision, and those differences define the characteristics of photographed material.



On a fundamental level, our eyes and the camera are very similar.

Field of View

The sensitivity of a camera sensor is balanced across its entire surface, and good lenses maintain a consistent sharpness and quality from edge to edge. The correlation between the focal length and the field of view is thus easy to measure and define. Human vision, on the other hand, has a distinct sharpness falloff from the focal center toward the fringes of the viewing field. If you gaze forward while waving your hand near your left ear, you can still see the hand – but it is quite blurry. To see the hand in focus, you must either bring it closer to the center of your vision, or instead turn your eyes hard left (which then makes everything at the front blurry). The nature of our peripheral vision means that unlike lenses, there is no precise definition of our field of view. Should we measure the entire width of the vision field, or only the sharpest area? And where exactly do we draw the line between sharp and blurry? So, while precise numbers are debatable, it is generally agreed that our overall field of view is roughly comparable to a 22–24mm lens on a full-sensor camera, and our effective (relatively sharp) field of view is comparable to a 43mm lens. Medium lenses are thus traditionally used to convey human vision, although they clearly do not mimic our wider peripheral vision.

Left: an approximate depiction of human vision (roughly 22mm center-focused). Notice how odd and "unreal" it feels when viewed as a photograph. Right: a 43mm equivalent of our effective viewing area.

The most important difference in relation to field of view, however, is the fact that we cannot change our focal length. In photographic terms, we are forever limited to a single prime lens – no switching lenses, no adjustable zooms. This does make sense if you think of our eyes as a spatial navigation tool (it would be very hard to properly assess distance if we constantly changed our focal length), but it also means that the wide variety of perspectives that characterizes photography, from the exaggerated depth of wide lenses to the compressed perspective of long lenses, is simply not available to us. Yet even though changeable perspective is foreign to our vision, we completely embrace the rich perspective vocabulary of photography and cinematography and accept it as "real". We have no problem watching footage shot with a 12mm or 250mm lens, even though both lenses show the world in a way that we can never see with our own eyes. To achieve photorealism, we must treat field of view in photographic terms, and all but ignore the fixed-perspective, peripheral nature of our own eyes. Interestingly, tilt-shift effects and other photographic techniques that somewhat simulate human vision are often perceived as artificial and strange. This is but one example that shows how accustomed we have gotten to the language of photography and to viewing the world through a lens.

Seeing with the Mind

We think, and cameras don't – this is an important difference between human vision and camera, and an essential concept for photorealism. To illustrate this difference, let us examine two scenarios that should feel familiar to anyone who's ever used a camera:

1) On a trip to the mountains, you are standing on a high overlook, admiring the breathtaking landscape of tall peaks and deep valleys. Inspired by the beautiful view, you pull out the camera and take some photos. But to your disappointment, the photos convey none of the sense of depth and grandeur you experienced.

2) While on an apartment hunt, you find a place you really like – spacious, well-lit, and with a nice view outside. You take some photos, but they don't do the apartment justice. If you expose for the interior, the windows blow out and you cannot see the view outside, and if you expose for the windows, the interior looks dark and depressing. Either way, the pictures of the apartment do not look and feel like what you've seen with your own eyes.

In the actual photograph (left), the camera records light exactly as it reaches the sensor, including haze and humidity that severely flatten the image. But we "see through" the haze with our mind, intuitively reconstructing detail and depth (right).

The extreme luminance difference between the interior and exterior are captured as muddy blacks and blown-out highlights by the camera (left). But our mind balances the exposure, lifting the shadows and toning down the highlights.

The camera merely records light that enters the lens and hits the sensor, and produces an objective snapshot of the environment. Whether that snapshot conveys anything meaningful is completely up to the photographer – indeed, the art of photography and cinematography is explained, debated, and taught in thousands of books, courses, and tutorials, because it involves so much more than just point and click. But there are no books about the "art of seeing" – maybe because we are all unrecognized masters of this art. While our eyes record light just like the camera, our brain constantly interprets and enhances that recording. We cannot separate the