Capture
Capture

Digital Photography Essentials

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Dedicated to our past, present, and future students
and readers for sharing our passion
for photography.
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Introduction
Photography has changed. It seems that a few years ago photography underwent a major shift that replaced standard silver halide technology with new solid-state electronics technology. Although this has been called a revolution, it is really more of an evolution. The change was not drastic, nor was it sudden. The move from silver-based photography to digital imaging was a natural movement from one technology to another that did not alter the overall concept of photography—the act of capturing light coming from a scene with a camera. Therefore, when electronic capture devices replaced silver halide films, it was not so much a change in photography as an evolution in the basic capture and processing technology.

The most important underlying construct of photography is its ability to make permanent the vision of the photographer. Even the name of photography, light writing, is still valid with digital imaging. A photographer sees the desired image in his or her mind, or as it exists in the visual environment, and then goes about capturing and communicating this vision. The change from silver to electronics only deals with the technology, not the concept, of photography.

The desire to portray the elements of the environment preceded the invention of photography. Early in our history, artists and philosophers developed methods to discuss and represent the world around them. It was not until 1826 when Nicéphore Niépce made a permanent image from life that this goal had been realized. Niépce aimed his camera out the window, and during the next eight hours he captured the light intensities reflecting from the scene outside. This was not the first captured image; however, it is the oldest image in existence that demonstrates the artist's desire to replicate his vision of the world and then make it permanent.

From before the time of Niépce to today, the camera has been a tool that allows artists to capture the world. It was first used as an aid to painters to allow them to trace what the eye might see. With the invention of heliography, sun writing in Niépce's words, the camera became the vehicle that could capture the light of a scene so it could be made permanent. The basic operation of the camera has stayed consistent to the present. The initial experiments with lenses, light, and chemistry have made photography as we know it possible, and it has evolved over time into the digital cameras that we know today.
The importance of early photographic processes and cameras in relation to digital photography is that they set in motion a way of perceiving and memorializing our world. The concept of digital photography uses the same idea, that light emanating or reflecting from objects around us can be captured and made permanent through a physical process. It is very important to realize that over time, photography has always been based on this philosophical idea, whether it was accomplished with light-sensitive tar as used by Niépce or a metallic oxide semiconductor as used in today’s digital sensors.

What we have learned since photography was introduced to the masses in the early 19th century holds true today. The invention of the charge-coupled device (CCD) in 1969 evolved the capture and processing technology, not the basic concept of photography. The process still involves light from a scene entering the camera through a lens that focuses it onto an imaging surface that then captures and holds the energy in place until a process can be used to make the image permanent.
When CCDs were introduced to most photographers, the prevalent method for making captured images permanent was through a chemical process that changed silver halide crystals from their manufactured state to an image structure made of metallic silver atoms. The change from this chemical process to an electronic process seemed radical at the time. Although the image capture techniques were new to photography, the controls to create an image and the basic relationship between light and the camera had not changed.

Before the introduction of the CCD to photographic capture, photography had already evolved through glass plate emulsions, film-based emulsions, color film, and Polaroid. Each approach altered how images were processed, but not the way light entered the camera and how it reached a photosensitive surface. Whether using film emulsions or a metallic oxide semiconductor, it makes little difference to the photons that enter the camera.

So why change? First, there is the natural tendency to make changes as new technologies emerge. Second, and more important, digital techniques bring advantages to the overall process of photography. These include everything from precapture to post-production. Within this book that deals with the capture of light, we can see various advantages of moving the photographic process from a silver-halide-based system to one that relies on solid-state electronics, including the ease of functions from exposure to output and the mobility of the captured images.

As we will see in the text, the electronic system allows an integration of processes that were separate in the silver-halide-based system. These include composition, metering, lens modification, exposure, soft proofing, and so forth. These activities are common to the photographic process. Beyond these considerations, ease of use and economic issues also encourage the use of digital photography.

It is our intent to help you master photography by understanding how to control the input factors. This has been the constant during the past two centuries. With good exposure that accommodates the capture medium comes the ability to communicate those things that attracted you to make the photograph in the first place.

In approaching this task we will present many concepts that will enable you to control how light is captured. For the most part, the control of the input to photography is critical for all steps that will follow. If the exposure does not create an image that is correct, then none of the subsequent steps can do more than save the technically poor image. On the other hand, if the exposure results in a proper image, then any steps applied to the image through processing can result in an image that meets our needs. Our approach is to master the input of reflected light from the scene to the sensor. This happens in the camera rather than tricks in a post-capture process.
In helping you understand how digital photography works, and thus how you can make better images, we need to start by defining who you are in relation to the topic. We do not mean to rate who you are, but simply to put your history in context with digital imaging. We define two groups of people: digital natives and digital immigrants. Both groups successfully make photographs.

Digital natives are people who have always known and used digital imaging technologies. They started taking pictures after the movement to digital photography, and their first camera was a digital capture device. This may have been a phone camera, a point-and-shoot camera, or some other type of camera. The important thing about natives in terms of photography is that they learned their basics without a history in film-based photography.

Digital immigrants, on the other hand, learned photography using film and have come to digital imaging with this knowledge. In many cases their understanding of the technologies, methods, and outcomes have been colored by the successes they have had with film-based photography. This does not mean they need to discard their knowledge to successfully make digital photographs; it means they need to understand that digital photography and film-based photography have commonalities, but the differences may be profound.

Therefore, as we endeavor to take you through this introduction to making photographs in the digital capture environment, we must be aware that in some cases we will make statements that are counterintuitive to people whose understanding of photography is based on film methods and processes. Many of these understandings will be valid, but they will need to be tempered with digital considerations and, in some cases, relegated to the evolutionary history of the art.
Ridi Pajliaccio © by Claudio Napolitano. Courtesy of the artist.
Part 1

The Basics
Photography allows us to consciously act to capture something from life. As we enter this discussion of the medium, it is important that we lay the foundation for learning how to use the exceptional tools of digital photography to say what we want to say with a concise still image. The chapters in Part One of this book lay out the basic understanding and tools you will need for digital photography and will aid you in making choices about equipment. After you have gained this knowledge from Part One, we will go on to discuss its application and introduce advanced concepts that build on the solid fundamentals discussed here.

Our approach is to separate the portions of basic photography into four areas: cameras, sensors, lenses, and exposure. These elements make up the tenets of photography and will apply no matter what type of camera system you utilize to make your pictures. When you complete Part One, you will have a clear understanding of all of the elements that are necessary to create an image.

The camera is the most basic tool required for photography. Although you may have a camera as you start this book, it is our hope that understanding the various types of cameras will allow you to make choices as your digital photography progresses. We will then explain how sensors work and some of the concerns that must be addressed to make good photographs with a sensor. Because the way in which light gets to the sensor affects your images, we will also discuss lenses and shutters and how they function. Last, we will discuss the basics of exposure so that by the end of Part One you will be off and running.
Capture Devices

*Denver to San Francisco, 2000 © by Julieanne Kost. Courtesy of the artist.*
Get the Picture . . . Cameras

The concept of the camera is far older than the idea of photography. The Chinese philosopher Mozi, who lived 400 years before Christ, developed the concept that would become known as the camera obscura. Aristotle used the concept around 300 BC to devise an instrument with which he could view a solar eclipse. The term *camera obscura* comes from Latin and means a darkened room. It is a room that has no light entering except through a small opening in one wall. The light energy from outside the room passes through the small opening and creates a projected image on the wall opposite the opening. This is the basic construct of the pinhole camera and all cameras that followed.

In the 17th century it was found that lenses could be placed inside the opening in the wall, which increased the light-gathering power of the opening. With this discovery the camera obscura was made smaller and became portable, allowing artists to use the device to create sketches for their paintings. The famous painter Canaletto was renowned for his paintings of Venice in the 1720s. The sketches for these paintings were made with a camera obscura.

The inventors of photography used the camera obscura as a device to capture their images. The famous mousetrap cameras invented by William Henry Fox Talbot were very small camera obscurae that utilized large lenses with very short focal lengths to focus light energy on the very insensitive paper he bathed with sodium chloride and silver nitrate to use as his light-capturing surface.
Basics of Cameras

A camera obscura is the basis for all cameras in use today. The lens and the size of the imaging surface determine the size and shape of the dark space between the lens and the imaging surface. The lens determines the depth of the darkened chamber. If the lens has a long focal length, then the depth, in optical terms, needs to be greater. The area of the imaging surface determines the width and height of the darkened area of the camera.

When we talk about the size of the imaging surface in this context we mean its physical measurements, not its pixel dimensions. This is because the pixels range in size depending on the manufacturer of the sensor. For most cameras the sensors are quite small compared to the size of film. However, some systems utilize sensor or capture systems that are as large as film. The physical size of the sensor determines the height and width of the darkened chamber in the camera and the angles at which the lens sees the scene.

In today’s digital cameras, regardless of the camera type, there are six common parts: the optical track that brings the light through the lens and focuses it on the imaging surface, the control unit, an image buffer, a viewing system, removable storage media, and the power supply.

For most cameras the optical track is constructed of a compound lens, either a fixed focal length or zoom lens, that is designed to focus the light from the scene onto the sensor to maximize the effectiveness of the light. For digital single lens reflex (DSLR) cameras, the optical track also includes a series of mirrors that are used in the viewing system. On some digital cameras, the optical track also includes a shutter to control exposure and possibly a protective device for the sensor. However, because they use electronic shutters, a mechanical shutter mechanism is not required in digital cameras.

The control unit is the computer that operates most functions of the camera. Today most digital cameras have more computing power than the small computer that was used on the Apollo spacecraft that took men to the Moon. The control unit for most cameras operates the automatic focus, exposure control, sequencing, liquid crystal display (LCD) viewing system, and memory for storing images. With many advanced cameras there are options that allow for manual operation to override the control unit.

An image buffer is most commonly found in higher-level, higher-priced cameras. The buffer allows images to be taken and held in short-term storage while the camera takes another image. Without an image buffer there is a delay between the time a picture is taken and when the camera is ready to take the next picture. This delay is the amount of time required to process and write the image to memory in the removable media.
There are several types of viewing systems used in digital cameras. They include LCD displays, viewfinders and rangefinders, and through-the-lens (TTL) systems. On many cameras the LCD display also serves as a reviewing system for captured pictures.

Removable media, or memory cards, are important parts of modern digital cameras. These memory devices can be used to record images until they are full, then they can be removed from the camera and replaced with another memory card to continue taking pictures.

The last part of the camera is the power supply. There are several types of battery systems, including standard batteries (such as AAA) and rechargeable battery units. The power supply is often overlooked, but it is important because all of the integrated systems within the camera use the electrical energy provided by the power supply. Although cameras and batteries are becoming more efficient, many aspects of taking digital images drain the batteries. The use of an LCD viewing system is one of the most taxing demands on the batteries.

Favino Piefrancesco © by Douglas Kirkland. Courtesy of the artist.
Camera Types

There are many ways to define cameras. However, we will use a combination of definitions that separate cameras by their common uses as well as their operating or viewing systems. We will define cameras as consumer, prosumer, and professional, and we will also differentiate cameras as “digital display framing” (DDF), rangefinder, and reflex. (DDF is a term that we coined and use throughout this book; you will not find it in other publications.) In addition we will describe digital camera backs for medium and large format cameras, and we will discuss scanners. This is the common equipment that is used in digital photography. Finally, a few specialized cameras will be defined. By looking at cameras in this way, we will not only describe the cameras in terms of their price points and common usage, but also by the capabilities they provide to the photographer.
Consumer Cameras

The first basic type of cameras is consumer cameras. These are defined as low cost and easy to use. This does not mean that the technology within them is not up to date, but rather the target audience for the sale of these cameras is photographers with limited budgets and/or limited expectations for the pictures. These cameras fall into two general categories: point and shoot and phone cameras.

At the time of this writing, when the general population was asked if they own a camera, 80 percent replied, “The one in my phone.” Digital cameras that are built into mobile phones have become a major selling point for these devices. Since the mobile phone is based on a computer, the capture and distribution of digital images is a natural addition.

Phone cameras have few options other than whether the image will be taken as a single picture or a video. These cameras have limited lens capabilities because of the small size of the imaging surface and the short distance between the lens and the imaging surface. However, this has not limited the size of the image, as might be thought. Mobile phones have been developed to capture five-megapixel images and have the potential to be even larger. Although the computing power of mobile phones can provide image processing, the cost greatly increases as the pixel count rises because the technical requirements, particularly for the lens and capture chip, become more demanding.

There are also cameras used with or as part of computers. These cameras use the same technology as is used in other cameras, and they are normally set up to capture moving images as well as still images. The primary uses for computer-based cameras are in surveillance systems or person-to-person communications.

However, when we think of consumer cameras, we most commonly think of point-and-shoot cameras. These are small DDF cameras that primarily use an LCD viewing system for framing. They derive their name from the way they are used, generally by aiming the camera at the subject or scene and taking a picture. To a certain extent this is the most natural part of photography—to help us remember where we have been, people we have seen, or what we have done. Because of their simple-to-use operating systems, these cameras allow us to simply point the camera at something we wish to remember and take the picture.
Don’t assume that consumer cameras are not capable of producing exceptional photography. Many of today’s consumer cameras have optical systems, sensor technology, and embedded computer operations that produce high levels of functionality and image quality. However, as the capability of the camera goes up, so does the price.

Like mobile phone cameras, most of today’s consumer cameras can capture both still and moving images. Many of them also utilize zoom lens technology to allow the user to change the angle of view, and users can change the speed of the camera by adjusting the ISO (the standardized valuation of film or sensor speed as established by the International Organization for Standardization) or adding light to the subject with a built-in electronic flash. There are even consumer cameras that can be used to pan across a still subject, and then the image parts can be stitched together to create a panorama.

**Prosumer Cameras**

The name *prosumer* indicates a camera type that is between a professional camera and a consumer camera. These cameras are commonly manufactured with most of the controls found in professional equipment, but a few expensive options are missing. These cameras use many of the same viewing systems as professional cameras, including optical viewfinders and rangefinders, single lens reflex (SLR) systems, and electronic viewing systems. They also use many of the same lens options and storage and file systems that can be found in more expensive professional equipment.

The major differences between professional and prosumer cameras can be found in the chip size, the number of pixels, and some operating functions. Although the size of the sensors in terms of pixel count continues to go up for all camera types, the highest-end sensors tend to be in professional equipment. The other major difference between professional and prosumer cameras is their operating systems. Professional cameras most commonly have faster recycle times and avoid the shutter lag that may be common in prosumer cameras.

Prosumer cameras tend to provide the photographer with a lower-cost camera that will produce very good images and provide the flexibility that is common with professional equipment.
A type of camera that crosses over from prosumer to professional is an augmented digital display framing (DDF) camera. When the lens of the camera can be changed, this type of system is sometimes called electronic viewfinder with interchangeable lens (EVIL). This type of camera uses a digital display in a viewer, similar to a viewfinder attachment on a camera system that might otherwise be a DDF camera. Higher performing EVIL cameras are often used by professionals as a crossover product because they tend to be small and they provide convenient digital information, particularly an adaptive histogram in the electronic viewfinder and the capability to produce RAW files.
Professional Cameras

When we discuss professional digital camera systems it is easiest to separate them by their viewing and operating systems. Since the pixel count on the imaging surface is not dependent solely on the physical size of the sensor, the descriptors used for professional cameras do not relate to size. Instead we define the cameras by their viewing systems or operating systems. Many professional cameras can also be operated from a computer. When the functions of the camera are controlled through the computer, it is said to be tethered.

Rangefinder Cameras

A rangefinder camera uses an optical system, separate from the system used to capture the image, to frame the shot and focus the camera. Although most modern cameras have built-in automatic focus, professional equipment has a manual adjustment that can override the automatic focus and allow the photographer to choose the point of focus for the image manually.

Most rangefinder cameras also provide LCD viewing, but the LCD is considered a reviewing method to be used after the photo has been captured rather than a system for selecting and framing the image. Rangefinders allow the photographer to view the scene and see how much of it will be captured by the sensor. The photographer can also see the magnification of the lens without holding the camera away from the face, as if the camera is an extension of the eye. This allows the photographer to act more instinctively as he or she follows action or composes images.
Karen © by Tim Meyer. Courtesy of the artist.
Reflex Cameras

For many serious photographers, the reflex camera has been the mainstay for the past half century. A reflex camera utilizes a mirror placed in front of the imaging surface and reflects the scene from the lens through a viewing system (in many cameras it is a pentaprism) to allow the photographer to see the picture as it will be captured. The photographer therefore sees the composed picture directly through the lens instead of through a separate viewing system. Reflex cameras allow the photographer to either change lenses to adjust the viewing angle or to utilize a zoom lens. Because the mirror inverts the image, the pentaprism restores the proper relationship of left to right in the viewfinder. When the shutter is released, the mirror rotates up to allow the light from the scene to strike the imaging surface. Because there is only one lens involved in the picture-taking process, this camera system is known as a single lens reflex (SLR). When cameras incorporated digital sensors, the word digital was added to the name, and the acronym became DSLR.

For professionals the DSLR is often the camera of choice. It provides various functions and flexibility in lens choices, image viewing, and composing through the primary lens. Importantly, it also offers familiarity with other cameras used in the past. Although this familiarity is not a requirement for the function of the camera, it has eased the transition to digital capture from film and contributes to its popularity, along with its handheld design.

Just as with rangefinder cameras, DSLRs allow photographers to bring the camera to their eye as an extension of their vision. Although cameras with this design are based on a reflex mirror system, there are cameras that have the appearance of a mirror reflex camera but use an LCD display that is viewed through an eyepiece on top of the camera. This gives the same functionality as a DSLR but allows the camera to utilize an electronic shutter without having moving parts within the camera’s body.

Even though DSLRs utilize a viewing system through an eyepiece on the camera, these cameras have LCD displays as part of their operating system to allow the photographer to review the captured images. Further, the integrated computer system in professional DSLRs allows the camera to process images quickly. This is a very important aspect of professional cameras because the camera processes images and stores them in a buffer for short times very efficiently, allowing pictures to be taken of rapidly moving objects. While the photographer moves on to the next shot, the buffer writes the image to the removable media. This is perhaps the greatest difference between professional cameras and prosumer cameras: The camera reacts quickly when the photographer presses the triggering mechanism, without camera lag.
The operating system of many professional and prosumer cameras can be updated within the camera by the photographer. Most of these higher-level cameras have the capability to modify their firmware through online plug-ins, which allow the camera to take advantage of new memory devices or operational changes. Plug-ins are provided by the camera manufacturers because of the rapid technological changes in this level of camera. When the cameras are released to the public, their operating systems might not be optimized. While professionals and testers use the cameras, the manufacturers make changes to the way the cameras operate, and these changes are shared with photographers who already own these cameras to keep their equipment from becoming obsolete. The way these upgrades are done is particular to each manufacturer, so you should become familiar with how to upgrade your camera's firmware.

Digital Camera Backs

A camera back is simply a piece of equipment that is added to the camera in place of the imaging surface, and it allows the camera to capture images digitally. Camera backs are most commonly used on medium and large format cameras. These backs replace either film magazines for medium format cameras or are used in place of film holders for large format cameras.

Digital camera backs allow for very high pixel count images because of the physical increase in size of the imaging surface. Also, since many professionals have already invested in high-quality lenses and bodies for these larger camera formats, the use of camera backs gives them the opportunity to be flexible and use either film or digital capture.

Camera backs are often directly attached to computers, which is called tethering. This allows the photographer to see a larger image on the computer screen to compose and control that image. Although tethering is available with additional software for some DSLRs, it is usually part of the operating system for digital camera backs.

There are two types of digital camera backs in common use: instantaneous capture and scanning backs. The instantaneous capture devices are similar in operation to digital cameras. They are most commonly manufactured using a single sensor chip. Scanning backs use a linear array that travels through the light pattern created within the camera. This makes scanning backs unsuitable for photography of moving subjects. However, scanning backs can produce very high pixel count images of still subjects because of their capture process.
Chapter 1

Capture Devices

Mango Tango © by J Seeley. Courtesy of the artist.
Scanners

Scanners are not often considered photographic capture devices, but they can be used to make images or portions of images in the photographic process. Similar to a scanning camera back, the sensor of a flatbed scanner moves across the imaging surface, and it has a light source that travels with the sensor to transmit light through or reflect light from the object on the scanning table. This produces a very flat light on the object being scanned. Although the design of flatbed scanners suggests that they are only good for reproducing flat subjects, they are actually capable of capturing images of three-dimensional objects.

Specialized Cameras

There are also specialized digital cameras that are used for surveillance, medical, scientific, and illustrative purposes. These include cameras such as those manufactured by Spheron, which are used for high dynamic range imaging (HDRI). These are scanning cameras that rotate 360° to create an image of the inside of a sphere as seen from the camera's location. These images are commonly used to create ray traced illustrations (three-dimensional graphics that are rendered by following the path of light) that include reflections.

The concept of light field rendering is also enabled by the use of digital capture technology. This type of photography uses multiple lenses to capture the light in a scene from various depths within the camera. Because of the integrated nature of the computing system used to handle the exposure, the image reproduces the detail within the scene.

Other specialized digital cameras are capable of using light that is not visible. This includes infrared, ultraviolet, X-ray, and other electromagnetic energy sources.
Sensors

© by Kelly Kirlin. Courtesy of the artist.
Capturing Light

The imaging surface of the camera is where the picture is captured. Being able to permanently capture an image was the critical factor in the invention and further development of photography. Nicéphore Niépce first made a heliograph in 1826 with a camera using a specific type of tar (bitumen of Judea) that hardens when it is exposed to light. Niépce covered a piece of polished pewter with the tar, and after an eight-hour exposure he rinsed the surface with a solution of lavender oil and turpentine. This made the exposed image visible because the light hardened parts of the tar and allowed other parts (those not hardened by the light) to be washed away.

This basic construct had an image projected on a surface that was prepared with a light-sensitive material. The important part of all types of photography is that light (in the form of photons, or energy from light) is captured and held in position until it can be processed into a visible image. This concept is the same today as it was at the beginning of photography.

In early photography silver-based surfaces were exposed to light focused by the camera’s lens. With the first photographic processes, the daguerreotype and the Calotype, polished silver plates or salted paper were used as the support part of the imaging surface. The images that were focused on these early photographic materials needed to be processed for viewing. They were latent images that could not be seen without a further chemical reaction. These photographic materials were quickly replaced with emulsions applied to glass, initially a wet base that had to be exposed and processed before it dried, and later a dry base that could be exposed and processed later. In both cases the glass plate was flat and allowed light to pass through the emulsion for later printing. The basic construction of the emulsions used on dry glass plates did not change when flexible film replaced glass. This led to the use of the term film plane to define the imaging surface. With the introduction of electronic sensors, the concept of an imaging surface becomes more valid for a discussion of the light-sensitive surface that captures the light coming through a lens.

When Willard Boyle and George Smith of Bell Laboratories invented the charge-coupled device (CCD) in 1969, electronically captured images were already being captured with vidicon tubes, which were used in television. A vidicon tube is an electronic analog system that uses electronic stream scanning, but a CCD captures light with solid-state technology that produces still digital images. The CCD was later followed by the repurposed complementary metal-oxide semiconductor (CMOS) as another capture sensor for digital photography.

Although the method of capturing light has changed from silver halide film to digital sensors, the overall concept is the same: Photons are captured on the imaging surface. With film this capture is done with an inert silver halide crystal that changes composition when it is exposed to light, then
it is processed chemically to reveal the latent image. Regardless of the type of capture system—glass, film, or silicon—the concept of the latent image remains. Just as the latent image needed chemical processing for early silver-based materials, processing is also required to reveal the image captured by digital sensors. With sensors, the photons are captured by a solid-state electronic device that can hold the charge until it can be processed electronically to reveal the image that was created by exposure to light.
Common Sensors

There are two major types of metallic oxide semiconductors (MOS) that are used in digital photography. First, the CCD is older and is a dedicated digital capture device. CCDs have only one purpose in the digital photographic process: to acquire the image. It is named for the method used to acquire and output the image. The word *charge* comes from the way the positive charges are put on the sensor prior to accepting light. The word *coupled* is based on the linear pattern that is used to remove the charge from the sensor after the exposure has been captured.

The other major sensor type used in digital photography is the CMOS. This type of semiconductor is used in other solid-state devices. The major difference between the CMOS and the CCD is that the CMOS contains transistors. This means that the CMOS can perform some of the image processing prior to exporting the signal from the sensor.

The difference between the two sensors can be seen in the way they are designed to output the image information after it is captured. The CCD passes the signal from the sensor in a linear pattern. This means that the charges from each pixel will be processed in a line pattern. For this reason the pins (the wires that transport the signals from the sensor) are arranged on opposite sides of the sensor chip. Because the CMOS contains transistors, there are pins on all four sides of the chip to transport the image information.

Both sensors are manufactured from photo-etched silicon. Silicon is used for three reasons. First, the silicon can be manufactured to create the very small structures that are required for the function of the sensors. Next, silicon is an electrical conductor that is required to capture light, and fine coatings of other materials can be applied to the silicon structure with electroplating. Last, silicon allows light to penetrate its surface, making light capture possible.

The CCD chip houses the components that capture the photons and communicate their energy to the image processor. The actual capture surface is in the center of the chip, shown in green.

The CMOS chip is a semiconductor and is therefore able to perform some image processing steps prior to exporting signal information from the chip. This means that the CMOS has a more complex infrastructure than the CCD, even though the imaging surface may be the same size. The imaging surface is shown in iridescent green and purple.
Basic Sensor Structure

Sensors are manufactured with multiple parts in several layers. Starting at the bottom of the stack we find a dielectric material that will support the very thin layers above it. This material not only supports the sensor, but it also insulates the silicon from random electrical charges that might be in the camera body. On top of the dielectric material we find the photo-etched silicon that creates the pattern of photo sites that actually capture the image. This silicon layer also contains electroplated connections that allow charges to move both on and off the sensor chip.

We can consider the surface of the sensor to have two important parts. First are the photo sites that actually capture the light. The rest of the sensor surface is known as overhead. The overhead is made up of the electronic connections. In the case of a CMOS transistor, this means that only a portion of the sensor’s surface is able to record light. The percentage of the sensor that will actually record light energy is known as the fill factor. Because there are fewer parts in a CCD’s overhead, it has a higher fill factor than a CMOS. This does not mean that a CCD has a higher photo site count, but a larger portion of its surface is available to record light.

On many devices, just above the sensor surface there is a material that will intensify the light that reaches the photo sites and/or slightly blur the light to reduce aliasing (a phenomenon where light energy is not accurately recorded on a digital sensor, resulting in distortion or artifacts in the final image). When the purpose of this material is to concentrate the incoming light, dual-internal lenses (DIL) are used. If the purpose is to soften the light, an antialiasing or blur filter is placed above the sensor surface.

As we move up in the structure of the device, we next find the color filter array. Digital sensors collect color information by filtering each photo site with one of the three primary colors of light: red, green, and blue. There is a filter directly above each light-sensitive photo site. Later in this chapter we will discuss how sensors capture color.

Most sensors, but by no means all of them, have microlenses above the color filter array. The purpose of these microlenses is to concentrate the light through the color filter array and down to the photo site. The microlenses are positioned directly above each of the filters, and they gather light from corresponding areas above the non-light-sensitive areas on the sensor surface. This increases the efficiency of the sensor. On some sensors the microlenses are different sizes, or strengths, over different areas of the sensor. This variation evens out the intensity of the light that reaches the sensor surface. For sensors that do not use microlenses, the rationale is to retain sharpness in the image. The choice of sensors with or without microlenses is available only on professional cameras and camera backs.
Last, in the construction of CCD or CMOS sensors there needs to be a way to remove unwanted energy sources from becoming part of the captured picture. These silicon-based sensors are highly sensitive to infrared radiation. Since this part of the electromagnetic spectrum is not visible to humans, we want to eliminate or filter infrared radiation before it reaches the sensor surface so it does not appear in the captured image. This is accomplished in one of two ways. A light cyan filter can be used over the top surface of the sensor to filter unwanted infrared wavelengths. The other alternative is to use a device known as a hot mirror to reflect these wavelengths away. Photographers who wish to capture reflected or near infrared often have their cameras modified to remove the cyan filter or hot mirror, or they purchase a camera that is constructed without either device above the sensor. It should be noted that we are not referring to the heat commonly thought of as thermal infrared. Rather these are the wavelengths in the electromagnetic spectrum that are just above the red values perceived by the human eye.

© by Jill Enfield. Courtesy of the artist.
How a Sensor Collects Light

To understand some of the functions of a digital camera, you need to have an understanding of how light is collected by the sensor. We will go into much greater detail about these functions later in the book, but for now we need to discuss some of the principles that are used to capture light.

Light can be described in two ways: a waveform or a particle. For the purposes of capturing light we will consider the light’s particle form, the photon. In scientific terms a photon is not an electronic particle; however, it acts like a negatively charged particle.

We need to realize that light in the world around us is analog. This means that it does not change in distinct units; it is a smooth, continuous pattern. The analog light pattern will need to be changed to make it digital.
Sensor Construction and Operation

In the construction of a photo site, we can think of the uppermost portion of the photo site itself as a gate. The gate is made of a transparent material that conducts an electrical charge. The most common material used for this purpose is indium tin oxide (ITO). The gate is connected to the overhead and can be charged either positively or negatively. In preparation for collecting light energy, a positive charge is applied to the gate. A positive charge is used to attract photons, which act as though they have a negative charge. This is the charge that is referred to in the name of a charge-coupled device (CCD).

When the gate is charged it quickly passes this positive charge through the sensor’s silicon to an area called the potential well. Charging the sensor has two purposes. First, the positive nature of the charge will attract the photons through the gate to the potential well. Second, by applying an even charge to all photo sites, the sensor now has a base value with which to calculate the amount of light that has been captured. It is this charging of the sensor that is responsible for the camera’s delay from the time the triggering mechanism is pressed to when it actually takes a picture. Professional cameras are usually designed to maintain the charge on the sensor so that camera delay is minimized.

When the shutter is open, the light can pass through the gate, and the photons are attracted to the potential well. Since the potential wells in each photo site have exactly the same positive charge, the amount of light captured at any site is the difference between the number of photons that reached the potential well and the original charge on all the photo sites. The photons, acting as negative charges, neutralize some of the positive charge on the potential well.

If the amount of energy, in the form of photons, that reaches the potential well exceeds the positive charge held by the well prior to exposure, the photo site is maximized, and no further differentiation of exposure can be seen. In this instance two things can happen. The excess photons can be ignored, or they can migrate to nearby photo sites in a process called blooming. In other words, the sensor does not tolerate overexposure. This has a major affect on the way we must look at the exposure.

When it is time to read the light that was captured, the sensor simply counts the remaining positive charges by calculating the level of exposure based on the original charge value. This is accomplished by the first image
processing function that takes place after the signal has been transmitted from the sensor. In a device known as an analog-to-digital converter (ADC), the electronic charge differentials are converted from the analog form in which they were created to digital numbers. Quantizing is the process that converts the analog light that was captured on the sensor and makes it into the digital form that will be used.

The numbers that are transmitted from the ADC are in the form of binary code. The base element of the binary code is the bit, which represents either 1 or 0 (on or off). The numbers in the sequence are a way of counting by powers of two. These numbers are used because they function well within the computing environment. A transistor, the basic unit of a digital computer, is either in the on position or the off position. Therefore, a numbering system that relies on the root number 2 works perfectly.

This basic building block of digital computing and digital images is known as a bit. One bit signifies the number 1 or 0, which indicates on or off for a transistor. When you put eight bits together, you create a byte. A byte is equivalent to 2 to the 8th power (2^8 = 256). One megabyte is 1,024 bytes, and one gigabyte is 1,024 megabytes. The scale continues, but this level encompasses most images used today.

Regardless of the actual number of photons captured by any photo site or the dynamic range of the sensor, when the ADC processes the signal coming from the sensor into 8 bits, it will have 256 intensity levels. Within digital imaging we set these 256 levels with the bottommost level at 0 and the highest level at 255. If the ADC quantizes at 12 bits, it creates 4,096 intensity levels (2^12 = 4,096). The number of intensity levels in an image is the bit depth. Many computer programs can produce a faux 16-bit depth (65,536 levels) for ease of handling within the software. The most commonly used bit depths in digital imaging are 8 bit and 16 bit.

The ADC interprets the light value captured on the sensor, but its size in terms of the number of photo sites is the important factor in determining the amount of detail that can be acquired in an image. The physical measurements of the sensor are not as important as the photo site count when it comes to capturing detail. For example, two sensors of exactly the same physical size can have different photo site sizes and fill factors. Although it is not technically correct, camera manufacturers have chosen to use the term *pixel* to refer to photo sites. A pixel refers to a picture element that does not exist until after the image has been formed, but the use of the term *pixel* simplifies the way camera manufacturers describe their sensors. We can therefore say that more
pixels (photo sites) on a sensor means higher resolution and greater detail in the image. All other factors being equal, a 10-megapixel sensor will acquire more detail than an 8-megapixel sensor.

The actual size of the photo sites has a direct impact on other issues concerning the light-capturing ability of the sensor. Although smaller photo sites yield better resolution, they have their downsides. Smaller photo sites decrease the sensor’s efficiency because of diffraction at small apertures. Also, small photo sites need more amplification to reach higher ISOs, which creates more noise (incorrectly recorded information that appears in the final image as specks or dots that were not in the scene) within the digital capture system.
Resolution and Detail

Resolution is critical to the success of a digital image. The concept of sampling is used to describe how detail is captured. When a photograph is taken, more than one photo site must be involved to ensure adequate detail. The Nyquist limit expresses the need to have two photo sites involved for each detail element. This means that an adequately sampled image will have twice as many photo sites along a line as the number of details captured along that line.

An image that does not meet the detail requirements is considered undersampled. The common artifact from undersampling is aliasing, which happens when the sampling is not high enough to adequately smooth an area of change in the image. This results in a jagged edge where the image detail changes faster than the sampling can handle. Aliasing can be corrected with software that blends tonal variations into the aliased edge to soften it.

Some camera systems use software to make the number of pixels larger than the number of photo sites used to capture the image. After the software increases the image size, it applies edge enhancement to provide antialiasing and contrast. Even if these images have a greater number of pixels than originally captured, the final image cannot have more detail information than the sensor originally captured.

These five images demonstrate the various resolutions available on different cameras. The same segment of each image has been enlarged to demonstrate the differences in clarity and detail resolution for each camera type.

1. Subject shot with a camera phone with a 1.5-MP resolution.
2. Subject shot with a 4-MP camera.
3. Subject shot with a 6-MP camera.
4. Subject shot with a 13-MP camera.
5. Subject shot with a 6-MP camera.
5. Full image from 13-MP without crop.
Acquiring Color

Sensors by themselves do not capture color. In order to capture color, digital sensors must first filter the light so that various wavelengths can be captured separately. In early digital photography, a monochromatic luminance capture sensor was used, which was then photographed using a process known as tricolor photography. This was accomplished by making three successive exposures of the same subject through a red, a green, and then a blue filter. Although it is not commonly used in today’s digital cameras, tricolor photography has specific uses in high-level technical photography.

Today digital sensors include a filter array that allows individual pixels to respond to either red, green, or blue light. These filters are aligned in a matrix known as a Bayer array. These tiny filters are arranged in a specific order so that any single line of photo sites will have alternating red–green or blue–green filters. This means that half of the photo sites are filtered green, one-quarter of the photo sites are filtered red, and one-quarter of the photo sites are filtered blue.

There are two main reasons the filter array uses 50 percent green filtration. First, because filters are not absolutely pure, the green filter allows some red and some blue through. This means that the green filter functions similarly to the way the human eye sees color. Second, the red filter allows a small amount of blue to penetrate it, which is also consistent with human vision. This makes the green filter the primary carrier for detail within the image because it covers more of the visual spectrum than either of the other primary colors. Because of the sensitivity of sensors, blue light creates the noisiest channel. Having only one-quarter of the sensors capture blue light reduces the overall noise in the image.

After the image is captured through the filter array, it is output in three channels: red, green, and blue (RGB). These channels are registered with one another so the colors from each channel can be mixed together to create the full-color image. This process is known as interpolation. For a simple model of how interpolation works, we can take a block of four photo sites/pixels. With the arrangement of filters found in the Bayer array, any block of four photo sites will always provide two green, one red, and one blue filters. In this simple model we can average the light intensities for the two green pixels and mix that average with the red and blue pixels. For example, if the two green values are 126 and 128, they would average 127. With a red value of 220 and a blue value of 120, we would have a color mix of red 220, green 127, and blue 120, which corresponds to a pink flesh tone. The actual interpolation method for each camera system is proprietary and far more complex than this simple model, which is one of the reasons that image converters are not interchangeable between camera manufacturers.
Tokyo to San Francisco, 2001 © by Julieanne Kost. Courtesy of the artist.
Noise

Sensors may generate noise because they are electronic. When electrons move in the sensor system, they can stray and be recorded as light. This is known as signal noise and is found in all imaging systems. This nonexposure noise is often referred to as dark noise because it is generally located in the dark areas of the image.

Noise cannot be avoided, and three situations actually increase noise: heat, increased ISO, and long exposure. The electromagnetic spectrum includes both light and heat, so heat energy can manifest as added exposure. When the ISO is increased, amplification (also known as gain) is added to the signal. The gain amplifies the noise as well as the signal strength. Last, long exposures keep the system active and allow noise to build up.

Sensors create a basic systemic pattern of noise. This can be corrected by software applications either in the camera or in post-processing. Another way noise is corrected is by taking one dark exposure that is as long as the original exposure, then creating a mask that is used to reduce or remove the noise by modifying the color value produced by the noise. This process is known as dark frame reduction. A modification of this process uses short-interval exposures that add up to the total time of a long exposure. The series of short-interval exposures are bookended by dark exposures that are the same length as one short interval. The bookends are used to create the mask that is used in dark frame reduction. For very long exposures that are prone to noise, the short-interval method is a time saver.

If the signal-to-noise ratio is low, meaning that the level of captured energy is not significantly greater than the noise level, the image loses quality because it will show the presence of noise.

In a studio where a sensor may be on for long periods of time, heat in the sensor can build up and create noise. For some studio camera backs and scientific cameras that are used for long exposures, the sensors are cooled to reduce the noise. Some studio cameras have fans and heat pumps built into the equipment to cool the sensors, and the sensors of many scientific cameras can be refrigerated, often with liquid nitrogen.
Lenses

*East Beach* © by Russ McConnell. Courtesy of the artist.
Lenses and Shutters

Though there are no written records, lenses were likely used more than 3,000 years ago in Assyria. These lenses are thought to have been used for magnifying or concentrating the light of the sun for starting fires. The first written history of lenses can be found in ancient Greece in the play *The Clouds* written by the playwright Aristophanes, who discussed the use of burning glasses similar to the assumed use of the Assyrian lenses. By 1000 AD Arab physicist Ibn Sahl used mathematic equations to calculate the effective dimensions of lenses so they could be produced with specific magnifying characteristics. During the 11th century, lenses called reading stones were introduced in Italy. They were the immediate predecessors to spectacles, which came into use during the 13th century and further refined the application of lenses.

This knowledge of optics, the study of light and its interaction with various materials, led inventive and creative minds to seek alternate applications for the technologies they were discovering. As the properties of lenses became better known, optical instruments such as the telescope were invented, allowing astronomers to begin to map the skies and unveil truths about the universe. The use of the telescope and the various complex lens constructions that he employed allowed Galileo Galilei to begin to understand the structure of the heavens and convinced him to support the theory of Copernicus, which asserted that the Earth was not the center of the solar system, but rather the Sun. The scientific discoveries of physicists such as Galileo worked hand in hand with the development of lens technology because the lens guilds in Italy worked in collaboration with the scientists to create better and more accurate optics. Galileo had lenses of all sorts created, including one tinted with deep blue lapis lazuli that he could use to observe the Sun.

As lens technology continued to improve and lens guilds gained dominance and prestige based on scientific discoveries, the application of the new optical devices spread to the arts, another revered Renaissance tradition. Lenses allowed artists to begin to utilize new methods of creating precise reproductions of the world around them. This led to the introduction of lenses into the camera obscura. As previously discussed, the camera obscura was the predecessor of the photographic camera.

As photography took over, the use of camera lens technology became more important in making lenses practical. Because lenses can gather and focus light, they made it possible to reduce the length of time needed for exposure. Further lens-making technologies allowed for increasingly larger optics, creating flexibility in the way photography could be used. Based on the work of Galileo, the concept of compound lens sets came into being. This use of multiple lenses to accomplish imaging goals was the breakthrough that led to modern lens technology.
The creation of compound lenses also benefited art in an unexpected way. The use of these lenses allowed artists to change the angle of view from normal perception. This means that we could capture images that showed more of the scene than was possible with human vision, and we could magnify portions of the image to make them seem as though they were closer. This ability to change the angle of view to present the world as the photographer wished to see it, rather than the angle of view based solely on normal human perception, became one of the interesting artistic expansions of photography.
Basic Optics

There are six primary optical interactions, four of which play a large role in digital photography: (1) refraction, the bending of light as it passes through one medium to another; (2) reflection, the redirection or turning of light after it interacts on the surface of an object; (3) diffraction, the bending of light as it passes by an edge; and (4) dispersion, the separation of light wavelengths as light passes through nonparallel surfaces.

When light passes through one medium, such as air, into a denser medium, such as glass, the light bends away from the perpendicular (if the light is not perpendicular to the surface of the glass). If the light moves through glass into air, it bends toward the perpendicular. The degree of bending is determined by the relationship between the densities of the glass and the air. We can also see this bending directly if we look at a straight stick in still water. When we look from above, the stick appears to go straight into the water, but when we see the image below the surface of the water, the stick appears to bend at the water’s surface.

If the surfaces on the two sides of the glass are parallel, the light will bend in one direction when it enters the glass, and when the light exits it will bend back to the original angle. If the surfaces on the two sides of the glass are not parallel, the light will bend in different angles at each surface, depending on the angles of incidence as it enters and exits the glass. In effect, this is the way a lens works. A lens that curves outward (convex) bends the light toward the central axis of the lens. A lens that curves inward (concave) bends the light away from the central axis. By using both types of surfaces with different radii, the light passing through a lens can be finely controlled.
Although the shape of the glass (convex or concave) determines the focusing characteristics of the lens, the other three optical interactions (reflection, diffraction, and dispersion) are also involved in lens design. For digital imaging both diffraction and dispersion can have a negative effect on the efficiency of the sensor. Diffraction can cause the sensor to lose light-gathering efficiency, and dispersion can cause color fringing in the captured image. Reflection causes flare, which is the spreading of light across the image surface.

The smaller the f-stop, the more likely there will be color fringing on the edges of the image and reduced sensor efficiency. For this reason, point-and-shoot cameras may have limited aperture sizes, even if they have manually adjustable f-stops. Smaller photo sites require a larger aperture for the sensor to be efficient, so the small size of sites in camera phones eliminates the possibility of variable apertures. In point-and-shoot cameras, the size of the aperture is also affected by the amount of magnification used in the zoom lens.

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These optical interactions are very important in the engineering of lenses; however, this chapter is about using lenses, so we will not explore these interactions further other than how they affect making digital photographs. Having said this, it is important to note that the quality of the optics often makes the largest difference in the performance of the camera. An expensive camera body with inferior lenses will give inferior results. Most camera manufacturers with excellent reputations have gained their status by the quality of their lenses. It must also be pointed out that, as with most things, higher-quality optics not only capture superior images, but they also tend to be much higher priced.
Lens Basics

Depending on the kind of camera lenses that are used, lenses can be very simple, but in most cases today’s lenses are made up of multiple elements that are designed to correct errors in focusing or provide a special functionality to the lens. For digital photography there are several aspects that are common to all lenses.

Greek Salad © by Mallory Morrison. Courtesy of the artist.
Aperture

The maximum aperture of the lens is a factor that should be considered when you choose a lens, and it determines how the lens will function. The aperture is defined as the opening through which light passes. An iris usually controls the size of the opening through which light passes on its way to the sensor’s surface. An iris is made up of a series of movable blades that create a changeable aperture size. When we discuss the speed of a lens, we are talking about the maximum usable aperture for the lens. Lens speed seldom refers to the maximum diameter of the glass in the lens.

Another major aspect of selecting a large-aperture lens is the way it renders out-of-focus objects in the captured image. This concept, known as bokeh, is used to define and isolate the subject in space. Both the diameter and the shape of the aperture affect the shape of the out-of-focus areas in the image.

Focal Length

The second major factor common to all lenses is their focal length. With a simple lens, as an object gets farther from the camera, the focusing distance from the lens to the imaging surface decreases until the subject is at optical infinity. Therefore, the focal length is defined as the distance from a specific point within the lens, the nodal point, to the imaging surface when the subject is at optical infinity. Optical infinity means that when an object is a great distance in front of the lens, its image is sharply focused on the imaging surface. Because the distance between the lens and the imaging surface is quite small, the focal lengths for interchangeable lenses are normally expressed in millimeters. The focal length of the lens also affects the way a captured scene will look. This is known as the angle of view, which we will discuss later when we explore types of lenses.

The maximum aperture and focal length are common to all lenses, and the shutter is included in the construction of some lenses. If a lens is not permanently attached to the camera body, it is described by its maximum aperture and focal length. This information is often printed on the barrel or a solid part of the lens.
The relative sizes of apertures decrease as the numbers increase.

The f-numbers are normally called stops or f-stops. The standard f-stops are f/1, f/1.4, f/2, f/2.8, f/4, f/5.6, f/8, f/11, f/16, f/22, f/32, f/45, and f/64. Note that the scale doubles or halves every other f-number. Also notice that the f-numbers have a relationship to the power of 2. For example, 1.4 is the square root of 2, and 4 is 2 squared. The intervening numbers (2.8, 5.6, etc.) are multiples of the square root of 2, which is 1.4. This is important because the surface area of a circle is calculated using the radius squared. Therefore, the calculated area of each f-number opening is either half the preceding f-number or twice the following f-number. This means that each successive f-number allows in half as much light as the previous number. Moving higher by one full stop, from f/2 to f/2.8, reduces the light by half, and moving lower by one full stop, from f/8 to f/5.6, doubles the light.

The f-stop number measures the relative opening in the lens, and it also controls the various distances that are in focus in the photograph. If we assume that the aperture is a pure circle, it will focus a cone of light toward the imaging surface. The section of the cone that intersects the imaging surface creates a different size circle depending on the sharpness of focus. This is called a circle of confusion. Small circles appear to be in focus, and large circles look blurred or out of focus. Appropriate focus is a personal choice depending on the size of the circle that you will accept as in focus. With higher f-numbers the opening in the lens is smaller, and they therefore create a narrower cone of light. In a narrower cone of light, more objects at different distances appear to be in focus because the circles meet your size expectation.
This image demonstrates two different-sized apertures, in blue and red, and their resulting circles of confusion. The depth of focus is designated by arrows between the two blue lines and the two red lines, where the resulting circles of confusion are the same diameter. In each case, the point of focus is designated by the green line.

Since circles of confusion are formed by the distance in front of or behind the sharpest point of focus, the distance of the subject from the camera and the range of distances that produce circles of an acceptable size establish depth of field. The depth of field is the area of acceptable focus that extends in front of and behind your focused subject. This gets shallower or deeper in both directions, toward the camera and away from it, as you adjust the f-number. Because higher f-numbers with narrower cones create smaller circles of confusion, they have greater depth of field in the picture.

The three targets demonstrate how the depth of field for any given aperture is divided. Within the area of acceptably sharp focus, the point of focus is designated by the middle target, and the remainder of the depth of field is divided in thirds. One-third is toward the camera, and two-thirds are away from the camera.
Hyperfocal Focusing

There is a convenient way to find the focal point for any f-number, which will allow the photographer to capture the greatest depth of field. This is known as the hyperfocal distance. There is often a scale on the lens barrel with f-numbers arranged on either side of the focusing distance indicator. When the indicator for the f-stop to be used is aligned with the infinity mark on the barrel of the lens, the image will be sharp within the maximum depth of field, including infinity.

Understanding the concept of hyperfocal distance allows you to zone focus and to control the depth of field by setting a front focal distance and rear focal distance with an f-stop that restricts sharp focus to your chosen distances. This is done by first focusing on the closest distance and noting the focus line on the barrel of the lens. Then repeat this process for the farthest distance you want to have in sharp focus. These two points are then arranged on the f-stop scale on the lens so they are equally spaced on either side of the focus indicator. This will set your camera to the proper focus point. Then use the f-stop scale to select the f-stop that is indicated by the points, which are the distance extremes of focus.

The three targets demonstrate the division of the depth of field, but with hyperfocal distance focusing, the largest possible depth of field for any given aperture is achieved from the closest point of focus (which, of course, will vary with every aperture) to infinity.

This lens is set for a hyperfocal distance at f/11. This will have infinity and objects 6 feet from the camera both in focus.
© by David Litschel. Courtesy of the artist.
Types of Lenses

There are two major categories of lenses. The first is prime lenses. These lenses have a fixed focal length and fixed angle of view. Prime lenses are normally associated with DSLR cameras. The other major category is zoom lenses, which have various effective angles of view.

It is easiest to discuss lens design by discussing prime lenses. Within the camera, the imaging surface does not change. Therefore, an angle of view can be considered the angle created by the intersection of lines from the corners of the imaging surface to the point at which the light passes through the lens. This point is known as the nodal point. If the lens has a short focal length, the nodal point will be closer to the imaging surface. Therefore, with a shorter focal length the angle created by the intersection of the lines from the imaging surface will be wider than the angle created with a longer focal length.
These images of the Santa Barbara Mission demonstrate how the angle of view of different lenses alters the final image.
We consider lenses to be normal, short, or long based on a comparison of the angle of view of the lens to human perception. Photographs appear normal to us when they approximate human vision. It has been found that a photograph looks normal when the focal length of the lens is approximately the same as the diagonal measurement of the sensor’s surface. Lenses that have shorter focal lengths than the diagonal measurement of the imaging surface capture pictures with an angle of view that is wider than human vision. Shorter lenses capture pictures that tend to reduce the size of the objects in the scene or make them appear farther away. Lenses with focal lengths that are longer than the diagonal measurement of the imaging surface appear to magnify objects or bring them closer in the picture.

It would be simple to think of lenses as normal, short, or long, but because of how cameras operate, we must design lenses that approximate the effects of these lenses. Particularly with DSLR cameras, the operation of the mirror demands that the back of the lens be far enough away from the imaging surface to allow the mirror to rotate up and down. This means that we must design lenses to have effective focal lengths rather than relying on normal, short, or long lenses. These lenses are known as retro focus, and their design captures an angle of view similar to a simple lens structure. Lenses of this type are known as either wide angle (when they approximate the image captured by a short lens) or telephoto (when they approximate the image captured by a long lens).

The lens is permanently attached to many cameras. Even with DSLRs there is often a desire to have one lens that has variable focal length. A zoom lens provides the opportunity to change angles of view without changing lenses.

Zoom lenses are manufactured with various-shaped lenses. They have combinations of concave and convex surfaces that move in relationship to one another to create different angles of view through the lens. Zoom lenses designed for DSLR cameras are referred to by their effective focal lengths in relation to a full-frame 35mm camera format (for example, 25 mm to 75 mm zoom). However, zoom lenses that are permanently attached, particularly on point-and-shoot cameras, are described by the amount of magnification change the lens produces (for example, 5x1 or 5 to 1).

Because the f-stop is a calculation involving the effective focal length and the diameter of the aperture, if a zoom lens is to provide a consistent exposure without adjustment to the aperture, there must be a mechanism that simultaneously changes the aperture size as the lens changes its angle of view, or its apparent focal length. This is the concept of a variable f-stop, which is common to most modern zoom lenses.
Another aspect of the angle of view is created by the size of the imaging surface. This is known as a *telephoto effect*, though it is actually a cropping effect. The effect is created when the lens was designed for a larger imaging surface and a smaller sensor. Because the angle of view is related to whether we see the lens as short or long, if the imaging surface size is smaller than the design constraints for the lens, then it will not use the maximum angle of coverage of the lens. This narrows the angle of view and makes the lens appear to be longer. If, for example, a lens is designed as a 50 mm lens for use with a full-frame sensor and it is instead used with an APS (a smaller sensor), it will have an angle of view similar to a 75 mm lens on the full-frame sensor. This is a telephoto or cropping effect of 1.5, which represents the magnification change created by changing the angle of view.
The larger the actual capture area of the sensor, the wider the angle of view for a specific lens. A full-frame sensor captures the same angle of view as film when a lens with the same focal length is used.

A telephoto effect (or cropping effect) happens when the sensor is smaller than the corresponding film size, turning a normal 50 mm lens into an effective telephoto lens by capturing a smaller area of the scene. This chart relates the effective angle of view through various focal length lenses based on the sensor size and the effective magnification of that sensor. The magenta highlighted boxes are the closest to human vision.
Digital Camera Lens Design

One of the major factors for the selection of both primary and zoom lenses, particularly for DSLR cameras, is to match the lens with the image surface size. This is because the digital sensor requires the light to strike the surface as close to perpendicular as possible. When the light does not strike the surface perpendicularly, some of the light may not be recorded accurately.

To address the potential deficiencies in the light beam, lenses for digital cameras are designed in two ways. First, many manufacturers design their cameras to use only the center portion of the lens. Using the center of the focused light beam forces the portions that are the most divergent from perpendicular to fall in areas away from the image sensor. The second design uses elements that direct the light beam at the sensor surface in a more concentrated and perpendicular manner. These lenses use a device known as a collimator, which is similar to the condenser in a spotlight.

Beyond the loss of efficiency in the lens because the light does not strike in a perpendicular manner on the imaging surface, there is a potential that the dispersion characteristics of the lens will cause color fringing. This happens because the refraction of the wavelengths differs as they pass through the glass of the lens. Also, small f-stops create a potential for diffraction, causing the light to separate into various wavelengths. When the lens produces a large conical beam of light, the distance between various wavelengths increases and makes the fringing more noticeable. This problem is more pronounced on the edges of images made with wide-angle lenses, and because of the intricacies of the elements in zoom lenses, they are also susceptible to fringing.
**Lens Flare**

Flare is an unavoidable part of photography. It happens any time light enters a lens system. When light enters a lens it is not only refracted and focused, but portions of the light beam also reflect off the interior surfaces of the elements and the housing for the lens. As the light reflects off these various surfaces, it also becomes a focused portion of the image. If the light source is very intense and comes from a point-shaped source, such as the sun, small portions of the light will appear in the final image as bright spots shaped like the opening in the iris. This is the most readily observable form of lens flare, but it not the only way flare affects images.

If the light illuminating the scene is very diffuse, such as an overcast sky, flare still occurs, but it is not as noticeable as an intense point of light in the field of view. In this case the flare causes an overall pattern of light to distribute across the entire image surface. Because of its low intensity, this pattern is seldom noticed. However, it does directly affect the color and contrast within the image. With overcast flare it is quite common to lose 5 percent of the density in the darkest areas of an image and the same amount of detail loss in the brighter areas of an image.

In both cases there is a simple solution to reduce the flare in a photograph: Use a lens shade or hood to reduce the amount of light that is not part of the picture from entering the lens. The lens shade or hood will also enhance the contrast and color saturation in all images.

This diagram demonstrates the way that a strong light source, such as the sun, can interact with the optics in the lens to reduce clarity and contrast in the image. If the sun or another bright light source is in the frame, you might not be able to reduce the flare. However, if the light source is outside the frame, you can significantly reduce the impact of flare by using a lens shade or hood to prevent the light from interacting with the lens optics.
These two images and histograms are from the same scene. In the image on the left, the lens is not shaded, the highlights are blown out, and the contrast in the overall scene is visibly reduced. In the image on the right, the photographer merely added a lens shade. The highlights are within tolerance, allowing for detail in the highlights, and the overall contrast is better.
Image Stabilization

Many modern digital lenses have image stabilization capabilities. This means that through various methods the lens will compensate for different amounts of shake or motion. Effectively these methods allow the camera system to be handheld at slower shutter speeds and still achieve sharp images.

There are four major ways that image stabilization is controlled: two rely on the optics of the lens, and two use functions associated with the sensor. Of the two optics-based systems, the easiest to understand is the distorted bellows. In this system the bellows is constructed behind the lens and has optic characteristics similar to the glass in the lens system. The bellows is constructed of two flat pieces of glass with material between them that allows the glass to rotate on horizontal or vertical axes. As the lens moves slightly, the bellows structure adjusts in a similar direction and in doing so refracts the light coming through the lens so it stays in the same position on the sensor.

The second system uses gravity to move a lens element either up and down or side to side. This lens does not deform the image when it changes location between the lens system and the imaging surface; instead it creates diffraction that keeps the image steady. For this system and the distorted bellows system, the lenses add stability to both digital and film-based cameras.

The third system utilizes imaging software in the camera to adapt to motion. The software allows the sensor to use image recognition to reinterpret the image as it moves on the imaging surface.

Last, and perhaps most complex, is a system that moves the sensor in relation to the camera's motion. Software maintains alignment of the image on the sensor by using servomotors that are controlled with integrated circuits in the camera.

Image stabilization does not eliminate lens movement from the image. These systems can only reduce the effect of shaking or small motions in the camera during exposure. Testing has shown that the best types of image stabilization can benefit handheld exposures as long as about one-half of a second.
Shutter Systems

Shutter systems are not always part of the lens. Depending on the type of digital camera, the shutter may be in front of the imaging surface or electronically controlled with the image sensor itself. Early photographers simply removed their lens cap then replaced it to stop the exposure. As lenses became more advanced and the need for more precise timing evolved, the shuttering mechanism moved into or behind the optics. Whether they were guillotine shutters that had a single spring-loaded blade that opened and then sprung shut or iris shutters, known as leaf shutters, they became integral parts of lenses for 150 years.

A leaf shutter is made of a series of blades similar to the iris that adjusts the aperture. When the camera is activated, springs rotate the mechanism and open all the blades simultaneously to the preset aperture size. After the timing mechanism reaches its end point, the springs reverse and close the aperture to stop the exposure. Because of the moving parts in a leaf shutter, the shutter speed is limited to about 1/500 second. These shutters are quite common in larger-format cameras that use either film or digital backs.

The major advantage of a leaf shutter is that it provides exposure over the entire imaging surface from the moment it opens until it is totally closed. Because the light intensity varies as the aperture is opened to the correct f-stop, exposure occurs for the entire duration of the shutter's operation. This is particularly important with electronic flash photography.

A second common type of shutter that can be used in both digital and film-based cameras is the focal plane shutter. A focal plane shutter derives its name from its location in the camera. The imaging surface is the focal plane. The shutter is placed directly in front of it and is opened and closed with electronics or springs. The shutter is made of metal louvers or curtains. The simplest structure of a focal plane shutter is two curtains that travel across the focal plane. When the shutter is activated, the first curtain starts moving. The second curtain starts moving at a time difference equal to the shutter speed setting. This means that at very fast shutter speeds, a separation of a predetermined size travels across the imaging surface. This allows the imaging surface to be exposed while the opening is in front of it.

Focal plane shutters became popular to allow lenses to be changed while the camera was loaded with film. When the focal plane shutter is closed, it prevents the imaging surface from being exposed. The focal plane shutter also protects the imaging surface from dirt when lenses are changed. Even if other types of shutters are used, there are often focal plane devices in front of the imaging surface to protect it.

With older focal plane shutters there is a problem with electronic flash photography. This is because shutter speeds faster than 1/60 second don't allow enough time for the opening created by the curtains to traverse the imaging surface and expose its entire length. Electronic flashes that have a
light duration of less than 1/60 second result in only a portion of the imaging surface being exposed to the electronic flash. More modern focal plane shutters that use either louvers or metallic curtains have faster motions and can therefore be synchronized with electronic flash at a higher speed.

Focal plane shutters are also susceptible to motion distortions. If the object being photographed is moving very fast and perpendicular to the motion of the focal plane shutter, an elongation or shortening of the subject results.

_Dandelion_ © by Russ McConnell. Courtesy of the artist.
Electronic Shutters

There are three types of electronic shutter systems that are used in digital cameras today: frame transfer architecture, global shutters, and rolling shutters. Frame transfer architecture was originally conceived as a buffering system, but it can be used as a shuttering concept. This architecture will be discussed in chapter 13.

Global and rolling shutters use the same electronic logic that allows the sensor to capture light. Since the photons of light that cause exposure act as negative electric charges, the sensor cannot capture the photons if it holds a negative charge. However, if a positive charge is added to the sensor to override the negative charge, it will then record the photons striking it. In this scenario the positive charge of the sensor is followed by another negative charge, which stops the exposure.

As the name implies, a global shutter exposes all pixels at the same time. A rolling shutter, also known as a block shutter, activates sequential columns or rows of pixels until the entire sensor is exposed. Although a rolling shutter is less expensive, it shares the same drawback as a focal plane shutter when it is used to photograph high-speed subjects.
Shutter Speeds

Shutter speeds can be measured with any time-based unit. However, the most common measurements for still photography are seconds and fractions of seconds. Shutter speed settings typically increase or decrease in increments beginning at 1 second. Shutter speeds that increase from 1 second can use any increment, but they are commonly arranged in a doubling sequence, such as 1, 2, 4, 8, 16, etc. When shutter speeds decrease, a halving sequence is typically used, such as 1/2, 1/4, 1/8, 1/15, 1/30, etc. This produces the same exposure variation as f-stops because, like f-stops, shutter speeds are based on the number 2.

As a final note, shutter speeds and apertures need to be adapted to the way sensors or film speeds are defined. The International Organization for Standardization uses a one-third stop increment for exposure ratings of imaging surfaces. Because the sensitivity of imaging surfaces is measured in thirds of stops, this increment has been programmed into the operating systems of cameras. This is evident in both f-stops and shutter speed settings for digital cameras.
4
Exposure Basics

© by Christopher Broughton.
From Light to Image

Dictionaries define light as that which makes things visible. Just as light is required for human vision, it is also required for normal photography. This is true regardless of the technology that is used to capture light. The capturing of light in the photographic process is called exposure.

The original name applied to the process of photography, discovered by Nicéphore Niépce, was heliograph (sun writing). At the outset of photography, the light energy needed to expose very slow emulsions required photographers to work with sunlight. Even with sunlight, the exposure times were lengthy. With early daguerreotypes the exposure times in bright sunlight were 20 minutes. In 1841 it was found that modification of the imaging surface could reduce the exposure time to only 25 seconds in bright sunlight. Even with great improvements in the sensitivity of the imaging surface, the requirement for high-intensity light restricted the type of photography that could be done at its inception.

Although arc lights had been in existence for some time, it was not until 1875 that the incandescent light bulb was patented. The invention of the light bulb, with its later improvement by Thomas Edison, provided the opportunity for photography to work within a controlled light environment and not to depend solely on the sun.

In 1851 William Henry Fox Talbot demonstrated that he could create a photograph using an electronic spark. This enabled stop-action photography. In 1864 the first attributed portrait photograph was made using ignited magnesium powder called flash powder. By 1930 engineers were beginning to understand light generation from gas discharge tubes. Although these concepts had been around since the 1870s, engineers and scientists were able to produce light with only very short durations. It was at this time that Harold Edgerton was able to put together the concepts of short-duration light linked to camera exposure, which led to today’s electronic flash photography.

Although improvements in light technology for making photographs were important in reducing exposure time, the vast changes in the sensitivity of photographic materials also aided photographers. With the use of emulsions on glass plates and films, improvements were made until, by the early part of the 20th century, handheld camera exposure was possible.

As films became more sensitive to light, a way to express their sensitivity was needed. The film speed became a standardized method of describing how much light was required to achieve a proper exposure. In today’s nomenclature the sensitivity of the capture surface is referred to as the ISO. Although the International Organization for Standardization sets standards for many materials and processes, we are interested in the one that deals with exposure. For film the ISO is a set value, but with the introduction of electronics to photographic capture there was an opportunity to amplify the signals generated from capturing light and to increase or decrease the sensitivity of the capture surface. This meant that flexibility for exposure was in the hands of the photographer, not a fixed value set by a film manufacturer.
Exposure Basics

The key action in the photographic process is exposure. Without adequate exposure there will not be an image, and if there is too much exposure there are other problems with the image. This means we need to understand and accurately utilize our exposure tools to effectively communicate our ideas, visions, and feelings through our photographs. If exposure fails, the best we can do is salvage an image, but with excellent exposure we can create a great photograph.

In starting to understand exposure we need to look at the basics. First we’ll discuss the overall idea of exposure, followed by how to maximize exposure, and then we’ll conclude with methods of measuring light and adapting exposure.

Exposure is equal to the intensity of energy reaching the imaging surface in conjunction with the time it is allowed to contact the surface. This is expressed in the equation

\[ E = I \times t \]

where \( E \) is the exposure, \( I \) is the intensity or the amount of light energy flowing to the surface, and \( t \) is the time that the energy is allowed to impact the imaging surface.

This formula or expression of exposure relies on one constant that is not expressed in the equation: the speed or sensitivity of the imaging surface. Although the previous formula worked well for film-based photography with fixed ISOs, digital sensors have variable functional speeds. Therefore, the equation for a digital camera must be viewed as

\[ E = I \times t \times f(ISO) \]

In this equation the sensitivity of the imaging surface is addressed as a function of the ISO. When the ISO is held constant in the equation, such as with film, the first formula holds perfectly. However, if there is a variation in the ISO, it must be used to calculate the proper exposure. As we will see later, this gives us greater flexibility to obtain the proper exposure for digital photography that is not available with film.
If we think about the basic equation $E = I \times t$ with the ISO being held constant, then the basic equation for exposure is a reciprocal equation. This means that exposure will remain constant as long as the product of the intensity and time remains constant. In other words, if the intensity of the light increases and the time that the light is allowed to act on the imaging surface decreases proportionally, we maintain the same exposure level. As intensity goes up, time must go down to maintain the same exposure. The inverse of this is also true (i.e., as the intensity goes down, the time must go up). In photography this is known as the law of reciprocity.

To understand how we can control exposure, we first have to understand the tools in the camera that are available to us. First is the aperture of the lens. As we discussed earlier, aperture is measured in f-stops. The full stops are arranged so that each successive stop reduces the light hitting the imaging surface by one-half its value. Conversely, each previous stop increases the light by twice its value. This controls the flow of energy to the imaging surface. Next we need to consider the time of the exposure. We use shutter speeds that are also arranged in ascending and descending order based on the power of 2.

An analogy that is often used to explain how the law of reciprocity works is to consider filling a bucket with water from a hose. If we use a hose with a small diameter, it will take longer to fill the bucket than if we use a hose with a larger diameter, if the pressure is constant in both hoses. In this analogy the diameter of the hose is the aperture, the time is the shutter speed, and the constant pressure relates to a constant ISO. Achieving optimal exposure is the same as filling the bucket to the desired level; you can increase the size of the hose and decrease the time, or you can decrease the size the hose and increase the time. This is a pure reciprocal relationship.
Auto Exposure

In digital cameras today, sensors are used not only to capture the image but also to provide exposure information. In most digital cameras you have the option to use many automatic settings, which use reciprocity to allow either the shutter speed or the aperture to be held constant. These settings are known as shutter priority and aperture priority. The camera also has a reciprocity-based, fully automatic system that allows the camera to adjust the exposure by selecting the best combination of shutter speed (to reduce shake) and aperture (to maximize depth of field).

A fully automatic system calculates adequate exposure in most situations. However, it limits your creativity for framing the image. Both aperture priority and shutter priority add more control, and thus more creativity, into the exposure process. An aperture priority system is most useful when you want to control the depth of field. You can either use a small aperture (high f-stop number) to have a greater depth of field where a large amount of the image appears sharp and in focus, or you can use a large aperture (low f-stop number) to create a limited depth of field and allow the central subject of the photograph to separate from the background and foreground. With shutter priority you select the shutter speed, and the auto exposure control sets the proper aperture to achieve a correct exposure. A high shutter speed stops action, and a low shutter speed introduces blur into the image.

Basic Daylight Exposure

Digital cameras have metering systems built into their operating system. However, using an auto exposure system will not always give the best exposure. There are situations when understanding light will allow you to make a better exposure, particularly when there is a large amount of dark tones or light tones in the scene. In these circumstances, when the scene is lit by either daylight or ambient light you can get better results if you don’t use the auto exposure controls.

One of the ways to improve exposure is to use basic daylight exposure (BDE). With BDE you can adjust the exposure based on the light rather than relying on a meter reading or allowing the camera’s auto exposure to take control. Using the concept of BDE, we can devise a list of recommended exposures based on different light situations. The idea is that sunlight on a clear day is a very consistent light source. With sunlight used to establish a standard exposure, other lighting conditions are described in comparison to the BDE. This process is also known as the sunny-day rule or sunny-16 rule, which means that on a sunny day the exposure will be f/16 at a shutter speed of 1/ISO. Based on this principle, the following tables provide light values and exposure recommendations for specific lighting situations.
The settings in the following table require both the shutter speed and the f-stop to be adjusted. Note that the exposure needs to be adjusted to compensate for the loss of stops in the light value column.

<table>
<thead>
<tr>
<th>Lighting condition</th>
<th>Light value</th>
<th>Aperture (if the shutter speed is 1/ISO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunny day</td>
<td>BDE</td>
<td>f/16</td>
</tr>
<tr>
<td>Sun on snow or sand</td>
<td>BDE +1 stop</td>
<td>f/22</td>
</tr>
<tr>
<td>Hazy</td>
<td>BDE –1 stop</td>
<td>f/11</td>
</tr>
<tr>
<td>Cloudy but bright</td>
<td>BDE –2 stops</td>
<td>f/8</td>
</tr>
<tr>
<td>Overcast or open shadow</td>
<td>BDE –3 stops</td>
<td>f/5.6</td>
</tr>
<tr>
<td>Lighted signs (to see the color)</td>
<td>BDE –5 stops</td>
<td>f/2.8</td>
</tr>
<tr>
<td>Stage lighting (bright stage)</td>
<td>BDE –5 stops</td>
<td>f/2.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lighting condition</th>
<th>Light value</th>
<th>Exposure (combination of shutter speed and aperture adjustments)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bright city streets (such as Times Square), fireworks, store windows</td>
<td>BDE –6 stops</td>
<td>Add 6 stops</td>
</tr>
<tr>
<td>Stage lighting (spot lighting), night football or baseball</td>
<td>BDE –7 stops</td>
<td>Add 7 stops</td>
</tr>
<tr>
<td>Inside well-lit buildings</td>
<td>BDE –9 stops</td>
<td>Add 9 stops</td>
</tr>
<tr>
<td>Floodlit buildings</td>
<td>BDE –11 stops</td>
<td>Add 11 stops</td>
</tr>
<tr>
<td>Distant city lights at night</td>
<td>BDE –13 stops</td>
<td>Add 13 stops</td>
</tr>
</tbody>
</table>

As a first example let us start with a sunny day and the camera set at ISO 200. In this situation the exposure would be at f/16 at a 1/200 second. Another common situation is when the sky is overcast. With the same ISO setting (ISO 200), three additional stops of exposure are required, resulting in an aperture of f/5.6 at 1/200 second. Artificial lighting situations are also common, such as theatrical stages or night shots at sports stadiums. Based on BDE this situation requires seven additional stops of exposure. With the ISO set at 200, the correct exposure would be f/4 at 1/25 second (f/16 to f/4 equals four stops, and 1/200 to 1/25 equals three stops, for a total of seven stops).
© by Matt Harbicht. Courtesy of the artist.
Light Meters and Basic Metering

Establishing the exposure without metering works, but exposure is usually calculated based on the measurement of light. This is accomplished with light meters, whether they are part of the camera’s operating system or separate devices. To understand metering it is best to consider a separate device, though most of the metering that can be done with handheld meters can also be done with a camera’s TTL exposure system.

There are two basic operating types for non-camera light meters. The first type is photovoltaic meters. These meters capture the energy from the light in the scene and convert it to a very low electrical charge that is measured with a voltmeter. The second type is resistance meters. They use various light-sensitive materials that alter electrical resistance based on the amount of light present, and they use an ohmmeter to read the in-line resistance to measure the light. Regardless of how a meter measures light, its function is the same: The meter establishes the level of light either falling on the meter or reflected from the subject, and it uses that energy measurement to calculate an effective exposure. The meter recommends an f-stop and shutter speed combination based on a specified ISO.

A light meter measures the light’s energy, though it has no way of determining whether the light is falling on the meter, if the light illuminates the subject, or if the light is reflected from the subject. The design of the meter and its onboard programming determines how the light will be evaluated. Some meters are designed to use reflected light, and others are designed to measure incident light. Advanced meters can be programmed to measure either reflected or incident light.

Reflective and Incident Meters

The most common method for measuring light in photography is with reflective meters. Light is reflected onto the meter’s sensor from the subject, or if the meter is a spot meter, the light is reflected through a lens system. The angle of view for the meter determines how much of the scene is taken into account when it calculates the exposure. The lens system in a spot meter creates a very small angle of view that is coordinated with a viewing system and allows you to see the exact area being measured.

Incident meters utilize diffusion devices to capture light from all directions and transmit it to the measuring sensor. The most common type of diffuser is a dome. Because the dome captures light from all directions, it acquires all the light that affects the meter from all sources illuminating the subject.
Exposure Calculation

Exposure is calculated by using a predetermined value as the average tonal representation for all subjects. This value is called middle gray, which has an 18% reflective surface. The meter assumes that it is measuring a middle-toned area or a mix of light values that have a combined value equal to 18% reflection. The meter uses the concept of 18% reflection to represent all light that could enter the meter from a normal scene. Most common reflective meters use an averaging procedure. An average scene contains a mix of light that creates a middle tone when all the light is combined. Using this logic, if a scene is normal and the meter determines the exposure based on 18% reflectance, the subject will be exposed correctly. Because most cameras use TTL meters, the majority of metering is done using an averaging method.

The sensor design in today’s digital cameras allows TTL-programmed metering for specified patterns rather than just an average or simple spot measurement. Programmed meters can weight the exposure to emphasize predetermined areas in the frame. When a small, specific area of the frame is chosen, the system acts like a spot meter. Some systems can be programmed to measure light in specific areas and create light weighting for those areas in the scene.

A problem associated with average reflective metering is subject bias. This occurs when the scene is not accurately exposed because the tone of the scene is either mostly dark or mostly light. When the scene varies greatly from an overall 18% reflective tonality, the exposure can shift to the opposite of the tonal bias in the scene. A dark scene will be overexposed, and a very light scene will be underexposed.

To avoid subject bias, incident metering can be employed. An incident meter measures the light that is illuminating the subject. It uses a translucent dome over the sensor, which diffuses the light and averages it. Unlike a reflective meter, an incident meter is pointed at the camera from the subject’s position, or it is pointed at the light source from the subject’s position. The dome’s shape averages all the light directed at the subject, including any ambient light reflecting onto the subject. This type of metering allows the scene to be accurately exposed regardless of the overall tonality of the scene. Flash meters are commonly incident meters.
Billy Casper © by Tim Mantoani. Courtesy of the artist.
Substitution Metering

Even without an incident meter, you can avoid subject bias by using substitution metering. With substitution metering, you place a material into the scene with a known reflectivity, such as an 18% gray card. Then you can bring a reflective meter close to the substituted material and measure the light reflecting from it to establish the exposure. The light reflected from the substitution material will represent 18% of the light that is illuminating the scene.

An 18% gray card should be placed in a critical area of the scene parallel to the image plane. By having the card in this position, the light reflected from it will include any glare that might be produced by the light on the scene.
Substituting a gray card provides the same amount of illumination that the camera will use to establish the exposure from a normally reflective scene. If the only thing the metering system measures is the card, the exposure will be based on the light falling only on the card. The card should be perpendicular to the lens to capture the effect of the light as well as the amount of light.

Other materials can be used for substitution metering when you know their reflectivity. For example, the palm of most hands reflect about 36% of the light illuminating it. Using the palm of a light-colored hand and reducing the exposure by one stop will provide a good exposure. A reflective measurement from the clear north sky is equivalent to an incident meter, or 18% reflection.

With digital photography substitution metering is very valuable. If the system allows multiple-point metering, you can use either a gray scale on a color checker or a series of flat painted cards (black, middle gray, and white) for multiple substitution exposure points. This technique provides good control of highlights, shadows, and middle gray tones in the image.

**Tonal Placement**

You might have a particular area of the scene that needs special attention. When this is the case, tonal placement metering can be used to center the exposure on the selected area. Tonal placement uses a reflective meter to measure the light coming from the chosen area. You can then adjust the exposure based on the difference in the number of stops between that area and 18% gray. If you want to lighten the chosen tonal area, you can open the aperture; to darken the exposure, you can stop it down.

**Average Value Metering**

Average value metering is a special case of tonal placement metering. The idea is to measure both the highest and lowest light values in the image and set the exposure in the middle. This can be done in two ways. First, you can use a metering device to measure the brightest desired highlight and the darkest desired tone. Then you can find the mathematical center exposure and use that setting.

The other method uses the histogram display on a digital camera. If the histogram is active or adaptive (capable of changing in real time as the scene in front of the camera changes), adjusting either the shutter speed or aperture while viewing the scene on the histogram allows you to manipulate the exposure. When the entire histogram is on the right side of the graph, the exposure is maximized for the scene. If the camera’s histogram system is not active, test images can be taken until the histogram fits within the graph. This method will be discussed in greater detail later in the book.
Part 2

Working Digitally
At the heart of this book is the art of making digital photographs. Up to this point we have discussed the basics, and the similarities and differences between analog and digital photography. In both photographic approaches we capture light and make it permanent as a photograph. Although many of the concepts are interchangeable between film-based and digital photography, there are several distinct differences.

The chapters that make up Part Two of this book explain how digital photography can be optimized. We will discuss specific options that are available only with digital photography. These concepts expand the ideas of exposure presented in Part One and present exposure concepts that are not available in film-based photography. We will discuss a total workflow that takes you from image preparation to session cataloging, and we’ll explain digital files, editing, and asset management.

The chapters in Part Two address five areas of concern: specific digital exposure techniques; a digital workflow; files; parametric editing; and asset management. We will discuss how to maximize exposure in the digital environment. Because of the capabilities and limitations of digital cameras, these approaches are particular to digital capture. We will introduce a workflow that starts with a newly acquired digital camera and continues to the point of saving the images. We will also help you understand digital files and file types and the advantages and limitations for the most common kinds. We will also review parametric image editing and how it can be used as a tool to optimize the images captured in the camera. As a conclusion to this exploration of basic digital photography, we will review asset management to ensure that you can safely and securely maintain your images for years to come.
Exposure for Digital Photography

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Exposures Become Digital

With digital photography we live in a world of temporary truths. We know what we believe to be the best capture methods today, but as this technology is evolving and maturing, our knowledge is growing and changing. The digital photography world is getting fleshed out and refined as we write this book. It will continue, and thus we will also continue adjusting our knowledge and methods.

In the last chapter we discussed the basics of exposure. Both the exposure methods and many photographers have moved from film-based photography to digital photography. The first DSLR cameras were basically film cameras with a digital sensor replacing the film. Because of this link to film and photographic traditions, the movement to a solely digital-based photographic process has been slowed.

Some digital immigrants maintain the school of thought that an image must be captured as perfectly as possible so it can go directly to print. This approach assumes that DSLR cameras simply replace film with a digital sensor. We instead work with JPEG files and are involved in little, if any, image processing as the picture moves from the camera to print.

Part of this approach developed during the time-intensive development of early image processing software. At this point in the history of digital imaging, the slower computer processors and limited software meant that even the simplest operations involved longer times.

The workflow model in this school of thought assumes that the in-camera processing of the image is all that will be needed to perfect the image. For this approach, JPEG or other interpolated image file formats work well. Because any modification to the file in this methodology will result in degradation of the image, there is no anticipation that the image, when captured, will need to be changed or manipulated before it is printed. These are limitations for the serious photographer but seldom for the point-and-shoot camera user.

A second school of thought involves a more active digital native. This concept relies on capturing and optimizing the image to create the strongest foundation for future processes. The basic understanding is that when a RAW file is captured, the only camera controls that affect the data are ISO, shutter speed, and aperture. This means that the captured image will not be perfect or ready to print, but rather it will require processing through conversion and possibly within imaging software to create the picture we envision. This is a huge leap for anyone who relies on film technology as the basis for understanding photography.
Even with the tools we find on the back of a modern digital camera, we run into issues of how to optimize photography in all situations. This is because there are no standards for the preview, the histogram, or the blinking highlight warnings. Each of these features is dependent on the model of camera, the manufacturer’s processing parameters, personal preferences in camera settings, etc. Effectively we need to determine the working parameters to create the best files to move forward to post-processing rather than think of the process as an endpoint capture.

This is not as difficult for the digital native as it is for the immigrant. Because the native has no basis in film, the film-based photographic process can easily be ignored on the way to optimizing capture. Although the concepts of exposure that were explained in the previous chapter are valid, they are not a pure requirement if a digital process is anticipated between image capture and printing.

For this school of thought, active feedback is built into the system. The camera’s onboard tools allow us to work in a feedback loop that includes the scene, the camera, our visualized image, and finally the exposure. In this way we allow the camera to aid us in making critical decisions about the structure of the data, not only the look of the final image.

Finally, the third school of thought involves a tethered capture system. This relies on more computing power than is normally available in portable photographic systems. Because a computer must be tethered to the camera, this system becomes bulky and cumbersome to handle in the field, though this will change with time. However, the great advantage of this system is that the immense computing power of a tethered system allows the photographer to utilize software to blend the first and second schools of thought. This hybridizes the process by combining the intense processing of RAW files with predetermined output in one step. At the time of this writing, this is exemplified in Phase One’s Capture One Pro, which is the industry standard for this type of software. Although this process is primarily available to tethered cameras, the evolution of this concept for handheld cameras is very likely. The computer will not only aid in optimizing the data, as discussed in the second school’s operational model, but it will also arrive at a completed image, as envisioned in the first school’s model.
Exposure Testing for Digital Sensors

Regardless of our school of thought, in order to optimize exposure we must know the limits of our equipment. We need to establish the actual exposure index (EI) for our digital camera, and we must consider how we will determine the clipping points for our sensor. Although this would be an excellent exercise for all cameras, only cameras that can be operated in a manual mode can perform an EI test. It is also best to record in a RAW file format. These two requirements restrict EI testing to higher-level prosumer or professional-level cameras.

Testing concepts rely on our ability to evaluate the sensitivity of the imaging surface compared to known quantities of light. First we need to use a measuring device to establish the light value for light outside of the camera that we are testing. This is required because the camera has a built-in bias to its own system and will anticipate that the ISO that is programmed is correct. Although the ISO setting for the camera will be close to the actual EI, there is no guarantee that it will be accurate.

The second part of the test is to establish the levels at which clipping occurs. Clipping happens at both ends of the exposure scale. When the energy reaching the imaging surface is greater than the sensor’s ability to absorb it, not all of the energy will register. The sensor can only record a certain energy level, and beyond that level there is no difference between the captured image and the limit itself. When the sensor’s white level is reached, all additional white is either spread to other areas of the sensor, known as blooming, or the energy is simply shunted as though it never reached the surface.

To evaluate the EI of the sensor you will need to be able to measure the available light and compare the captured levels of exposure to accomplish the desired results. For this purpose it is best to use an incident light meter or a reflective meter with a known reflectance target, such as an 18% gray card.

Setting Up for the Exposure Test

The scene needs to include a test target consisting of white, 18% gray, and black cards that will generate a large enough pattern on the sensor so you can read it after exposure. Manufactured targets can be used, such as the MacBeth color chart or the Accu-Chart Grey Scale target. However, if such targets are used they must be large enough in the image so you can accurately read the various tonal patches. With these targets specific values are indicated for some patches. A model should also be in the scene so you can capture skin tone. White material that has a heavy texture will also be needed in the scene. This could be a heavy-textured, ribbed, or cabled sweater or a deep-pile white towel.
The setting needs to be evenly illuminated with an even, dark background. Ensure that the light is nondirectional by using diffuse light. Do not use specular spotlights. A bright background or backlighting will reduce the accuracy of the test. Place the target on a stand near the model's face, and make sure you can see part of the white fabric and its texture. The test will be accurate only if the gray, black, and white cards are parallel to the sensor's plane (the back of the camera).

Set the ISO on the light meter to be the same as the selected ISO on the camera. Because noise can appear at the dark end of the tonal scale, use the camera's lowest-available ISO, or ISO 100, for testing. Using the meter, measure and write down the recommended exposure settings (f-stop and shutter speed).

_Solstice_ © by Douglas Dubler. Courtesy of the artist.
Conducting the Exposure Test

Before you start the test exposure sequence, neutralize the files. Do not use auto white balance. Rather, manually set the custom white balance to match the light source. Then take information readings on the white areas of your target.

Make a series of exposures starting with the camera opened up two stops from the exposure setting recommended by the light meter (either by adjusting the aperture or shutter speed accordingly). Record the f-stop and shutter speed for this frame and each of the upcoming frames. Decrease the exposure by one-third stop (or one-half stop if only halves are available on your lens) by adjusting either your aperture or shutter speed and take your second exposure. Continue by decreasing another one-third stop (or half stop) and make another exposure. Repeat this process until you have a complete four-stop range, which will result in 9 to 15 images. The reduction of light can be accomplished by stopping down with the aperture, shutter speed, or both.

To determine your camera’s true EI, use imaging software to read the white area of the gray card by hovering the information or eyedropper tool over the white area and reading the corresponding RGB values. The correct exposure will be the frame where the white areas of the target have approximately a 245 value for each of the R, G, and B readings. This exposure is closest to the true white reading you obtained with the light meter.

Analyzing the Exposure Test

On your computer monitor, arrange the results from most exposure to least exposure. You can see which exposure’s white point is closest to 245. That exposure is closest to the ISO you set on the light meter and the camera for the test. The EI is the number of stops (the number of full, thirds, or halves) away from the camera’s ISO that results in a correct exposure. From now on, when you use this meter and camera combination, the correct exposure will require the adjustment of your camera settings by reducing the exposure if the EI is less than the meter’s setting and increasing the exposure if the EI is greater than the meter’s setting. This adjustment is valid only if you used manual mode and the same light meter from the test.

Since digital photography is not very forgiving of overexposure, it is important in our testing that we not only determine the EI for the sensor but also its ability to accept overexposure. To avoid clipping, adjust the exposure control within the image processing software by setting the white target area at 245. Magnify the view of the white textured fabric and look for loss of detail, color shifts, and blooming. Observe the highest amount of overexposure your camera will allow without loss of detail in white and highlights or significant degradation of the image. This observation is accurate when the camera is used in manual mode or any automatic mode.
It is easy to set the handheld meter to a different ISO, but the in-camera meter is another story. Digital cameras differ from film cameras because film manufacturers rate their film stock at different ISOs. But you cannot set the ISO on your digital camera without adjusting the processing gain, which may create more noise or other unwanted attributes. If your camera’s EI test shows that your camera underexposes by one-third stop, manually increase your exposure by one-third stop or set the exposure value (EV) adjustment to +1/3.

It is best to understand how both handheld meters and in-camera meters function in different situations. The rationale for using an in-camera meter is a need to react quickly to your subject or lighting. When time permits or when you are photographing in a consistent light condition, a handheld meter may be preferred.

To correctly do your EI test, you will have between 9 and 15 images to evaluate (depending on if you have a one-half stop or one-third stop camera). This particular test was done with a one-third stop camera and resulted in 15 total images, but for the purposes of illustration, the middle five images are shown to demonstrate what the underexposed, correctly exposed, and overexposed images look like. The proper exposure in your series of images will be appropriately exposed in all three areas of the card (white, gray, and black) and demonstrate accurate skin tones and white texture with detail (as in the model’s shirt). These values can be measured in image editing software.
Histograms

Within the digital environment, the histogram is a valuable tool for making correct exposures. A histogram is a graphical representation of the way the light energy from the scene was captured and processed by the camera. Saying that it is a graphical representation does not mean that it is an accurate accounting, but rather it is a proportional representation that can be a very powerful tool in making digital photographs.

You can’t judge the final outcome of an image based on the preview from your camera. The preview image is an interpolated file, whereas the RAW file is the actual data from the captured light. In this illustration, the preview image appears brighter, with more contrast and a limited dynamic range, whereas the corresponding RAW file is not clipped, not saturated, and has a more accurate dynamic range according to the scene. It is always preferable to use the histogram for the captured image to judge exposure.
The histogram does not show the exact light energies captured; it is relative to the preview file seen on the LCD. The histogram is generated from the JPEG file that was processed and interpolated by the onboard computer to be shown as the preview. As part of this processing, a curve adjustment is applied so the image looks better on the LCD screen and displays the characteristics that the average person would want to see, which is not necessarily how the image was captured. This adjustment slightly compresses the highlights and shadows and slightly enhances the contrast by redistributing the tones from the RAW file. Therefore, the information displayed by the on-camera histogram for the preview image is approximately correct but not actually correct.

With some professional cameras the parameters used to produce the preview histogram can be adjusted to more closely match the RAW histogram. This allows for limited adjustment of the end points of the histogram. The operation manual for each camera will give instructions to make this adjustment if it is available.
The histogram analyzes the digital image by counting and displaying a proportional representation of the number of pixels in the image with their corresponding light values. The vertical scale of the histogram represents the number of pixels that have been exposed at various light values, and the horizontal scale of the histogram represents the dynamic range that the sensor can capture.

Although the vertical representation on the histogram is proportional, the horizontal representation is actual. That means we have more accuracy in relation to the dynamic range. When the graph shows captured light, it accurately locates the light value along the dynamic range continuum, but it does not accurately count the number of pixels with that value; rather, it proportionally represents the number of pixels with that value. Therefore, we can see where the light is, its value, and the proportion of that value.

Histograms typically represent darker tones on the left side and lighter, higher-intensity tones on the right side. When the light value is at either horizontal extreme, the histogram does not indicate how much of the light is beyond the limit; instead it indicates all the light that is at that value as well as all the light above or below the boundary value, all of which is blocked up at the edge of the histogram graph. This is known as a spike. The spike indicates that the light has either not been captured beyond the exposure or it has been clipped. With this representation you can’t see what proportion of the image is above or below the capture thresholds of your sensor. Also, because of its display size on the camera, an on-camera histogram gives only an indication of the lighting situation. However, this does not mean it can’t be used as an exposure aid.

**Exposure Based on the Histogram**

To use the histogram to inform us about what can actually be accomplished with exposure we need to bring into play how and where noise appears as well as the captured tone distribution.

Regardless of the reasons for noise, it will be most obvious in darkened areas of the image, which are represented on the left of the histogram. The acceptance of noise is a subjective choice. Noise increases when we modify the file to open up the shadows and gain shadow detail. However, the noise level, the acceptance level that you have established, has not changed.

The second concern is the sensor’s distribution of captured light and where these energies are represented in the histogram. Although we can think of a sensor as a device to capture light in a continuum, the sensor resolves more of the light differences in high-energy light than low-energy light. If we consider an 8-bit channel with 256 tones (0–255), we can better understand the distribution all of image information and how this will be reflected in the histogram.
© by Russ McConnell. Courtesy of the artist.
If we think of each value of light as being represented by the number of photons in the value number (a value of 127 corresponds to 127 photons), then the captured light can be thought of as the relative number of photons captured at any sensor site. We can easily see that the brightest light would capture 242 units at a pixel, and black areas in the image would capture perhaps 4 units on a pixel. If we then think about how a manipulation of this number would occur, we see the problem with the left side of the histogram. Although we may intuitively work on corrections to a digital image, the process actually involves mathematics.

Perhaps we have a dark tone with a value of 4 and we divide the number to stretch it over a larger area of the histogram. We can divide the number 4 in half only twice before we are unable to perform this operation and still have a whole number as an answer. On the other hand, we might have a value of 242, a highlight tone, and we can continuously divide this number by 2 seven times before we are unable to continue and still have a result that is a whole number. This shows us that there is more ability to stretch and manipulate the numbers at the higher values that represent light tones, which are toward the right on the histogram. The numbers toward the left portion of the histogram have less adjustability. If the adjustment is used in an area of the image that has captured a low number, then as stretching occurs the space between the tones becomes less distinct, and transitions between tones are lost. This creates banding or posterization in that area of the image.

The previous example is based on an 8-bit per channel capture. We used this example because most current cameras have ADCs that produce images at 12 or more bits per channel. With a 12-bit per channel capture, there will be 4,096 variations in light values at the right boundary, compared to 256 variations in an 8-bit per channel capture.

On the right end of the scale we have a different problem: digital sensors do not tolerate overexposure. In this situation we need to realize that if we exceed the threshold at all, clipping will occur. When the light value is clipped, the data is lost. Regardless of the image processing method, overexposure of detail cannot be resolved.
Optimizing Exposure

To effectively use histogram-based exposure to optimize files, the camera needs to be operated in manual mode, and it is best accomplished with RAW files. Although this section discusses a method that optimizes RAW exposure, the process will still produce proper exposures if JPEG exposures are used.

Although the preview can give you strong information about the composition of the image, it is an interpolated image that does not accurately convey the data distribution in a RAW file. For exposure we want to look at the histogram, regardless of the light intensities that are shown in the previewed image on the LCD. When the dynamic range of the scene does not cover the entire histogram, the exposure is better when the representation of tones is on the right side. The preview may look weak and overexposed, but the image file will be better for processing without degradation as long as highlight detail is preserved in the exposure.

An optimally exposed RAW file will create a histogram that is skewed to the right side. We do not want the histogram to extend to either side, but we are far better off if the preponderance of tones represented by the histogram are on the right side of the graph. Because of the way reciprocity works in photography, the potential of 75% of the available light variations will be captured in the furthest right two stops of exposure as represented on the histogram. Also, each stop of underexposure reduces the potential of tonal representation by up to 50% of the variations in captured tones.

Using a histogram-based exposure with the graph skewed to the right allows for the most processing of the image without losing tonal transitions. If there are many tones toward the left of the histogram and we need to stretch the image to the right to modify the highlights, we will both posterize the image and expand the noisy region of the image. Therefore, we can see that if we have a choice in the distribution of tones, the histogram of a well-exposed photograph shows a pattern of tones that do not extend to either end, and it will favor the right portion of the graph. This is often easier said than done because we are so visually oriented that the image on the preview LCD can be misinterpreted in terms of optimal exposure.

It is important to understand that the look of the preview on the camera is not an accurate guide to exposure. Although the preview can give you strong information about the composition of the image, its interpolated image does not relate to the distribution of the data captured from the scene. To determine exposure we want to look at the histogram, regardless of the light intensities that are shown in the preview. When the dynamic range of the scene does not cover the entire histogram, the exposure is better when the representation of tones is on the right side. The preview may look weak and overexposed, but the image file will be better for processing without degradation as long as highlight detail is preserved in the exposure.
These images demonstrate how to expose an image based on reading the histogram.

1. It is difficult to gauge the exposure for an image like this that is primarily light and bright because an in-camera meter reading will not accurately reflect the tonality of this image.

2. Even though this image is very light and white, the tones are pressed up against the right side of the histogram with minimal clipping, but it is difficult to tell where the clipping occurs.

3. With the clipping warning turned on in the camera display, it is easy to see which tones are losing detail. You can therefore take the best possible image with the tones pushed up against the right side of the histogram without extensive clipping.
4. The minimal clipping in the highlights can be diminished by using the recovery slider in image processing software. This slider brings the white tones down in tonality, leaving some density in the blown highlights.

5. In the image processing software, the overall dynamic range of the image can be adjusted by spreading the darker tones into the left side of the histogram as desired.
A further problem with accuracy on the preview is that the color space used to render the JPEG may clip the image’s color makeup and thus the distribution of the histogram. Even with the inaccuracies introduced by the use of the JPEG image on the histogram, we can still use the graph to make better exposures.

Because the histogram on the camera is small, its accuracy at the extremes is visually suspect. Therefore, the blinking of the clipping alert on the LCD shows you when there is a spike, even when it’s not clearly visible on the camera’s histogram. If the bright sun is in the image, the histogram can have a spike against the right end. The blinking can indicate that one or all of the channels are overexposed and clipping, depending on the luminosity absorbed in each channel. Where the blinking occurs depends on the camera, JPEG settings, color space, etc. If you don’t mind the clipping, you can keep the current exposure settings, but when the clipping is objectionable or not to be tolerated, the blinking warning on the LCD lets you know that the exposure needs to be reduced.

As we close this discussion we need to bring up one issue that is important to many photographers: low-key images. Examples include a portrait taken against a dark background or a scene in the evening when the environment is dark but the important subject has lighter tones. In low-key situations, if a histogram-based exposure is to be made, the camera needs to be brought close to the critical detailed area of the image, for example the subject’s face in a portrait. The exposure can then be set with an adaptive histogram, or an exposure must be used that includes only the critical detailed area so the histogram is generated for only those tones, without the influence of the larger dark portions of the image. At this point the detailed histogram is used to set the manual controls for the correct exposure. Then the camera can be placed back in its original position so you can frame the image as desired. The histogram for the overall image will be skewed to the left because the critical area was used to set the exposure. However, when you convert the file from the RAW format, you can use the histogram to make adjustments as usual.
© by Kelly Kirlin. Courtesy of the artist.
Digital Equivalent Exposures

Equivalent exposures are series of apertures, shutter speeds, and ISO adjustments that can be used to achieve the same exposure level. Film-based photography holds ISO constant, but in digital photography we add ISO as a variable for equivalent exposure. All exposure methods for film are valid for digital photography. The f-stops, shutter speeds, and ISOs are based on photographic reciprocity (2:1 ratio), which can easily be used to make equivalent exposures. By holding one of the three adjustments constant, the other two can create equivalent exposures.

Consider the following examples:

• With ISO held constant, the following settings create the same exposure:
  f/4 at 1/125; f/5.6 at 1/60; f/8 at 1/30; f/11 at 1/15; etc.

• With speed held constant, the following settings create the same exposure:
  f/11 at ISO 400; f/8 at ISO 200; f/5.6 at ISO 100; etc.

• With f-stop held constant, the following settings create the same exposure:
  1/125 at ISO 400; 1/60 at ISO 200; 1/30 at ISO 100; etc.

Although the exposures in these examples can be held constant, there may be attributes of various choices based on which factor is held constant. When the f-stop is constant, the depth of field will be constant. When the shutter speed is constant, the blur or stopping of action stays the same. Finally, when ISO is varied, the noise inherent in the photographs will vary. As the ISO is increased, the potential for noise increases. With increased noise, the effective dynamic range is reduced.
Understanding Dynamic Range and Bit Depth

Many digital photographers are interested in the representation of the dynamic range of light on the histogram and how this is translated into bit depth for the image file. To truly understand the first part of this, the dynamic range, we need to define it. This can be done in two separate but related ways.

First, we can think of the dynamic range in the scene as the difference between the brightest and the darkest tones that we wish to capture. To a certain extent this range is a subjective choice that you make. For example, you may choose to have many bright light sources in the scene represented as white and some of the darker shadows as black. These tones may fall above and below the dynamic range that you choose for this scene, so these light values will be clipped.

On a sunny day, it is common for light to exceed seven stops in dynamic range. However, depending on the scene and the lighting conditions, the scene may have a dynamic range of greater than 16 stops. An indoor/outdoor scene with bright sun can easily produce 20 or more stops of dynamic range. Human vision approximates 20 stops.

Second, it is important to understand that the dynamic range of the scene does not necessarily directly correlate to the dynamic range captured by the sensor. The dynamic range of the sensor is scientifically defined as the difference in light sensitivity between the noise level as the dark point and the maximum capacity of the sensor to absorb light as the high point. Then the ADC translates the captured light in the sensor to a RAW file. These two factors, the range between noise and sensor capacity and the ADC, establish a sensor’s dynamic range. At the time of this writing, it is common to see professional sensors capture between 12 and 14 stops, and consumer cameras often capture up to 10 stops. Because of the way the dynamic range is captured and the issue of acceptable noise, capture beyond the top six stops loses its effectiveness, regardless of the total captured dynamic range.

The relationship between the dynamic range of the scene and the dynamic range of the camera is simple. When the dynamic range of the scene is less than the capacity of the sensor, then no clipping occurs and the exposure can be adjusted so the histogram shows a preponderance of tones on the right side without any spiking at either end. If, on the other hand, the dynamic range of the scene is greater than the ability of the sensor to capture the light range, then clipping will occur. In this situation you must decide on what tonal values can be sacrificed and clipped or captured below the noise threshold.
Another factor that is often confused with dynamic range is the bit depth of the file. The bit depth of the file refers to the number of divisions that are used to divide the captured dynamic range into usable tonal levels. Because of the way imaging software works, most of them will be in 8-bit or 16-bit per channel formats. This is where the confusion arises for many people about the capture dynamic range.

Many people assume that if a camera puts out a 16-bit file, then its dynamic range is 16 stops because the bit relationship is similar to the f-stop. However, the bit depth only refers to the number of divisions of the dynamic range, not how much light was captured. For example, if you have a light scale from 0 to 4,096 (the dynamic range of a 12-stop sensor), you can divide it into two parts that would be one bit, four parts that would be two bits, eight parts that would be three bits, etc. So bit depth only refers to the number of total steps (the number of tonal variations or values) that are represented in the image file in each of the three color channels. In this example, regardless of how many divisions our 4,096 units are divided into, the total range is still 0 to 4,096.
© by Stephan Zirwes. Courtesy of the artist.
Digital Capture Workflow

© by Tim Mantoani. Courtesy of the artist.
Progressing to Capture

Unlike many other art forms, photography is a less impromptu way of making artwork. Photography, once engaged, can be spontaneous and instantaneous, but unlike other art forms, when it is performed there are many more specific steps that are involved in capturing an image.

A sketch artist will have to take along paper and pencil, but photographers need to prepare their equipment and ensure it operates properly, then capture the image. Although it can be argued that making a photograph is only pushing a button, the reality is that for quality image making, many steps are involved.

The concept of a photographic workflow has been part of the art form since its inception. Prior to 1851 and Frederick Scott Archer's development of the dry plate photographic process, the concept of making a photograph in the landscape was daunting. The photographer had to prepare the materials so they could be taken along and applied to the glass plates, not to mention that they had to be exposed and developed while the emulsion on the plates was still wet. This meant that the photographer not only took along a camera and tripod, but also an entire darkroom to prepare and process the exposure.

With the invention of the dry plate photographic process, the need to transport a darkroom ended. However, it did not remove the need to prepare for photographing on location. In the 1940s, Weegee (Arthur Felig) carried a complete darkroom in the trunk of his car to allow him to rapidly process his pictures so they could be delivered to newspapers in a timely manner. In the 1990s, photojournalists carried transmission equipment that required film to be processed and then scanned in order to send the images to their newspapers or magazines.

Since the beginning of photography the way photographers have made their images has always had a great affect on what the viewer sees. Whether images are made with the wet-plate collodion process or the digital photographic process, the important ingredient has always been the creativity of the photographer. Although modern technologies have allowed photography to progress beyond the old cumbersome and caustic processes, creativity has always been a signature of the true artist. Artists strive to exemplify their work and creativity, but it is their workflow that allows them to consistently create the images they envision.

Even with digital photography, the process is still more involved than other art forms. We can look at the photographic workflow in three parts. First is the workflow in preparation for making photographs. Second is the workflow involved in optimizing the exposure and capturing what we intend to communicate. Last, we need to concern ourselves with how we will edit, store, and catalog our images. In this chapter we will address the first two of these workflow concerns, and in the following two chapters we will address editing and storage issues.
Preparation Workflow

The preparation workflow starts when you acquire a digital camera. Although it is somewhat obvious, the materials and equipment that are packaged with a camera should be inspected to ensure that all the pieces are present and functioning. These pieces are listed in the owner’s manual, one of the most important supplementary items that comes with the camera.

The owner’s manual is the guide for not only to how to use the camera, but also how to troubleshoot issues that may arise while using the camera. It’s not imperative to read the entire manual when you first get the camera, but you should read all the operational portions that address your initial needs. For example, if you will not be using the camera to record video or HD video, then those portions may not be important to you. However, you do need to read about how to properly expose with the camera. This will include understanding the menus and how to navigate through them to establish the working parameters for your camera. It’s a good idea to carry the owner’s manual as part of your regular camera kit, particularly for new or rented equipment.

Firmware

One of the items you will find in the owner’s manual is a discussion of the camera’s firmware. The firmware is the operating system that runs the computer within the camera. This is often an overlooked part of the camera’s operating system. Since the camera can be turned on when it comes out of the box (if the battery is charged), we often disregard the operating system.

The firmware not only operates the camera as it focuses and calculates exposure, it also has embedded parameters on how it will process the image files and write to the storage media. Camera manufacturers continuously update their operating systems and file format standards, so even with a new camera fresh out of the box there is a potential that the firmware has been upgraded since the camera was manufactured and shipped. This means that you should update the firmware as soon as you get the camera and periodically check to see if updates have been posted.

The procedures for updating the firmware can be found on the websites of the various manufacturers. Particularly with professional-level equipment, any updates will be listed as well as instructions on how to check for and update the firmware.

After you have confirmed that the firmware is up to date, any embedded metadata capabilities should be set up. With many cameras today it is possible to do more than simply number the images. Metadata, such as the photographer’s name and copyright, can be added to the time, date, exposure
data, and so forth that is commonly part of the capture file. This capability is usually available only on professional-level cameras, so you should read your owner’s manual to find out which metadata is part of the image file and how to enter other metadata if that capability is provided. If you rent equipment, it is important to clear out all existing metadata and custom settings that previous users may have installed.

Erika © by Douglas Kirkland. Courtesy of the artist.
Batteries

For nontethered digital cameras, the batteries are important for all operations. There are two major types of batteries in the camera. The easiest to locate is the operations battery, which is often rechargeable. In some lower-end consumer cameras, the batteries are not rechargeable and must be replaced periodically. In this situation, whenever you prepare for a photography outing you need to remember to take extra batteries with you. With rechargeable batteries it is important to recharge them prior to a photographic session.

The second type of battery is a small watch battery that keeps the clock mechanism operating and provides a grip charge to maintain computer data. If this battery is allowed to drain, there will be no power in the camera when the operational battery is removed. The camera will reset to the manufacturer’s defaults, and you’ll lose the time, date, and other metadata settings you have chosen. This battery is not normally in a convenient location, so refer to the owner’s manual to help you find and replace this battery if necessary.

Testing

When preparing for a photographic project you should test your equipment ahead of time. Although most photographic equipment will operate properly, occasionally a piece of equipment will fail to function. The more important the photographs, the greater the need to test the equipment, and in many cases prepare backup equipment, to assure that the important moments are captured.

As part of this testing it is a good idea to perform a dust test to see if the sensor needs to be cleaned prior to use. A dust test is performed by photographing a uniform middle-toned subject, such as a neutral gray card or the clear north sky, at the camera’s smallest aperture. The subject should fill the frame, and it’s not important if the subject is in focus. View the resulting digital file at a high enough magnification to see if there are dark spots in the image. Dust on the sensor creates a shadowed pattern that is consistent on all exposures. If dark, crisp spots appear in the uniform field, there is probably dust or other foreign materials on the sensor, which should be carefully removed as recommended in your owner’s manual.
Memory and Storage

Regardless of the type of media being used in the digital camera, the memory cards should be reformatted to assure a maximum amount of space is available. This means that the images from previous photographic sessions need to be moved to other storage media or a computer. When the images are moved to other storage media and backed up to avoid loss, the removable media can be reinserted into the camera and erased or reformatted through the menu options. We will discuss the 3-2-1 storage paradigm later in the book when we talk about asset management. Images may be erased from the removable media in the computer, but because of potential errors we recommend that reformatting and clearing images from the removable media be done in the camera.

If you will be using multiple media cards, it is best to identify each card independently with a numbering system that is readily visible. Also, the camera’s file numbering system should be adjusted for the upcoming photographic session. Set it to operate on a continuous basis to limit the potential that two exposures will have the same number. Since media cards have sensitive electrical contacts, they should be stored in clean card cases to avoid damage. Some types of damage to media cards can ruin the camera’s connection pins and make the camera unusable.

As a last step in the workflow, set the defaults on the camera so you will be able to react quickly if a picture opportunity arises prior to the actual photographic session. This includes setting the ISO; exposure method, such as aperture or shutter priority; auto white balance or other preset white balance setting for your lighting conditions; RAW or JPEG file format; and resolution. Setting these defaults is particularly important if you will be photographing in JPEG file format because the white balance will inform the processor how to make the image appear when it is photographed.
San Jose to Chicago, 2005 © 2005 by Julieanne Kost. Courtesy of the artist.
Capture Workflow

Whether the capture is made with a tethered or handheld system, there are only three parts to the workflow. These are determining correct exposure, creating a method for neutral balance, and, most important, expressing your creativity. Coupled with the preparation workflow, these steps assure that your envisioned photograph is accurately captured and saved as an appropriate file type.

With a good preparation workflow, the capture portion of making a photograph becomes technically easier. This is important because when you are actually making the images you want to concentrate on the creative process of capturing the best image possible. Although the energy in the photographic session is focused on the creative aspect of the photograph, there are still technical requirements or methods that allow you to make the best photographs.

Exposure is the primary concern of the workflow during the photographic session. For RAW format, only the ISO setting, shutter speed, and aperture setting are recorded, or baked in, as part of the file. Interpolated formats, such as JPEG, bake in other controls, such as the white balance setting.

The workflow should be the same regardless of whether you’re using RAW or JPEG format. In most photographic sessions, using a more extensive workflow beyond just attending to the exposure will simplify post-processing. Also, because some cameras use dual storage systems that record both the RAW file and a backup JPEG file, using a more robust workflow can potentially save a photograph if there is a defect in the RAW file.
Capture and Exposure

When the lighting is established, whether you’re in a studio with creative lighting patterns or in the natural environment with the light sources identified, deciding on the proper exposure is the next critical step. We previously discussed various exposure techniques, and they can all work in different situations. It is always most efficient to use an exposure method that you are comfortable with and that has provided good results in the past. For example, in an average outdoor setting many exposure methods can give good results, such as the BDE method, automatic settings, and histogram-based exposure. In low-key scenes, where there is a large amount of very low tones, incident metering at the critical detail, rather than automatic settings or a histogram-based exposure, will achieve better results. Regardless of the method used, you should use the lowest ISO setting on the camera that will provide adequate exposure to eliminate excessive noise. You may need to change the ISO for specific lighting situations or certain subjects, but try to use the ISO adjustment as a last resort and be aware of the ultimate result.

With both manual and automatic exposure, it is important to check the highlight and shadow details in the histogram or watch for the blinking warnings when clipping occurs. Even though the histogram is small on handheld cameras, it can give good indications of potential problems. This is particularly true with the highlight portion of the image because there can be blooming or loss of detail in overexposed areas.

Although we encourage utilizing the LCD screen to review the histogram for setting and adjusting exposure, we are opposed to chimping, or constantly looking at the preview on the LCD screen to admire or check the image for composition. Even in a portrait session when you want to see if the subject’s eyes are open, looking down and not attending to the subject takes you away from your main concern: making photographs. In photojournalism, looking down can mean that you miss the action you are trying to catch because your gaze was not on the subject or scene. If you need to check to see what images were captured, wait until there is a break in the action or an appropriate stoppage in the photographic session, such as when the light changes and the exposure needs to be changed.

Don’t edit your vision while you make your photographs. If in doubt, take more exposures and leave the editing for later. If you think about capturing an image, then capture it. Quite often the creative and capture process is very different from the choices you will make while editing the images.
During the photographic session, don’t erase or delete images or reformat the storage media. This is a very time-consuming and potentially destructive working method. Instead, have multiple formatted media cards available, and change them regularly before they are filled. As suggested earlier, numbered cards should be used in the order that they are numbered so the imaging sequence will be easier to follow later in post-processing.

With a studio-based tethered system that is designed for interactive control through the computer screen, the highlights and shadows can be measured and adjusted by using the software or rearranging the lights to optimize the exposure. The computer screen is meant to be used as the viewing system. Some tethered systems allow simultaneous recording to the camera and the computer hard drive while shooting, which is called mirroring.
Capture and Neutral Balance

The other major workflow consideration for the capture portion of the photographic session is the neutral balancing of the light. This is important because our visual perception cannot see or adjust to small changes in the light’s color balance. Although post-processing can correct many color imbalances, if the color is not near balanced when it is captured, problems can arise later during image processing. Even though the neutral balance for the light is not baked in to the RAW file, this information does become part of the metadata of the file.

There are two basic approaches for neutral balancing an exposure: at the time of capture or during post-capture image processing. In both cases a similar workflow is used, which is that a neutral-colored target is placed within the image and used to establish the neutral balance of the scene. This is necessary even when preset white balances are used to assure accurate color representation during post-capture processing.

Many cameras have preset and auto white balance settings that can be used quickly. Although these systems can closely estimate the color balance, the exact balance depends on the mix of light sources, cloud cover, time of day, and so forth, which may be quite different from the white balance desired for the image. For example, auto white balance at sunset will remove the warmth from the light, but photographing the scene with a daylight preset will preserve the colors.

Another approach is to create a custom white balance at the time of exposure. Cameras with this capability allow you to use a neutral colored target and adjust the camera to use this parameter as the white balance. More common is the use of custom white balance in post-processing or conversion software. Using a neutral target, all images captured under the same lighting conditions are synchronized with the same neutral balance.
Saving Captured Images
The File Cabinet

Photography is about memories. From its very inception the photographic arts have largely been used to memorialize events, people, and places and to make fine art. And there has always been an attempt to keep these objects and develop methods to remake them.

A major issue for photographers and museums has been the desire to store and maintain photographs for later use. In the early days, daguerreotypes and ambrotypes were displayed in leather cases that could be carried. When the Kodak camera became available to casual photographers, scrapbooks and photo albums became the way to store and display photographs.

The key to much of photography’s allure is its ability to reproduce an image over and over. Although the early photographic processes were singular events, the development of various negative film processes allowed for duplication and reinterpretation of photographs. At this point it became important for the photographer to maintain the original captured image to allow for duplication.

For amateurs this was often a shoe box filled with negatives under the bed. The serious photographer’s storage became a filing system, with negative sleeves, inventory boxes, and care and handling of the original captured image: the negative. At an even more strenuous level, museums developed not only methods to store photographs and their negatives, but they also studied how they could restore damaged images or negatives.

Many fine art photographers filed printing information, such as dodging and burning instructions, along with the negatives. For photographers who used more complex printing methods, such Henry Peach Robinson or Jerry Uelsmann, other types of meticulous records had to be kept. They created diagrams of how the images go together, masks, and so forth that would allow them to make multiple copies of their images. In addition to the information that tells which parts of what negatives to use in putting together the image, the documentation included information on where the negatives were stored.

As photography moved into the digital age, the concept of storing images did not change. The same desires to memorialize and replicate are still present. However, the digital photographic environment is not built around a physical object, such as a negative. Instead, the image is actually a set of electronic data. This is much different and perhaps one of the largest changes in photography: the need to save data as opposed to saving a physical object.
**File Basics**

The file is a mechanism for transporting and saving the information captured on the sensor. We can think of the image as being a series of locations called pixels. After the ADC has completed its task, the light information takes on the form of a series of binary numbers. These data, the binary numbers for each pixel, are not visible in that form and must be processed. To understand the data, certain things must be communicated about the file. We can understand the captured light intensity information from the sensor by looking at the header for the file.

**Header**

The header contains information and a set of instructions that tell the computer how to open, read, and interpret the information in the file. The first piece of information is the name of the file. Most cameras apply file names in sequential order so they will remain separate in the memory system of the camera. Many cameras allow you to create a naming protocol for your images. This allows you to manage your images without having to rename them as you make your exposures. Other file properties and information are likely to be included in the header instead of an attached metadata file. These pieces of information include the date created, modification date, size, resolution, and bit depth.

Regardless of the way the camera names the files, you will need to have a naming convention and a way to apply and consistently add a new name if there is not enough information to organize the captured images. In your lifetime you could make hundreds of thousands, or millions, of images, and without a naming convention it will be difficult to maximize your use of these images over time. This need will be addressed later in the book when we discuss asset management.

The most important information in the header is the type of file format that is used. Although this information is embedded in the header, it is also normally seen as an extension following the name of the file. The file format tells the computer how to open and read the data within. If this information is not included, or if there is a mismatch with the file format, the image cannot be decoded and opened. Most importantly, this includes the bit order. The bit order indicates whether the number at each pixel will be read in an ascending or descending order.

For example, the number 23 in binary can be read from either end (10111 or 11101). Since these numbers are not inverse or complementary, it cannot be assumed that reading the number in the wrong bit order will produce a positive or negative image based on the data within the file. Only one bit order will produce a proper image.
Another piece of critical information that will be used to construct the image from the file is the way the color should be interpreted. This includes both the bit depth of the file and its relation to a color space (a specific set of colors that relate to data points expressed in a collection of numbers). Although the preview image for most cameras is interpolated in the form of a JPEG file, this may not be the format associated with the file. Therefore, the color information that is shown on the preview is not necessarily the same information that will travel with the file.

**Compression**

The last piece of information contained in the header is how the image will be decompressed and by how much. Almost all cameras compress data to a certain level before the initial file is written. This is the reason that RAW conversion software is not interchangeable among manufacturers. Although converters such as Adobe Camera Raw can convert these files, it must be noted that this software is not resident in the camera; plug-ins must be installed so the converters can read the headers from various manufacturers and various cameras.

Although camera systems provide a certain amount of file compression, several file formats allow further compression. Compression is used to make the file more manageable in terms of size while at the same time allowing the image to be reconstructed when it is opened so the original picture can be displayed. Compression can be applied within the camera’s operating system or subsequently after the image has been processed externally.

There are three basic types of compression: lossless, lossy, and visually lossless. These terms describe what will happen to the file and what the resulting decompressed image will contain. Lossless refers to a process in which the decompressed file will result in exactly the same image that was compressed. At the other extreme is lossy compression, in which the decompressed file does not contain all the data that was in the file prior to compression. Visually lossless compression uses human perception to minimize the visual aspects of compression while providing a reasonable reduction in file size.

To simply explain the difference between a lossless and lossy system, we can use a simple arithmetic demonstration. If we use the simple equation $2 + 3 = 5$, we can then reverse the elements and function of the equation to $5 - 3 = 2$. We can see that we have recovered the number 2 from reversing the equation. We started our statement with the numbers 2, 3, and 5, and we ended up with a statement that has these three numbers. On the other hand, we can begin with the equation $2 \div 3 = 0.667$. When we reverse this equation to $0.667 \times 3 = 2.001$, we do not end up with the same numbers we started with.
Therefore, we can say that in the second example our equation is not mathematically reversible. Lossless compression is based on a mathematically reversible set of compression instructions, and lossy compression does not adhere to a purely mathematically reversible construct. Therefore, with lossy compression the image data will not be the same when it is decompressed as it was when it was compressed.

A common method used to provide lossless compression is known as run length compression. In this system the compression is accomplished by counting the number of pixels in any string, which is the run length, and defining that string by its color number and the number of pixels that have that number. For example, if you have a blue sky where the gradation is slight, you might have a string length of 50 pixels with exactly the same color. This would require 50 bytes of data in an uncompressed file. Using run length compression, these data would be expressed with two numbers: 50 and the color number. This would probably not require more than two bytes of data. Although this method is effective in reducing the size of the file, it has severe limits. The amount of compression can only achieve about a 3:1 ratio.

In lossy compression there is no intention to decompress the image to its original data. Therefore, choices can be made in the way the information is handled that will allow for more efficient file size reduction without the need to exactly reconstruct the original data. For example, with this system small color variations may be ignored and assumed to be the same as nearby colors to allow more efficient saving. Within JPEG compression the image is broken up into blocks of 8 pixels by 8 pixels, and an algorithm reduces the data by applying compression to each group as a whole. Lossy systems provide very high compression ratios, potentially as high as 300:1. However, to avoid major artifacts, the compression ratio should be 25:1 or less.

Visually lossless compression uses the way we see as the basis for how it will reduce the files. Human perception is far more attentive to detail than color. For this reason, visually lossless compression reduces or discards a portion of the color information while maintaining all the luminance information. For example, if only one pixel in a block of four pixels retains its color information, then when the image is decompressed the color can be interpolated for the pixels whose color information was altered. Since the detail information contained in the luminosity of each pixel was not altered, the human eye is not likely to perceive the difference between the original and the decompressed image.
Metadata

Metadata refers to information that is attached to an image file. It is not part of the image or instructions on how the image is to be handled by a viewing system. The metadata may be carried in the header or in a companion file (sidecar file) that can be in two formats: extensible metadata platform (XMP) or exchangeable image file format (EXIF). With a RAW file the only metadata that is baked in to the original file is the ISO, aperture, and shutter speed. Other data, such as copyright, photographer, or camera information, is not actually in the RAW file. Instead, it is carried in a sidecar file or in the header. The information in the header is added to the sidecar file when the RAW file is converted.

Other information not baked in to the RAW file, such as lens focal length, GPS, etc., may be captured by the camera at the time of exposure and then written to the metadata file, or it can be added later by the photographer to preserve important information about the image. Metadata that will normally be captured by the camera includes exposure details, camera type and model, date and time, image size and resolution, color space, etc.

An important part of contemporary metadata is the International Press Telecommunications Council (IPTC) Core. This information is individually added to the metadata so the asset can be managed efficiently. Most IPTC Core information settings include more than 30 items, including keywords, headlines or captions, creation information, use parameters, copyright and ownership, etc.

This is an example of an XMP sidecar file. This file shows metadata as well as all of the information necessary to translate the RAW file through parametric image editing.
File Types

A native file is created in the camera, but it is not usable until it is processed in the array processor and exported in a readable file format. Although many people believe that the RAW file format is exactly the same as the native file, the array processor usually arranges the light intensities and compresses the information slightly; it therefore does not provide an exact copy of the data it captured. However, it is as close as we will find to the actual luminosity from the scene as captured on the sensor.

There are two major types of files that can be used: interpolated or uninterpolated. An interpolated file allows the image to be seen in color without conversion. This means that each pixel in the file has all three channels (RGB) represented. An uninterpolated file requires conversion to be seen. The images recorded on the sensor are uninterpolated, but the actual native file cannot be viewed on the camera’s preview or the computer.

The image detail here is an artistic representation of what the data in a RAW file would look like as individual color sites. The neutral densities are represented with equal intensities of light in each of the red, green, and blue photo sites, where the red object has high intensities in the red areas and lower or no intensities at the green and blue photo sites. It is important to understand that the information as captured on the sensor is interpolated from a collection of data, such as seen in the detail here, to create the overall image.
JPEG

The most commonly used digital file format was created by the Joint Photographic Experts Group (JPEG). It is an interpolated file that allows direct viewing without conversion. The JPEG file extension is usually .jpg, but it may also be expressed as .jpeg, .jpe, .jfif, or .jif. These files are universally compatible with browsers, viewers, and editing software for all platforms. Because JPEG files have a high compression ratio, they are commonly used for transmitting and storing images. The preview and histogram on the displays of DSLR cameras are JPEG files. These files have 8 bits (256 values) per channel in only the standard RGB color space.

The ability to compress images with high compression ratios has a major drawback. Every time a JPEG image is saved, the compression is applied automatically. This means that even though the image size is reduced slightly on the first application of compression, each time a JPEG file is saved, the compression algorithm is applied again, which further reduces the file size and compounds any image artifacts associated with the compression. This degrades the image quality.

TIFF

Another interpolated file format is Tagged Image File Format (TIFF). Just like the JPEG format, TIFF is a universal image format that is compatible with most image editing and viewing software programs. The file extension is .tif. This format is used to store images that can easily be used in printing. The format is compressed using run length compression, which is lossless. Although it cannot be compressed to the same extremes of JPEG files, the compression is valuable. Although it is less common, some cameras can output this file format.

The TIFF file format has several advantages over JPEG. It can support 16 bits (65,536 possible levels) per channel in both RGB and CMYK (cyan, magenta, yellow, and black) color spaces. It is also compatible with imaging software that includes layers and channels. Photoshop document (PSD) files are a modification of the TIFF standards.
RAW

RAW is not an abbreviation like TIFF or JPEG; it literally means raw unprocessed sensor data. We capitalize the abbreviation to indicate the file type; lowercase refers to the data or a native file. A raw file contains the original image information as it comes off the sensor, with little or no in-camera processing so it can be processed later with more control than is possible with the onboard camera processor. The file is a **read only** file; after it is rendered, it cannot be written back to a raw format.

The file extensions vary with manufacturers; for example, Nikon uses .nef, Canon uses .cr2, and Leaf uses .mos. These file formats are proprietary and not interchangeable between camera manufacturers, which means that proprietary software will seldom convert RAW files for other manufacturers’ cameras.

A RAW file contains three channels of information: one for green, which has 50 percent of the recorded light; and two more for red and blue, which each have 25 percent of the recorded light. Because the file is in channels, it is not ready to be used or even viewed without conversion to a color space that interpolates the file. With this approach a RAW file is actually one-third of an uncompressed interpolated file of the same image. If the camera creates a JPEG preview, then after the native information is interpolated or transferred as a proprietary RAW file, the JPEG thumbnail can be part of the final file.

To address the variety of camera formats, Adobe created a program called Camera Raw. This conversion software uses plug-ins to convert proprietary RAW file formats into useable interpolated files. Camera Raw also creates a sidecar XMP file that contains the conversion interpolation information and metadata that enables smart asset management and facilitates working with multiple software programs. These open standards are designed to enable flexible searching, and they are forward looking to work beyond today’s file formats.
© by Matt Harbicht. Courtesy of the artist.
DNG

Digital negative (DNG) is an open standard/open source format that was created by Adobe as a single document that will allow for interpretation of data into the future. The file extension is .dng. DNG promotes nondestructive processing, known as parametric image editing (PIE). The purpose of PIE is to maintain the integrity of the data as the file is processed. The file itself is a container that can hold a group of image information and versions regarding a single image. Whether the DNG image information is created in the camera or through an image converter, the idea of DNG is to keep the image’s information from being destroyed in the editing process or becoming unreadable over time.

Beyond the DNG-generated raw information, the DNG container can also hold other the proprietary RAW files, and it has a preview option that uses a full-size JPEG to allow faster imaging editing. It also has medium- and small-sized JPEGs for other uses, eliminating the need to resize files. One of the powerful aspects of DNG is that it stores the PIE instructions for both Adobe and other software. These DNG design elements maximize workflow. One of the most notable inclusions in the DNG format is a verification hash, a mathematical checksum that allows the file to be checked for failure between the original and the migrated (or copied) versions of the file.

Memory Devices

Regardless of how the file is created or what its format is, it will need to be saved twice: first in the camera, then in some type of asset management system.

Originally digital cameras had short-term storage onboard that could not be removed. Today various removable media are used that allow you to continue taking photographs without having to transfer the data from the camera-based media to another storage device. These media cards are manufactured in many types but basically have the same storage concept. They are solid-state electronic devices known as flash memory. These devices include those that are designed to be removed from the camera system in order to transfer information to longer-term storage, be cabled to a computer or external storage, or in the case of some systems, to transmit stored images by a wireless device or Bluetooth.

Flash memory works on a basis similar to the sensor. A computer chip has a grounded silicon base with two structures on top of it. The top structure is the control gate, which is activated to give or not give a charge and record
one bit of information. If the gate is charged, the memory holds the number 1, if it does not receive the charge, the gate relates to the number 0. When the charge is applied to the control gate, the grounded silicon substrata attracts the charge and pulls it into the middle layer, which is the floating gate. The floating gate is insulated so the charge cannot be removed easily. In this way the charge remains trapped in the floating gate until erased or the media is reformatted.

Two factors are involved in the selection of media, regardless of the type. First, the write speed refers to how quickly the solid-state device can record. The standard is one unit of speed that equals 150 Kb/second. Therefore an 8x device will record at 1.2 Mb/second. The second consideration is the stability of the device after erasing or rewriting. The more times a solid-state memory device is erased or rewritten, the more its ability to hold a charge diminishes. This means that the more you use, reformat, rewrite, or erase the device, the shorter its life will be.

Though you may choose to maintain your images on your camera, this is not a good idea. All electronic media can be erased as easily as it can be written. Beyond the potential loss of images due to failures in the media, if you use the storage media in your camera for long-term storage, there will likely come a time when you may need to erase images to make room for more. After the media is overwritten, the images are not recoverable.

As a last comment on storing images, we need to realize that regardless of where we eventually write the image files, there is one overriding issue facing digital photography in the future. There is a strong potential that the technology used to store files today may not be readily available in the future. This means that the images we take today will need to be saved so we can open them in the future. Some storage methods used as recently as 10 years ago, such as Kodak's Photo CD products, are obsolete because equipment is no longer readily available to read the data on the media. It is therefore imperative that we understand the issues of file formats to ensure access to our images in the future.
8 Image Editing and Corrections

© by Randy Duchaine. Courtesy of the artist.
Perfecting Capture

Photographers have been working with the concept of global corrections long before the inception of digital capture. Global corrections cover the choices that a photographer makes, from setting up lights and choosing film to adjusting filtration and making the final print. Whether with film or in the digital environment, cameras seldom capture the color or the quality of the light as we envision it. For this reason there is often a need to correct images after they have been captured.

Since the very beginning of photography, various methods have been used to change the intensity, contrast, color, or many other variables in a photograph. For example, with an imaging technique developed in the 1840s called the cyanotype, the contrast inherent in the image is increased by using hydrogen peroxide. With silver prints you can apply a selenium toner to expand the total range in the image to make the blacks richer. Even modern black-and-white printing paper is manufactured to adjust the contrast to correct negatives that may not have the desired contrast range.

Even more obvious in terms of corrections that are applied to photographs after exposure is the issue of color balancing that needs to be applied to almost all color printing. When prints were made with C type material they often needed to have the colors adjusted to remove inaccuracies that were captured when the photograph was made. This was accomplished by viewing test prints through special filters that indicated the amount of cyan or magenta light that needed to be added or subtracted from the color print package to achieve the proper color balance within the print. In the heyday of color film photography, professionals had to determine the color temperature of the light they would be photographing under and correct the color balance by choosing a balanced film, using color correction filters, or correcting the color in the final print.

The application of global corrections may be approached differently in digital photography, but the basic tenets are the same. You still need to be aware of the lighting conditions of the scene, though there are settings in most digital cameras that allow you to choose sunlight or tungsten as your general white balance, and you still need to properly expose and process your image to result in a neutral-balanced print. Today we apply parametric image editing (PIE) to address these global concerns. The name comes from the way the parameters of the image are adjusted as controls without actually changing the image file. These parametric changes travel with the image file and are applied when the image is opened and interpolated.
PIE

PIE was originally envisioned to work with RAW files. However, today's PIE programs can be used with interpolated and rendered files, but the effectiveness of PIE programs is reduced with the limited bit depth and color spaces of compressed file formats, such as JPEG. The PIE editing paradigm is nondestructive to the original captured file.

PIE corrections can be made through various types of software, including those that work on a single image at a time in a pixel-based approach, such as Adobe Photoshop, and those that work on proxy files that do not affect the RAW file, such as Adobe Photoshop Lightroom or Apple Aperture. PIE is a text-based concept that generates instructions for the editing process for application to any number of files. Photoshop can be used in a nondestructive manner with adjustment layers. Proxy or text-based PIE software works better with large numbers of image files simultaneously, and Photoshop processes each file individually.

Imaging software programs use two processes to control the images for correction or manipulation. They are called transforms and point processes. Transforms include image rotation, cloning, drawing, and so forth. They are highly involved mathematical operations that are used specifically and are not normally part of general correction. On the other hand, point processes, notably color, contrast, tonal value, and so forth, are most useful in global correction. Regardless of whether point processes or transforms are used, adjustment layers allow these processes to be applied to an image in a nondestructive way.

With PIE the file is not actually modified at the point of adjustment. Instead, a proxy image (a low-resolution image on the screen that represents the file) shows the changes and corrections that will be made to the image when it is finally processed. The key here is that the editing steps actually become a set of commands that will be used later to process the image file. When the file is in a RAW, uninterpolated format and is then processed, it cannot be saved back to the RAW format. With PIE, no destruction occurs in the original file. Any processed versions of the file will be saved with a different extension and thus have a different name. If these files are saved in the DNG format, the raw file information—at least the instructions for processing and a proxy image (normally a JPEG)—will be saved within the DNG. If the image is processed through a converter and saved as a RAW file, then an XMP sidecar will be generated that will carry the global corrections along with the RAW data.

It is important to realize that although we capture the image in a RAW format, that will not be its final form. When we convert the image to a printable format, we must take care to balance the image so the output is as close as possible to the image we envisioned when we made the exposure. With today’s editing software we can retrieve older images and adjust the global settings if the original data in the RAW format was not destroyed in previous adjustments. Therefore, we want to use a nondestructive method for applying global corrections.
© by Sol Hill. Courtesy of the artist.
Correction

One of the first decisions you must make after downloading the files from your camera is whether they all need generalized correction. This might be because the light that was used to make the photographs was not consistent with the white balance setting on the camera. For example, the camera might have been set for bright sun, but perhaps there was a small amount of haze, or photographing on the north side of a building may have created a color bias in the image. If all the images in a single group were photographed under these conditions, you would need to correct all of them. Further, the entire image would need to be corrected to change the color rendition because of the inconsistency between the light and the white balance.

This example brings up two considerations. First is the need to correct the lighting for the entire image. This is known as a global correction since it is applied to all pixels within the file. If the correction for light is only in a small area of the image, it is a local correction. The most common global corrections are for exposure, color bias, image contrast, and sharpness. The second consideration is that all of the images made under the same lighting will need to be corrected, and they can all be corrected in the same way. When all of the images are corrected in the same way at the same time, it is called batch processing.

Corrections for Capture Irregularities

Since it is better to have the exposure at the right end of the histogram, there is a strong possibility that some compensation will be needed to correct for a slight overexposure. Exposure compensation redistributes the captured light intensities to present the image we desire, not just the image we captured. With exposure correction the inherent contrast or dynamic range within the image does not change. The change will occur in what is brightest and what is darkest, as well as their relationships to the limits of the bit depth. In this way we can move the exposure up or down, provided our image was not clipped at either extreme.
Color Correction

We can’t correct any color imbalances created by either intentional or unintentional white balance errors. Even when a custom white balance is used to make the exposure, particularly when more than one photograph is made without rebalancing, there is a potential for some imbalance to occur. Auto white balance does not address the issue of proper balance of the light itself because it is not specific to a gray or neutral patch. Also, the white balance presets for sunny, cloudy, tungsten, and so forth are based on color temperatures, and they may not be accurate for the color bias of a specific light.
If we make a test exposure with a known neutral tone (not black or white) in the image, we can batch process all images made in this light environment with a synchronized color balance. However, the color patch used for balancing must be a true neutral. For example, 18% gray cards are designed for exposure, not color balancing. Therefore, because the card is not color neutral, the white balance will be skewed if it is used for this purpose. There are many tools, such as the X-Rite ColorChecker Passport, that have color neutral patches for setting the white balance.

Neutral balance, often referred to as white balance, within advanced imaging software uses two controls. The first is the color temperature control that relates to the Kelvin temperature. With this control the light can be balanced based on the predominant source or sources that illuminated the scene. Color temperature bias moves from red, such as an open hearth or sunrise, to white, such as daylight, and finally to blue, such as open shade illuminated by the north sky or an overcast sky. The other white balance control in the software is tint. The control varies the color on a magenta–green axis, which allows you to adjust the feeling of an image, such as warming up a sunrise.

Specifically within portrait photography, white balance takes on a slightly different aspect. Because the skin tones are critical, balancing may be done to the skin tone itself. This can be done in the RAW converter by using a face mask, which is a temporary crop of an area of skin that includes bright highlight and shadow. A curves adjustment can then be used to balance the skin tone to match the desired look. Although this can be done by eye, it can also be done by using percentages of cyan, magenta, and yellow in an image that is balanced in the CMYK color space. Using the curves with the Info dialog open, adjust the curves in the midrange of skin tones to have percentage relationships. The value of each color is measured on a scale of 0–100%. For moderate Caucasian skin there is generally slightly more yellow than magenta in the color sample, with cyan representing only a very small portion of the color values (e.g., 43% yellow, 40% magenta, and 7% cyan). Light-colored dark skin is generally equal in magenta and yellow, and the cyan value is about one-third of the magenta and yellow value (e.g., 45% yellow, 45% magenta, and 15% cyan). Neither of these skin tones includes black. However, with dark skin, black is part of the mix (e.g., 45% yellow, 45% magenta, 15% cyan, and 5% black).
Light and Exposure Corrections

Vibrance, contrast, and brightness controls can be applied by adjusting the levels captured in the image or by adjusting the total curve. These two basic applications can be applied in further ways, which are primarily aimed at adjusting specific areas of the image’s tonal values.

Within Photoshop the recovery control compresses the image from the brightest captured light downward in intensity. This can be seen where the histogram’s right end and its indicated values spread toward the left and compress the intensities at the left end of the histogram. Regardless of the lowest value captured, when recovery is used it does not affect the darkest tones. Also, it can recover only about two-thirds of a stop of overexposure. The opposite of the recovery control is the fill light control. This operates the same as the recovery control from the opposite end of the histogram. It spreads the tones in the darker areas of the histogram and compresses the highlight tones.

Of these two controls, the recovery control damages the image less because it primarily functions within an area of the image that has the most data variations. Using an extreme amount of fill light may cause banding in the image, but a similar amount of recovery will not. Therefore, given the choice, stretch your image toward the lower tones and avoid stretching it toward the highlight tones. When using either recovery or fill light, the idea is to move the histogram off the extreme so that any spiking is eliminated or reduced to its lowest amount.

Other Global Corrections

We may want to adjust the vibrance, contrast, and brightness. Vibrance controls the strength of yellow within the image and can add sparkle. The contrast adjustment modifies the total pattern within the image by either spreading the tones to either extremity to increase the contrast or moving more of the tones into the center to flatten the image. Brightness works on the midtones by anchoring the end points of the histogram and rearranging the pixels so that the midtone detail becomes brighter or darker.

Although both the contrast control slider and the curves control will provide contrast adjustment, curves provide a better method for adjusting contrast. With the curves dialog activated, the image contrast can be seen in the steepness of the curve itself. When you open the curves dialog box, the curve is represented as a straight line from the bottom left of the graph (black) to the top right (white). This represents tones graphically. In many software programs a histogram is also visible in the dialog so you can see how the change in the curve affects the tones that are represented in the histogram. A downward curve will darken the pixels in the area of the histogram where the curve declines in elevation. The opposite holds true with an upward curve that lightens the pixels. Most imaging software programs allow you to either draw and then smooth the curve or drag and bend the curve to a smooth new shape.
PIE allows you to adjust your images to meet your vision. With PIE software like Adobe Photoshop Lightroom, you can edit your images in a variety of ways and maintain the original data unaltered. The images here demonstrate some of the manipulations that you can easily make in modern software.

1. The fully modified image.

2. In this image, you can see the before and after versions of the modified image.
3. In Adobe Photoshop Lightroom you can white balance your image whether or not you are using a RAW image. In this case, you find a tone that should be neutral in your image, and Adobe Photoshop Lightroom will white balance the entire image with an algorithm that will adjust all of the tones in the image to make your chosen tone neutral.

4. You also have the ability to zoom in and choose your neutral tone more precisely.
5. The flexibility of Adobe Photoshop Lightroom allows you to adjust the curve of your image and review any curve adjustments you previously made.

6. You can also adjust more specific information with the custom modifications panel by adjusting globally or choosing specific control points to apply gradients, exposure, contrast, brightness, etc.
Sharpening

Sharpening is the last of the global corrections that are often applied to digital images. This may be needed because of the way digital sensors are made and how this affects the look of the captured image. In many digital sensors there is a diffusion material that slightly blurs the captured image to eliminate unwanted effects, such as moiré pattern. Both pixel sharpening and edge sharpening correct these effects. Pixel sharpening is applied to the pixels with processes such as unsharp masking. Edge sharpening is applied only to the pixels that the software can identify as being on an edge.

To our eyes, particularly as we look at a rasterized image on a computer screen, the image sharpness will always seem like it can be improved. However, this control should be used very sparingly to avoid oversharpening the image. Oversharpening increases the contrast and often distorts color relationships. Sharpening may be applied in all steps of the imaging process: capture, processing, and printing. It should therefore not be applied in the camera because it can be corrected in processing and printing.

Working Methods

Beyond correcting inaccuracies in the exposure or color bias, you need to decide how you will handle the images you have made. Because of the nature of digital photography, you can potentially take more pictures than you could with film. This means that you will have two major considerations in handling your images. You can either process all or most of the images, or you can select the best images for future use. These two options define the two major methodologies used in digital photography post-processing: batch processing and optimization. With batch processing you define the parameters for a group of images and apply them to the entire group. With optimization you select a subset, usually one image, of the larger group of images and perfect it with more specific controls or corrections to the pixels.

PIE software is an excellent tool for batch processing. Rather than performing the pixel operations on each image, the software writes instructions for how each image should be rendered, and these instructions are carried with the image file until it is opened at full resolution and the instructions are applied. This allows large groups of images to be processed in a much more economical fashion. Beyond allowing the total group to be processed or corrected with the same instructions, PIE software allows the introduction of keywords and metadata (such as job number, location, copyright, creator, etc.) and also allows you to select and rate images for later use. The metadata and the instructions on how to process the image will be carried along either as a sidecar or within a DNG file.

It is best to work in a nondestructive manner as long as possible. It is possible, depending on how you make your photographs, that well over 90 percent of the
corrections you make to your files can be done in PIE software. In fact, if you use your camera as the primary tool and consider programs like Photoshop to be available only to correct errors, all of your corrections may be done parametrically. Regardless of your intent to process as much as possible within a parametric environment, there may be a point when the image needs to be rasterized, reduced in bit depth, flattened, or converted to a smaller color space.

In the optimization approach, you will go beyond global corrections and work on making the most out of selected images. You can choose which images to optimize by rating them. Regardless of the software you use, you can set aside the best images, then you can optimize, print, transmit, or use the files in other ways.

During optimization you will work in a pixel process. Nondestructive editing can still be used for many operations through the use of smart objects and adjustment layers. As you optimize a file, you will create a master file that will be used as a final image or a substantial jumping off point for further adjustment. You will be able to make variations of the image without affecting your original intent because the master file will allow you to recover the starting point image.

You can edit the entire image in two distinct ways. First, editing can be accomplished globally. This means that the entire image is used as a work area for making corrections. Second, you can select a critical area of the image (for example, a person’s face) and use it as a work space, then apply the corrections you made to the rest of the image. With this method, the zoom tool is used to select the critical area (it is not cropped). After the corrections are made you escape from the selected area, and the corrections are applied to the entire image.
An Editing Checklist

The following is a brief checklist that you can use for your image editing. This will help you organize your thoughts about how you will correct or edit your images.

1. **PIE**
   First and most important, you should use PIE software as far into the editing process as possible. If an image can be corrected entirely with PIE software, then this should be the point where you create the master file without any pixel editing.

2. **Bit depth**
   Work at the largest bit depth (16 bits when possible) to maximize the potential of the image and to eliminate some attributes that occur with smaller bit depths. To maintain image quality, perform as many pixel operations as possible in 16 bits before converting the image to an 8-bit file. The point prior to the 8-bit conversion is a good time to define your master file.

3. **Color space**
   Use the largest color space available for your editing. The color space not only defines the colors you can use, it also eliminates potential colors. Even though all of the available colors may not be used for future operations, such as printing, a larger color space allows more flexibility in image processing. In today’s imaging environment, ProPhoto RGB provides the largest color space, with Adobe RGB (1998) as a potential second choice.

4. **Keep files large as long as possible**
   For the most part you should keep your data file as large as possible into the master file stage. Although the future use of the file may dictate a smaller image size or less resolution, this is not advisable for the master file because after the data is reduced, information is lost and cannot be restored.

5. **Nondestructive editing**
   When using pixel processes, use adjustment layers and layer masks. It is also advisable to use smart objects and smart filters where possible. When using layers or masks it is advisable to name them appropriately so you can track your operations.

6. **Master files**
   Although your file will be larger with layers and masks, it is better to keep the master file with all layers and masks intact, unmerged, and not flattened. After the layers are merged or the image is flattened, you will not be able to work effectively with variations in the layers that you used to create the master file.
Asset Management

© by Juliane Rückriem. Courtesy of the artist.
Keeping Track of Images

Since the middle of the 19th century our history has been told with photography. In the beginning, photographs, particularly daguerreotypes and ambrotypes, were so precious that they were presented behind glass in small leather-bound cases. But as tintypes and *cartes de visite* became available, photographs took on different uses and were presented differently. Specialized folios were designed to hold the smaller-size tintypes and cards that became the forerunners of today’s photo albums.

Early photographers documented their travels and the people around them as amateurs and as paid professionals. These included several important land surveys, documentation of wars, and a thriving portrait industry that created many of the images that contribute to our understanding of anthropology and history. The images made for various purposes found their way into museums and collections, creating a reservoir of visual information about the world. William Henry Jackson made one of the most famous early folios of images in the United States. This folio consisted of photographs of the Yellowstone region that was given to members of Congress to promote the creation of Yellowstone National Park. Congress voted without dissent to create and protect the area as the world’s first national park.

As amateur photography became popular and inexpensive, people’s memories could be captured and shared through the use of photo albums. The photographs that people made documented their way of life, their travels, and the people who were important to them. These photographs were collected and became easily referenced volumes. The prints were put into albums, but only the most serious amateur photographers cataloged and stored the negatives that were used to make the prints. Often negatives were stored in shoe boxes, sometimes in proper sleeves and sometimes not. In many cases the negatives were simply disregarded after prints were made.

For professionals, however, photography was a longtime career, and the photographs themselves, including the negatives, were considered the assets of the photographic business. Because both the prints and negatives could create income beyond the original printing, the negatives, prints, and instructions on how to handle the printing were carefully cataloged for future use.

As digital photography evolved, several things happened that impacted how people use, view, and maintain their photography. For the most casual photographers using phone cameras or point-and-shoot cameras, the pictures can be instantaneously and electronically transferable. Although this allows for rapid image sharing, there is seldom consideration for how the images will be stored or remembered. It is a concern of many historians that there may be a gap in the public history record for this period of time because much of the casual photography that documents today’s societies will be lost.
The fear is that images from ordinary individuals will disappear because the images are stored electronically, and the storage media will become obsolete.

On the professional side of photography, however, this issue has received a lot of attention. Groups such as the American Society of Media Photographers (ASMP), with funding from the Library of Congress, have worked hard in establishing workflow practices that can be used to maintain the visual records and art that are created as digital photography. The ASMP process and discussion of best practices can be found at dpBestflow.org. The idea is to establish and maintain a working methodology for post-processing and storing images. The process was designed to ensure that images can be used far into the future.

Our goal is to ensure that you can maintain, find, and use the images you have made beyond the instantaneous capture. We have therefore broken down this last portion of the workflow into post-capture processes and long-term storage.
Active Use

The post-capture workflow consists of one preparatory consideration and five activities to maintain your images. The preparatory consideration is your computer’s operating system. Just as updating the firmware for your camera is important to ensure that you are working in the most current version, keeping your computer’s operating system current is important for maintaining your images into the future. Although operating systems are often forward and backward compatible for one or two versions, old operating systems are not always able to convert files to readable document or image formats.

Beyond the issue of compatibility, there is a major concern as you update your firmware or purchase newer cameras. Many older operating systems do not support current camera operating systems or file formats. This may mean that a new camera is not compatible with your older computer, so you can’t easily process your images.

*Hiding Out* © by Jesse Strigler. Courtesy of the artist.
Importing Image Files

Today most cameras sequentially number all the images. The camera will either begin with 001 on every card or sequentially number the images across numerous cards. If the files are numbered sequentially across cards, the numbers attached to the files will be in the order they were taken regardless of how many media cards you use. However, to facilitate a smooth workflow it is best if the media cards are numbered and then used in numeric order. This will allow you to download the images in a logical manner and track down any problems with a specific card.

There are three practical ways to download the images from the camera to the computer. The first and most basic is to utilize the operating system within the camera to transfer the images to the computer. This requires that you install the camera manufacturer’s software on your computer so you can download the images from the media card to the computer. The camera and computer are usually connected with a USB cable, but sometimes wireless transmission is available with Bluetooth or other protocols.

The second, and perhaps most common, method for transferring files is the use of a card reader that allows the media card to appear on the computer’s desktop as a secondary drive. You can then move the files directly from the media to a destination folder on the computer.

The third method is the use of media cards that are dual ended. This means that the media card can be directly plugged into the computer like a USB device. Normally these cards have a fold that exposes the USB connection. When dual-ended cards are used, they appear as a secondary drive on the computer without the aid of a card reader.

It is important when you transfer the images from a media card to the computer that the files remain segregated from other images on the computer until you can apply an appropriate naming protocol. The best way to facilitate this is to create a new folder and import all the images from the photographic session into that one location.
© by Harald Mante. Courtesy of the artist.
Naming Protocols

Folders should be named to differentiate them from other photographic sessions. The easiest way to establish a naming protocol for both the folders and the files is to include the date of the photographic session as part of the name. It is important that the names can be read in both Apple and Windows computing environments, so the naming protocol should be limited to numbers, letters, hyphens, and underscores. As an example, a folder can be named with the date (YYYYMMDD) followed by an underscore, then the name of the photo session with underscores to separate words. A folder for a session photographed at a birthday party would be named 20101225_Susan_Birthday.

The file numbers on the media cards will be sequential, and not necessarily different from other files on the computer, so you might end up with duplicate numbers for different files unless you rename them. Renaming can be done manually, but it is best handled with the batch rename tool in software such as Adobe Bridge or Lightroom. Most software can use the metadata from the camera to append the date to the file name when the files are downloaded, so you should use this capability if it’s available. You can set up this protocol as a preset.

Backing Up Files

Before you do anything with the files or reformat the media card, it is important to back up the folder on an external drive. We recommend following the ASMP guideline, which is the 3-2-1 concept of image file storage. This means that there are three copies of the files: the original transferred files and two backups stored on two different types of media (hard drive, DVD, etc.), with one backup off-site and one on a read-only medium. Although this seems cumbersome, it is designed to assure that in the future the photographic session can be found, even if an unforeseen event compromises some of the stored files. None of the stored files reside on the processing computer; they are on separate drives or media. This might seem to be a heavier than needed demand for a beginning photographer, but as you become more involved in photography and the images become more important, this methodology will be increasingly appropriate.

If the media cards have multiple photographic sessions on them that have not been transferred to the computer and backed up on external media, then multiple folders should be created so that each photo session will have its own folder to avoid confusion and ease the search process in the future.
Evaluating and Adding Metadata for Images

When the files are transferred it is appropriate to examine the images to be sure there are no flaws or corrupted files by reviewing all the previews and thumbnails generated from the RAW files. With cameras that capture both a RAW and a JPEG file, if the RAW file is corrupt, the JPEG can be used to avoid loss. At this point in the process, defective or inadvertent images, such as those taken with the lens cap on, can be deleted. Although evaluating all of the images might suggest that some of them be eliminated, this decision should be made very carefully because after the file is eliminated and the media card is reformatted, it is unlikely that the image can be reconstructed.
After the images have been evaluated, you can use the image management software to assign keywords and ratings and sort the images for future use. When the images are brought into the image management software, bulk keywords, such as the session location, copyright, contact information, and so forth can be added to all of the images from the photo session. Though it is not actually image management software, conversion software can be used to both convert the images and add keywords. For example, the DNG converter will both convert the RAW files to DNG format and allow keywords to be added to the metadata.

Although bulk keywords can be added to all files within a folder, it may be desirable to add specific keywords for individual images. This can be done through the image management software by grouping the images and applying individual keywords to selected files. You can do this individually while you sort or rate the images, or you can do it at any other point in the process.

With image management software, all the files from any photographic session can be viewed either individually or in groups. This allows you to evaluate and rate the images for future use. This is done through the use of previews, which are small files that represent the full-size RAW file. The image management software or converter also allows you to apply parametric adjustments to all of the files to correct for neutral balance, exposure, contrast, etc.

The final step in the post-capture workflow is storing the images. With the cost of storage media decreasing, the 3-2-1 method of storing images is not overly burdensome compared to the potential cost of losing the image files. If you use external hard drives as backup sources, use them regularly to make sure they function properly so you can retrieve the files when needed.

Also, you should decide if the original captured files in their proprietary raw format should be kept or if only the DNG files need to be retained. This is a personal consideration, not a totally functional consideration. If you think you'll need to process the files through the manufacturer’s conversion software, then one copy of the file can be kept in its original proprietary raw format. On the other hand, the DNG file contains the raw data along with parametric information and a preview that can be used in the future.
© by Matt Harbicht. Courtesy of the artist.
Archiving

Though it is not actually part of your workflow, what happens to the images and their corresponding files in the future may be of concern to you. These concerns are addressed in the way images are archived. There are several approaches to consider.

You might conclude that the use of the images in the future is the responsibility of those who wish to use them. If this is your opinion on the matter, nothing beyond what has already been discussed needs to be done. It will be up to image archaeologists of the future to decode your images.

Perhaps there will be products in the future that will translate our image files. This means that there will be a computer or software that will be able to understand the files as they are presently written and translate them into an appropriate form for future imaging applications or processes.

A third approach is to prepare the images as permanent artifacts. This means that you could print the images at full resolution on permanent materials. Although they are not totally permanent, pigmented ink printing processes have extensive life expectancies well beyond digital storage. This means that permanent images will be usable in printed form.

Fourth, you can migrate the images and their files. This means that as newer technologies emerge, the existing files can be converted to the newer technology. Migration can also be used within currently available technologies. If one or more of the backup systems fail, then a remaining backup can be migrated to another system or type of media to recreate the failed backup to maintain the 3-2-1 system previously described.

Last, we can assume that there will be computer museums in the future. This would allow older file formats that use outdated software to be opened and migrated into available technologies. As ironic as this sounds, too often older data has been lost because antiquated equipment and processes have not been preserved.
© by Kelly Kirlin. Courtesy of the artist.
Part 3

Beyond
In Part Three we will introduce you to three image-making concepts that are based on what you have previously learned to expand your opportunities in various photographic situations. We will also present more technical information about the capture process and function of the sensor.

The real skills of many photographers are evident in the way they approach various lighting situations. Many lighting conditions are outside the normal range of capture devices, or they can present uncommon situations that can't be dealt with through standard practice. Here we present three ways to acquire digital images in the hopes that you will see these approaches as part of the scope of digital photography.

The first approach we will discuss takes the ideas of the Zone System and applies them to digital photography. This technique will assist you in controlling exposure within the tonal realities of the scene and maximizing the rendered detail of the image. Next, we will explore high dynamic range imaging (HDRI), which captures very long-range lighting situations. We will discuss methods to control high-dynamic-range situations using prosumer or professional DSLR cameras. Then we will enter a discussion of hybrid imaging that uses a combination of photographic film and digital technology to create images. For those with an appetite for a more technical discussion, we will present a more detailed explanation of digital capture, starting with when light hits the sensor and continuing with how the camera processes the image.

At the end of this book, your knowledge of digital imaging, both technically and creatively, will give you the power to share your vision, communicate through your imagery, and create images worth remembering.
Beyond Exposure 1: Digital Zone

© by Torsten Andreas Hoffmann. Courtesy of the artist.
Expressed Light

From the beginning of photography there has always been a desire to improve control over the final image, allowing for maximum creativity. For early photography, this resulted in the creation of new emulsions, better cameras, and more exact exposure.

Even with the improvement in photographic sensitivity, early emulsions were overly sensitive to ultraviolet light, which created an inability to photograph both the sky and the ground correctly under most lighting conditions. In the 1850s Gustave Le Gray found that he could make separate exposures of the sky and the foreground and then merge the two to expand the tonal range in the image. At a similar time, Henry Peach Robinson created his photograph *Fading Away* by putting together both an image that showed the outside of a building and other images that showed the inside.

With improvements in emulsions it became possible to expose a larger dynamic range in the scene; however, the ability to easily print these negatives was problematic. The obvious solution was to control the light while printing. With an addition of light (called burning), the tonality in the sky could be increased, and with a reduction of light (called dodging), the detail in shadows could be maintained. The terms *burning* and *dodging* are still used in digital software because of their prevalence in the photographic process.

By the middle third of the 20th century, photographers had mastered many of the issues that allowed them to create exemplary images within the black-and-white realm. It was at this time that Ansel Adams set upon his life’s work. In 1941, Ansel Adams and Fred Archer created what is now known as the Zone System. Although the Zone System was developed to enhance the photographer’s ability to create and communicate with black-and-white film-based photography, many of the concepts that are inherent to the system are usable within digital photography, both black-and-white and color.
Digital Zone System

Digital photography gains the most from the Zone System by using its primary idea: We must consider the outcome of the photograph as we are making the image. This means that as the exposure of an image is considered, the way the print will represent the image becomes the driving force for making that image. This will lead us to better images that more completely communicate the scene we wish to photograph. This is known as previsualization.

To maximize previsualization within digital photography, we need to understand and control several parts of the system. These include the dynamic range of tonality in the scene, the dynamic range that can be captured by the sensor, and the abilities of the post-processing software and hardware to represent the captured intensities as desired. To do this we will need to test and quantify the aspects just mentioned. Although we can rely on the manufacturers’ published abilities of the equipment and software, it is far superior to test each portion of the system to ensure that we know the limitations of our equipment, methods, and processes.

One of the limitations that affects a digital approach to the Zone System is the maximum level of brightness that can be captured without clipping. If a sensor receives more light than it can absorb at any pixel location, it will bloom and/or clip the intensity at the maximum absorption level of the sensor. When this level is reached, no further exposure or discrimination of light is possible. Although many photographers believe that by using RAW files they can open detail in overexposed whites, if a sensor reaches its maximum absorption
level, then all values captured will read as white because all values above the maximum limit of the sensor are clipped or shunted off as excess energy. Overexposure in digital photography cannot be compensated for.

Unlike film, a digital sensor’s capture range cannot be manipulated through development of the captured image. This means that the second concern of digital photography as it pertains to the Zone System is the difference between the dynamic range of the scene and the total capacity of the sensor. We must work within the limits set by the sensor or accept clipping at one or both ends of the dynamic range.

There are two issues on the darker end of digital exposures. First is the lack of tonal variations that exist in the lower end of the captured dynamic range. As discussed earlier, this can lead to banding in the dark areas if the contrast is altered. The other is the level of exposure that is required to produce an image without unacceptable noise.

Last, an inkjet printer can produce only a little more than seven stops of dynamic range. This means that the image file sent to the printer must correspond to that range in order to maximize printing. Therefore, the processed image file must hold all black-to-white detail and tonal information.
Zone Vocabulary for Digital Photography

Although the Zone System was developed for black-and-white photography, the vocabulary for many parts of the system can be transferred directly to digital photography without further interpretation. The terms that have the most direct transference are the zones. The zones are the values, or the light energies, that reflect from the subject and are used to previsualize the final image.

Described briefly, there are 11 zones that range from zone 0 to zone X (10). Zone 0 is unexposed or, in digital terms, at or below the acceptable noise level; zone X is pure white. In the Zone System as taught by Ansel Adams, there were only 10 stops from zone 0 to zone IX. In either zone structure the zones relate to the light intensities in the scene. When applied consistently, either system works. For our purposes and based on the linear nature of digital capture, we will use the 11-zone system.

Within these zones we can define three specific areas of concern. First are the dark zones: 0, I, and II. These dark zones add the richness to the image. Next are the middle zones: III, IV, V, VI, and VII. These zones carry the detail for the image and are the most communicative portions of the image. Last are the light zones: VIII, IX, and X. These three light zones add energy and life to the image.

The zones represent a 10-stop range of light intensities. Although there are 11 zones, for our purposes we are interested only in the intervals between the zones, or a 10-stop range. This means that as we envision our image and use the zones for previsualization, they will fit easily within the dynamic range of most sensors. From the standpoint of exposure, each zone represents twice or half of the exposure value of adjacent zones, with the exception of zone 0 and zone X. This means that the value of each zone in the final image can be moved by one zone for each stop change in the exposure.

Although the exposure information on the camera’s histogram can give us some indication of how to adjust our exposure, it is far better to use a handheld spot meter in conjunction with our digital camera to determine the exposure. The histogram on the LCD is only a rough indication of the light intensities in the scene, but a spot meter will allow you to accurately determine the dynamic range of the light in the scene and give you better exposure settings.

Because the light intensities in the scene do not always correspond to the desired values for an image, the way the image is handled after it has been exposed determines the way it can be used to make a print. In the Zone System with film, variations in the chemical development times affect the outcome in the printing of the image.
For digital imaging we use post-processing in the same way we would use developing for film. We can either expand (stretch) the intensities to make them cover larger areas of the dynamic range that we can use in printing, or we can compact (compress) the intensities to make them conform to the limits that will be available in printing. However, compression of a file is not as effective for an overall image because digital sensors clip over- or underexposure. You cannot compress data that is not in the RAW file.

Expansion and compression can be handled in one of two ways within common imaging software: with levels or a tone curve. Regardless of whether a file is adjusted during RAW conversion or later in post-processing, these controls can be applied to maximize the potential of an image.
Using the Digital System

To apply the digital Zone System approach, we need to use an overall previsualized view of the light environment. We do not try to manipulate the zones during capture; rather, we maximize the tones when we process the file. It’s best to use a handheld meter with the digital Zone System.

The exposure steps are as follows:

- **Step 1:** Place the sensor’s EI into the light meter.

- **Step 2:** Using the handheld meter, measure the light reflecting from the brightest point in the image for which you want detail. This is zone VII.

- **Step 3:** Measure the point in the image where you want shadow detail. This is zone III.

- **Step 4:** The detailed scenic dynamic range is the difference between steps 2 and 3. When counting the stop differences between the steps, count the end stops as well as the ones in between. Therefore, the difference between f/4 and f/8 should be counted as three stops.

- **Step 5A:** If the detailed scenic dynamic range is six stops or less, the exposure should fit well within the capacity of most sensors. In these conditions, open the aperture by half the number of stops available or measured for your sensor. Depending on the amount of dynamic range in the scene, expose the image as brightly as possible without overexposing to create a histogram that has as much image data as possible represented in the right half of the graph.

- **Step 5B:** If the detailed dynamic range is beyond the capacity of the sensor, normally beyond seven stops, you must make a choice. In this situation, such as a bright sunlit day on snow or sand with deep shadows, you need to choose what you will sacrifice: the highlight or shadow detail. If the shadow detail is more important, open the aperture further to include the dark tone detail. This will blow out the highlights. If the highlight detail is more important, close down the aperture instead.

It is important that you capture RAW files to maximize the potential of this approach. Other file formats, particularly JPEG, compress the images, which can cause data loss. With a RAW file, the captured dynamic range is intact. Though the RAW converter in your imaging software will spread the captured dynamic range across all 16 bits as seen on the computer screen, a RAW file is the best representation of the captured light.
Post-Capture Processing

The following discussion is based on the Camera Raw converter in Adobe Photoshop. The image needs to be processed in 16 bits per channel. This does not expand the scenic dynamic range, but it avoids the loss of image information that would occur if the image were compressed into 8 bits per channel. Do not convert the RAW file in Auto mode because the light captured in the scene, regardless of the exposure control applied, will be spread as much as possible across the entire 16-bit range for the image file.

If you use the RAW converter with the basic or slider control window, you will find the exposure, recovery, fill light, brightness, contrast, and saturation controls. Particularly in the shadows, the brightness and exposure controls can be used to change and open the detail that has been underexposed. The Exposure control can be used to adjust the amount of dynamic range seen in the image file. Even with good control of the exposure, the histogram may show too much light at the right side, which is highlight exposure that can be moved toward the left with the Recovery control. The Recovery control locks
the shadow areas or left end of the histogram and moves the right end. The Fill Light control anchors the highlight end and affects the shadow areas. Since the image was created with consideration for the highlight level, the Exposure control will be very effective. The Brightness control anchors the shadow end and allows the image highlights to be shifted. The Contrast control adjusts the overall distribution of the light captured within the file and maximizes the output tones for the file. Last, the Saturation control has little effect on the light captured from the scene. It locks both the highlights and shadows and reorganizes the distribution either toward or away from the center of the histogram.

You need to experiment to find the best controls for your exposure preferences, but the following steps are designed to generally maximize the image:

- **Step 1:** Adjust the Exposure control to 0. Although 0 will bring the exposure as close as possible to the light as captured, if the light represented in the histogram is predominately on either the right or left, this adjustment will be required to avoid excessive brightness or darkness in the image.

- **Step 2:** Using the Recovery control, adjust the right end to move the histogram toward the left. If there is a spike created by a bright light source, such as a specular light or the sun, there will be some intensity that cannot be removed from the extreme.

- **Step 3:** Adjust the Fill Light control to a point where the left end (the shadows) of the histogram is close to, but not at, the left extreme.

- **Step 4:** Adjust the Brightness control to achieve the appearance you want in critical areas. Because the left end of the tonal range shown in the histogram is anchored, moving the slider will adjust the right end (the highlights). This should be adjusted so it is close to, but not at, the maximum. Likewise, the Black control can be used to move away from the left end of the histogram.

- **Step 5:** Adjust the Contrast control to achieve the desired range and contrast within the image. When the slider produces a positive number (+), the distribution of the tones represented in the histogram is spread out, indicating a higher-contrast image. A negative number (−) compresses the tonality into the center to create a lower, flatter contrast.
Use the Saturation control carefully. It can be used to enhance the color in the image or convert the image to grayscale, but the increase in saturation may create an unrealistic portrayal of the scene. Also, desaturation of the image creates grayscale, but is not necessarily the best way to create a black-and-white rendition of the scene.

The basic controls (the sliders) can be used to make adjustments based on a linear distribution of the intensities that are present in the image, and the tone curve gives you the option to create a perceptually balanced distribution of the captured light. When using the tone curve in the RAW converter, the best option is to use the linear choice under the point selection. This presents a curve represented by a straight line with the ends at the black (zero) and white (maximum) points of the graph. Also, the histogram will be reproduced in the middle of the curve field. The end points of the curve can be moved so that their values are slightly beyond the indication on the histogram. This adjusts the light values from the captured image and maximizes their potential in the processed image. The curve can be distorted into a slight S shape to slightly compress both the lightest intensities and the darkest intensities in the image. With these compressions in place, the image will have the characteristics that most closely match human vision.
Digital Black-and-White

The Zone System began as a technique for black-and-white photography. There is still a great reverence in the photographic world for black-and-white images, whether they are made with film or digitally. There are several ways (some good, some not so good) that a digital black-and-white image can be made.

There are two ways that cameras can create black-and-white, monochromatic images. Some cameras do not have a filter array over the sensor, so they capture only light intensities. Other cameras contain software programs that reinterpolate images back to their intensity levels after they have been captured through a color matrix filter set. We do not recommend the latter because the system processes and interpolates the color image, then it desaturates the color image to arrive at grayscale.

For the best results in making your image black-and-white (grayscale), it is imperative that the image be captured in RAW format. We prefer to capture the image as an RGB RAW file and use external software in the RAW converter or imaging software to extract the luminance information from the file to create the grayscale image. There are many ways to accomplish this. A few examples are as follows.

First, you can use the software to either desaturate the image or create grayscale. This is basically the same thing that is done in cameras that contain software to create grayscale, that is, the software reinterpolates the image to remove the color. Just as the in-camera option for creating black-and-white images is less than satisfactory, this approach does not provide a superior grayscale image, although it can be done quickly.

A second method is to use software to convert the image to the L*a*b* color space and then change the image to grayscale. This is accomplished by using the structure of the L*a*b* color space, where L* stands for luminosity, a* is the red–green axis, and b* is the yellow–blue axis. When the image is separated into channels, you can remove the a* and b* channels, leaving only the luminosity information.

Next, when converting a RAW file in Camera Raw, Photoshop, or Photoshop Lightroom, the black-and-white option can be used. This allows you to select a grayscale image and then use the color sliders to modify the filtration, similar to using a color filter on the camera. If you wish to have columns within the red spectrum lighter in tone, you can move the red slider in the positive direction. If you want to darken the tone of a blue sky, either move the blue slider in the negative direction or move the yellow slider in the positive direction. Moving the blue or yellow slider will darken the tonal values in blue, similar to using a yellow filter on a camera with black-and-white film. Other black-and-white conversion software is available. Two examples are Nik Software’s Silver Efex Pro and Power Retouche’s Black & White Studio.
The last method we will mention is the channel mixer. You can open the image in channels and evaluate each channel for the best detail. With the best detail selected, add the channel mixer adjustment layer to the monochrome option on the control panel. Then adjust the channel mixer with the sliders so their total equals 100 percent.

Regardless of the method you use, we strongly recommend that you use a nondestructive PIE method. This way, the originally captured intensities will remain in the underlying RAW file, which can be used later to interpret the image in other ways, including color.

Although the methods described here will result in black-and-white images, printing may be problematic unless you have a black-and-white raster image processor (RIP), such as QuadToneRIP or Epson’s Advanced Black & White Photo Mode. Alternatively, you can add a Hue/Saturation adjustment layer in Photoshop to slightly modify the color if your printer doesn’t have a black-and-white RIP. Adding a controlled and weak amount of color to the image will make the print look better. For example, within the Hue/Saturation adjustment layer, activate the colorize option and add a small amount of saturation (+2 to +6) of your preferred hue. This can also be accomplished in Photoshop Lightroom in the grayscale palette.

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Beyond Exposure 2: HDRI

© by Matt Harbicht. Courtesy of the artist.
Expanded Light

As discussed in the previous chapter, it is possible to manipulate the development of film to adjust to various light conditions. As far as extending the dynamic range is concerned, the use of underdevelopment known as compaction allows film to accept a longer than normal dynamic range from the scene and create negatives that will print the longer dynamic range. This, along with the film’s native ability to capture this longer dynamic range, provides the opportunity to create pictures where the dynamic range from the scene is greater than normal. A normal subject (scenic) brightness range is about 128:1, or seven stops. This corresponds to an approximate value range of 25 to 245 in an 8-bit per channel capture (24-bit color).

The light ranges of photographic environments often exceed what is normal or what is potential for our digital cameras to capture. Most high-end digital cameras can capture 12 stops of dynamic range that will likely be processed into 16 bits per channel in RAW format. In understanding HDRI we need to agree on the difference between what is captured and what is usable.

A sunny day will produce incident meter readings indicating a dynamic range of seven stops between the light measured in open sunlight and the intensity measured in the deep shadows. As previously mentioned, this corresponds to an approximate value range of 25 to 245. We must also realize that the very dark values, those up to about three stops, will be unimportant beyond noise and dark pattern.

When the subject tonalities are taken into consideration, such as a wedding with the bride in a white gown standing in the bright sun and guests in the background shadows, or a scene at sunset where the bright sky is present along with backlit detail in the shadows, the dynamic range can easily exceed the 12 stops of capture available in a digital camera. In situations where both the inside detail of a building and external bright sunlit detail are required, the dynamic range can be 20 stops or more.

For digital sensors, unlike film, there are absolute thresholds at either end of the dynamic range. The number of stops that can be gathered and processed through the ADC limits the dynamic range capabilities in digital photography. At the low end there is an absolute threshold based on the ISO setting for the sensor. The well depth controls highlight exposure, which represents the absolute number of photons that can be gathered by the potential well. Any exposure over the maximum of the potential well will either bloom into nearby pixels or be shunted off and lost.
Many photographers misconstrue the ability of a RAW file to be recovered in the highlight area of the captured scene. Although a certain amount of recovery through image processing is possible, only about two-thirds of a stop of additional exposure can be recovered. Similar to what was discussed as dark value capture, recovered highlights do not constitute detail. At best, they become part of the final image as pattern, and more likely just as density difference.

Today there is a growing use of and need for HDRI, particularly in automotive and architectural photography. HDRI is also used in portrait and wedding photography, particularly when photographing outside the studio. While the portrait and wedding application deals primarily with the subject bias brought to the setting by brides, grooms, and portrait sitters, for architectural and automotive photography the need is to portray the reflections from shiny surfaces.

When surfaces are specular (shiny), the image reflected in the surface will have a high dynamic range. The current approach to some automotive photography is to utilize wire frame rendered constructs of the car or truck and to texture map environmental reflections into the shiny metal surfaces. When this method is used, HDRI is required because reflections lose some of the intensity of the scene when they are reflected. Therefore, we need to capture a longer dynamic range if it will be texture mapped onto a rendered object and needs to look shiny.

For architectural photography, the need is to acquire detail both in brightly lit areas and in the shadows of porticos and architectural details. Also, with the large amount of highly reflective glass used in many architectural structures, sky reflections will take on the same attributes as those just discussed for automotive photography.

Some Basics of HDRI

The considerations for creating high-dynamic-range images are primarily based on the scale and bit depth used to capture the light. Although specialized cameras are capable of capturing and outputting images that meet these requirements, this book is aimed at the person who will occasionally wish to use HDRI but not invest in expensive HDRI cameras and computing equipment. It must also be understood that true HDRI requires a very sophisticated monitor because of the limited output capabilities of print, projection, and other displays.

For capturing a normal dynamic range, cameras and software have been designed and developed to capture 16 bits per channel. Although the ADC in your camera may capture 12 to 14 bits per channel, the onboard software produces a 16-bit per channel file. For HDRI the standard is 32 bits per channel.
One of the major problems facing photographers who wish to use prosumer or professional-level DSLR equipment to produce a high-dynamic-range image is the need to fill a 32-bits per channel depth with images that are created with less than half the bit depth required in the final file format. This cannot be done by simply stretching the fewer bits per channel that were captured across the much larger HDRI file format without major degradation of the image, particularly in the darker tones. This degradation will be seen in most of the image as banding or posterization because there will be a large separation between tones, and the continuous nature of the higher-dynamic-range scene will be lost.

Further complicating our use of nonspecific HDRI equipment to produce this kind of image is the way the tones are distributed within the captured image. As discussed in the chapter on digital exposure, the histogram shows us that more than 75 percent of all captured tonal variations will be represented within the brightest two stops of the dynamic range. This is true of a 32-bits per channel file as well as an 8-bits per channel file. Therefore, we need to find a way to utilize the greater bit depth of HDRI while capturing images with equipment designed to produce much smaller bit depths.
The goal is to produce multiple exposures that can be layered and processed to produce what appears to be a seamless high-dynamic-range picture. This requires that the camera remain stable on a tripod during the multiple capture sequence and that the major functions of the lens, aperture, focus, and zoom are not changed. Bracketing for exposure variance needs to be done with the shutter speed or ISO. It can be accomplished with either auto bracketing or manually changing the settings. The requirements also suggest that the more exposures that are made over the entire dynamic range of light in the subject, the better the HDRI output will be. This will allow for tonal separations using the top portion of each exposure to produce the HDRI output.

The rest of this chapter explains two approaches that can be used to photograph and present images of high-dynamic-range scenes.

Faux HDRI

The first process is called faux HDRI. This indicates that the process does not use 32 bits; instead, it appears to gather the long dynamic range of a scene. Faux HDRI is appropriate only for certain kinds of scenes. These tend to be situations where one part of a scene has a dynamic range that differs from other portions of the scene. These types of scenes include photographing an object with a highly reflective, and therefore bright, area that can be isolated; alternatively, a scene could have an isolated dark area that greatly varies from the shadows in the rest of the scene. We can consider these scenes to have a normal dynamic range for the majority of the scene, with a portion of the scene outside of the normal range. A common example is a building interior where the interior is one illumination level, and light coming through the windows is brighter. This is easy to handle with faux HDRI by blending two exposures.

Faux HDRI (and the other method described in this chapter) does not work with images that include large amounts of motion. This is particularly true when the smaller portion of the scene that is outside the normal range contains the most motion.

A tripod must be used to assure that the two exposures stay aligned. The exposures are made by first capturing the normal portion of the scene. Any procedure can be used to maximize the exposure of this image. For the second exposure of the scene, which will capture detail in the portion outside of the normal range, we recommend calculating a histogram-based exposure prior to the first exposure or using the clipping alert to adjust the exposure. Either method will assure that detail has been captured in the second exposure. After the two exposures have been made, one file will be a normal scene with
a portion that is grossly under- or overexposed and is exceptionally white, black, or below the noise threshold. The other file will be either a very light, extremely overexposed image or a very dark, underexposed image. In either case, the smaller portion of the scene that is outside of the normal range will contain detail.

In post-processing, handle the normal exposure the same as other images, regardless of the out-of-normal portion. You can reconstruct this portion of the image when you process the second exposure.

In post-processing the second exposure, the idea is to eliminate the portion of the image that was properly exposed in the first image, leaving only the portion of the scene that was originally outside of normal. Depending on the extent to which detail was illuminated in the first exposure, various selection techniques can be used to delete the normal portion of the scene. First, if the detail from the normal portion is almost totally obliterated by either the over- or underexposure, you can use tonal selection (color range selection) or masking and then delete the selected portion. You should then clean up the areas that remain. Second, if there is greater detail in the normal portion of the image even though it is over- or underexposed, you may wish to manually correct more of the image and delete the rest. In either case you want the file from the second exposure to contain only the portion of the image that was outside of the tonal range in the first exposure. Note that it is handy to retain at least three of the corners of the second exposure to assure accurate alignment in the layering process. You can delete these corners later after the two layers are aligned.

If the out-of-normal portion of the original scene was bright, then the deletion should leave all other areas white. This means that the color selection will display a black square on top with white underneath (this is the normal or default setting). When you delete the unwanted area, white will replace it, or the area will become transparent. If the out-of-normal portion of the original scene was dark, then the deletion should leave all other areas black. The color selection should display a white square on top with black underneath. When you delete the unwanted area, black will replace it. In either case, you should use feathering to soften the edges of the selected area.

Now you can open the first exposure as the background layer for the newly compiled image. The mostly white or black second exposure is then added as a layer over the background. If the second exposure is mostly white, set the blending control to Darken. If the second exposure is mostly black, set the blending control to Lighten. The opacity control for the latter can then be used to affect the strength of the black, depending on the context of the rest of the scene.
1. This image (the first exposure) has been exposed properly to get good detail in the shadow areas, but the highlight areas have been blown out.

2. A detail of the first exposure.

3. A detail of the second exposure, which was underexposed to compensate for the blown-out highlights.

4. In this version of the image, the blown-out highlights have been brought under control by layering the underexposed highlight image over the clipped highlights.
DSLR and Small-Camera-Based HDRI

Because this book is aimed at photographers who do not have specialized HDRI equipment, we will discuss a process that can produce images from scenes with high dynamic ranges with manually operable digital camera equipment. This approach spreads the exposure across the scene's dynamic range to capture as many light values as possible. However, the camera cannot be operated in a purely automated fashion.

We need to expand the captured range by adding exposures above and below what would be considered normal. With a normal exposure, when the scenic dynamic range is very long, there will be excessive clipping at either or both ends of the dynamic range. To avoid this, we will combine various exposures to extend the capture and eliminate clipping.

We can use the same understanding of how light variations are captured that was discussed in the chapter on digital exposure. Recall that the histogram carries the vast majority of light variation in the brightest few stops, so we will need a substantial number of exposures; each will need to capture a portion of the scene's dynamic range, exposed to capture that part at the highest possible intensity. The exposure for the brightest areas should not spike or be clipped in the preview or the file, so the overall image will appear quite dark. However, we will use only the portion of the image information that contains the brightest areas. The exposure of the darkest areas will be quite weak, and when we expose those areas toward the right side of the histogram, there will be a high level of clipping in the bright areas and no clipping in the dark areas.

For faux HDRI we discussed capturing two frames, but we are not limited to two frames. For more accurate HDRI we will use a 32-bit dynamic range. With the need to fill in a broader intensity range, we will be required to link several exposures that capture a longer dynamic range than the sensor is capable of.

Suppose that an ADC can capture 12 stops, and the dynamic range of the scene is 18 stops. If we use only two exposures (one at the high end and one at the low end), we will find that our light variations are adequately captured in the middle and high end. When we process this into a 32-bit per channel work space, we will have large gaps. This will create a high potential for banding in the darkest areas and in one area slightly above the maximum of the low-value exposure. Therefore, to capture the light variation for an 18-stop dynamic range scene, we need at least five exposures to cover the entire range.

To create a high-dynamic-range image we will assemble the two end exposures and the intermediate exposures into a 32-bit format and merge various midrange intensities from the intermediate exposures. We mentioned that five exposures are required, but this might not be enough. The number of intermediate exposures will increase as the dynamic range increases.
As explained earlier, the low-end exposures have the least tonal variations, but we will eventually have to use these intensities. However, they will make up only a small fraction of the millions of light variations that are available in the 32-bit format. The majority of the intensities will be merged from the intermediate exposures. The highest intensities from the high-end exposures will have to be used without merging, but remember that this portion of the dynamic range has the most intensity variations. Specialized software or tools within standard software, such as Adobe Bridge (Tools>Photoshop>Merge to HDR Pro), can merge multiple images into a 32-bit high-dynamic-range image file.

1. This is a composite high-dynamic-range image of the Denver skyline at night. Let’s look at how this image was achieved.
2. To start with, each image was taken of exactly the same perspective by placing the camera on a tripod and duplicating the composition of the image while varying the exposure. In Adobe Bridge we reviewed all of our exposures and picked the images that we needed to create our high-dynamic-range image.

3. With the images that we wanted to use selected, we navigated to Tools>Photoshop>Merge to HDR Pro to let the program create the composite.
4. Merge to HDR Pro allows you to manipulate elements of how your composite images fit together so you can create a final image to your liking without having to work with all of the layers individually, as in the faux HDRI approach. There are options to control Edge Glow, Tone, and Detail and Color for 8 or 16 bits per channel images.

5. Last, we can use the Set White Point Preview to set the overall tonality of 32 bit images.
This approach to HDRI requires a series of exposures that vary in at least one-stop intervals. Depending on the accuracy of your exposures, you will need five one-stop intervals to capture an 18-stop dynamic range scene with an ADC that is capable of 12 stops. The scenic dynamic range and the interval requirements can be measured either by spot metering the brightest and darkest points for which definition is required or by calculating the number of stops by finding the stop requirements between clipping points.

When the files are assembled into a 32-bit HDRI file, it will be very large. The size of the file and its 32-bit format allow few adjustments and little editing. Also, the file needs to be exported, or the bit depth needs to be reduced, in order to print the file.
Beyond Exposure 3: Hybrid Digital Photography
A Place for Silver

When we started this book, we said that photography's change from film to digital has not been a revolution, but instead a natural evolution of processes, technologies, and aesthetics. When we look back at the start of photography, we see that three individuals—Louis Daguerre (daguerreotype), William Henry Fox Talbot (calotype), and Hippolyte Bayard (direct positive printing)—introduced their photographic processes in 1839. This confluence of energy flowing in one direction was the evolution of thinking about the problems that would need to be solved to create a photographic process.

Within a dozen years of the introduction of photography, the original processes had been replaced by the wet plate collodion photographic process. This process only had a 13-year run before it was replaced with the dry plate photographic process. The processes evolved further with the development of gelatin-coated paper and then transparent film. As changes occurred and the photographic processes evolved, parts of the earlier photographic processes were still used with the newer technologies and processes.

Today we can see that the use of film and printing technologies have not been totally surpassed by digital photographic techniques; in many cases they have been included in today's imaging technology. This includes the use of silver halide printing techniques to output digital capture and the use of film as a capture medium to create digital images.

As we view the evolution from silver-halide-based photography to an electronically enabled present, let us look at the useful intersection of these processes. In today's photographic workplace, both digital capture and a hybrid technique using both silver halide and digital technologies are valid. Each has unique application advantages. Regardless of the future of digital photographic technology, today's photographers use a hybrid of silver halide and digital technologies. Though there are other hybrid approaches, the most common is to utilize film as a capture medium and then scan the negative to create a digital file.

Just as the historic evolution of photography retained some older techniques, equipment, and processes, we need to consider how and why we will use film-based technology as we work within digital imaging. Primarily, we need to compare film-based technologies and equipment with the same methods and processes associated with digital technologies.
Megapixels versus Grains

Depending on the number of pixels on a sensor and their arrangement, it can be said that digital sensors have reached an image density equal to film. This is true for the highest-count sensors. Even based on the size of the sensor sites themselves, it is possible to manufacture a sensor with photo sites equivalent to silver halide crystals.

To understand the differences between film and sensors, we need to start with the number of photo sites, pixels, and silver crystals (grains). For a 35mm film frame, the emulsion contains in the neighborhood of 100 million silver halide crystals, but the count alone can be somewhat misleading. When silver halide crystals develop, they tend to cling together and reduce the actual grain. Further, with color film the generated color dyes are not related directly to one specific exposed silver halide crystal, but rather to the area where development occurs. For both of these reasons we can think of a 35mm film frame as having about 14 million image locations. In other words, approximately 14 million distinct and countable parts make up the image.

When we compare film’s image locations to a sensor’s pixels, it seems that some cameras have more pixels, or more image locations. At the time of this writing, there are full-frame sensors that have more than 22 megapixels. However, we need to deal with how the photo sites are arranged on the sensor and how this affects the capture of detail. There is a concept known as the Nyquist limit that comes into play when using a sensor to capture image detail. The Nyquist limit says that the frequency of the capture device must be one-half the frequency of the detail. In other words, you need two pixels to capture the smallest required detail. As we write this book, sensors are approaching numerical equality with film based on the Nyquist limit.
Pixel Arrangement

The arrangement of the photo sites on sensors, or the grains in the film’s emulsion, also presents another point of comparison. For film we can assume a random arrangement, but sensors have a rectilinear arrangement in rows and columns. Because film’s silver halide crystals are randomized both in size and location over the image capture surface, we can assume that light can be captured at any location across the film frame. When compared to the random capture of film, sensors have two distinct and very different structural elements in the image capture. First is the rectilinear structure of a digitally captured image, and second is the percentage of the surface that is not sensitive to light.

Sensors are manufactured in rectilinear patterns regardless of the shape of the photo sites themselves. Though Fujifilm argues that their FinePix sensor is not in rows and columns because the photo sites are hexagonal in shape and alignment, the sensor still uses a Bayer array for filters, which sets up a regular pattern of rows and columns that are positioned at 60° to each other rather than 90° as in a rectangular alignment. These alignments of photo sites break up captured light into these patterns. Further, when the image is output from the sensor, regardless of the sensor type, the image is in rows and columns. This can cause artifacts in the image, most notably a moiré pattern when photographing subjects that have image elements that are similar to the alignment of the sensor.

The fill factor (the percentage of the sensor’s surface that is actually light sensitive) is the second issue. Since part of the surface of the sensor is not light sensitive, the sensor cannot acquire image information at all locations across the sensor. Microlenses can be used to gather some of the light that falls on the part of the sensor where there is no light sensitivity, but this light energy is added to other light that is focused on the area above the photo site. Though this light is captured, it is not acquired as a discrete image part.
Color

Color is an important part of photography. When we think of using color, we must consider the color bias of the medium that captures it. Film and digital sensors capture color in different ways. Film uses only a yellow filter to prevent blue light from affecting green- and red-sensitive emulsions. As discussed earlier, a digital sensor captures color through red, green, and blue filters. This difference, along with the algorithm used to process the digital image and the chemical dye generation process used to create color within film, creates entirely different spectral reactions.

Silver halide film requires more spectral energy for exposure than sensors. This leads to different interpretations of color. Digital sensors are far more sensitive to infrared energy than film, and sensors are noticeably less sensitive to blue and violet energy than film. Therefore, different color spaces are created for images captured with digital sensors and film.

Differences in the interpolation algorithms of image processors, as well as the actual colors in the filter arrays, determine the color bias that will be seen in the final output. Therefore, the color from a digital capture will vary from manufacturer to manufacturer. Even when an image is neutral balanced, different cameras will record color in dissimilar ways. Similarly, there is a color bias in film from different manufacturers and among film types from the same manufacturer. These differences provide photographers with a great deal of control in terms of color in the images they will make.

Because of the way film develops and generates color, there are potentials for color shifts because of reciprocity failure. This is the failure of various layers that generate color dye to adapt in the same way to very long exposures or effects from nonstandard development. All of these exposure and development conditions can cause crossover, which occurs when the intended relationships among the three dye-generating layers are shifted. Crossover can produce colors that were not originally captured.
Dynamic Range

Recall that dynamic range and exposure are not the same thing. We can think of dynamic range as a bucket for capturing light, and the way the bucket is filled is dependent on exposure. The bucket does not change in size, regardless of how fast or slow the light is poured into it.

Dynamic range describes the film or sensor’s ability to differentiate the amount of light and the light variation. Exposure controls how the light from the scene is captured by the system, where a histogram displays a representation of the light. An exposure can be increased to move the representation of light toward the right on the histogram, but this does not change the amount of light that is captured. The change in exposure only changes where the light is recorded within the dynamic range, and does not influence the number of variations that can be used to interpret the final image.

Because of the way film and chemical developing work, film captures a larger dynamic range than all but specialized sensors. For most photographers, film provides a larger simultaneously captured dynamic range. With controlled development some films can be manipulated to capture up to 18 stops of dynamic range, while human vision has a 20-stop range. It needs to be noted that transparency film has a very short dynamic range of only 5–6 stops. Most manufacturers of sensors for higher-level DSLRs say that their sensors are limited to 12–14 stops. This dynamic range includes very dark tones that may not be useful. Because of the reduced usefulness of the dark tones, think of the functional dynamic range as being less than the total dynamic range. To discover the functional dynamic range of your sensor, you will need to test it to find how many stops there are in the range between unacceptable noise and white clipping.

Digital cameras that have auto bracketing and burst exposures (rapidly making a series of exposures) can be used to capture scenes with expanded dynamic ranges. However, if there is motion in the scene, there will be an alignment problem within the image. With the ability to modify exposure latitude through processing, film provides simultaneous exposure up to its maximum dynamic range.
With the dynamic range of color films, you can get all the information you need to create a high-dynamic-range image without compromising the subject, in this case, the woman in the photograph. Standard HDRI can’t be done if the subject is moving, so unless she is a statue, hybrid photography might be the only way to get a properly exposed subject and background with this particular scene. Illustrations produced by Tim Meyer.

1. If we take a digital image and print it, the subject’s skin tone is properly exposed, but the background is blown out.

2. If we take the same image on film but scan the negative only once, we have the same problem.
3. If we scan the negative twice, once exposing for the subject’s skin tone and once exposing for the background illumination, we can create a hybrid image that looks balanced and includes the high dynamic range that was present in the scene. The final image doesn’t change the composition or force the subject to stay perfectly still between multiple images; rather, it combines the elements of the scene from the usable dynamic range of the film.
Workflow and Time

Workflow is best defined as the steps we take to make an image. This can be from when the camera is turned on to when we have viewable or printable images. In a film-based workflow, our first step is to choose the film, and in a digital workflow, we neutral balance the system, if we have time, or select an ISO and preset white balance.

When we photograph in a studio, color correction filtration or neutral balancing simplifies workflow. This is true for both film and digital capture. Within the studio digital capture may be tethered, providing more control in the workflow through the computer’s software.

However, neither neutral balance nor film choice are as simple or consistent when the photographic session is in a variable setting, such as a mixed light location or where action makes rapid angle changes. These variables affect the workflow and increase the effort later in the digital process.

Two steps are required to see captured images from negative film: process the film and create the prints. Other people will do this work unless you have your own processing equipment. This can be time consuming, but with digital systems the files can be viewed immediately without further processing.

Since the processing and printing of color film is done by somebody else, it’s not time consuming for photographers themselves to prepare, correct, and print the images. This means that although the workflow for a film-based photographic session has more steps, the photographers themselves do not spend more time on it; they delegate the responsibility for these operations to other individuals. Therefore, photographers can spend more time in photographic sessions rather than in post-processing. The decision to use film or digital capture becomes an issue of whether you wish to spend your time taking photographs or editing captured images.

Lens Issues

As discussed earlier in the book, digital sensors, unlike film, require the light to strike their surfaces in near perpendicular rays. This creates certain problems for some photographic applications. View cameras (usually large format) have the advantage of controlling perspective and depth of field with the movement of the lens in relation to the film plane. When these movements take place, the axis of the light being focused through the camera is changed from its perpendicular position to a different angle. With digital capture, as the angular change occurs, there is a loss of efficiency in the sensor.
Requirement for Electronic Systems

Last, a major difference between a film-based and a digital photographic system is the requirement to utilize a totally electronic system. Although many film-based cameras utilize batteries for metering and exposure control, older manual cameras are available that do not use batteries or electronics to control and make photographs.

This may seem to be a minor point, but it can have important impacts on several types of photography. When a photographer is away from electrical sources for an extended time, such as in a remote or wilderness area, there is an advantage to using equipment that does not require electrical interaction. Further, electrical systems, particularly batteries, have difficulties with temperature extremes. And although extremely cold temperatures cause other problems in photography, there can be more problems with a totally electronic-dependent system.

Choosing a Hybrid Approach

Understanding the basic differences between film and digital capture allows you to make a choice. There are many advantages to working in a digital environment, but there are times when digital photography can be a disadvantage.

The choice to use a hybrid approach to digital photography is based primarily on the application. You must consider several factors to decide if using film as the capture medium provides the needed flexibility or attributes that are not found in digital camera technologies. These factors include location considerations, optical needs, the light environment, and the workflow needed to obtain the required digital files.

When considering how the location might influence your decision to use a hybrid approach, perhaps the easiest selection criteria is the accessibility to electricity to recharge batteries or operate equipment. Therefore, outdoor photography that will occur over many days on location may be a prime candidate for hybrid photography.

If a view camera is to be used with camera movements to change the angle of the light striking the imaging plane, then film is a better capture medium than a sensor because film allows exposure at different angles and sensors lose efficiency when exposed by angular light. Therefore, film allows greater perspective and depth of field correction with view cameras.

Another prime consideration for using hybrid photography is when rapid changes occur, such as at a wedding. Particularly if the lighting moves quickly from one light quality (color bias) to another and if the subject moves in and out of various light situations, the use of a hybrid approach may facilitate good photography without undue pressure on the post-processing of digital images.
This is because film, with its greater latitude for exposure, provides the ability to rapidly acquire images with the proper exposure. With the large number of images that might be captured at a wedding and reception, you could have the negatives scanned and color balancing done at a photo lab. Although this would incur an added cost, there is a great savings in the amount of time that would be needed to process digital files.

Sometimes there is both a large dynamic range and motion within a scene. This can easily occur when a portrait is made and the subject is in a shaded area with bright sun in the background. The dynamic range in this setting will often exceed the capabilities of a sensor, but not negative film. In this situation the photograph can be made with film, and a film scanner can be used to capture both the highlight and shadow details.

One other consideration in choosing a hybrid approach is if you like the look, feel, and working parameters of film. Certain qualities of film cannot be duplicated directly or easily with digital photography. These include, but are not limited to, the look of a specific film grain structure, color palettes that are particular to certain films, perspective control and other lens movements that are not available with digital capture, and non-standard processing choices. For these reasons you may wish to use film and migrate the negatives to digital files for printing, archiving, or other uses.
How Digital Images are Created

Fly Away © by Claudio Napolitano. Courtesy of the artist.
Capture to Visible

It takes two steps to create a photographic image. The first step is to capture the light energies from the scene. Since the beginning of photography in 1827, the second step has been to process the photograph to make the image visible.

The first practical photographic process, the daguerreotype, used sensitized silver-coated plates to capture the image; after the image was captured, the plates were fumed with mercury to create a direct positive image. At the same time, the calotype used a salted paper imaging surface that was processed to make a permanent paper negative. As photography matured through the 1850s, various photographic methods were developed, which eventually settled into a silver-halide-based emulsion process that utilized chemistry to process the latent image and make it visible. Regardless of the capture technology, in photography there has always been a requirement to process the captured light to make it visible.

Throughout the 20th century, the most common process was to utilize developing solutions to reduce the exposed silver halide emulsion into metallic silver negatives or dye-coupled images. If a negative was created, it could then be printed to reveal the captured scene. With color photography either a negative or direct positive was created by chemically processing the film; dyes in the emulsion formed the image. A major limitation of film that was used throughout the 20th century was reciprocity failure. This caused both very long and very short exposures to be captured inaccurately, which required adjustments in processing to create the desired image. In some situations compensations were made in exposure and processing to counteract reciprocity failure and extend the capabilities of the film. Some reciprocity failure created color shifts that could not be corrected.

Although these physical and chemical processes are still used today, digital photography has reduced their use to specialized projects. The process of capturing, processing, and outputting pictures now involves solid-state electronics instead of chemicals, but the digital process still requires a series of steps to create a usable image. The flow of activities for making a digital photograph requires conception of the image, capture, processing, and output.
© by Harald Mante. Courtesy of the artist.
As we begin to describe the specifics of digital photography, we need to realize that the theoretical basis of photography is very similar for film and digital capture. Light is analog, and it is captured by both film and sensors as analog energy. Further, energy in the form of photons is captured and held by both film and sensors in very similar electrophysical ways. Photons are gathered by film, and the electrons are held within the silver-halide crystals, creating a latent image that is made permanent through chemical processing. In digital capture, the movement of electrons/photons creates the image parts held in the silicon of the sensor that will be electronically processed into an image.

The Digital Photographic Sequence

A digital sensor must be prepared to accept light energy as an electronic signal. We can think of this preparation as leveling a sandbox so that pressing down with your hand will leave an imprint. With the digital sensor we need to make sure that the electronic values of all pixels are exactly the same. To level the values on the sensor, a low-level positive charge is uniformly applied to the gates of all the photo sites. This gives the photo sites a uniform charge so
that when the light energy (the photons) is focused on the imaging surface, variations in the light energy charges the values on the corresponding areas of the sensor to match the energy in the scene. This process creates an analog representation of the light emanating from the scene.

## Charging the Sensor

A low-level positive charge is applied to the sensor because opposite electrical charges attract each other. When the sensor has a positive charge, it will attract and hold light energy that acts as a negative charge.

Photons themselves are subatomic electrometric spectral particles that have no mass or charge. In photography we interpret photons as light, but they are also packets of energy for radio transmissions and other parts of the electromagnetic spectrum. The word *photon* is derived from the words *photo* and *electron*. The photons travel as particles or waves of electrons and function as negative charges (as electrons) when they are captured.

When the low-level positive charge is applied to the sensor, it does two things. First, it neutralizes any negative charge that might be found in the sensor structure. Second, it has a smoothing effect. This smoothing happens when a positive charge migrates from the gate, where it is applied to each photo site, to the potential well. Since the potential well has a maximum capacity, any excess charge that passes to it will be grounded and shunted away from the electronic system. This means that every photo site's charge is exactly the same. Therefore, when the photons arrive at the sensor, there will be an equal positive charge across the sensor.

## Exposure

At this point the light reaches the surface of the sensor, which is when the exposure occurs. The photons are attracted to the sensor because they function as negative charges that are attracted to the positive charge that is held in the sensor’s potential well. When the photons pass through the gate of the photo site, a dopant (a substance that increases electrical and optical properties) helps the potential well to pull the photons toward it. The number of photons captured by the potential well dictates the exposure. It is a misconception that sensors capture light in a digital form. The light in the scene and the original capture is analog.
These images demonstrate how light is captured in a photo site.

1. A positive charge is applied to the sensor.

2. The positive charge moves to the potential well.

3. When the shutter opens, the photons, which are acting as electrons, pass through the gate and are attracted toward the positively charged potential well.

4. The photons are captured in the potential well. They are recorded as the number of electrons that reduced the applied positive charge. This difference is then interpreted as the intensity and color of light, depending on which filter in the color array is dedicated to that photo site.
Chapter 13
How Digital Images are Created

Moving the Charge from the Sensor

After the light energy has been captured in the potential well, the photons become electrons and must be moved from the potential well to either be measured or stored for a short time. The architecture for short-term storage with CCDs will be discussed later, but for now we will consider how the charge is handled and measured as if the captured energies go directly to processing.

The charges on the sensor are very small, so the signal strength is amplified in many systems. Because CMOS sensors contain transistors, amplification can be accomplished on these sensors. Amplification for a CCD sensor will occur after the signals exit the sensor. This amplification is known as gain, which reduces the amount of light needed to create a meaningful signal. Depending on the amount of amplification, the sensitivity (ISO) of the sensor is raised. Gain is a major cause of increased noise when the ISO is increased because all parts of the signal (both the image and any noise in the system) are increased by the amplification. When amplification occurs after the image moves through the on-camera processor, the noise is not increased. This will be discussed later.

The easiest way to think of how the charges are removed from the sensor is to visualize each column of photo sites as a tube and the charges as balls that fit neatly into the tube so they stack on top of one another. If the tube is vertical and we remove the bottom ball, all the balls above it will move down one space. If we place the ball we just removed in an angled slot, the ball will roll to the end of the slot. If we then take another ball from the bottom of the tube and place it in the slot, it will roll down to the first ball, and all the other balls in the tube will descend one more space. As this process continues, we will end up with all the balls out of the tube and aligned in the slot in the same order as they were in the tube. This process is the coupling that is referred to in the term charge-coupled device (CCD).
This metaphor describes two parts of the process in which captured light becomes a digital image. First, the balls represent packets of charges that migrate from one photo site to the next. Effectively, the first charge from a column of photo sites is removed, and the successive charges from the other photo sites migrate to the photo site that was just vacated. Each charge acts as a packet of electrons. The slot in the metaphor represents the second part of the processing, which is called the shift register. This keeps the electron packets in order for future processing, and it changes the electron packets into voltage that can be used later.

This illustration demonstrates the way accumulated charges are moved from a single column of the CCD. Each tube shows a different iteration of how charges are removed from one column. The captured charges on the CCD are drawn off in a chain, with the information staying in order so it can be correctly read by the ADC and saved as a digital file.

Changing the Image to Digital

After the electrons are off the sensor and converted to voltage, which is analog, the voltage is converted into a digital form. This happens in the analog-to-digital converter (ADC). In the ADC the voltage of each packet of electrons relating to the photo sites is measured and converted into a binary number. The higher the voltage, the higher the digital number. This process is known as quantization.

An ADC has a maximum ability to quantize. This is the true dynamic range of the system. For example, if the ADC can quantize to 10 bits \(2^{10} = 1,024\), the system will record 10 stops, or 0–1,024 luminance intensity levels. Although the scene may have more intensity levels than this, the system can record only 1,024 levels. Light above or below the selected 10-stop range will be clipped
or cut off. When the scene’s dynamic range is less than the capacity of the ADC, all of the light values from the scene will have a corresponding digital number, if the scene is exposed correctly.

For all of these steps to happen accurately, there must be a timing device that tells the sensor and the supporting electronics when to function. This is known as a clock driver. The clock driver synchronizes all activities of the sensor, from the time the shutter is activated to the point where the digital image moves to the ADC.

**Image Processing**

After the signal moves through the ADC, it is a digital raw image. This is not the same thing as a RAW file. The image now represents the light as it was recorded by the sensor and after it was mathematically processed into digital numbers. As the numbers are generated by the ADC, they are arranged in a grid, raster, array, or bitmap. This is the final shape of the image, in rows and columns of light intensities.

If the image stays in a raw form, the three color channels (red, green, and blue) can be exported from the processor into a proprietary RAW format. The file structure can be thought of as a stack of three overlapping patterns of red, green, and blue pixels. However, for the preview that will be displayed on the camera’s LCD, or if the image will be exported from the camera as a viewable file format, the image will need to be interpolated.

At this point the digital image travels to the in-camera processor as a mosaic of three overlapping color channels that contain all of the illumination and color information for the image. The processor then performs the critical function of demosaicing the captured file structure and interpolating the color.

**Interpolation of Color**

None of the overlapping color channels are completely exposed; rather, they are exposed in the matrix pattern described by the Bayer array (RGRGRG, GBGGBG), as discussed in the chapter about sensors. At most, only one-half of the pixels in the green channel and one-quarter of the red or blue pixels in their respective channels actually have numbers that correspond to the exposure. When the three overlapping color channels are compressed into a flattened image during raw conversion, either in the camera or in computer software, the true nature of the mosaic becomes apparent.
Bored at Work © by Jesse Strigler. Courtesy of the artist.
The term *interpolation* means to establish or explain the meaning or significance of something from other data. The purpose of interpolation is to calculate the RGB values that will represent the color and tone of the light that was captured at each pixel in the image. Interpolation estimates a pixel’s value from data that is derived from other pixels.

The easiest method of interpolation to understand is called bilinear rendering, or *nearest neighbor* interpolation. This method uses the intensity and color information from the adjacent pixels to interpolate any pixel’s color and value. It is by no means the only way color can be interpolated for an image. Another common rendering technique is bicubic. This method uses data from many pixels at every angle from the pixel that is being interpolated, with increased weighting applied to data from pixels that are in closer proximity. A spline algorithm, which uses a graphical mapping process, creates a value for the pixel so it fits into a smooth curve. Finally, a Laplacian matrix uses a mathematic estimation of the light value at any given pixel based on probabilities of the color.

Regardless of the method used to interpolate the colors in the image, some of each color will be seen in each pixel that is interpolated, with the notable exception of pure black, which is comprised of 0 red, 0 green, and 0 blue, as black is the absence of all color. In 24-bit color the hue of the pixel is biased by the color that has the largest number, and the luminosity of the pixel is made up of the other two color numbers. For example, a color number might be 220 red, 120 green, and 100 blue (220, 120, 100). The largest number (red) tells us that the color is in the red area of the color space, with the addition of 120 green and 100 blue to bring the luminosity to a middle tonal value. The higher the sum of the three color numbers, the more luminosity is present in the color.

There are two other concerns that the system needs to address during interpolation. First, there is the question of how the color of the pixels at the edges of the sensor can be interpolated when they are not surrounded by other pixels with light values. In this situation the processor reduces the size of the pixel array that forms the image to ensure that there are enough pixels to capture light beyond the image boundary and assure proper interpolation. The processor doesn’t use the pixels around the edges for image capture; it uses them only for interpolation. Second, the processor needs to be able to establish the base-level black for the tones that will be interpreted in the image. This is accomplished by having photo sites around the edges of the sensor that are not allowed to accept light during exposure but are functional in all other ways. These two concerns are reflected in the way sensors are defined. Usually a sensor’s total number of pixels is noted, with another smaller number given as the effective number of pixels.
Regardless of the interpolation method, the image becomes a flattened mosaic with all the pixels and their respective color values. The end result of the demosaicing and interpolation process is a set of three numbers that represent the color and value of each pixel. The difference between the ADC and the interpolation process is that the ADC is limited in bit depth, and the interpolation process can choose the bit depth that the file will use. For example, even if the ADC created 1,024 values (10 stops), the interpolation process can produce a file that has 24-bit color (8 bits per channel, or 256 values per channel) or 48-bit color (16 bits per channel, or 16,384 values per channel). With a 10-megapixel sensor, a raw file at 24 bits (8 bits per channel) has three layers that contain 10 Mb of data for each channel. An interpolated file from the same sensor will create a total of 30 Mb of data. When the sensor captures less dynamic range than the bits per channel (for example, if the sensor captures 14 bits per channel and the processor creates a file with 16 bits per channel), the smaller dynamic range is placed within the larger format even though it contains a smaller amount of captured data.
Although the Bayer array is the most common color filtering method, there are other ways to input color to the sensor, both in terms of the filter colors themselves and the way the light is captured by the sensor. One example is the red, green, blue, emerald (RGBE) color filter array that expands the green spectral area for the sensor. Another example is the cyan, magenta, yellow (CMY) color filter array that doubles the number of photo sites that receive yellow filtration. This means that 50% of the sensor surface is affected by yellow spectral energies, and each half of the remaining surface is filtered with cyan and magenta, respectively. This filtration idea arises from concerns that with RGB filtration in the common Bayer array, each photo site is sensitive to only one-third of the color spectrum. By using complementary colors (CMY), each photo site is affected by two of the three primary colors.

Other Color Interpolation Designs

There are two other sensor designs that change how the color of light is captured. The first is a buried photo site design that utilizes the ability of longer wavelengths of light to penetrate deeper into silicon, allowing a silicon wafer to have layers that are sensitive to different parts of the color spectrum. This design, which was developed by Foveon, includes a stack of three layers, with blue on top, green in the middle, and red on the bottom. This sensor design eliminates certain color artifacts, reduces the need for high levels of color interpolation, and eliminates image problems like moiré pattern, which is caused by the rectilinear structure of the sensor.

Photo sites can be any shape or configuration that meets the needs of the manufacturer. Most manufacturers produce rectangular photo sites. Fujifilm uses hexagonal (six-sided) photo sites in its FinePix sensor. There are also multiple-sized or combination photo site arrays. These designs have different amounts of coverage on the sensor’s surface, which is called the fill factor. The shape or alignment of the photo sites can affect the fill factor, as can other considerations, such as whether the sensor is a CCD or CMOS and the need for circuitry to move charges around the sensor.

The other design type, a trilinear sensor, is found in scanning cameras and camera backs. The sensor is made up of three parallel lines (or multiples of three) of red, blue, or green photo sites. With this design stepper motors are used to move the three lines of photo sites through the light pattern that is projected by the camera lens, or a slit camera assembly passes a light pattern over a stationary trilinear array.

Foveon sensors and trilinear sensors share an advantage with tricolor photography. Instead of having to interpolate color based on neighboring photo sites, all of the color is captured for each pixel at its corresponding photo site.
As you can see in this variety of approaches to capturing color and interpolation, the way individual cameras capture and process color can create different appearances. Testing the same camera types and brands will show variations in color, even for the same model. It is therefore important to establish your camera’s color profile and use it in post-processing to attain the colors you want.

© by J. Seeley. Courtesy of the artist.
Buffering

To allow a rapid sequence of photographs to be taken, the camera requires two processes: quickly writing the file from the image processing system and storing the file in short-term memory before it is transferred to the media card. This is known as buffering. Buffering can occur at one of three points during the processing of the image: right after the image has been captured, which is called preprocessing; after the image has initially been processed; or it can be applied prior to and after processing, which is known as smart buffering.

The advantage of buffer preprocessing is that the frames per second (fps) burst can be increased. However, after the buffer is filled, the system cannot take further images. When buffering is done after processing, the capacity of the buffering is a function of the file type that is being saved. JPEGs are smaller than RAW files and thus increase the buffering capacity, but the burst speed (fps) is based on the throughput of the processing.

Because smart buffering holds both preprocessed files and those that are processed after initial capture, the write speed of the storage media does not create congestion in the flow of files. Also, since the files can be processed into compressed files, space can be freed up in the buffer as the files are written to the storage media, allowing another burst of exposures before the previous images are completely processed.

Most buffering is accomplished with random access memory (RAM). However, some buffering is a function of the sensor design. This is known as the architecture of the sensor, and it applies only to CCD sensors. There are three types of architecture that are commonly used with CCDs. First is a frame transfer design. In this architecture the sensor is manufactured with a duplicate structure that cannot capture photons. There is a direct connection between the active sensor and its duplicate that allows the captured photons to be transferred to the duplicate unit before processing. A second architecture is called interline transfer. It contains inactive photo sites that are parallel to the columns of active photo sites. Once again, the inactive photo sites do not capture photons; they are used to move the captured photons quickly. A third architecture is a combination of frame transfer and interline transfer designs, which is called a frame-interline transfer.

These architectures, along with buffers, allow cameras to take photographs in bursts. The architectures are faster than buffers, although architectures are more limited in the number of images in a burst. However, buffers can be exceptionally quick depending on the write speed of the solid-state memory to which the images are transferred.
Expansion of Dynamic Range

If digital sensors are to rival film in their capture potentials, their dynamic range must be expanded. There are several ways to increase a sensor’s dynamic range; however, most of these approaches adversely affect the lower end of the dynamic range. The most common way to expand the dynamic range is through noise reduction since the dynamic range is defined as the difference between the noise level and the maximum capture of photons.

Noise can be reduced in three ways. First, software can be used to eliminate excess noise. The camera’s onboard processor analyzes the image, then it modifies the dark areas to reduce the noise. The next method is cooling the sensor with fans or refrigeration to reduce noise. Cooling is most common with tethered camera systems. Last, dark noise subtraction can be used to reduce noise from long exposures. This is accomplished by creating a dark frame (an unexposed frame) that is the same length as the image exposure. The dark frame is then used to subtract (or cancel) the noise from the image.

Another way to expand the sensor’s dynamic range is through the manufacture of multiple sensitive photo sites. This approach is used in the Fujifilm Rs sensor, which has two photo sites at each pixel location. One photo site is a standard size, and one is smaller. Both photo sites are covered by the same filter in the array so they will record the same spectral area. Because of the difference in size, the ability of the photo sites to record varying light energies is affected. The smaller photo sites record bright, higher-energy light, and the larger photo sites are more sensitive to dark, lower-energy light. The camera couples the captured ranges from both photo sites to create a single output with an expanded dynamic range.

Last, several scanning cameras have specialized sensors or other scanning technologies that are capable of HDRI. The sensors in these scanning cameras can either use multiple sensitivity photo sites or change the gain on the sensors to create various intensity layers that are then merged to create one image. With HDRI the commonly used file is 32 bits per channel.
Glossary
18% gray
The midpoint of the light intensity scale between absolute black and absolute white. This middle tonality is used to determine the proper exposure in all metering methods.

active feedback
The LCD screen on the back of the digital camera provides immediate feedback upon image capture. The active feedback can contain the histogram, clipping information, or file data, or it can be varied based on the camera settings to display the desired information. This information is considered active because it can be reviewed at the time of image capture.

active post-capture
This includes any actions that you would like to perform on your images as soon as you capture them. It requires appropriate operating systems, software, and workflow practices to take your images from your camera to final use.

adaptive histogram
A histogram that is seen on the camera's preview to provide active feedback.

adjustment layers
Layers that are specifically designed to apply curves, levels, or other global adjustments as a separate layer without modifying the actual pixel data beneath. These allow you to return to an adjustment and modify or preview the changes nondestructively.

aliasing
A phenomenon in digital photography where light energy is not accurately recorded on a digital sensor, resulting in distortion or artifacts in the final image.

analog-to-digital converter (ADC)
The electronic component of the sensor that relays information from the potential well to the storage media in digital terms using quantizing.

angle of view
The area of the scene in front of the camera that is imaged by the lens.

aperture
The opening in the lens that lets light into the camera.
arc light
A light source that creates an arc of light between two electrodes in a gas-filled chamber.

archiving
The act of digitally storing image file data in such a way that it can be recovered for use at a later date.

ASMP (American Society of Media Photographers)
A group of professional photographers working with the Library of Congress to create a best practices workflow for digital photography that will ensure that digital image files will be available for retrieval in the future.

average value metering
A form of light metering that reads the entire scene and finds a mathematical average and treats it as middle gray (18% gray) to create the exposure value.

backup
The act of storing multiple copies of data files in multiple formats and in multiple locations to protect the image data in case of catastrophic failure of any single device or media.

baked in
The image data that is preset within the operating system of the camera and appears in the metadata.

banding
When image data in the darker tones are stretched in post-production to cover a greater dynamic range, the resulting image can contain blocked lines of stepped color rather than a fluid transition of tonality.

basic daylight exposure (BDE)
A hard-and-fast rule regarding exposure values on a normal, sunny day anywhere in the world. The equation is an exposure of f/16 at a shutter speed of 1/ISO.

batch processing
A method of applying an action or set of actions to a group of files at one time.
Bayer array
A filter array used in some digital camera sensors that determines which color of light the photo site will receive and record. The array is on top of the photo sites. There are two green filters for each set of one red and one blue filter so that any square of four photo sites will contain two green, one red, and one blue filter.

bicubic
A form of interpolation that uses data from a range of pixels that are in close proximity to the pixel being interpolated to determine the pixel value. Increased weight is given to pixels that are closer to the pixel being interpolated.

binary
A base-two number system consisting of 1s and 0s. This system is used by computer systems to encode data.

bit
In a binary system, a bit is the smallest unit of data, with a value of 1 or 0.

bit depth
A quantification of the levels of distinct color available in an imaging device.

bit order
An indication of the reading order of a set of bit information in a byte. This information is embedded in the file header and indicates to the program opening the file whether the bit information should be read in ascending or descending order.

blooming
A phenomenon caused by overexposure where extra photons from one potential well migrate to a neighboring potential well, altering the exposure of the second potential well and distorting the image.

bokeh
The areas of a photograph that are not in focus, resulting in blur outside the depth of field.

bracketing
Making several exposures of the same scene while varying the exposure settings to achieve brighter and darker versions of the scene.
brightness
The intensity of the image or the apparent reflectance of a tone or color within the image.

buffering
A system built into the digital photo sensor that allows for short-term storage of information between the time when the image is captured and when the file is written to the removable media.

bulk keywords
Keywords that can be applied to an entire session at one time, such as copyright statements, date, session title, and photographer.

burning
Locally darkening a specific area of an image.

byte
A unit of information consisting of a certain number of ordered bits. They can be represented as 8 bit, 16 bit, 32 bit, etc.

calotype
One of the first photographic processes. It was invented by William Henry Fox Talbot in 1841. The process used high-quality paper that was sensitized with silver iodide. This paper could then be placed into a camera and exposed, either while still damp or when completely dry, to create a latent image that could be revealed with a gallo-nitrate solution and then fixed with potassium bromide. This resulted in a paper negative.

camera back
Some types of cameras have interchangeable backs that allow for different types of media capture, such as Polaroid, film, or a digital imaging surface. These cameras are typically medium or large format, and the same camera body can be used with any of the available camera backs.

camera obscura
Translated from Latin, this means darkened room, but the term has been applied to any sort of dark space, such as a room or a box, that can utilize controlled light to view something outside the space.
**capture thresholds**
The capture threshold for a digital camera system extends from the lowest amount of photon energy that will register on the sensor to the highest amount of photon energy that the sensor can hold. This is also the effective dynamic range of the sensor.

**card reader**
An external device that can accept the storage media of the camera and allow it to be read by a computer as an external drive.

**carte de visite**
In the 19th century, a small photograph printed on thin paper and backed by thicker paper stock that could easily be transported and stored for viewing. They were commonly used as greeting cards or calling cards.

**CCD (charge-coupled-device)**
An electronic system utilizing photo-etched silicon wells to electronically capture and record photons, or light activity, as perceived through an optical device.

**channel**
The color information in a digital file is separated into channels that represent the individual parts, such as the RGB channel structure (red, green, blue).

**chimping**
Constantly referring to the LCD preview after each shot rather than trusting the photographic process and personal experience. This can lead to lost moments and drain the camera battery much faster than having the LCD screen turned off during a session.

**clipping points**
Clipping occurs when the light energy hitting the sensor either exceeds or falls short of the capture thresholds established by the manufacturer. If the image data falls outside of the clipping points, it will not register as detail in the image.

**clock driver**
The device within the camera that coordinates the charging of the sensor, the shuttering mechanism, the exposure of the sensor, and the release of image information from the ADC.
CMOS (complementary metal-oxide semiconductor)
An electronic sensor utilizing photo-etched silicon photodiodes and transistor gates to capture and transfer photons, or light activity, as perceived through an optical device. A CMOS sensor is capable of higher-level functions than a CCD, which more directly communicates information to the control unit.

collimator
A lens element that takes the light gathered in the angle of view and bends it to create parallel light rays that strike the image plane.

color bias
A shift in light that affects the whole scene and creates a color cast in the image if it is not corrected.

color profile
The information that is necessary for imaging systems to communicate and translate color. Color profiles can be found in capture software (within cameras and scanners), working spaces, and output devices (monitors, printers, and projectors).

color shifts
Color shifts occur when the light of the scene is not registered in the sensor correctly, such as with overexposure or steeply angled light hitting the sensor. When this occurs, the sensor can bias toward a specific channel and give a color cast to certain areas of the image that didn’t have a color cast in the scene.

color space
A specific set of colors that relate to data points expressed in a collection of numbers (such as the three-number RGB or four-number CMYK systems).

color temperature
Specific quantifications for certain colors of light, such as tungsten or daylight.

compaction
The process of lowering the dynamic range of a negative by underdeveloping the film to compact the highlights.
compound lens
A series of optical components (various concave and convex lens components and mechanics) that focus the light from the subject in the most effective way possible to allow for even illumination and a consistent plane of focus on the imaging surface.

compression
A method of encoding a large collection of bits (a file) and using as few bits as possible to represent the same information. The compression of image information can be lossless, lossy, or visually lossless, which will determine the final file size as well as the quality of the decompressed image.

compression ratio
The amount of compression that can be applied to a file based on the compression used.

concave
A term for an inward-curving or hollowed surface.

consumer camera
A camera intended for average users that is low cost and easy to use, often with programmable modes as opposed to manual operation.

contrast
The difference in darkness between one tone and another.

contrast control slider
A control that can be adjusted to globally increase or decrease the difference in darkness among the tones in an image.

control unit
The computer portion of a digital camera that controls all of its electronic functions, such as exposure, automatic focus, shutter, and preview.

convex
A term for an outward-curving or bowed surface.

crossover
A shift in the color relationship among the three dyed layers of color film, causing an inaccurate reproduction of the originally captured scene.
curve
A graphic representation of the relationship between the base image and global corrections made to the overall image or each individual color channel. Curves are initially represented as a linear slope between 0, 0, 0 and 255, 255, 255.

curves adjustment
An alteration to the initial curve of the image that can be used to globally adjust color or contrast in an image.

daguerreotype
An early photographic process created by Nicéphore Niépce and Louis Daguerre. A copper plate was sensitized by iodine vapor and silver and then exposed to light. A negative image of the scene formed, but due to the nature of the mirrored surface of the metal, the resulting image appeared to the eye as a positive, monochromatic image.

darken
A photo editing software tool that blends two layers, with the information in the top layer darkening the information below it.

demosaic
The interpolation of color that interprets the arrayed data points of the mosaic.

depth of field
The range in front of and behind the area of sharp focus that will appear in focus on the image plane.

desaturate
To lessen or remove the color information from an image, leaving the image either more or completely grayscale.

dialog box
A user interface in some software programs that prompts you to enter information or respond to a question.

diffraction
The phenomenon that occurs when light bends around corners or through small openings.
diffusion
A mechanism by which light is scattered in many different directions through a translucent material, creating a soft, even light on the subject or as part of an incident meter. (On an incident meter, the diffusing material is an evenly coated, translucent plastic dome that is placed over the sensor.)

digital display framing (DDF)
Consumer cameras that primarily use a viewing screen on the back of the camera to evaluate the cropping of the image. See point-and-shoot camera.

dispersion
The phenomenon when light hits a translucent material that scatters the light into many different directions, creating a less directional light source.

DNG (digital negative)
An open-source file format that is not specific to any one manufacturer and can be used for nondestructive archiving to preserve digital images for posterity, prevent the need to upgrade software to access files, and work among various programs for ease of workflow.

dodging
Locally lightening a specific area of an image.

dopant
A substance within a photo site that assists the photons that are attracted to the potential well by increasing electrical conductivity in the photo site.

DSLR (digital single lens reflex)
A digital camera in which the imaging surface and the viewfinder share the optics of the lens, ensuring identical focus and capture of what is seen through the viewfinder.

dual internal lenses (DIL)
Lenses created for digital photography that are specifically designed to concentrate the light energy entering the system onto the sensor.
**dynamic range**
The range in stops that is perceptible to various technologies. Dynamic range refers to the difference in stops that will be contained within a printable range from black with detail to white with detail. Stops beyond the limits of the capture medium (blown highlights and blocked shadows) are not considered part of the dynamic range.

**edge sharpening**
A method of sharpening where the difference between two adjacent tones is slightly increased for the highlight area and slightly decreased for the shadow area at the edge where the two tones meet.

**effective focal length**
The desired focal length of a lens that is designed to work with the necessary elements of the camera, as opposed to a simple short, normal, or long lens focal length. The effective focal length approximates a simple lens. See retro focus lens.

**effective pixel number**
The number of pixels that will be used to create the final image, as opposed to the full number of photo sites on the sensor.

**electromagnetic spectrum**
The range of frequencies of all types of radiation. Within that spectrum lies the visible light spectrum that the human eye can perceive.

**electronic shuttering systems**
The use of electronics in a digital camera to trigger exposure rather than using a conventional bladed shutter in the lens. There are three types of electronic shuttering systems: frame transfer architecture, global shutters, and rolling shutters.

**emulsion**
A gelatin mixture composed of light-sensitive materials suspended on a type of substrate, usually either paper, glass, or film.

**equivalent exposures**
Certain combinations of shutter speed, aperture, and ISO that result in the same exposure of the scene but vary in stop action, depth of field, or noise ratio in the final image. After a meter reading is taken, that reading can be adjusted to maximize or minimize the desired effects by using equivalent exposures.
EXIF (exchangeable image file format)
A type of sidecar file that accompanies some RAW file formats and holds the file’s metadata.

exposure
The act of allowing light to interact with the photo sites and recording the amount of light that is reflected from the scene.

exposure index (EI)
A more accurate determination of the sensitivity of a digital sensor as determined by the user, specific to a certain meter and camera system. After the EI is determined for a system, it takes the place of the manufacturer’s ISO rating.

external drive
A memory drive for a computer that is stored outside of the computer and connected to the computer with a cable that usually has a USB connection. External drives are valuable for storing backup image files because they will not be affected if the computer system crashes. They can also be easily transported and stored.

f-number
Numbers that pertain to the camera’s aperture size, or f-stops.

f-stops
The specific aperture positions available within the lens, where each subsequent stop doubles the amount of light entering through the aperture. For example, f/4 allows twice the amount of light into the camera as f/5.6.

file extension
The suffix attached to all digital files that indicates the encoding logic and format of the file. This communicates how the file will be read and indicates the type of information that the file might contain. Some examples of file extensions are .jpg, .tif, and .png.

file format
The way that binary data is encoded for storage on a computer system. The file format, followed by a specific file extension, allows computer programs to store and retrieve data based on specific criteria.
file name
The titling mechanism preceding the file extension. This information can be chosen by the user, but it must be unique for each file to avoid confusion or loss of data. Certain characters, such as spaces, slashes, or periods, should not be used in the file name to ensure that it can be appropriately saved and retrieved by the computer.

fill factor
The percentage of the silicon detector surface (of both CMOS and CCD sensors) that is capable of recording light.

fill light control
A control that works with the RAW file data to stretch the darkest tones in the image and compress the lightest tones.

film plane
A traditional term for the imaging surface.

film speed
A standardized valuation of the sensitivity of film to light. The lower the number, the slower the reaction to light. The higher the number, the faster the reaction. “Film speed” is a colloquial expression for ISO, though it can be interchanged with sensor speed.

filter
A translucent material that is placed in the path of light entering the sensor that transmits only certain wavelengths of light and absorbs the rest.

filter array
A specific orientation of color filters located over individual photo sites to enable accurate color photography by ensuring that the sensor reacts to all light at each photo site.

firmware
The computer elements within the camera that dictate its operation. Firmware can be updated with downloads or plug-ins without modifying the electronics of the camera.

fixed focal length lens
A lens that has one designated focal length and cannot shift to other focal lengths (as opposed to a zoom lens).
**flash memory**

The most common type of nonvolatile technology used for the storage of digital information, including memory cards and flash drives that can be removed from digital cameras.

**flatten**

A function that takes a multilayered image and creates a single layer with all of the visible information. It discards any information from the multilayered image that was not visible.

**focal length**

The designation of an optical system that determines how much the light rays entering the system will be bent. A long focal length refers to light rays that are not greatly bent, resulting in a telephoto effect that translates a small area of the scene; a short focal length refers to light rays that are widely bent, resulting in a wide-angle view that captures a greater portion of the scene.

**focal plane shutter**

A set of blades or a curtain located directly in front of the focal plane.

**frame–interline transfer**

A specific sensor design that allows for buffering of image data with a combination of frame transfer and interline transfer technologies.

**frame transfer design**

A buffering design within a sensor that has two layers with the same architecture. The entire image on the upper layer is transferred at one time to the lower level, which is not sensitive to light.

**frame transfer electronic shutter**

Architecture within DSLRs that is used for buffering the image. The image information is dropped to channels beneath the sensor in specified increments of time, effectively blocking those signals from further exposure.

**frames per second (fps)**

The number of frames that can be processed in the camera per second.

**gain**

Amplification of small charges in the sensor signal.
gamut
The range of color that can be produced within a color space (capture, work space, or output).

gate
A transparent and electrically conductive portion of a photo site that can be charged positively or negatively to attract or repel photons. A positively charged gate attracts photons, which act as electrons, and can be used as a base value to calculate how much light has entered the photo site.

global corrections
Adjustments made to the whole image at one time, such as color, contrast, or brightness.

global electronic shutter
A device that uses the electric current provided to the sensor to turn on and turn off the sensor’s light sensitivity recording capability.

gray card
A specifically manufactured piece of plastic or cardboard that is painted or dyed to be an even, accurate representation of 18% middle gray. A gray card can be used for substitution metering and for white balance in digital cameras.

gray scale
A black-and-white, monochromatic image with no color information. It uses shades of gray to represent tonal variance.

header
A set of instructions in a digital file that instructs a computer regarding how the file can be opened, read, and interpreted.

heliograph
The first photographic process to use light-sensitive material that could be fixed in place after exposure. It was created by Nicéphore Niépce in 1826.

high dynamic range imaging (HDRI)
A process that takes advantage of multiple exposures of the same subject to increase the printable dynamic range of the subject by controlling the brightest highlights and revealing detail in the darkest shadows. All component images are then stitched together in editing software to create a seamless, high-dynamic-range image.
**histogram**
A graphical representation of the image data captured in each channel of the image file. Each light intensity is represented with a rectangle indicating the percentage of light in the scene that was captured at that intensity during exposure. A histogram is a standard part of the active feedback system of a digital camera and can be used as an exposure aid.

**hot mirror**
A device that rests between the lens and sensor that is specifically designed to reflect the slower wavelengths of light to which the sensor is more sensitive (red and infrared).

**hyperfocal distance**
The maximum depth of field that can be achieved with any specific aperture size, from infinity to the closest possible point of focus.

**image buffer**
A function in more advanced cameras that allows for rapid image capture. It transfers information from the sensor to a secondary location to free up the sensor for the next image.

**image locations**
The functional recording location of light information on an emulsion or sensor.

**imaging surface**
The area of a camera that records the light entering the optical system. The imaging surface size is denoted as a physical size, not a resolution.

**import**
The act of bringing external data into a computer program.

**incandescent light bulb**
A continuous source light bulb used in standard home light fixtures before the advent of halogen bulbs. Special incandescent bulbs can be purchased for studio use that maintain a consistent light temperature of 3200°K.

**incident light**
The light falling onto the subject from the light source.

**indium tin oxide (ITO)**
The most common material used to create sensor gates that conduct an electrical charge.
instantaneous capture camera back
Like most common cameras, this back uses all pixels simultaneously to capture an image in an instant.

intensity
The brightness or amount of light available for exposure in the equation \( E = I \times t \times f(\text{ISO}) \).

interline transfer
A buffering technology that allows image data to transfer from the imaging surface to parallel sites that are not light sensitive, but they mimic the structure of the top layer of the sensor.

interpolated files
The way a digital file is constructed based on the data that is actually available and the final product that is desired. Interpolation constructs new data points based on a mathematical analysis of the existing data.

interpolation
The mathematical construction of color data taken from a series of filtered photo sites on the sensor. The photo sites are covered in a predetermined array, and a processor determines the valuation of a certain pixel in the image based on the information from each photo site.

IPTC (International Press Telecommunications Council)
An association of press agencies that create and maintain technical standards for the global exchange of data, encouraging improved communication of digital information.

IPTC Core
A schema of specific metadata that is individually added to a digital file to assist with efficient asset management.

iris shutter
See leaf shutter.

ISO
The standardized valuation of film or sensor speed as established by the International Organization for Standardization.

JPEG (Joint Photographic Experts Group)
A common file format used for digital files that uses adjustable lossy compression.
Kelvin temperature
The quantitative expression of color temperature, expressed in degrees Kelvin.

keyword
A specific designation given to a digital file to denote the content or attributes of that file, such as copyright information, date the image was made, session title, or any number of other specific categories determined by the photographer. A keyword can be applied to many files simultaneously with batch processing, or it can be applied to individual images. Keywords assist in searching for a specific set of images.

keywording
The act of adding keywords to image files.

L*a*b*
A color space that is split into three channels, where L* represents lightness, a* represents the red–green channel, and b* represents the blue–yellow channel.

Laplacian
A form of interpolation that uses the probabilities of color to mathematically determine an estimated light value of a pixel.

latent image
An image that forms on a light-sensitive material because of exposure. It is not visible until the image is processed.

law of reciprocity
The intensity of the light in the scene is directly proportional to the amount of time needed for correct exposure.

layers
Individual sets of information that can be stacked on top of one another to adjust or manipulate an image in stages. Any layer of a multilayered image can be edited independently of the other layers.

LCD
Liquid crystal display.

leaf shutter
A camera shutter that opens from the center of the lens outward, spiraling to the edges of the aperture and then back in to the center for the duration of the designated shutter speed.
**lens**

An optical device that utilizes a translucent material to transmit and reflect light in a specific way so as to converge or diverge the light as desired. A camera lens is generally a collection of different individual lenses, called a compound lens, that is used to converge light so it focuses on a designated focal plane.

**lens hood/lens shade**

A simple device that can attach to the end of the camera lens to protect it from extraneous light. The device reduces the amount of flare that reaches the focal plane.

**lens speed**

The rating of the maximum aperture of a lens. An f/1.4 lens is faster than an f/2 lens.

**levels**

A linear representation of the tonal range of an image that can be manipulated to manually place the black point, gray point, and white point of the image where desired.

**lighten**

A photo editing software tool that blends two layers, with the information in the top layer lightening the information below it.

**long-term storage**

An archive of images on CDs, DVDs, or external drives; alternatively, images can be archived as hard copy, high-resolution prints.

**lossless compression**

An image compression methodology that decompresses the image so it is identical to the original image.

**lossy compression**

An image compression methodology that is not designed to recreate the original image, but rather it loses information each time it is compressed, or saved and opened, based on the compression ratio.

**luminance**

The intensity of light coming from a subject, either through emission or reflection.

**luminosity**

A measurement of the brightness of light in a scene.
masking
A process of limiting certain information in a layer so it is not visible.

masks
Sets of information joined with layers that can reveal or hide specific adjustments in the layers to be applied to the image.

master files
Files that have been determined to be worthy of further work and are renamed and saved as high-quality reference files, with all appropriate corrections and modifications applied and layers intact.

megabyte (MB)
A unit of data that consists of 1,024 kilobytes.

megapixel
A common term associated with the area (number of pixels wide by number of pixels tall) of a camera sensor’s capture capability. One megapixel is equal to 1 million pixels.

merge
Collapsing two or more layers into one layer based on the visible data from the layers.

metadata
Information about a file that is embedded within that file or carried in a sidecar file, such as an XMP file. Metadata contains elements such as camera type, lens, date acquired, copyright, and so forth. Metadata can be customized in some professional systems or in some post-production software.

microfilters
An element of digital sensors that allows the sensor to capture color information. The microfilters within the sensor are arranged in a specific color pattern so that each photo site records appropriate color information.

microlenses
Tiny lenses positioned between the primary optical device (lens) and the sensor to help focus light from the non-light-sensitive areas of the sensor onto the sensitive ones. The purpose of microlenses is to increase the efficiency of the sensor.
middle gray
The exact middle tonality between black with detail and white with detail in a scene. This value is 18% gray.

migration
The process of converting image files to current standards. Migration is a way to ensure that, as new versions of existing software or new software is released, files that are stored under previous versions will be updated to the current standards. This will ensure longevity and availability of the image files.

moiré
An interference pattern created in a digital image due to undersampling.

naming convention
See naming protocol.

naming protocol
A titling logic that ensures unique file names for all digital image files and associated folders. The best naming protocols should include the date of the session as well as some indication of the nature of the shoot.

native file
The file that is captured by the imaging technology before it is interpolated or compressed by an ADC.

nearest neighbor interpolation
A form of interpolation that uses data gathered from the pixels immediately adjacent to the desired pixel site to determine the color value of that pixel.

negative
The resulting object when a light-sensitive material has been exposed to light, processed, and fixed onto a substrate of some kind. Negatives contain an inverse image of the scene and can be used to create multiple copies of a final image by exposing an additional light-sensitive material to light passing through the negative.

neutral balance
See white balance.
noise
The loss of additional positive charges in a photo site due to extraneous electrical charges, heat, or an increased ISO. Noise results in incorrectly recorded information from the sensor and is rendered in the final image as specks or dots that were not in the scene.

Nyquist limit
The lowest number of points that must be sampled to accurately record a detail in a digital environment. At least two photo sites must be engaged to record one photographic detail without distortion.

open source
A philosophy that simplifies the exchange of file information by making the code for the software available via licenses that allow for modification and improvement.

open standard
A royalty-free technology that is available for anyone to read, use, and implement.

optical infinity
The imaging of objects that are at a great distance from the lens so that the light rays hitting the lens are essentially parallel to the lens orientation, creating a sharply focused image on the focal plane when the lens is set to the infinity mark on the barrel.

optical track
The path through which light travels into an optical system to hit a specified imaging surface (from the scene, through the lens, through the dark chamber, and onto the imaging surface).

optimization
Applying specific controls or corrections to prepare images for a specific purpose, such as printing or use on a website.

output
The final iteration of a digital file that can be printed, projected, or used on a website.

overhead
The portion of the digital capture device that is covered by the infrastructure, or electronic connections, of the sensor.
parametric image editing (PIE)
A process of file editing that prevents the original data from being corrupted by the editing process. The changes made to the files are tracked as changes in the parameter settings rather than changing the pixels.

photo site
The portion of a digital sensor that is sensitive to light and records the light information for the digital image.

photons
The basic units of light that can be described as waves or particles, depending on the physical interaction. Photons are the light energy that interacts with the sensor in a digital camera to form an image.

photovoltaic
A type of metering system that uses a light-capturing device in which the captured energy is converted into a volt and can be read with a voltmeter.

pixel
A single data point (picture element) on a digital image that is made up of interpolated data collected from corresponding photo sites on the digital sensor.

pixel processing
An editing process that permanently changes the data in a pixel.

point-and-shoot camera
Small DDF cameras that may or may not have a viewfinder and almost always have an LCD viewing screen. These cameras get their name from their ease of use for amateur photographers. The cameras are supplied with specific program modes to aid in image capture.

point processes
Processes for image correction that adjust each point in an image based on global adjustments.

posterization
A phenomenon in digital photography where a smooth gradation of tonality is represented as distinct blocks of consistent color. This can be caused by in-camera errors, such as overexposure, or in post-production when the bit depth of an image is reduced.
potential well
   The portion of a sensor that is light sensitive. Potential wells are separated on the sensor surface into individual photo sites, or pixels.

power supply
   A required component of modern digital cameras is the power supply, which can range from standard batteries to proprietary rechargeable battery units. Every digital camera must have a power supply to function.

preview
   An image on the LCD screen that shows the approximate exposure, color, and cropping of the captured file.

previsualization
   Deciding how you want the final output of the image to look before you adjust the exposure and take the photograph.

prime lens
   A lens with a fixed focal length and angle of view.

prosumer camera
   Intermediate-level cameras with greater functionality than beginning-level cameras, but they are usually less expensive and do not have the advanced features of professional-level cameras.

PSD (Photoshop document)
   An Adobe proprietary file format that provides lossless compression.

quantization
   The process that converts the captured light energy on the sensor to a digital signal.

rangefinder camera
   A rangefinder camera is fitted with a focusing aid on top of the camera that assists the photographer in focusing on the subject. The image is not seen through the lens of the camera, but rather it is determined by the photographer based on the range from the subject to the camera.

RAW format
   A file that contains all of the information for a digital image as it was recorded in the system. RAW format files are usually proprietary to the company that manufactured the camera system.
raw image
A collection of data points from the sensor after the image has been processed through the ADC.

reciprocity
The inverse relationship between the controls for exposure—as one control goes up, another must go down. For example, when the aperture is widened the exposure time must be decreased. With film, this relationship fails at very short and long exposures times.

recovery control
A control that works with the RAW file data to stretch the lightest tones in the image and compress the darkest tones.

reflected light
A type of metering system that uses the light reflecting off the subject to determine a middle gray value and proper exposure.

reflection
A phenomenon when light bounces off a shiny surface, where the angle of incidence equals the angle of reflection.

reflex camera
A camera that allows the photographer to utilize the image plane optics for focusing and cropping the image with the use of a mirror between the optics and the imaging surface. The light from the lens is reflected from the mirror to the viewfinder.

reformat
The act of clearing all data and information from a storage device and resetting the device to accept the image format from the camera in which the device is inserted.

refraction
The phenomenon in which light bends in response to traveling at a non-perpendicular angle through substances with different densities, where the refractive index of the media dictates how the light waves travel.

removable storage media
Devices that store image information from the camera. These are referred to as memory cards, and they can be removed and replaced as needed. The data on the media can be downloaded onto a computer or other storage device, and the media can be reformatted and used again.
resistance
A type of metering system that uses light-sensitive materials to capture light and then determine the appropriate exposure based on the amount of electrical resistance present in the materials.

resolution
The level of information available in a capture or display device described in pixels.

retro focus lens
Lenses specifically designed to be used with the camera that allow for the internal camera body elements to move while also replicating a similar angle of view to a simple lens.

rolling electronic shutter/block shuttering
A shutter system that records light information in a linear scan across the sensor rather than exposing the entire sensor at one time. This can cause fast-moving subjects to distort and remain in sharp focus at the same time.

run the length compression
A type of compression that effectively reduces file size by compressing large rows of solid color into two bits of information: length and color.

saturation control
A control that locks down the white and black points and can be used to enhance color or remove color from the image.

scanning camera back
In this type of camera back, single rows of pixels are captured one at a time, scanning down the length of the image surface to record the image. These backs are best used with still subjects because any movement in the scene will record as distortion.

sensor
The light-sensitive component of a digital camera that takes the place of film as the imaging surface.

sharpening
A process of increasing the contrast of edges or details in an image to counteract the softness inherent in digital images.
**sharpness**
The detail contrast within the image that is perceived as crispness of focus.

**shift register**
The device within the sensor system that shifts the charges into voltages to be interpreted by the ADC and keeps all of the charge packets in order for processing.

**shutter speeds**
The speeds with which the shutter inside the camera can open and close to expose the focal plane. These speeds relate to the aperture settings and are available in one stop, one-half stop, or one-third stop increments. As with f-numbers, one full shutter speed stop doubles or halves the amount of light reaching the focal plane. (One second provides twice the amount of light as one-half second.)

**sidecar file**
A file that accompanies some file formats and includes conversion information that will adjust the original file data to the desired output without destroying or affecting the original file data.

**slider**
A tool within a dialog box that allows you to manipulate global controls in a linear fashion, as with the levels control.

**smart filter**
A preview of what effect a filter function will have on the smart object that is referenced within an image. Smart filters are nondestructive and alter the pixel data only when the smart object is rasterized.

**smart object**
A feature of some image editing software that allows you to infinitely adjust, warp, or transform pixel data without destroying the original pixels.

**specular**
A hard and directional light that creates crisp shadow edges.
spike
A graphical representation on the histogram that shows areas of over- or underexposure as sharp peaks of information butted up against the edges of the histogram. Although the spike doesn't tell you how much information has been lost, it does communicate that clipping has occurred.

spline algorithm
A form of interpolation that uses a graphical mapping system to interpret pixels in relation to one another so they form a smooth curve.

spot meter
A metering system that determines the appropriate exposure of a small angle of view of the scene that can be used as a standard for the whole scene.

stability
The reliability of a storage medium that can be written and rewritten.

string
Within a digital image, a set of pixels in a straight line that have the same color information.

substitution metering
A form of metering where something is placed into the scene that is a known value, such as an 18 percent gray card, and the light of the scene is measured from that object to determine the exposure. The substituted item is then removed to capture the desired photograph.

telephoto
A type of lens that has a long focal length, resulting in a smaller angle of view of the photographed scene. This provides longer distance viewing than human vision.

terabyte
A unit of data that consists of 1,024 gigabytes.

tethered
A way to shoot digital photography while a camera is connected to a computer. This provides a greater processing speed than an in-camera system can accommodate.
**Glossary**

**TIFF (Tagged Image File Format)**
A common file format used for digital files that uses lossless compression.

**tint**
A control within the white balance dialog box that allows you to vary the global color of an image by adjusting the magenta–green axis of the image.

**tone curve**
A graphic depiction of the original image data that can be manipulated in two dimensions to create a desired tonal representation in the image.

**transforms**
Processes that apply mathematical equations to selected data within an image and alter it, such as with a rotate or resize function.

**TTL**
Through the lens.

**verification hash**
A method of file verification that uses a mathematical function to verify the integrity of a digital file before the file is opened. If the file's hash value matches the calculated value, the file is uncorrupt and unmodified.

**vibrance**
The amount of yellow applied to the image, where more yellow increases the apparent vivacity of the image.

**view camera**
A camera where the photographer uses the actual image surface to compose and focus the image. These cameras are usually constructed with a front standard that houses the lens and a rear standard comprised of ground glass to aid in focusing. After the image is composed and focused, a film or digital back is placed in the position of the image surface for capture. The photographer cannot see the actual image that is created after the capture media is in place.

**viewing system**
The screen on the back of a digital camera that allows the photographer to view a thumbnail of the image as well as various menu and image information.
**visually lossless compression**
A type of digital image file compression that takes into account human visual perception to create a file size reduction that won’t be perceptible upon decompression.

**white balance**
Correcting color bias by using a neutral source, such as a gray card, to determine the actual color of the scene.

**wide angle**
A type of lens that has a short focal length, resulting in a larger angle of view of the photographed scene. This provides a wider view of the scene than human vision can perceive.

**workflow**
The process used to create photographic images, from previsualization to final output.

**write speed**
How quickly data can be transferred from the image capture device to the removable storage media.

**XMP (extensible metadata platform)**
A type of sidecar file that accompanies some RAW file formats and holds the file’s metadata. This file must be used in conjunction with the RAW file to provide the desired conversion information for the image output.

**Zone System**
A method of previsualizing and executing black-and-white images that separates the dynamic range of a capture device into 11 distinct zones. The Zone System was created by Ansel Adams and Fred Archer.

**zones**
The 11 distinct light intensity levels determined by Ansel Adams and Fred Archer in the Zone System. The levels start with zone 0, which is absolute black, and end with zone X (10), which is absolute white.

**zoom lens**
A lens that has moveable parts that allow it to adjust to multiple focal lengths.
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I am a Creative—

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About the Authors

Dr. Glenn Rand has been teaching photography since 1966, and has taught in the graduate program at Brooks Institute in Santa Barbara, California since 2001. He has developed and reorganized several curricula for fine art photography, commercial photography, digital imaging, and allied curricula. He received his BA and MA from Purdue University and his Doctorate from the University of Cincinnati. He also served as a Visiting Scholar at the University of Michigan. Dr. Rand’s photographs have been exhibited widely and are held in the collections of thirty public museums in the United States, Europe, and Japan. He has published and lectured extensively about photography and digital imaging and has authored several books including *Black and White Photography, 2E*, *The Portrait*, and *Teaching Photography*. He contributes regularly to various periodicals and is a contributing editor for *Rangefinder* magazine.

Christopher Broughton has been a faculty member of Brooks Institute since 1996 and recently created a new, digitally-based curriculum for the school’s introductory photography class. Prior to becoming a full-time faculty member he served as Director of Laboratory Operations while completing his MS at Brooks. Broughton has authored articles in *Petersen’s PHOTOgraphic, Outdoor Photographer, PC Photo*, and *Studio Photography & Design*, and has been a featured lecturer for Hasselblad USA and Eastman Kodak. His photographs are exhibited and represented by Four Friends Gallery in Thousand Oaks, CA and on his website, [www.christopherbroughton.com](http://www.christopherbroughton.com). He has been active in working on digital capture, workflow, and output since it was introduced into the photographer’s workflow.

Amanda Quintenz-Fiedler is a writer, photographer, and educator. She graduated Phi Beta Kappa from Purdue University in 2000 with a major in Interdisciplinary Film Studies and minors in Photography, English, and Math. She went on to pursue her MFA in Photography from Brooks Institute, graduating in 2009. Her MFA culminating project, American Narcissism, was a visual and verbal examination of modern American attitudes. She has written articles about photographers, digital fine art theory, and fine art education for publications such as *Rangefinder, Digital Photo Pro, Photographer’s Forum*, and the Photo Imaging Education Association (PIEA) Journal.