Part I

Understanding Your Camera

Chapter 1

The Differences between Digital and Film Photography

At first glance, digital cameras pass the "duck" test with flying colors. That is, if it looks, waddles, and quacks like a duck, it must be a duck.

To the casual observer, there's little or no difference between a digital camera and a film camera. Both have a lens, shutter, diaphragm, and viewfinder. Both take pictures when you aim them at the subject and pressing a shutter button. And to the untrained eye, both produce almost-identical-looking photographs that can be pasted in albums, mounted on refrigerator doors, used in business communications or hung in art galleries.

However, as much as digital cameras and film cameras are alike, they are also as radically different as a jet plane is from a helicopter, or a dog is from a tiger.

Some differences are obvious. Film is a chemical-based process, while digital is an all-electronic medium. Digital can provide instant feedback on your just-shot images, while you have to wait to see your film photos. Other dissimilarities become apparent only after you start using a digital camera.

The many significant and subtle differences between the two technologies can and will affect the way you take pictures. In this chapter, we'll examine how both film and digital work their magic in recording photographic images and how using digital cameras impact upon the choices you must make.

Why Film?

Film has lasted over a century and a half as the world's most popular medium for capturing and preserving visual memories for lots of compelling reasons:

- **It's cheap—**A film cassette or roll costs only a few bucks.
- **It's ubiquitous—**You usually can buy film at any convenience store, drugstore, or even newsstand anywhere in the world. And you can get it processed within an hour at almost any mall or drugstore.
- **It's portable—**Film is small, light, and travels well in a pocket or purse.

- **It stores well—**Negatives and transparencies fit very nicely in folders, sleeves, loose-leaf binders, shoeboxes, drawers, and so on.
- **It's instantly viewable—**All you have to do is hold a developed negative or transparency up to a light, and you can see the image. You don't need special equipment to view what you have.
- **It's easy—**Single-use cameras (SUC) (also called film-in-a-box) are instantly ready to shoot and require no learning or shooting skills. Just advance the film and press the shutter. No wonder 60 billion SUCs were sold last year.
- **It lasts—**If stored properly, that black-and-white negative shot by your great-great-grandfather will probably yield a print almost as good as when it was originally taken.
- **It's versatile—**There's an *emulsion* for just about any need or preference—color, black and white, fine grain, high speed, infrared, and so on.
- **It's good—**35mm fine-grain film can be blown up to poster size and maintain great color, razor sharpness, beautiful tonality, and image fidelity.

Film photography is a mature technology that has been giving us satisfaction and pleasure for generations. Is there anything more wondrous and representative of our culture than a shoebox of old fading and foxed photos of family memories? And the quality of film photos can't be beat. But film does have its disadvantages:

- Though it has fairly wide temperature latitude, film degrades quickly in extreme heat (as in a car's glove compartment in summer) and loses sensitivity in extreme cold.
- Undeveloped film must be kept in lightproof boxes or containers before and after shooting—one brief accidental exposure to the sun, and it's toast.
- Unexposed film has a practical life expectancy of 2–4 years, depending upon the emulsion and how well or badly it had been stored. Outdated or short-dated film gradually loses both sensitivity and color fidelity.
- It must be processed with environmentally hostile chemicals in a darkroom or by a photo lab, a precise, time-consuming, and costly procedure. If the temperature is too warm or too cold, the chemicals are not mixed in the correct manner, or the film is immersed for too short or too long a time, the film can be irreparably damaged, and the photos on it can be permanently lost.
- Developed color film degrades and deteriorates over time, to the point where it may be almost unusable after only a few years.
- If not handled and stored properly, film is prone to scratches, gouges, and dust, all of which adversely affect image quality.

Is Film Dead?

It was the end of the world as they knew it. This new-fangled invention, called photography, would put landscape and portrait painters out of business. Oils were obsolete and pastels passé, because almost any yahoo with the right equipment and some basic skills could produce photographs that were more realistic-looking than the best painters could put on canvas.

Of course, they were wrong: the invention of photography in the 1830s did not make fine art painting obsolete. To the contrary: it produced a veritable renaissance and resurgence of painters and paintings. Now that they were no longer expected to paint primarily in a realistic style, artists were free to experiment with a wide variety of creative expressions, which led to innovative and free-spirited art movements such as Impressionism and Cubism.

Similarly, motion pictures didn't kill live theater, and television hasn't made the movies go away. More to the point, the advent of color film didn't knock black-and-white film from the shelves. Although the general public embraced color photography wholeheartedly, photojournalists, architectural photographers, and fine artists continue to use black-and-white film for its ability to express certain moods or impressions much better than color.

It is likely that film will probably survive against the digital tsunami for decades to come, albeit in a different and diminished capacity. Fine art photographers will sing praises to film's presumed greater tonality, grain, and other technical and aesthetic virtues and values. And until cheap disposable digital cameras become readily available (yes, they've been around since last year in some parts of the world), there's nothing in the digital world that comes close in quality and convenience to the ubiquitous single-use, film-in-a-box cameras you can buy at any minimart or corner newsstand.

Why Digital?

Digital photography is a new and growing technology that most observers predict will replace film in short order. Here are some of digital's numerous advantages:

- **It's economical—**You'll never again spend another nickel on film or processing (known in the industry as "consumables"), since your digital camera's built-in electronic memory or external memory cards can be used and reused thousands of times.
- **It's immediate—**With a digital camera, you can take a shot and instantly review it in the camera's LCD viewfinder. If your subject blinked or is out of focus, if you don't like the composition, or if the picture is too dark or light, you can then simply erase the picture at the push of a button and shoot over.
- **It's versatile**—Many digital cameras do more than take a still photograph. Your digital camera may allow you to record video or audio, create panoramas, stamp time/date and GPS coordinates on your pictures, and check world time. And if you have a camera cell phone, you can even call your friends between snapshots and quickly send the pictures to them.
- **It's contemporary—**In this day and age, the vast majority of our communications are digital. This covers everything from email to Web pages, business presentations to recordkeeping. Even material that ends up printed starts out digitally in our computers, where it is created, assembled, edited, and saved. If you want pictures to be part of your communications ("a *picture is worth a thousand words*"), then you'll need digital photos.

- **It records its own history—**A digital file of a photo can contain much more than a picture. Attached to that file can be all kinds of valuable information (called *metadata*) about where, how, and when a photo was taken. That data can be appended or edited, used to help identify and organize files, and in some situations, even be offered as legal evidence. (For more information on metadata, see Chapters 5 and 21.)
- **It's permanent—**Stored correctly on a high-quality CD or DVD, a digital photograph will never fade, fox, or lose data, and can last over a century.
- **It gives pro-like control—**Digital photography offers the average user the kind of control over the creation, editing, and use of his photos that used to be the domain of only expert photographers.
- **It's fun—**Beyond the immediate feedback and ability to display them right away on any computer screen or television, you can play with digital photos, change them artistically or humorously, remove your wrinkles, or add a mustache, try a new hair color, or paste yourself onto a Hawaiian beach. Using photo-editing software in your computer, you are limited only by your imagination. (See Chapter 18.)

As you read this book, you'll discover and master many other advantages of digital photography. But you'll also need to be aware that that digital does have its disadvantages, too:

- Digital cameras can be pricy, certainly more expensive than comparable film cameras.
- Digital cameras can be complicated. Except for the least expensive point-and-shoot models, most digital cameras offer a bewildering array of choices and options that can intimidate many users.
- Many digital cameras aren't as fast or sure shooting as film cameras. With many models, it takes a few seconds for the camera to power up before you can take the first shot. You may also encounter a frustrating, unavoidable delay between the time when you press the shutter and when you actually take the picture, so you may lose the shot if the subject moves in the interim. And because it's necessary to process and save the just-captured image, it can take anywhere from a second to a half-minute before your camera is ready to shoot again. (See Chapter 3 for tips on dealing with and reducing shooting delays.)
- Press the wrong button, and you could accidentally delete one, or even all, of your pictures.
- Connecting your digital camera to your computer can be a difficult, intimidating job. (See Chapter 17 for advice on how to get images into your computer.)
- Digital cameras may eat up batteries at an alarming rate. (See Chapter 4 for tips on buying batteries and Chapter 11 for advice on how to save on batteries.)
- The days of stumbling across a stored shoebox of memories and just sitting on the floor looking at photos of your family and friends will eventually fade away. Unless you make prints of your digital photos, you will need some sort of digital device to view them. That's why an archiving plan is important. And, of course, why those photos that are most precious to you should be printed. (Please see Chapter 20 on printing and Chapter 21 to learn about archiving.)

Still, the advantages of digital photography far outweigh the disadvantages. Besides, the genie is out of the bottle. Digital photography is here to stay. Film will soon be as foreign to the average person as old-fashioned rotary dial phones, and as obsolete as buggy whips and coal scuttles.

The Beauty of Working with Digital

When we first started doing digital photography, over 10 years ago, our fellow professional photographers tended to divide into three camps:

- Many established professional photographers poo-pooed digital as being inferior and inappropriate for the kind of high-quality work their clients expected from them.
- Others were openly or secretly fearful about what the new digital era would mean to them and their careers, often acting like ostriches with their heads in the sand. Would everything they knew and depended upon be outmoded and useless?
- The forward-thinking, adventurous pros embraced digital photography and ran with it.

Today, all the professional photographers we know do at least some of their work digitally, and many have completely retired their film cameras and closed their darkrooms. When they discuss with us what digital has meant to them, they don't talk so much about the technology as about what it has meant for their art and creativity, as well as their productivity and ability to more quickly and economically deliver what clients need and want.

Greg Gorman, the Los Angeles–based photographer well known and respected for his celebrity portraits (`www.GormanPhotography.com`), told us that he really enjoys working digitally. "It certainly surpasses film. The way digital sees light in low luminance is great. I always prefer the way natural light works, and with digital I get more of the nuances of the lighting. Of course, it's great knowing right away that you have the image you're looking for . . . the immediate gratification. But then, once I know I have the picture, I can push myself even further, get a little bit more out of it all."

All Cameras Are Alike . . .

The word *photography* literally means "writing with light." Photography as an art and a science has existed and evolved for about 170 years, give or take. It had a hundred births, in the cramped closets and kitchens of inventors and innovators who labored in absolute darkness, coating paper, metal, and glass surfaces with photosensitive silver salts, exposing them inside light-proof wooden boxes affixed with lenses appropriated and adapted from telescopes and eyeglasses, and then immersing them into witches' brews of caustic chemicals to develop and fix those images permanently. Although the process has been vastly improved and greatly refined through the years, film-based photography is still essentially the same as it was back in the 1830s.

At its most basic, photography requires a device that creates a photograph (see Figure 1-1). We call that device a camera, which is a box that captures the light reflected from a scene, person, or object and converts it into a tangible representation of that light, that is, a picture.

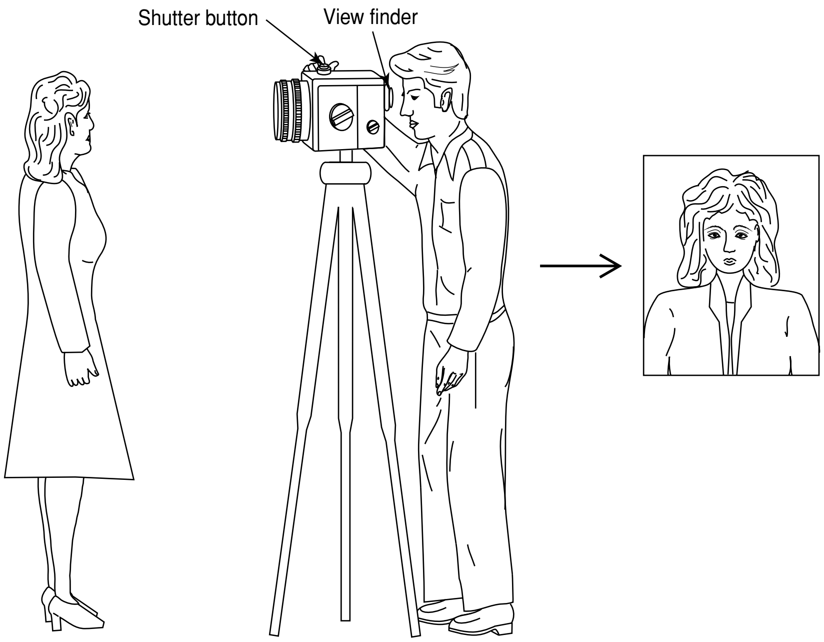

Figure 1-1: All cameras do essentially the same thing. Point the lens at a scene. Look at the scene through the camera's viewfinder. When you are satisfied with the composition you see in the viewfinder, press the shutter button. And you will end up with a photograph of that scene that looks very much like it did in the viewfinder.

To do this, most cameras typically have the following components:

- A lens for directing and focusing the light into the camera
- A *diaphragm* for regulating the amount of light allowed to pass into the camera, as well as controlling the *depth of field*
- A *shutter* for controlling the duration of the light passing through the camera
- A button or shutter release that tells the camera when to take the picture
- A photosensitive element (film or an electronic *image sensor*) to record the photo
- All contained in a light-proof box

In addition, most modern cameras also have:

- A window (or viewfinder) of some sort for the photographer to preview what the camera lens sees
- A photoelectric light *meter* for calculating exposure settings
- A built-in *electronic flash* or interface for connecting an external *strobelight*
- An electronic sensor to regulate flash intensity and duration for proper exposure

How a Film Camera Works

All of us have been using film cameras our entire lives, but most of the time it's been like driving our cars, with no thought as to what is really happening under the hood. To understand digital photography, it's important to consider its antecedents in film photography. Then, it will be easier to recognize the differences and similarities between the two technologies, which will lead to more easily and fully mastering the new world of digital photography.

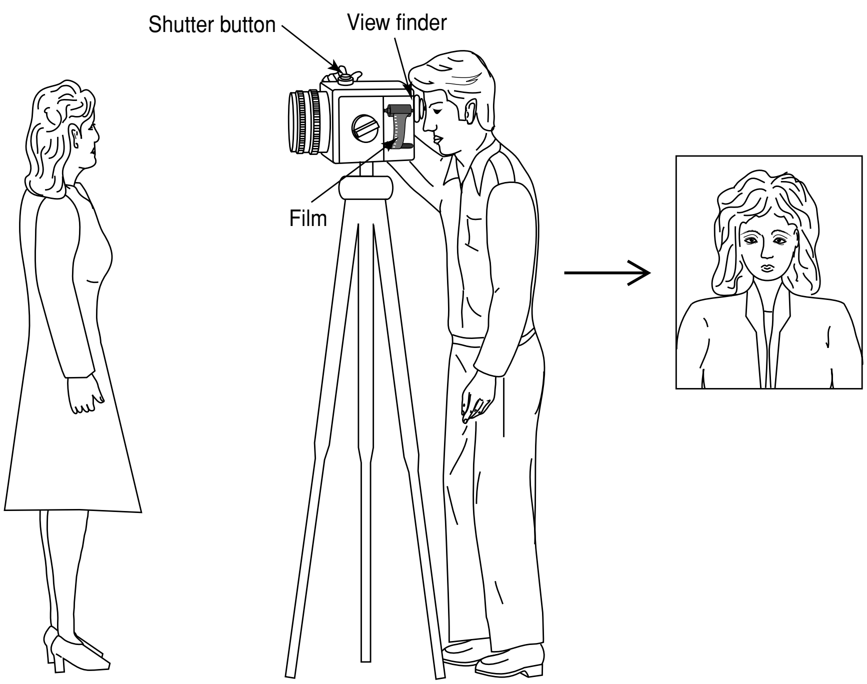

Figure 1-2: The most obvious difference with film cameras is that they record photographs onto film.

Film

Of course, the most vital part of any film camera is film. Without it, the camera is simply an expensive, useless mechanical toy.

Film is any medium or material (usually a flexible plastic Mylar base) coated with photosensitive silver halide crystals. Inside the camera, light passes through the lens and is focused onto the film. When the shutter opens, the film is briefly exposed to light, which causes an immediate chemical reaction: the sensitized silver halide crystals (*grain*) turn dark, creating a latent image. And where no light strikes, the crystals remain unchanged.

When developed and fixed (in total darkness) through a series of chemical baths, the latent image becomes visible, all reactions cease, the image becomes stable, and the unused (unexposed) silver halide crystals precipitate and are washed away.

What makes film particularly interesting for those of us who want to understand digital photography is that the attributes of both technologies are described in similar or even identical terms:

- *Sensitivity* to light (which, in film, is rated in *ISO* numbers)
- *Grain*, or the size and appearance of the small particles (crystals) that make up the picture
- *Resolution*, or the degree of sharpness and detail
- *Dynamic range*, the measure of how much detail the film can capture in the full tonal range, from deep shadows to bright highlights.

Sensitivity, grain, resolution, and dynamic range are closely related because they directly affect each other.

- A particularly sensitive, or high-speed film (that is, one that can be shot in lower-light situations), is somewhat grainer than a lower-sensitivity film.
- The bigger the grain crystals, the lower the image resolution and dynamic range.
- The finer the grain, the lower the sensitivity to light, but the wider the dynamic range and more detailed the resolution.

High-speed film (400 ISO and above) is useful for capturing available-light and low-light subjects, sports action, photojournalism, industrial and scientific processes, fidgety kids, and squirming pets.

Conversely, a low-sensitivity film (such as 64 ISO) is what you want when shooting brightly lit beach or snow scenes, portraits, and subjects where you want to capture great detail with fine subtlety and smooth gradations.

For most shooters, in typical situations, medium-grain, medium-sensitivity film (100–200 ISO) is the best choice.

Some digital cameras have controls that allow you to adjust their sensitivity to light, which are described in terms of their ISO equivalencies. (See Chapter 6 on understanding and using ISO equivalencies.)

No Free Lunch

Wouldn't it be wonderful if you could shoot with a fine-grain, high-speed film that produces top resolution and incredible dynamic range, and with spot-on accurate colors so vibrant that they would knock your socks off? Sorry, it just won't happen.

Like most things in life, film is a careful compromise, offering certain advantages balanced against corresponding deficiencies. The laws of physics and chemistry can be stretched only so far, so if you want ultrafine grain, you must give up on also having high-speed sensitivity. Or, you can shoot a film that captures accurate color, or one that produces saturated, brightened color, but not both.

As you'll learn later in the book, shooting digital always involves similar compromises and choices. You can select greater sensitivity—but you'll also get increased electronic *noise*, the digital equivalent of grain. Or, if you set your camera to *burst mode*, for faster shooting, you'll usually have to forego using the electronic flash.

Making the best choice for each picture and situation is what photography, be in film or digital, is all about.

No Film Is Color Film

You may be surprised to learn that technically, there is no such critter as color film. What we call color film typically consists of three layers of very thin black-and-white film sandwiched in between layers of red, green, and blue plastic filters. (See Figure 1-3 in this chapter and also Color Figure 1 in the color insert toward the back of the book.)

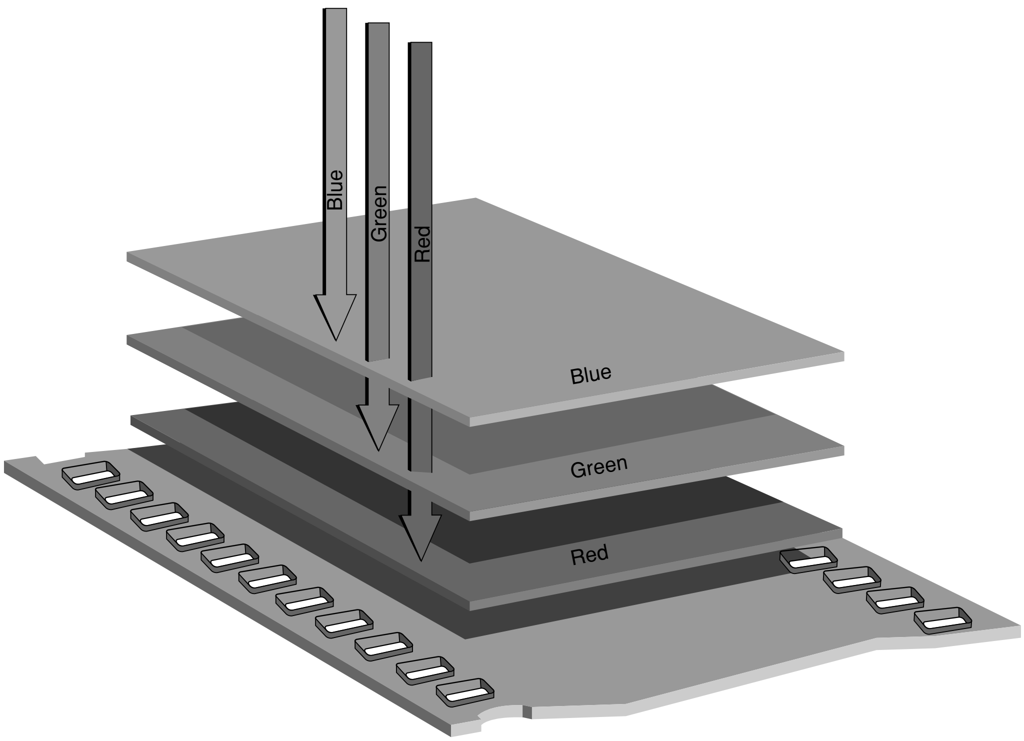

Figure 1-3: Basic color film actually consists of three layers of black-and-white film sandwiched in between red, green, and blue filters, all attached to a thicker piece of plastic. When developed, the black-and-white silver halide in each layer is replaced by corresponding red, green, and blue dyes. When composited (sandwiched) and viewed together, they appear as full color. Please also see Color Figure 1 in the color insert toward the back of the book. (Illustration based on another supplied by Foveon. © 1998–2004 Foveon Inc.)

Why red, green, and blue? Because they are the primary colors that make up *RGB*, the *color model* that governs the science behind film (and image sensors, too). Mix red, green, and blue in varying amounts, and you'll get all the different colors that a camera can capture. According to the RGB model, the absence of color (light) is black, while combining 100 percent red, green, and blue will give you white. All other colors are created by varying the percentages of the primary colors. (See Chapters 8 and 20 to learn more about color models.)

Getting back to how we get color film . . . each filter layer allows only its corresponding color through to the black-and-white film layer beneath. Then, when the film is developed, the filter layers are replaced with dye, so the black-and-white image captured beneath each filter is transformed into a red, green, or blue version of the scene photographed. When viewed together, the composite red,

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green, and blue layers appear to our eyes as continuous, natural color. Keep this in mind when you read about how image sensors capture color. It's really quite similar. (See Color Figure 5 in the color insert toward the back of the book.)

The World's First Practical Color Film Was Invented in a Kitchen Sink

Although various kinds of color photography have been around since the late nineteenth century, they were, without exception, difficult, cumbersome processes that often involved exposing three separate plates of the subject and compositing them to create the full-color photo. While Kodak was pumping millions into the search to come up with the first practical amateur color film, an unlikely pair of professional musicians and avid amateur photographers named Leopold Mannes and Leopold Godowsky concocted a color film in 1935, literally, in a kitchen sink in their New York City apartment. Kodak hired the pair and bought the process, calling it Kodachrome. After nearly 70 years, Kodachrome is still considered to be the color film gold standard among serious photographers (although its composition is much different from the original 1935 version).

Digital Cameras Are Similar to Film . . . but Different

Like a film camera, the digital camera consists of a light-proof box with a lens, diaphragm, and shutter. The key difference is that in a digital camera the light is focused not onto film, but onto a photosensitive silicon chip or semiconductor, called an *image sensor* (see Figure 1-4).

Having an image sensor instead of film entirely changes things on the camera's back end. With film, once you capture the image, the only job left for the camera is to advance the film roll or cassette to the next unexposed frame. But with digital, pressing the shutter is only the beginning of a complex process that requires numerous other components and engineering considerations.

Most digital cameras incorporate the following components (see also Figure 1-5):

- *Image sensor*, to actually capture the photo
- *ADC* (analog-to-digital converter) to create the digital data of the photo
- Lots of digital circuitry, including one or more DSPs (digital signal processors) and one or more ASICs (application-specific integrated circuits), to process the data and create the image file
- *LCD viewfinde*r, for composing pictures, reviewing photos already shot, and accessing some commands and controls
- Memory card slot and/or built-in memory, to save the digital image
- *USB* port for connecting to a computer
- Video out port for connecting to a TV or projector, where you can view your photos
- AC adapter port, to try to save on the cost of batteries

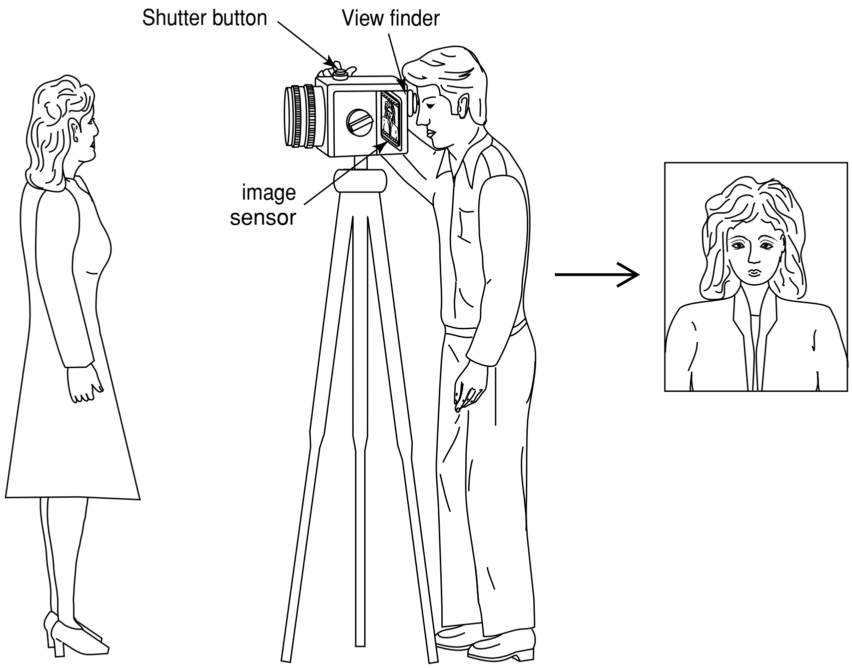

Figure 1-4: Instead of film, digital cameras capture photographs using silicon chips called image sensors.

Image Sensors

An image sensor is the photosensitive element in a digital camera that actually captures the photo. Essentially, it is what replaces film, though it doesn't do everything that film can do. Several functions (such as creating a photo and saving it) are handed off, instead, to other parts of the camera. (See Figure 1-5.)

Technically speaking, image sensors are photosensitive semiconductor chips that create an electrical charge when and where they are struck by light (photons). The more light, the greater the electrical charge generated. Digital camera image sensors have many thousands or millions of sampling points, each of which separately reacts to light. Each sampling point is called a *photosite* or *photoreceptor site*, a tiny etched area that collects light, like a bucket collects rainwater.

Photoreceptor sites are better known by their popular name: *pixels*.

WHAT IS A PIXEL?

Pixel is short for picture element. Think of a pixel as an atom: it's the smallest indivisible unit of a picture, the fundamental building block of an image.

Pixels are everywhere in computer graphics; it's what we call the dots on your screen, and when we measure the size of a digital image or photo, it's often in terms of how many pixels per inch (*ppi*) it has. But at the beginning of the imaging chain, a pixel is nothing more than a tiny etched point on an image sensor that is sensitive to light. And yet, this tiny photoreceptor site, when activated by photons, sets in motion a remarkably complex process whose end result is a digital photo.

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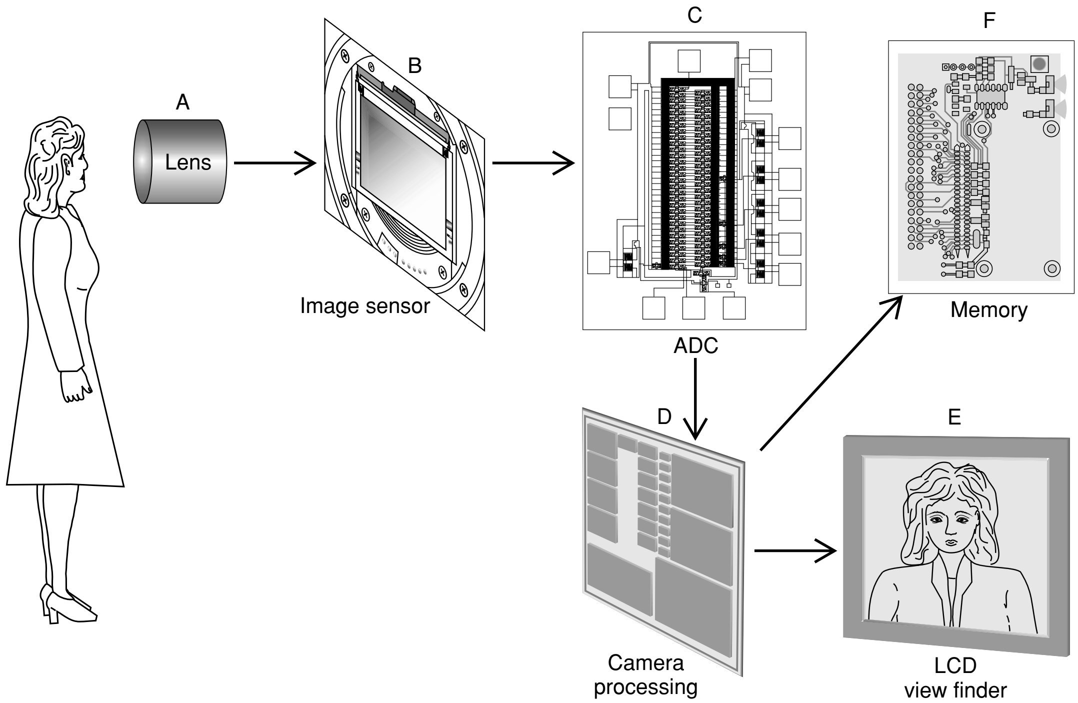

Figure 1-5: A digital camera is a complex system that when reduced to its most basic includes (A) a lens, (B) an image sensor; (C) an analog-to-digital converter (ADC); (D) extensive circuitry for image and color processing, which includes ASIC(s) and DSP(s); (E) an LCD viewfinder; and (F) internal memory and/or a slot for a removable memory card. Actually, the processing inside of a digital camera is not so linear as this illustration indicates; it includes lots of feedback, information, and controls moving back and forth and among components. In addition, your camera will certainly have many more components.

Tip: If You Want to Learn More Technical Details

For those who really want to dig into the technology behind pixels, image sensors, and digital photography, please go to `www.ExtremeTech.com` and read Sally's articles on the "Anatomy of a Digital Camera."

Megapixels: A Measure of Volume, Not Quality

The second most frequent question we hear when people ask us about digital cameras is "How many megapixels is that camera?" People ask the question even though they usually have no idea what a megapixel is, or even that it isn't a description of a camera, but of the amount of data an image sensor can capture. We don't blame them. It's the camera manufacturers' fault—or, at least, their advertising and marketing departments' fault. It's easier to sell by the numbers rather than explain the really important differences among cameras.

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Size is everything in our society. Having the biggest and the most seems to mean more than just about anything else. Last year, 5 megapixel (MP) cameras were the hottest, best thing around. This year, it's 8MP cameras. And yet, we have seen 3MP cameras that produced better photographs than some 5MP cameras. And 8MP is simply overkill for almost every amateur photographer we know.

The fact is a camera's megapixel rating is only a measure of how many pixels (photosensitive sites) an image sensor has. More pixels means more image data, which translates directly into larger pictures. If you have larger pictures, you can get bigger prints. (See this sidebar's table for how megapixels relate to print size.) If you try to create a print that's too large for the amount of data in your photo file, the image may look soft, unfocused, and blocky and may exhibit *jaggies* (staircase-like edges where diagonals and curves should be smooth). Larger photo files can also be zoomed into to view small details without losing image integrity. But larger is not necessarily better.

An image sensor is simply one component of an entire system that produces a digital photograph. That system includes the lens, the processing of the data, the color and imaging science applied, how the photo is saved, and many other factors—starting with the photographer's eye for beauty and composition. So resist buying into the megapixel hype when you're choosing a digital camera.

Resolution	***Print Size***
1.3 megapixels	3.5″ × 5″–4″ × 6″
2 megapixels	4″ × 6″–5″ × 7″
3 megapixels	5″ × 7″–8″ × 10″
4 megapixels	8″ × 10″–8.5″ × 11″
5 megapixels	8.5″ × 11″–9″ × 12″
6 megapixels	11″ × 14″–14″ × 17″
8 megapixels	14″ × 17″–16″ × 20″

To read our response to the number one question, "What is the best digital camera?," turn to Chapter 2.

DOES THE SIZE OF YOUR PIXEL MATTER?

Pixels can be large or small, shallow or deep. While the number of pixels isn't a measure of image quality, their size can be. (See the sidebar "Megapixels: A Measure of Volume, Not Quality.")

Large and deep are better, because they can collect more light. And more collected light can (but does not always) translate into sharper detail, better color, greater dynamic range, and increased sensitivity. (Keep in mind that all pixels on any kind of image sensor are infinitesimally tiny and not visible to the naked eye. In fact, literally millions of pixels can fit on an image sensor the size of your pinky's fingernail.)

So why would anyone want smaller and shallower pixels?

It's all a matter of economics and practicalities. Large and deep pixels mean that the image sensor itself must be physically larger, and larger image sensors are more difficult and almost always significantly more expensive to manufacture. What's more, larger image sensors require bigger (heavier) lenses, larger camera bodies, and a host of faster, more robust components, all of which adds to the cost of a camera.

Image sensor size, and therefore pixel size, is one of the important factors that separate consumer and professional digital cameras.

Reality Check: Just How Large Are Image Sensors?

The size film that you would use has always related to what you want to do with your photographs.

- Most people use 35mm film, which measures 24 × 36mm, and is called 35mm because that's the length of the diagonal across the frame. 35mm film is what we use to shoot anything from snapshots to 16″×20″ posters.
- Many professionals who want or need greater detail, control, and larger prints will use 120 roll film (which is 2¼″×2¼″ square).
- For billboards, pros might use cut film for studio view cameras (which is usually 4″×5″ or 8″×10″ per sheet).

Like film, image sensors come in various sizes. If all other things are equal, larger image sensors will tend to produce clearer, brighter, better pictures. And yet, most image sensors are proportionately much smaller than film. That's because manufacturing large image sensors is a very expensive and difficult process; the more surface area a chip has, the more likely it is to have blemishes or other imperfections. So the rejection rate of large sensors is much higher than small ones.

Larger chips also are an order of magnitude more expensive to support, since they require larger lenses (lots more glass), bigger camera bodies, more robust components, and increased power to operate. (In fact, some professional studio cameras with large image sensors draw so much electricity that they must be AC powered and electrically cooled.)

The following table contains a brief sampling of digital cameras, the sizes of their image sensors, and the corresponding sensor resolutions:

Camera	***Resolution***	***Image Sensor Size***
Casio GV-10	1.3MP	4.54 × 3.2mm
Sony DSC-U50	2.1MP	5.27 × 3.96mm
HP Photosmart 945	5.24MP	7.18 × 5.32mm
Leica Digilux 2	5.24MP	8.8 × 6.6mm
Olympus E-1	5.6MP	18 × 13.5mm
Canon EOS-1D Mark II	8.5MP	28.7 × 19.1mm
Kodak DCS SLR/c	13.9MP	36 × 24mm

In case you can't easily visualize millimeters, 4.54 × 3.42mm is about the size of a Tic-Tac mint, 5.27 × 3.96mm is roughly the equivalent size of a small pea, and 7.18 × 5.32mm is approximately the size of a postage stamp.

The largest CCD currently used in a professional digital camera is, not coincidentally, 24 × 36mm. This one-to-one equivalent to a 35mm frame of film makes it easy to use conventional 35mm *SLR* camera lenses. (See Chapter 4 regarding lenses.) Professional studio digital cameras may have image sensors as large as 2″×2″, which is many times bigger than consumer digital camera image sensors.

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HOW DO IMAGE SENSORS CREATE COLOR?

Like film, image sensors are inherently black and white (grayscale) devices. They acquire the ability to capture color through elaborate engineering wizardry that is based on a concept similar to that of color filters used for film (See Figure 1-3, and see also Color Figures 1 and 5 in the color insert in the back of the book.).

One big difference with image sensors is that the color filters used are microscopic, to match the size of each individual pixel. But the one constant is that, like film, image sensors use RGB—red, green and blue primary colors—to create all the other colors that the camera can capture.

The most widely used method for creating color out of black-and-white image sensors is called the *Bayer pattern*. (See Figure 1-6, in this chapter, and Color Figure 2 in the color insert at the back

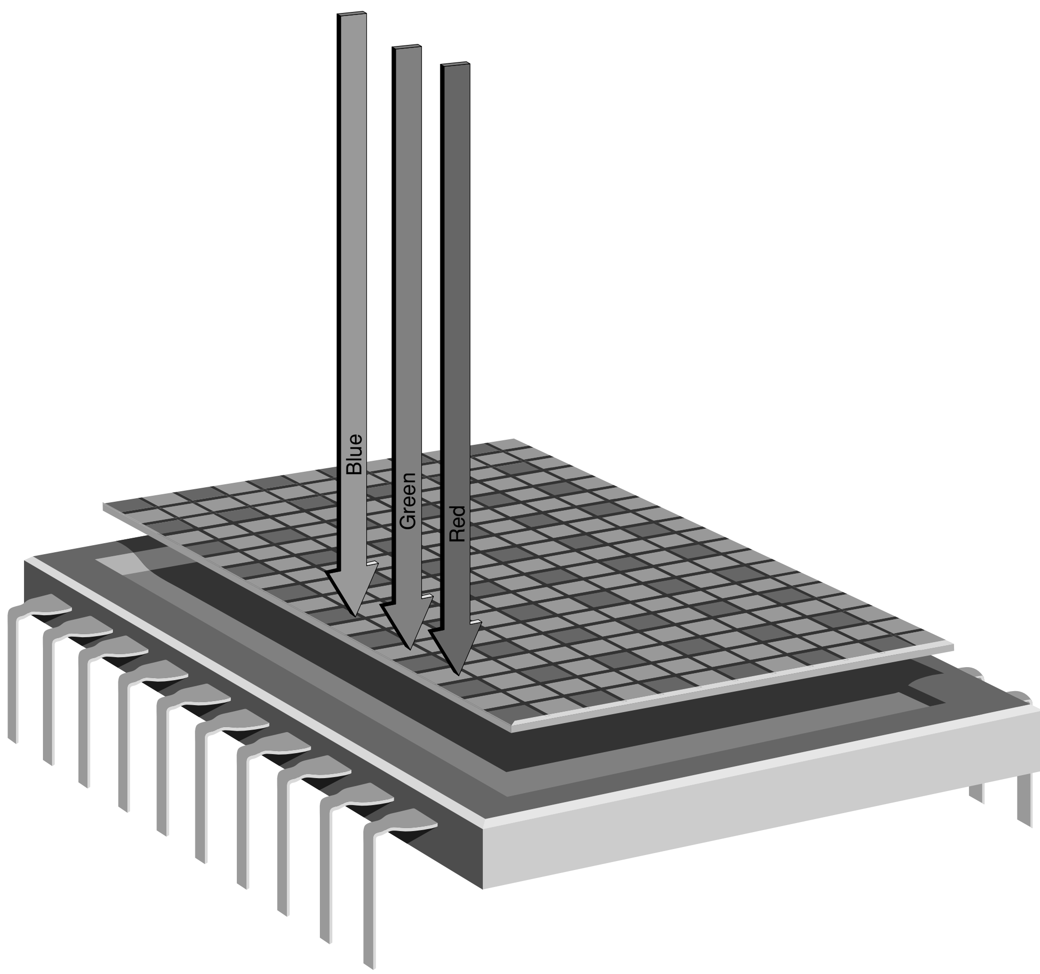


Figure 1-6: A Bayer pattern color filter array. Note the checkerboard pattern of alternating red/green/blue/green filters. The number of green pixels is doubled, because, due to a combination of psychology and physiology, the color green makes the image appear sharper to the human eye. (Based on an illustration by Foveon. © 1998–2004 Foveon Inc.)

of the book.) Named after Dr. Bryce Bayer, whose research team at Bell Labs developed it in the late 1960s, the Bayer pattern incorporates an array of primary-colored filters bonded over pixel wells. This elaborate checkerboard pattern alternates squares of red, green, blue, and green filters. (The green is doubled because the human eye sees green as an important defining element for sharpness.) The color of the filter covering the pixel allows only photons of that color to pass through. In other words, when light reaches the red square over a pixel well, only that light that is red will get through to the pixel. The other primary colors will be blocked.

When processed, the individual red, green, and blue pixels are combined, producing a composite that appears to be full, continuous color.

Some digital cameras use a similar checkerboard pattern, but with slight variations in the colors of the filter array. For instance, Sony has a color filter array that they call RGBE, in which the second green pixel in the Bayer pattern is replaced with blue-green, which they call emerald. Sony claims that when combined, the results are closer to how we humans perceive color.

The only image sensor used in commercially available consumer or prosumer digital cameras that doesn't use the Bayer pattern (or a variation on a Bayer-type checkerboard) is Foveon's X3 chip.

TYPES OF IMAGE SENSORS

While many different types of image sensors exist, four are used in most digital cameras:

- *CCD* (charge-coupled device)
- *CMOS* (Complementary Metal-Oxide Semiconductor)
- Fujifilm's *SuperCCD*
- Foveon's *X3*

CCD

CCDs are far and away the most popular and ubiquitous image sensors used in digital cameras, as well as camcorders, digital camcorders, and commercial television broadcast cameras. CCDs are generally considered to be better and more accurate at recording images than comparable CMOS chips.

While Kodak, Mitsushita, Sharp, and others manufacture CCDs, Sony currently supplies approximately 80 percent of the CCDs used in all digital cameras. Interestingly, even among cameras that use the same model CCD, we have seen wide variations in color and image quality, which only proves our earlier statement that the image sensor is not the only determining factor in how good a camera is.

CCDs are an established technology that may not sound as exciting and innovative as newer sensors. But in the numerous roundups we have done for *PC Magazine*, testing a wide variety of digital cameras, Editors' Choice for the best digital camera in the group has always gone to a CCD-based camera . . . so far.

CMOS

CMOS is ubiquitous among all kinds of computer equipment: your desktop computer probably has a battery-powered CMOS chip that retains the time, date, and other default settings when your system is switched off. When used as a photosensitive image sensor, CMOS chips have several advantages as compared to CCDs:

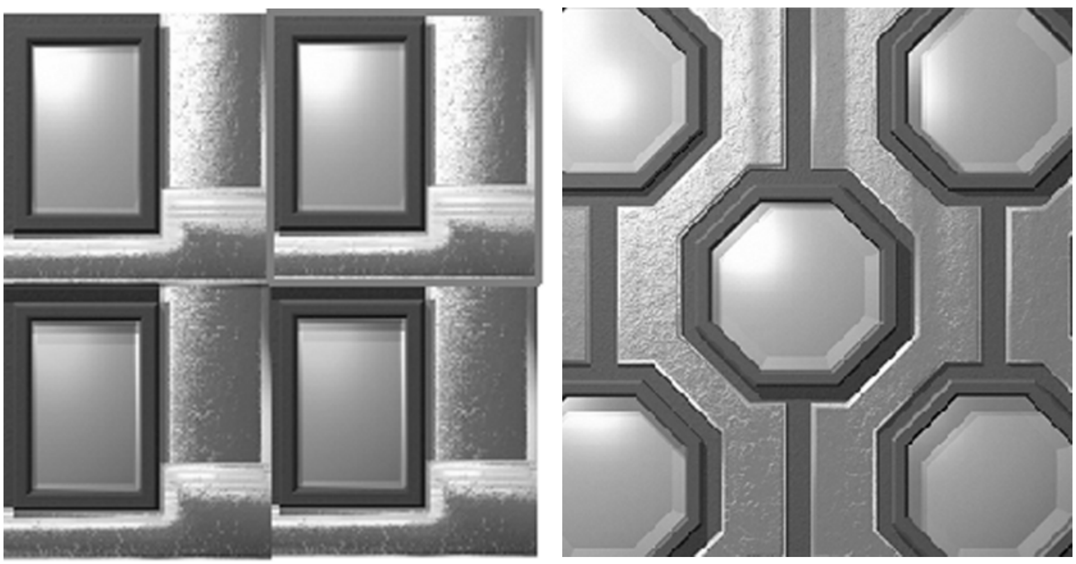
- CMOS sensors are much more versatile than CCDs. That's because while all a CCD can do is capture light and turn it into electrons that are then processed elsewhere in the camera, a CMOS sensor can carry out a variety of extra functions, such as image processing, right on the chip.
- CMOS sensors require significantly less power than a CCD, which helps stretch digital camera battery life.
- CMOS is less expensive to manufacture. A CMOS fabrication factory costs about $150 million to bring on line, while a comparable CCD fabricating facility goes for well over a billion dollars. A typical 3 megapixel CCD may cost a camera manufacturer $30 in quantities of 10,000; a comparable CMOS chip may cost only $18.

Now for the downside (maybe): CMOS has a checkered reputation for image quality. There's no question that early CMOS-equipped digital cameras were terrible; images often were dark, muddy, and speckled with artifacts, and straight lines had a tendency to waver. But they got much better, to the point that both Canon and Kodak use CMOS in their newest ultraexpensive, high-quality, high-megapixel (11MP and 14MP, respectively) professional *D-SLR* (*Digital Single Lens Reflex*) models.

Almost every digital camera under 3 megapixels or costing less than $79 is outfitted with a CMOS rather than a CCD image sensor.

SuperCCD

Fujifilm used some nifty engineering legerdemain in designing a honeycomb-looking image sensor that they call a SuperCCD. (See Figures 1-7 and 1-8.) When all the other components of the camera



(A) (B)

Figure 1-7: Unlike the rectangle pixels of a traditional CCD (A), Fujifilm's SuperCCD has a honeycomb of octagonal pixels (B). (Copyright by Fujifilm)

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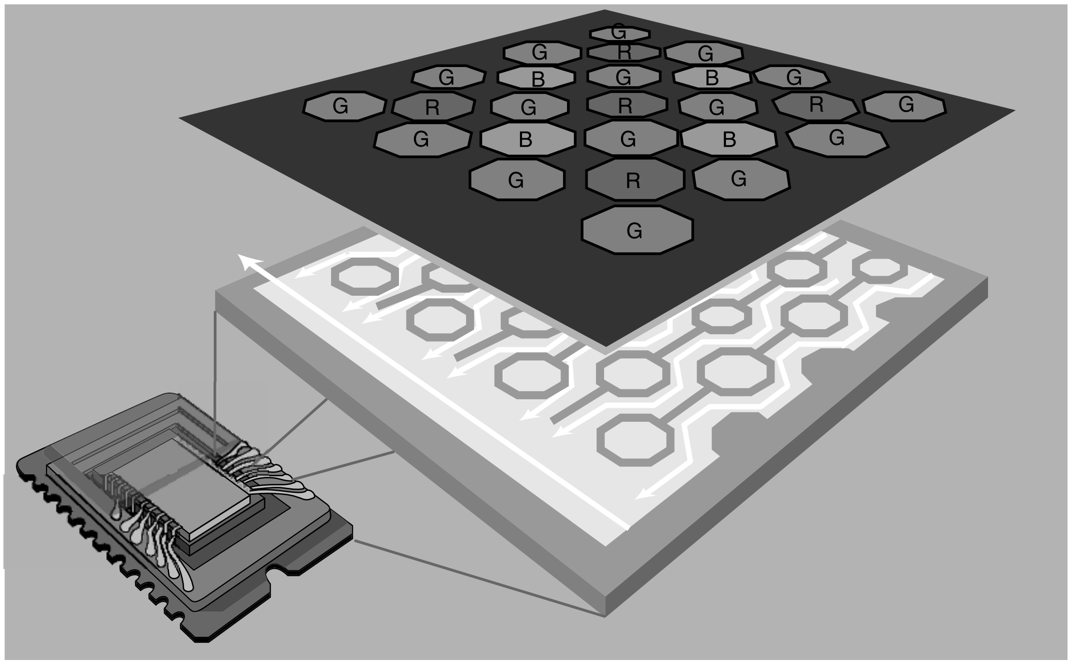

Figure 1-8: Fujifilm's SuperCCD image sensor uses an interlocking honeycombed design that forces each octagonal pixel to abut each other. See also Color Figure 3 in the color insert toward the back of the book. (Illustration based on another provided by Fujifilm.)

are tuned well, the SuperCCD can improve color, dynamic range, and image quality. In addition, the camera's smarts have the ability to hardware *interpolate* resolution to approximately double its actual physical resolution.

Fujifilm, the only manufacturer and user of SuperCCDs, currently produces several fourth generation versions of its chip. Two of its SuperCCDs, available in several camera models, have the ability to capture *two* pixels at each photoreceptor site. The HR version uses the extra pixel to double resolution, while SR's extra pixel helps extend dynamic range, for greater tonality. So far, Fujifilm hasn't combined both extended functions for a super-duper CCD with 4 pixels for each photoreceptor site that features both doubled resolution *and* greater dynamic range, but we wouldn't be surprised to see an announcement for such a hybrid within a couple of years.

X3

Back in the 1970s, Kodak reportedly experimented with engineering a CCD image sensor that would eschew the Bayer pattern checkerboard mosaic for creating color and instead would be able to capture red, green, and blue data at every photoreceptor site. We're told that Kodak abandoned work on the design because it proved to be either impractical or too difficult to commercially manufacture. Still, the idea of being able to capture all color information at each photoreceptor site was alluring, sort of a Holy Grail of image sensors.

The quest was taken up by Foveon, a small company originally known for its professional high-end studio digital cameras. In 2002, it announced the X3, the world's first commercial image sensor capable of capturing all three primary colors at every pixel. The X3 is an impressive piece of engineering. By bonding a tri-pack filter overlay to the image sensor, light representing all the primary colors is allowed to pass through into the photoreceptor site. Then, because of the differences in the wavelengths (think of how a prism splits sunlight into colors), red, green, and blue electrons are collected and register electrical charges at different depths within the photoreceptor site. (See Figure 1-9.) So, instead of the Bayer pattern's checkerboard mosaic that requires triple the number of pixels to produce composite color, the X3 needs only one photoreceptor site to create full color. Also, Bayer pattern image sensors require that the data go through a process called interpolation, to create color and build the image. The X3 has all colors and therefore does not need to be interpolated, and at least theoretically, it creates

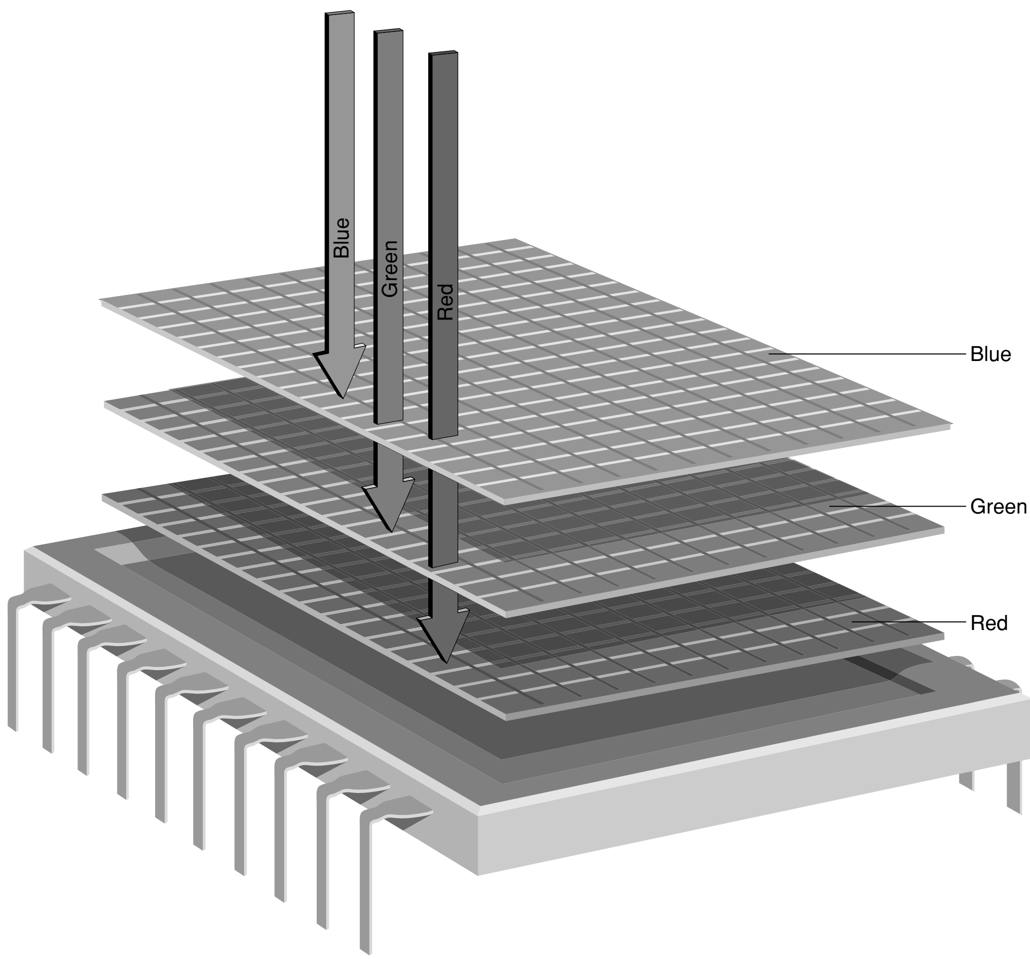

Figure 1-9: Foveon's X3 image sensor captures red, green, and blue light at each pixel by collecting the various wavelengths of light at different depths. See also Color Figure 4 in the color insert toward the back of the book. (Based on an illustration supplied by Foveon. © 1998–2004 Foveon Inc.)

better, more accurate color, as well as eliminates or minimizes common image sensor problems, such as *color aliasing*.

Other Image Sensors

While almost all digital cameras currently use CCDs, CMOS, SuperCCDs, or X3 image sensors, others certainly exist and are being used to capture digital images. Actually, we can't know exactly how many types of image sensors there are, because some are classified and used by the military. Two other sensors are worth noting—Nikon's LBCAST and Matsushita's v(nu)MAICOVICON. (And no, that last one is not a typo, though it should be.)

Famed camera manufacturer Nikon spent 10 years developing its LBCAST chip, which it says combines the high quality of CCDs with the versatility of CMOS. Nikon—which currently buys most of its CCDs from Sony—says that its proprietary LBCAST offers "high-speed, power-efficient, low-noise" capabilities better than any CCD on the market. That's why its first iteration is in Nikon's flagship digital camera, the $3,200 D2H D-SLR. The D2H is a 4 megapixel model (it's designed for sports, photojournalism, and other applications where speed is paramount and image size secondary), but Nikon will probably have higher-megapixel LBCAST image sensors in future products.

Japanese multinational Matsushita (Panasonic) recently announced production of their tongue-twister of a chip, the v(nu)MAICOVICON (try saying that rapidly six times). Developed primarily for camera cell phones, PDAs, and other small devices, the v(nu)MAICOVICON claims to combine the superior image quality of a CCD with the low power consumption and reduced cost of CMOS. The first v(nu)MAICOVICON chips are 1/4-inch square and have a resolution of either 1.3 megapixels or 2 megapixels. Future generations may offer higher resolution, and could eventually find their way into truly tiny cameras (like a cufflink-sized digital camera).

DO I REALLY CARE WHAT KIND OF IMAGE SENSOR MY CAMERA HAS?

Like most open-ended technology questions, the answer is an unequivocal yes . . . or a qualified no. It all depends upon your shooting style and preferences, and how big a budget you have.

The most important thing you should realize is that an image sensor is only one of a number of important components that affect overall image quality. The best image sensor in the world, when coupled with a mediocre lens, will produce a mediocre picture. The same goes for the other critical components that make up a digital camera.

A good case in point is the roundup of five 8 megapixel *prosumer* digital cameras we did for *PC Magazine* ("Five Super Eights," May 18, 2004). What these cameras had in common was that they all were using Sony's ICX456 CCD. On the other hand, all had different lenses, image and color processing, and other design and engineering dissimilarities. Not surprisingly, image quality and performance varied, not due to the type or brand image sensor used, but due to all the other components combined The point is that choosing a digital camera according to what kind of image sensor is inside is much less important than considering the camera in its entirety.

Then there is the reality that you really can't always know exactly what brand of image sensor you'll be getting. Digital camera manufacturers that buy components from other companies are notoriously close-lipped when you ask them what kind of image sensor their products have inside, mumbling some nonsense about how revealing the details would somehow void contractual agreements they have with the image sensor provider. Nor can you pick and choose what kind of image sensor you desire in the digital camera you hope to buy. Unlike an automobile, for which you can select the type engine, hubcaps, paint color, and accessories, image sensors are *not* interchangeable. You simply won't have a choice of what chip will be inside the model you want.

More Really, Really Technical Stuff about Image Sensors That You Don't Need to Know

There are hundreds of white papers and dozens of books written about image sensors, filled with lots of boring and virtually incomprehensible scientific formulae and engineering jargon. Equipment junkies trade information and opinions online about problems, advantages, and design deficiencies of specific types of image sensors on professional photography forums and Web sites. From these sources, you may read or hear about such technical issues as blooming and anti-blooming, smear, MTF, pixel amplification, quantum efficiency, dark current, signal readout, microlenses, lux, interline transfer verses full frame transfer, and so on. While all these and other aspects are important to pros who need to know how an image sensor works and what are its strengths and weaknesses, it's unnecessary, extreme technical overkill for most digital camera users.

ADC and Your Digital Camera's Bit Depth

It may come as a surprise to learn that all image sensors are *analog*, not digital, devices. In fact, the entire universe, except the world that exists inside a computer, is analog. Including film. Digital's sole inhabitants are zeroes and ones, period.

So how do you get digital data from an analog capture device?

That's what the ADC (analog-to-digital converter) does inside your digital camera (and in fact, the reason why it's even called a digital camera). All digital cameras have an ADC chip inside that converts the picture captured by the image sensor into digital data. Not all ADCs are created equal, however. How well and how quickly it does its job depends upon the manufacturer, chip design, and most importantly, the number of data bits it can process.

The ADC works by taking the analog data stream from your camera's image sensor, registering the charge, or number of electrons related to each photoreceptor site, and then deciding whether a piece of data should remain a zero or be a one.

These digital pixels consist of data bits that establish exactly what color that pixel will be. The more bits, the more possibilities for more precisely defining the color's hue, saturation, and brightness. Most inexpensive digital cameras process 8-bit pixels. Better digital cameras may have 10 bits or 12 bits per pixel. That's good, because more information usually translates into better color, more subtle transitions or gradations, and increased clarity of detail in the highlights and shadows. Professional digital cameras and studio digital cameras may even associate 14 or 16 bits of data with each pixel.

Since it's the job of the ADC to convert the analog pixel that the image sensor captures into a digital pixel that your computer can recognize and use, how many bits the ADC can handle (or its *bit depth*) is an important factor in rating the power and quality of your camera.

As with image sensors, you can't specify what kind of ADC your digital camera should have. But you can choose to buy a camera that has, for example, a 12-bit ADC over a 10-bit ADC by carefully looking over the specs on the manufacturer's Web site. If it's not listed, your digital camera probably has an 8-bit or 10-bit ADC, as do many inexpensive consumer models. Better, but pricier models will list the camera's bit depth.

But remember, an ADC's bit depth is only one of many components that contribute to a digital camera's image quality. So, avoid obsessing on buying only a model that has the highest data bit depth, since the lens, programming, and image sensor are equally important.

Not All Electronic Cameras Are Digital Cameras

Back in the early 1990s, when we first started working with and writing about filmless photography, we scrupulously avoided calling every electronic camera a digital camera. Why? Because most of the electronic cameras back then weren't, strictly speaking, digital devices.

Remember, all cameras are analog devices. A camera is only considered to be digital if it has a built-in ADC chip that gives it the ability to instantly convert captured analog information into digital data.

Almost all early electronic cameras used CCD image sensors, but the analog models lacked a built-in ADC chip. So, instead of instantly converting the just-shot image to digital data, it stored the analog information on tiny silver-dollar-sized floppy diskettes in hard plastic shells. (It's very similar to how nondigital camcorders record video, except the camcorders save to analog tape instead of floppies.) Once saved, the floppy was removed from the camera and inserted in a very expensive shoebox-sized disk drive attached to a PC or Mac via a SCSI (Small Computer System Interface) cable. When activated, the drive would read the tiny floppy, process that data through its built-in ADC chip, and transfer the digital file to the computer—a cumbersome, time-consuming procedure.

Not surprisingly, external ADCs quickly went the way of the dodo when affordable digital cameras began reaching the marketplace. But the concept of post-shooting processing lives on, not in hardware, but as the RAW file format so popular with professional photographers. (See more about RAW in Chapter 5.)

Tip: 8-bit Color Is the Same as 24-bit Color

Sometimes, it feels as though computer jargon is purposely complicated just to make things more difficult. When talking about color inside a camera or scanner, bits are described according to how many there are per primary color. Since all cameras and scanners use the RGB color model, that means there are three primary colors—red, green and blue. When those bits are brought into the computer, they are described according to how many there are for all colors. Therefore, 8-bit color in your digital camera becomes 24-bit color in your computer.

What Happens to All Those Data Bits?

If 12, 14, and even16 bits per primary color sounds like an awful lot of data to you, you're right. It is. (See Table 1-1.)

If left intact, all those data bits would inflate image file size and considerably slow down in-camera processing. And it wouldn't really be of much benefit when you view the pictures. The human eye is capable of discerning approximately 12 million different colors, which is why 8-bit color is considered photo-realistic. What's more, only a handful of image-editing programs, like Photoshop, have the ability to work with image files larger than 8 bits. Even if you are able to work in 12-bit or 16-bit color, you can't really output it in that form because there isn't a desktop printer made that can use anything other than 8-bit color.

Table 1-1 How Much Data Is in Those Bits?

Bits	***Formula for # of Colors in RGB***	***Total Possible Colors***
8 bits	256 × 256 × 256	16.7 million
10 bits	1024 × 1024 × 1024	1.07 billion
12 bits	4096 × 4096 × 4096	6.87 billion
14 bits	16380 × 16380 × 16380	4.39 trillion
16 bits	65536 × 65536 × 65536	281.47 trillion

So what happens to those extra bits? They get thrown away, in a process called *sampling*. You are probably thinking: why the heck should a digital camera collect all those data bits if they're only going to be discarded? That's where the camera's smarts come into play. The camera's image processing includes examining all the captured bits, and by using mathematical formulae developed by the manufacturer's engineers, deciding which set of data bits will produce the best image. Some cameras have built-in stored profiles to which they compare the just-shot image, looking for similar pictures and then selecting the best bit set. Professionals and experienced hobbyists who don't want a camera making that decision for them will shoot in RAW file format, which keeps all the bits intact until the photographer can view them in special software in the computer and choose how they should be processed. (See Chapter 5 to learn more about RAW.)

A Computer in Your Camera

When you get down to it, the biggest difference between film and digital cameras relates to the fact that an image sensor is not an exact replacement for film. Shoot a roll of film and your pictures are saved onto the roll. Expose an image sensor to several different scenes, and all you have are a bunch of electrons, converted by the ADC into digital data. The job of turning that data into an actual photograph is handed off to a very small, but very complex computer within the camera. (See Figure 1-10.)

The camera's circuitry and chips, including ASICs and DSPs, process the data to produce form, color, contrast, and luminance and then organize and format it so it can be saved in a recognizable file format. (See Chapter 5 about the file formats, including the RAW format, which postpones much of this processing until the picture is *uploaded* to your computer.) All this is done according to manufacturer-specific proprietary imaging and color science, which is what really sets each camera apart from its competitors. And that is why you can't really tell how good a digital camera is going to be just by reading the specs about its image sensor, ADC, or other components.

Note: Lewis Kemper, Fine Art Nature Photographer

"I like to shoot digital because of the control I have in post-processing. But now you are the processing lab. A lab could take a 36-exposure roll and process all the pictures at once. Now, you have to process them one at a time yourself . . . if you want the most control." (`www.LewisKemper.com`)

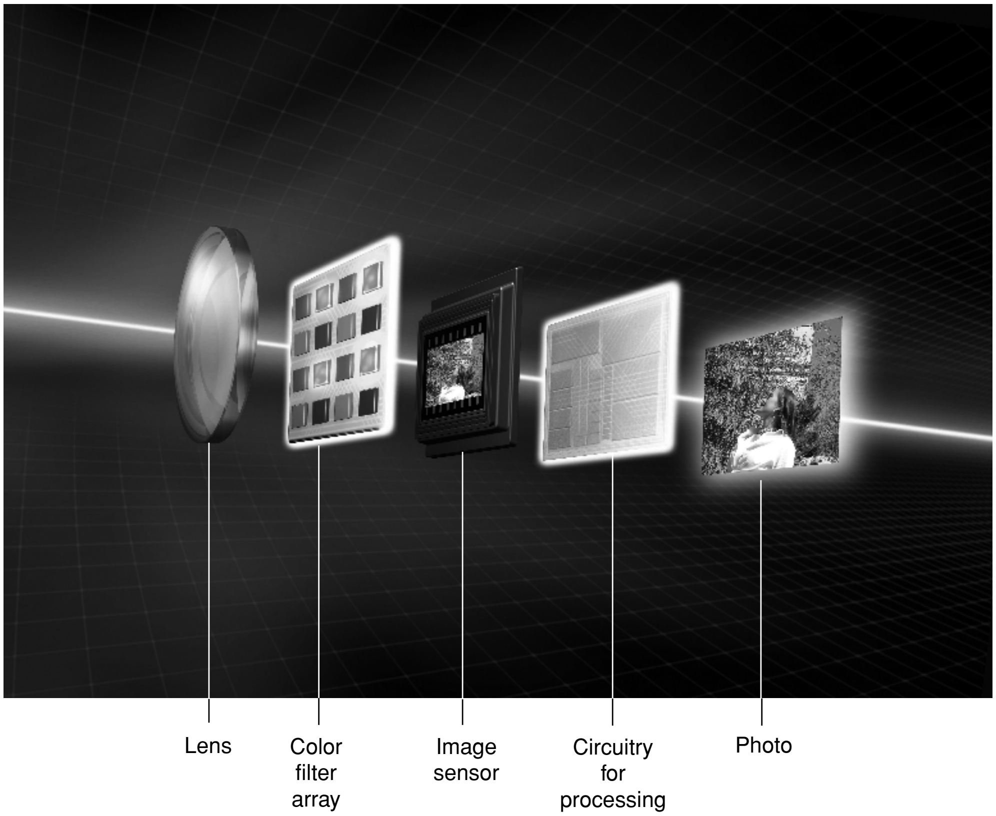

Figure 1-10: A digital camera is a system consisting essentially of a lens, image sensor (with color filter array), and extensive circuitry for processing—all designed to produce a photograph that is indistinguishable from film to all extents and purposes. (Copyright by Sony Corporation.)

Summary

This chapter covered many issues concerning the differences between film and digital photography. Some of the key points included the following:

- Film and digital cameras are quite similar in that you can point them at any subject and take a photograph by pressing a shutter button.
- Film and digital cameras are, however, quite different inside because of all the processing that is required to support the digital technology.
- Much of what we understand regarding film can be used to help us understand digital photography.

- Photography often involves making compromise choices between opposite possibilities, such as choosing between film type (or an image sensor setting) that would have greater sensitivity to light or one offering finer resolution and detail.
- Having an image sensor instead of film entirely changes things at the camera's back end. Pressing the shutter is only the beginning of a complex process that requires numerous other components and engineering considerations.
- Using a digital camera opens up lots of creative possibilities, but it also means that your job isn't over after you press the shutter button.