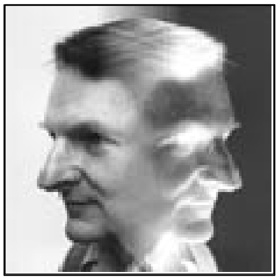

# 2 Image Processing

One of the first machines that was specifically built to translate a photograph into a digital code was the Bartlane cable picture transmission system from the early 1920s. In about three hours the Bartlane system could transmit a photo from New York to London, with sufficient resolution to allow the photo to be printed in a newspaper. Image processing with computers did not start until the sixties, when the first lunar probes were launched. Somehow the people at NASA's Jet Propulsion Lab in Pasadena were able to transform the fuzzy and distorted little pictures returned by the Ranger and Surveyer spacecraft into the detailed images that hit the pages of *Life* magazine. How was this done? There is in fact quite some theory behind these image enhancements. The good news, however, is that the process is by now so standardized that it can be translated into a small set of "digital darkroom tools" that can be used and understood by anyone.

## Digital Photos

Computers work well with numbers, and they can in principle handle any problem that can be translated into numbers. This is not just true for problems with a mathematical flavor. It is also true for photos. A photograph, after all, is just a large collection of dots on a piece of paper. Each dot can have a brightness and perhaps a color. The number of possible dots, brightness values, and colors can be large, but is usually limited. This means that any photo can be translated into numbers and stored in a computer. How many numbers does it take to define a photo? In the next chapter we will see that roughly 20 million numbers can record *all* the information on a single 35mm black-and-white negative, where each number has a value between 0 and 255. Since this is quite a fixed number, we can even calculate the maximum number of different pictures that can be made on a 35mm negative. It is estimated that all photographers, amateur and professional together, take about 10 billion or $10^{10}$ pictures per year. The maximum possible number of pictures is $256^{20,000,000}$. At our current rate, then, we will not run out of things to photograph for another $10^{48,164,799}$ years, give or take a few.

It is actually remarkable that we can translate (digitize) a photograph, any photograph, into a set of numbers without losing information. The numbers are much like a negative: at any time they can be used to recreate the original image. But better still, these digital negatives are much easier to store. They do not age or fade, and they can be manipulated just as easily in a computer as real negatives can be manipulated in a darkroom. It is not unlikely that within the next ten years the conventional camera we all use today will be replaced by a *digital* camera that takes photos on a floppy disk that is "processed" in a normal personal computer with the type of software presented in this book. The photos can be shown on a television set or printed with a high-resolution film printer that may someday be as standard as the dot matrix printer of a personal computer today.

There are signs that this development is under way. Equipment for image recording and replay has over the years become smaller and smaller, so much so that the difference in size between the latest video "camcorders" and a normal SLR (single-lens reflex) photo camera has become almost negligible. In the fall of 1986 companies such as RCA, Hitachi, NEC, and Toshiba introduced the first digital video recorders that internally sample and digitize video images. So far, the digital capabilities of these recorders are used mostly for special effects such as high-quality freeze frame, slow motion, and "insert pictures" (a second video image inserted in the corner of the screen). The move, however, is in the direction of a completely digital video system, and with that it will become very easy to hook up a video recorder to a computer and capture video images on a computer disk.

### Digital Cameras

Digital SLR cameras have been in development for almost ten years. It first became possible to build these cameras with the availability of large CCD arrays. The CCD or charge-coupled device was invented by Willard S. Boyle and George E. Smith at Bell Labs in the early 1970s (the patent is dated December 31, 1974). It works much like a photocell, translating brightness values into electrical signals. By packing thousands of these CCD elements onto a chip, a solid-state image sensor can be constructed that can almost instantly sample an image and encode it into an electrical or even a digital signal. The first application of the CCD image sensors was in solid-state video and television cameras. The resolution of the image sensor depends trivially on the number of CCD elements in the array. The largest CCD device currently available is a 2048×2048 array made by Tektronix, Inc. It measures 2.5 inches square, which makes it also the largest integrated circuit made to date.

The CCD image sensors have a number of important advantages over other types of photo detectors, and even over conventional photographic film. First, they have a much higher quantum efficiency, that is, they are more sensitive to light. They also have a superior linearity and a large dynamic range, which means that there is a simple fixed relation between the brightness of an image and the response of a CCD element for a wide range of brightness values. Finally, the CCD sensors produce a high-quality and stable signal, with very little noise. They have, in fact, only one real disadvantage. The larger cells are still hard to make and are therefore expensive.

*Willard S. Boyle (l.) and George E. Smith*
*Demonstration of the First CCD Camera in Dec. 1974*

The first truly digital cameras for making photographs have yet to be built. Kodak's subsidiary Videk has developed a high-resolution black-and-white CCD camera, named the *Megaplus*, that comes close to such a general purpose digital camera. The camera is built around a 1340×1037 dot image sensor and produces digital output. So far, though, the Megaplus camera has no independent image storage capability; it is meant to be used as a scanner with a fixed connection to a personal computer. The first version being marketed by Videk is also quite expensive (over $10,000). It has, however, all the features of a serious forerunner of the digital camera of the future.

A low-resolution alternative to a fully digital camera is already available today: the still video camera. It has a CCD image sensor, it records photos on floppy disk instead of film, and in fact the only difference from a real digital camera is that it is based on video technology rather than computer technology. Let us look in a little more detail at some of these cameras, though it is good to keep in mind that they cannot compete with the price and resolution of conventional photo cameras and films just yet.

### Still Video Cameras

Several large companies, most notably Canon, Fuji, Kodak, and Sony, have developed, or are in the process of developing, a new generation of SLR photo cameras using CCD image sensors and video technology. In 1980

Sony demonstrated the first “still video image” camera, the *Mavica*, at the Photokina in Germany. Canon soon followed with a still video camera called the RC-701. An experimental version was tested in practice during the Los Angeles Olympic Games in 1984. In May 1986 Canon announced it as a commercial product, and with that it became the first such camera actually being sold. Sony began marketing the Mavica camera in October 1987. Kodak followed with a prototype still video camera in the first half of 1988.


*The Canon RC-701*

Shown above is a picture of Canon’s RC-701 camera. It looks like a normal SLR photo camera, it has all the same controls, but it takes photos on a floppy disk instead of on a film. All main companies are working on a line of products to support the new still video imaging systems. Canon, Sony, and Kodak all have developed still video recorders and players that accept the new photo floppy disks. All three companies also have developed still video image printer systems for producing hardcopy output.

The floppy disk format for the still video cameras has been standardized among the major companies. The roll-film of the future is a small 2×2 inch floppy disk that can store up to 50 color photos. To ease the transfer of images to and from video recorders, the photos are stored in video format, not in digital form. An immediate consequence of this choice is that the resolution of the still video cameras is rather crude. The CCD image sensor in the cameras is capable of recording approximately 780×490 dots per image. The effective resolution of a video image, however, is typically not higher than 480 dots per line and 480 lines per image. To make matters worse, the Canon still video camera records only one of the two “fields” that make up a video frame, e.g., only the odd-numbered lines of the picture. This reduces the effective resolution of the pictures to about 480×240 dots per image. The Kodak prototype camera and the Sony Mavica camera do not have this restriction, but also the resolution of a full video frame is still a far cry from the roughly 4000×3000 dots of a conventional film.

The reason for this poor resolution is clearly not in the cameras but in the recording format chosen and its origin in video technology. To compete with conventional films the resolution of the new cameras will have to get at least 5 times higher, and the price will have to get at least that much lower. There is, however, reason to believe that this can and will happen. One possibility is that the next generation of digital cameras will use truly digital storage of data on miniature floppy disks that can be read directly by a personal computer. The other possibility is the adoption, at least for digital photography, of the new high-definition television standard (HDTV) that has, quite independently, also been in preparation for several years. The HDTV standard would double the resolution of television and video images. Below we will talk a little more about the type of equipment that is available for digital photography right now.

### Scanners and Digitizers

The simplest method to digitize a photograph is to send it to a graphics lab that has good scanning equipment. For a modest fee, say between $10 and $15, they will digitize a print or a slide and provide you with a floppy disk or a computer tape in the format you specify.

Another possibility is to buy a graphics board for the specific personal computer that you own (e.g., one of the TARGA boards for the AT&T personal computers). Most graphics boards have a *frame-grabbing* capability, that is, they have a video input port that allows you to digitize video frames directly from a video recorder or video camera. The resolution will be lower than what you can get from a good scanner, but the convenience of having your own digitizer on line will be a definite plus.

By far the best method is, of course, to purchase your own *photo-scanner* or *digitizer*. For not too much money you can buy small, low-resolution scanners that connect directly to a personal computer. They are advertised in many popular journals, such as *Byte* magazine. Commercially available high-resolution scanners range in price from a few hundred to a few hundred thousand dollars. As can be expected, the more money you spend, the better scanner you can buy. A good scanner that connects to an IBM PC or an Apple Macintosh, for instance, is the SpectraFax 200, made by the SpectraFax Corporation, in Naples, Florida. The scanner can digitize 8×10 inch color prints at 200 dots per inch, and costs about $4000.

The scanner that was used to digitize photos for this book costs about $30,000. It can scan both opaque and transparent images (i.e., both prints and negatives) at up to 750 dots per inch (8 bits per dot) over an image area of maximally 8×10 inches. It is sold by Imagitex Inc., in Nashua, New Hampshire.

Most digitizers of this type hold a single array of photo cells or CCD elements that can be moved mechanically along the length of a picture. Line by line the picture can then be scanned, with a resolution that is determined by the number of cells in the array. The electrical characteristics of the photo cell change under the influence of the light that falls on it. The scanner obtains a reading from each cell in the array that corresponds to the brightness of the image at the precise spot within the image that was focused on the cell. The cheaper scanners have fewer cells in the array and a smaller range of brightness values that can be distinguished. We will come back to the effect of this on image quality in Chapter **3**. Be warned, though, that if you want to be able to process images of acceptable quality you need a system that can produce 512×512 dots (pixels) or more, with at least 8 bits per dot for black-and-white images, and at least 24 bits per dot for color images (8 bits each for red, green, and blue).

### Video Printers and Film Printers

After you have scanned in the image and processed it in the digital darkroom that lives in your home computer, the image must somehow be put back on film or paper. The cheapest solution is simply to snap a picture from the monitor of your system with a Polaroid camera, but you are not likely to be satisfied for long with the quality of such prints.

A good solution is again to send a floppy disk or a tape with the digital output to a graphics labs and have them produce a high-quality image with good equipment. The graphics lab in this case performs the function of the camera store where you would go with a conventional film to have prints made. The problem for the time being is that there are not many graphics labs that process digital images. But that may change.

An alternative is to use a still video image printer that will allow you to produce a medium-resolution print of any video image. Still video image printers are sold by Sony, Kodak, and Canon. The price is around $4000 for the printer and about $1 per print made.

The best, but also the most expensive, solution is to buy your own high-resolution digital film printer that allows you to write back images onto either Polaroid film or 35mm negatives. A digital film printer reads the encoded image and varies the brightness of a light beam that writes the picture back to film in accordance with the processed information stored in the computer. As with scanners, there are cheap solutions that work slowly, at low resolution or with only a few brightness values that can be written back to film, and there are expensive solutions that can work miracles. The most expensive film printers, such as the ones used to make animation movies at the Disney Studios, can cost up to half a million dollars. The one that was used to prepare this book is the QCR D4/2 system made by Matrix Instruments Inc. in Orangeburg, New York. It has a maximum resolution of 4096×4096 dots with a brightness range from 0 to 255. It is relatively slow: it takes about 20 minutes to put a color image back on film at full resolution. Compared to its (up to 50 times) faster brothers it is also relatively cheap. It costs about $20,000.

### Further Reading

A gentle and readable introduction to image processing, including an overview of the early work done at NASA’s Jet Propulsion Lab in Pasadena, can be found in the March 1987 special issue of *Byte* magazine. The more theoretically inclined will probably find more than they bargain for in the following books:

*Digital Image Processing*, by William K. Pratt, John Wiley & Sons, New York, 1978, 750 pgs., ISBN 0-471-01888-0.

*Digital Image Processing*, by R. C. Gonzalez and P. A. Wintz, Addison-Wesley, Reading, Mass., 1977, 431 pgs., ISBN 0-201-02596-5.

*Digital Filters — Theory and Applications*, N. K. Bose, Elsevier Science Publishing Co., New York, 1985, 496 pgs., ISBN 0-444-00980-9.