Computers make images in one of two modes. Object oriented (aka vector, draw) graphics are made of lines and polygons whose shape, size, color, position and other attributes are remembered by the computer. This is the type of graphic used for charts, diagrams and for the most part, text. Although in the hands of an artist, this type of graphic can be quite realistic, it can never reproduce the exact realism of a camera or the character of a drawing rendered by hand.

To create real pictures which can be stored and displayed with a computer, an image is divided into a grid and each cell in the grid is given some value. In the simplest case, the value can be on or off. Pictures then are constructed of a pattern of dots.

Depending on how many dots you use, and how much information is conveyed by each dot, this scheme can vary from the rather crude images of the original MacPaint, to the incredible images produced by the Hubble Space Telescope.

Resolution

The basic unit of a digital image is the pixel, short for picture element. In the purest sense, the one measure of how sharp an image is, is the number of pixels it contains. Here are four variations of the same image, displayed at the same size, but with different numbers of pixels.

It's rather quickly apparent, that the more pixels you have, the clearer the image is, but the amount of information you have to remember is greater. Notice that the fourth picture, although only 10 times greater in resolution than the second picture, requires 100 times more information, since Area = (b x w). Actually, the second picture takes less than 2K, but that's the smallest unit my computer measures these things by.

Another noticable effect is that in the fourth picture, the image no longer seems to be square pixels, since the resolution exceeds the ability of the output device (in this case a laser printer) to display detail.

An image displayed as a bit map, and as an object oriented graphic. The illustration of the bit map is a little misleading. In order to illustrate the idea of a pattern of dots, I've included the grid of lines to define each pixel. When displaying a bit mapped image, there are no grid lines, only black dots (which you can see) and white dots (which you can't).
Rather than expressing resolution as the number of pixels that make up the image, resolution is more commonly measured in **dots per inch**, or **dpi**. This takes into account the size of the image, and therefore the size of the pixels.

Here is the same 40 x 60 pixel image from the previous page displayed at three different sizes. Since all three versions contain the same amount of information, the amount of memory involved is still the same. The size of the pixels is noticeably different. In the smallest version, the size of the pixels is smaller than the output device can display, and therefore the image appears smooth and continuous. Any additional resolution is unnecessary. In addition to occupying extra disk space, it will take longer to load, transmit over a network, or print.

**Pixel Depth**

Images can be classified into several categories based on the amount of color information necessary to display them

**Line copy**

Line art contains only black and white with no intermediate shades of grey. It is only necessary to remember whether that pixel is on or off. Since computers work with binary numbers, only one number (or bit) is required to remember how that pixel is displayed, on or off, 0 for off, 1 for on. This can be referred to as a **1 bit**, black and white, or in some programs the term **bit map** is used for this class of images.

There are some ways a range of tones can be simulated using only one bit per pixels by varying the density of dots. This is called dithering, and there are several ways of doing it. It does not render a very realistic image.

**Gray Scale**

Photographs contain a continuous range of tones. By using more bits to describe each pixel, more shades of gray can be specified. Typically this is done using 8 bits per pixel, which yields 256 possible shades. (2^8 for the mathematically minded). This is about as many shades of gray the the human eye can distinguish.

**Color**

Color images require much more information to describe. Generally colors are remembered by computers by determining the relative intensity of their red, blue, and green components (RGB) which can be combined to create a full range of colors. (Not all the colors the eye can perceive, but most of them). As with gray scale it is typical to specify 8 bits for each component. This boils down to 24 bits per pixel, which gives a possibility of over 16 million colors (2^24).

**Indexed Color**

It is possible to define a color image using only 8 bits per pixel. The computer samples the image and sets up a table of the complete 24-bit descriptions of 256 colors that best match those in the image. Then each pixel is identified with a color in the table. This creates file sizes one third that for full color.

However, 256 colors are not enough for a totally realistic image but is sufficient in most cases. Some banding might result where a color blends from a lighter to a darker shade.

Most programs that allow significant editing of an image require that image to be in the full color RGB mode. Converting from full color to indexed color usually results in some loss of information. It’s usually a good idea to keep an image in full color as long as you intend to work on it, then convert to the smaller 8 bit mode to use in your layout or graphics program.
So how do I decide what resolution to use?

You want to your images to be as clear and accurately displayed as possible, but it’s important to use the minumum amount of information necessary. Any additional information is not used by the computer and takes additional time to load, to transmit over a network, to process if you’re manipulating it, to print and extra disk space to store. Since file size increases by four times as resolution doubles, using excessive resolution can fill hard disks and slow down performance rather rapidly.

Using too little resolution will make the individual pixels obvious. It’s important to take into account whether your going to enlarge or reduce the image when determining resolution. If you acquire an image at 72 dots per inch and then enlarge it two times, the effective resolution will be 36 dots per inch.

The basic formula for determining resolution is to multiply the resolution of the output device by the enlargement (or reduction). For example, if you need a 100 dot per inch image, and you’re going to enlarge it by 2 times, you’ll need to acquire it at 200 dots per inch. Most scanning programs will allow you to specify these two parameters separately and will make the calculation for you.

Choosing the resolution and pixel depth of your images depends on the image and how you intend to use it.

**Line copy to be printed**

Line copy images should be acquired at the full resolution of the printer. These days with inkjet printers and laser printers that means 300 dots per inch. Less resolution will result in jaggy, stairstep edges.

**Gray scale or color be printed**

In order to simulate shades of gray or colors, printers make clusters of dots according to a scheme known as halftoning. This has been done optically for printing presses since long before computers. Halftone screens are generally measured in lines per inch. The general recommendation for the best image quality is to have one and a half times the halftone screen your printer uses to create halftones. Remember to take into account the enlargement or reduction you intend to use.

<table>
<thead>
<tr>
<th>Printer</th>
<th>Halftone screen</th>
<th>Scanning Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 dpi Laser Printer</td>
<td>55 lines per inch</td>
<td>75 dots per inch</td>
</tr>
<tr>
<td>600 dpi Laser Printer</td>
<td>70 lines per inch</td>
<td>105 dots per inch</td>
</tr>
<tr>
<td>360 dpi Color Printer</td>
<td>55 lines per inch</td>
<td>75 dots per inch</td>
</tr>
<tr>
<td>4800 dpi Imagesetter</td>
<td>133 lines per inch</td>
<td>200 dots per inch</td>
</tr>
</tbody>
</table>

**Image to be displayed on screen**

Most computer monitors have a resolution of 72 or 75 dots per inch. Since each pixel on a monitor can display its own color without halftoning, line copy, gray scale and color images are all acquired at that resolution. Again remember to take into account any enlargement or reduction. Incidentally, most monitors display 640 x 480 pixels, so if you’re planning on using an image on the screen, it might be easier to specify the number of pixels you need rather than holding a ruler up to the screen.

Scanners

The most common method for acquiring digital images is by scanning. Scanners contain a small device that scans across the image, illuminating it with a light, and measuring the amount of light reflected from it. It does this for dots of extremely small sizes, eventually building up the image from the pattern of dots.

There are quite a variety of scanners on the market that vary in a number of ways.

**Types of scanners**

*Handheld.* These palm size devices are operated by dragging them across the image by hand. They do a reasonable job, but scan only a 4” wide strip and usually suffer from minor distortion caused by uneven scanning. Most have software that will stitch several strips together. Since they were intended as an inexpensive alternative, they have become less common as the low end of flatbed scanners approach the same price, but are making a comeback for people using laptops computers.

*Roll type.* These scanners have a slot into which you insert a piece of paper which is then rolled past the scanning array. These were quite common in early desktop publishing but virtually disappeared in favor of flatbed scanners. They are making a comeback as specialized devices for Optical Character Recognition, and input devices for fax modems. Usually limited to gray scale.

*Flatbed Scanners.* By far the most common type for imaging. They look like a flat copy machine. The image is placed on a glass and the scanning array passes underneath it.

*Slide Scanners.* Usually very high resolution devices to input 35mm slides and negatives. Some flatbed scanners have adapters for slides.

*Drum type scanners.* This is the type that has traditionally been used in high end publishing systems. Very high quality, very high resolution, very, very, expensive. They are making some appearance in the desktop publishing market.
Resolution
Advertisements for scanners state resolution in two ways. In bold print at the top is usually interpolated resolution, in which the software looks at a lower resolution scan and "interpolates" it by some computational method to a higher resolution. Buried in the fine print is the optical resolution, which is the actual resolution the device is scanning at.

Although better than using a scan with too low a resolution, an interpolated scan will never be as good as one scanned with a device that has an optical resolution as high. Interpolation also often leaves some artifact or noisy pattern in the image.

Flatbed scanners are available at resolutions from 300 dots per inch to 1200 dots per inch. Often you'll see resolution listed as two numbers such as 300 x 600. This means the machine is more accurate in one dimension than the other. When scanning above the lower number, the one dimension is interpolated. These gives a better result than interpolating the whole thing.

As you might expect, higher resolution costs more. As noted on the previous page, you might not need more than 300 dpi unless you plan to be scanning small images and enlarging them.

Pixel Depth
Most scanners give you the option of scanning at 1 bit (black and white), 8-bit gray scale, 8-bit indexed color, and 24-bit color. Some more expensive scanners will scan at 30 to 36 bits which allows a greater range between light and shadow, which is then interpolated down to a 24 bit RGB image.

Size
Most flatbed scanners have a scanning area of 8½" x 14" but some have only 8½" x 11". Scanners are available up to 12" x 17", but they are very expensive.

One or three pass
One pass scanners sample all three colors on one pass, three pass scanners sample each color in a separate pass. It's difficult to say which is superior. One pass scanners have a slight edge in sharpness and speed, three pass scanners have a slight edge in color accuracy.

Control
Scanners are most typically controlled by a “plug-in” module that allows access from inside an image manipulation program like Adobe Photoshop which often comes bundled with the scanner.

A new wrinkle to this are graphics and desktop publishing programs which can use these “plug-ins” to acquire images directly into those programs if you don’t need the image manipulation magic of Photoshop.

Less often a stand alone program will come with the scanner which will create a file you can import into a document or open and edit in an image manipulation program.

Below are the control screens for two different scanners. Both give you the ability to preview and select the image, choose pixel depth, resolution and magnification, and make adjustments to the brightness and color of the image.
Digitizing Video

The image from a television camera can be digitized to yield a still image. It makes a difference if the camera is a normal TV camera or a Digital Video Camera.

Specialized input boards are available that allow you to connect a normal camera or VCR and capture images. Most recent ones connect via a USB port.

Like scanners, these can be controlled either by Photoshop type plug-ins or by standalone programs provided by the manufacturer.

Television images are interlaced. The image is made up of about 525 lines. When the camera makes the image, every other line is scanned, and then the other set is scanned to complete the picture. Each pass takes a sixtieth of a second, for a total exposure time of a thirtieth of a second for the whole frame. The difference in the two segments can be someone different with a fast moving image. You usually have the choice of capturing the whole image, which will generally yield more information and better quality on a still image, or to capture only one of the interlaced scans, which will usually yield a better image of motion. In some cases the computer will fill in the missing lines based the difference between the lines above and below.

If you've worked with video cameras and VCR's much, you've probably notice that the tape recorded signal is not as good as the original camera image. The same is true when the image is digitized. This is more noticable in color than in gray scale, and for small image sizes might not be noticable at all.

Digital video cameras typically connect over a Firewire port and yield sharper pictures more like digital still cameras.

Unlike scanning, the resolution of a digitized video image is fixed at a certain number of pixels, which limit the amount they can be enlarged. Typical sizes are 640 x 480 pixels for the both scans to

Digital Cameras

Still cameras which capture digital images are available at a wide range of quality levels ranging from small black and white cameras that must be connected to the computer to professional SLR bodies with digital back that can capture magazine quality images.

Web Cams

At the low end are web cams, futuristic looking little things that cost about $100. They have no viewfinder and must be used connected to the computer. They create usually create images at a fixed resolution of 640 x 480 pixels. Their biggest attraction has been that they can be connected to the serial port of any computer and require no special devices. They also works with some free and inexpensive internet videoconference software. One was featured as the eyes of a robot on The X-Files. Images are captured with a stand alone program.
Point and Shoot digital cameras

A variety of cameras have been developed in the last year or so that behave much like the point and shoot cameras we all use. The first one was the Apple Quicktake, but now many others are available, for between $200 and $1000.

They take full color, from 640 x 480 to 3000 x 1800 pixel images. They can store anywhere from 8 to 400 images. You usually have the choice to store more pictures at lower resolution.

At the low end of the price range they have fixed focus lenses that let you take pictures from four feet to infinity, although zoom lenses and supplementary close up lenses are common as the price goes up.

The exposure is completely automatic, but most have override. They vary in how well they work in low light levels, but all come with automatic flash.

Many connect to the computer over the serial or USB port but alternatives to utilize the floppy drive are available or special readers. Most save as JPEG files which can be opened in Photoshop or come with applications that will convert to other commonly used file formats.

Professional Digital Cameras

Built into the back of a professional single lens reflex camera, professional digital cameras can acquire images at 3000 x 2000 pixels. Each one of these images requires several megabytes of storage. Some of these cameras actually have a tiny hard drive built in and some use memory cards. Starting prices are about $5,000 and go through the roof.

They are catching on because of the flexibility they give. I've heard stories of photographers on a location shoot sending photos to their art directors in New York over modems so they can make suggestions and revisions while the shoot is still going on.

File Formats

Since all digital image really are basically a grid of pixels, you'd think there'd be a simple way to save these files. However, there are numerous schemes of how this data gets organized and therefore a lot of different file formats. As with choosing resolution and pixel depth, a lot depends on what you intend to do with them. The basic differences in formats usually relate to compatibility with programs you'll import them into, and file compression. Since digital image files can be rather stunningly large, many schemes have been developed to reduce these file sizes.

Most programs that manipulate files also have there own format that also saves information specific to that program like custom color palettes, clipping paths, layers etc.

There are also many formats for exchanging files between programs.

File formats for printing on the Macintosh

PICT - The PICT format was developed as the standard way to save graphics files on the Macintosh. (Object oriented files can also be save in PICT format.) When you're cutting and pasting to and from the clipboard you're basically moving a PICT file around. PICT is particularly good at compressing flat areas of color, so it would be a good way to save drawings with a lot of plain background. It is probably going to be importable and openable in just about any graphic, layout, or wordprocessing program on the Macintosh.

TIFF (Tagged Image File Format) This format was developed to exchange documents between different applications and different computer platforms. This format can describe files of just about any size or pixel depth. It supports LZW compression which can reduce file sizes considerably without any loss of image quality. TIFF files can be read by all professional high end graphics, page layout and image manipulation programs. Some lower end graphics programs might not recognize TIFF files. You might have to install a specific filter to import them into your word processing application. It is probably the the best format to use if you're sending your files to a service bureau for output. TIFF files created on a Macintosh are also usable on a PC but may not display correctly in a page layout program, but they'll probably print OK.

EPS (Encapsulated PostScript) This format is supported by professional high end graphics, page layout and image manipulation programs. It creates larger file sizes than most file formats, but some programs, notably Adobe Illustrator, prefer this format. This format is also transferable to DOS/Windows but may not display correctly. If your printer doesn't support the PostScript page description language, these files may print poorly or may not print at all.
File formats for printing on DOS/Windows

It's probably a good idea to remember to put the appropriate three letter extension at the end of the file on DOS/Windows. Some programs won't recognize graphics files without the proper extension.

**BMP** - a common DOS/Windows file format for saving digital images.

**PCX** - developed for PC Paintbrush. It's probably one of the most commonly supported formats used by word processing programs. If your program won't insert TIF, try using PCX.

**EPS** - Same as on the Macintosh, but uses a different scheme for the image on the screen. If you're printing to a Postscript printer it will probably print OK even if it just displays a box on the screen. If you're printer isn't PostScript, it may print poorly or not at all.

**TIF** - Same as on the Macintosh, but a slightly different file structure. Most professional page layout, graphics, and image manipulation software will accept TIFF files from either platform, but some word processing or graphics modules from integrated programs may be not recognize or not display files from the other platform.

File formats for Internet applications

Web browsers don't handle object oriented graphics so everything must be converted to a bit map. When saving files for transmission over the Internet two criteria take priority, file size and compatibility. Two formats are available which perform this function admirably.

**GIF** - Graphics Interchange Format developed by CompuServe. Does a tremendous job of compressing files without degrading the image. It is particularly good when you have large flat areas of color and straight lines, like a graph or chart. Can be read by almost all applications used on the Internet. Requires the image to be 8-bit indexed color.

**JPEG** - Joint Photographic Experts Group format can obtain tremendous compression depending on the kind of image. JPEG offers several levels of compression. At the most extreme levels image quality can suffer. Most applications that save in this format will give you the choice of what compression/quality level you prefer. The loss of quality at the moderate level is hardly noticeable. Opening a JPEG file and then saving again as a JPEG repeatedly can degrade image quality considerably. JPEG requires 24 bit color images. Can add noise to images with large flat areas of color.

Image Editing Applications

Programs which deal with the kinds of images we are talking about are sometimes referred to as Paint programs. PC Paintbrush is the grandaddy on the PC side, and MacPaint was one of the first programs available on the Mac.

In practical term, anyone really wanting to manipulate digital images is going to be using Adobe Photoshop. Other programs which compete with Adobe, but have special applications include ColorIt, Fractal Design Painter, and if you're really professional XRes. Many general purpose graphics applications like Canvas, and Clarisworks have some ability to edit digital images. You may find that memory requirements are much greater for these programs when working with digital images.

The basic things you need an image editing application for are retouching flaws in an image, changing pixel depth or resolution, and translating files into other format.

When you get into the higher level functions of Photoshop, the sky's the limit. You can combine images in a variety of modes with features like transparency, and transform images from photographic realism to turning into something that looks like a watercolor.

![Quicktake image combined with landscape downloaded via internet from the Smithsonian](image1)

![Dry brush effect applied to the image to give the impression of a painting.](image2)
Application Notes

Size or Pixels

I've emphasized repeatedly that it's important to determine the size and resolution you need when creating a digital image. Most presentation, graphics and page-layout programs in which you will use your image take the size information and use that to display the image no matter what its resolution. Web Browsers, like Netscape and Microsoft Internet Explorer, however, only take note of the number of pixels. An image you have created as 3" x 5" at 110 dots per inch will display in your web browser as 4.6" x 7.5" because the browser just takes into account the number of pixels (330 x 550) and displays them at the screen resolution of 72 dots per inch. When preparing images for web pages always use the screen resolution.

Linked or Embedded

Programs which import images have two schemes for storing the information. Some programs give you the option of choosing either method.

Embedding

When a picture is inserted, a complete copy of the image is incorporated into the new file. The advantage is that the new file is now self contained. It can be copied or moved without losing track of the original file. This is especially useful if the image was obtained from a CD-ROM which may not always be available. The disadvantage is that the new file grows by the size of the image.

Powerpoint fully embeds image into it’s files

Linked

When the picture is placed, only a fairly low resolution copy of the image is stored inside the file and the location of the original image file. When it's necessary to have the best quality image for printing and display, the program goes to the original file for the information. In this scheme, you must keep the original file available to the program in the location it was when you imported it. If the file has been moved, the program will probably prompt you for its new location. If the file is unavailable, depending on the program, it will display the low resolution copy it has stored, or not display it at all. The advantage to this scheme is that the program files are much smaller. You don’t have to take up extra disk space if the image was completely copied inside the new file, and it’s easily accessible if you want to edit or update it. The disadvantage is, you have to keep close track of it. With this type of program, it’s best to create a subdirectory (Windows) or folder (Mac) and keep all the files associated with a project in that subdirectory/folder. If you copy the project, copy the entire subdirectory/folder and the program won’t lose track of its linked files.

On the internet all images are linked and must stay with the web page file in order to be displayed.

Some Size Comparisons

All files created from a 3" x 5" image at 72 dots per inch

<table>
<thead>
<tr>
<th>Image Type</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 bit full color image</td>
<td>356 K</td>
</tr>
<tr>
<td>8 bit 256 color image</td>
<td>119 K</td>
</tr>
<tr>
<td>24 bit full color image saved as TIFF with LZW compression</td>
<td>188K</td>
</tr>
<tr>
<td>24 bit full color image saved as JPEG (maximum quality)</td>
<td>85K</td>
</tr>
<tr>
<td>24 bit full color image saved as JPEG (lowest quality)</td>
<td>32K</td>
</tr>
<tr>
<td>8 bit 256 color image saved as TIFF with LZW compression</td>
<td>102K</td>
</tr>
<tr>
<td>8 bit B&amp;W image saved as TIFF with LZW compression</td>
<td>94K</td>
</tr>
<tr>
<td>8 bit 256 color image saved as GIF</td>
<td>94K</td>
</tr>
<tr>
<td>8 bit 256 color image saved as PICT</td>
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</tr>
<tr>
<td>PageMaker file with linked B&amp;W TIFF</td>
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<td>PageMaker file with embedded B&amp;W TIFF</td>
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<td>PowerPoint '97 file with 1 blank slide</td>
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</tr>
<tr>
<td>PowerPoint '97 file with maximum quality JPEG</td>
<td>107K</td>
</tr>
<tr>
<td>PowerPoint '97 file with 256 color TIFF</td>
<td>110K</td>
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</tbody>
</table>