

Lecture 1: An Introduction to Computer Graphics

We are all familiar with computer graphics, in the sense that we see them everyday: on television, in films, in books and magazines, on posters, and - of course - on our computer monitors. They are so ubiquitous that we no longer pay them any special heed.

Yet, even though computer graphics surround us, most of us know very little about them. What are they? How can they be created and edited? How can we use them? Why should we use them?

Even people who use graphics packages are often unaware of the nature of the graphics they are manipulating and are unable to understand, for example, the difference between vectors and bitmaps, or why resizing a picture can distort and degrade it, or how to calculate the required resolution for printing an image, and so on.

This lecture attempts to answer such common questions and to thus enable the reader to understand computer graphics and use them (more) effectively. The information is aimed at multimedia and graphics profession, with an emphasis on the practical application of the theory behind computer imaging.

We will be looking at the two different types of graphic - vector and bitmap (raster) - and the associated pros and cons of each. We will then explore the mysterious concept of image resolution, image size and how they relate to screen display and printing.

What are computer graphics?

A computer graphic is really nothing more than an image represented by a computer, usually on screen and sometimes on a printout. The image may come from the real world - such as a photograph or a drawing that has been *digitised* (converted into computer-readable form) - or it may have been generated in a computer using graphics software.

In essence, a computer graphic is no different from an ordinary picture on paper, at least in appearance; however, being stored in digital form provides many advantages. Digital images can be:

- copied freely and stored safely on disk
- distributed with ease, either on disk or by data transmission along communications lines
- manipulated in literally hundreds of different ways by software
- incorporated into documents such as reports and publications (*Desktop Publishing* or DTP)
- archived in image libraries
- output to a wide variety of devices, particularly monitors, TVs and printers

The vast majority of the images we see today - in books or magazines, on advertising boards, on television - are, or at some time have been, computer graphics. All computer graphics fall into two broad categories: *vector graphics* and *bitmap images*, the difference between the two being the method of storing and describing the image data.

Before working with computer images and shapes, you will need a thorough understanding of the main differences between bitmap images and vector graphics. Both types contain a range of formats, which are suitable for different applications.

Understanding which type, and format, is appropriate for different applications is of critical importance in Multimedia where both file size and image quality can be affected by the type and format you choose for an image.

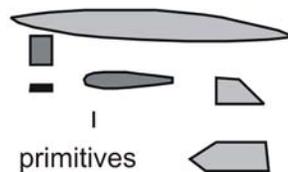
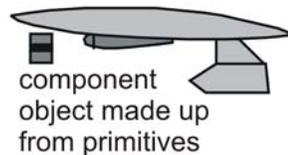
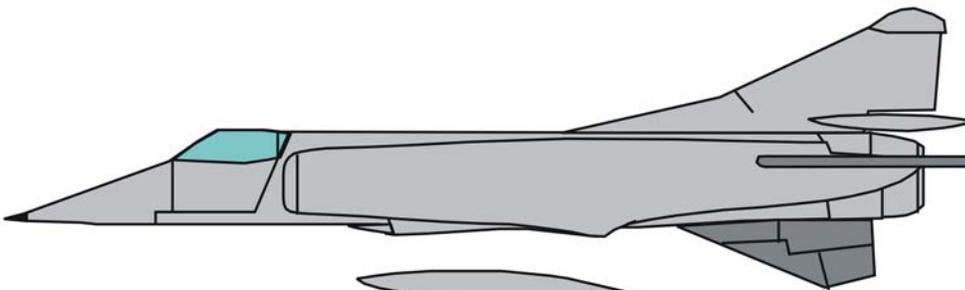
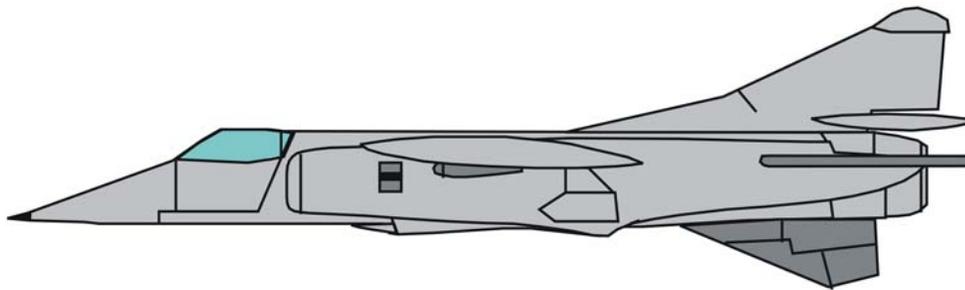
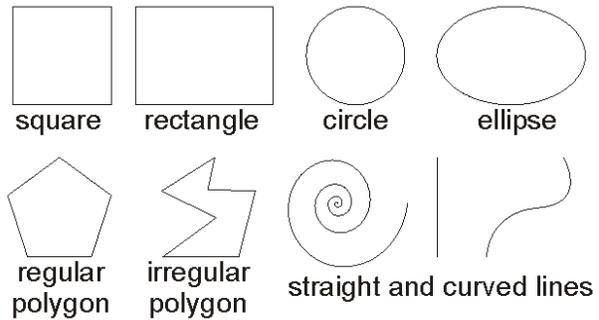
Vector Graphics

Vector images are composed of *objects*. All objects are built up from *primitives* - basic drawing instructions such as *line*, *rectangle* and *ellipse*.

These objects may be grouped together to form new composite objects to form an *object hierarchy*.

Consider, for example, a picture of an aircraft in vector format.

Some Primitive Shapes



At its simplest level it is composed of primitives such as circles, lines and rectangles; however, it can also - and more usefully - be represented as a collection of objects (wheels, engines, wings, doors, etc) that can be composed of primitives *and* objects.

So, for instance, the wing object is composed of component objects (ailerons, flaps, engine) which in turn contain other objects (the engine contains a propeller, fuel feed, etc) and so on down the hierarchy until primitives are reached. The wing object itself, of course, is part of the overall aircraft object. In a drawing package objects can be aggregated and disassembled at will, giving the designer of the graphic considerable flexibility.

The Advantages of Vector Graphics

Vector graphics are highly flexible in terms of image manipulation: they can be resized in any direction and to any magnitude without loss of quality (although if scaled by different amounts in the horizontal and vertical directions some distortion of proportion will occur) and their constituent objects and primitives may also be scaled or moved at will.

Vector images are also very 'cheap' in terms of memory, as the image data is simply a set of graphical instructions to the computer - e.g. *line* ($x1,y1,x2,y2$), *circle* ($x,y,radius$) - together with their *parameters* (or *operands*) - $x1$, $y1$, *radius* - and any associated colour data, all of which is coded as a small set of numbers which take up very little disk space, enabling a complex image to be stored in a file only a few tens of kilobytes in size.

Vector graphics are resolution-independent - that is, they can be scaled to any size and printed at any resolution without losing detail or clarity. As a result, vector graphics are the best choice for representing bold graphics that must retain crisp lines when scaled to various sizes - for example, logos.

Disadvantages of Vector Graphics

All vector graphics are computer-generated - by definition - and thus are rarely, if ever, truly accurate representations of real-world objects.

It would be extremely impracticable - and in all likelihood impossible - to draw a vector image of, say, a tree with knots and organic growth on the trunk and the intricate structure of branches. It would certainly be possible to draw an abstract version of the tree to show its general shape and form, but it would contain only a fraction of the visual information present in a photograph of a particular tree.

Similarly, whilst a vector image of the Mona Lisa would be recognisable as a representation of Leonardo's work, it would not be capable of storing the level of detail that exists in the original painting.



A bitmap version of Leonardo's Mona Lisa



A vector version of Leonardo's Mona Lisa

Bitmap Images

Bitmap images - also called raster images - use a grid of colours known as pixels (short for Picture Elements) to represent images. Using a fixed grid, pixels are assigned a colour and location, which together fool the eye into seeing a complete image.

Because every pixel can represent a different colour value, bitmap images are the perfect electronic medium for continuous-tone images such as photographs, paintings or images with a lot of detail, as they can represent subtle graduations of shade and colour.

Bitmap images are resolution dependent. They contain a fixed number of pixels, which will appear jagged if printed at too low a resolution or viewed on screen at too great a magnification. As a result, they can lose detail and appear jagged if they are scaled on-screen or if they are printed at a lower resolution than they were created for.

Advantages of Bitmaps

The bitmap format is ideal for detailed art and real-world images. Bitmaps can potentially store immense amounts of information (as reflected by the large file sizes) and can be edited in great detail, even to adjusting the colour of individual pixels.

Artistic brush and smear effects can be applied to simulate 'real' painting. Sophisticated effects can be achieved on bitmaps with the right software. Image Processing (IP) techniques can be applied to sharpen or smooth details, adjust contrast and brightness, apply different coloured filters to the image, remove noise and so on.

This sort of image enhancement is frequently used in graphic art and multimedia studios to manipulate the appearance of bitmap images.

Disadvantages of Bitmaps

Because bitmaps are resolution dependent, it is difficult to resize bitmaps without image degradation or information loss. Enlarging a bitmap means that new pixels have to be created (so as not to leave blank spots) and the colour of each new pixel is commonly based on the colour of its neighbours - this usually results in a blocky, unnatural appearance.

Reducing a bitmap involves discarding pixels, which necessarily results in loss of information and detail. Bitmaps can be quite expensive in terms of memory as the value of each individual pixel is recorded: the size of the bitmap in bytes is the product of the horizontal and vertical dimensions (in pixels) and the number of bytes per pixel.

Image Resolution

When dealing with bitmap images, a key concept is image resolution (or the number of pixels which make up an image). Resolution relates to the quality of bitmap images. For example, a high-resolution image contains more pixels and hence is more detailed than a low-resolution image. Different resolutions are required for different output media because of the way our eyes work to assemble pixels into images.

Computer monitors display pictures by dividing the screen into thousands (or millions) of pixels, arranged in rows and columns. The pixels are so close together that our eyes assemble them into one complete image. The quality of a display system largely depends on its resolution (how many pixels it can display) and how many bits are used to represent each pixel. The lower the number of bits available to represent a pixel, the fewer number of colours that pixel can be. Modern monitors display at 24 bits per image or around 16 million different colours.

Typically, monitors display 72 pixels per inch (ppi). This means that in every inch on the screen there will be 72 pixels displayed horizontally and 72 vertically or a total of 5184 pixels. One of the easiest and most common ways to express resolution is in pixels. For example, an image that is 1000 pixels by 1500 pixels is expressed as (or has a resolution of) 1000 x 1500 pixels. This, however, does not tell us the actual horizontal/vertical dimensions of the image. That depends on the resolution of the display/output media.

For example, 1000 x 1500 px displayed on a monitor at 72ppi would be as follows:

$$\begin{aligned}1000 \text{ px} / 72 \text{ ppi} &= 13.8 \text{ inches or } 35.28 \text{ cm} \\1500 \text{ px} / 72 \text{ ppi} &= 20.833 \text{ inches or } 52.9 \text{ cm}\end{aligned}$$

If the same image were to be professionally printed at 300 dots per inch (similar to pixels per inch, but used when the output medium is print based) the calculations would be:

$$\begin{aligned}1000 \text{ px} / 300 \text{ dpi} &= 3.33 \text{ inches or } 8.47 \text{ cm} \\1500 \text{ px} / 300 \text{ dpi} &= 5 \text{ inches or } 12.7 \text{ cm}\end{aligned}$$

The most important point to remember when dealing with resolution and image size is that the actual number of pixels does not change, just how close they need to be positioned to each other in order to fool our eyes into seeing a cohesive image. Typically images displayed at 72 pixels per inch on a computer monitor appear seamless to our eyes. To appear the same way on professionally printed material, the image needs to be printed at around 300 dots per inch (otherwise the image will appear blocky or 'pixelated'). This is why the display/print dimensions of an image change depending on the output medium.

Once you understand the relationship between resolution, image size and dpi/ppi, if given any two of the values, you can calculate the third. While this seems a pretty useless skill to cultivate, it's actually of vital importance in Multimedia.

Using the resolution 1000 x 1500 pixels, an image size of 4" x 6" and a dpi of 250 pixels, let's look at the calculations:

$$\begin{aligned}\text{Resolution (in pixels) / image dimension (in inches)} &= \text{DPI} \\1000 \text{ pixels} / 4 \text{ inches} &= 250 \text{ dpi}\end{aligned}$$

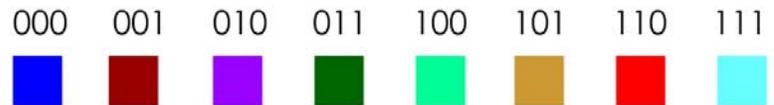
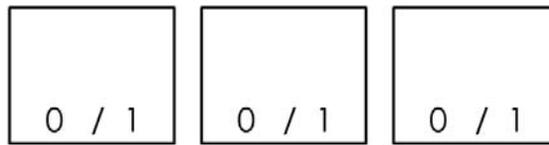
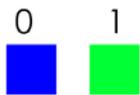
$$\begin{aligned}\text{DPI} \times \text{image dimension (in inches)} &= \text{resolution (in pixels)} \\250 \text{ dpi} \times 4 \text{ inches} &= 1000 \text{ pixels}\end{aligned}$$

$$\begin{aligned}\text{Resolution (in pixels) / dpi} &= \text{image dimension (in inches)} \\1000 \text{ pixels} / 250 \text{ dpi} &= 4 \text{ inches}\end{aligned}$$

Colour Depth

Beyond resolution, another important factor in determining image quality is colour depth. Colour depth is expressed in bits, and by knowing the number of bits each pixel has available to express colour information, it is possible to calculate the total number of potential colours a pixel can represent.

Because one bit can only express two values (0 or 1) a pixel in a one-bit image can be one of two colours.



Pixels in a 3-bit image can be one of 8 possible colours, due to the total number of bit combinations.

Once you understand how it works, calculating the number of colours a pixel can potentially be at each colour depth is easy.

Number of colours = $2^{\text{colour depth}}$

e.g.

- 1 bit colour = 2^1 (2 colours)
- 2 bit colour = 2^2 (4 colours)
- 3 bit colour = 2^3 (8 colours)
- 4 bit colour = 2^4 (16 colours)
- 8 bit colour = 2^8 (256 colours)
- 16 bit colour = 2^{16} (65536 colours)
- 24 bit colour = 2^{24} (16777216 colours)

You'll remember from our earlier calculations that total image size is calculated by multiplying the physical dimensions of the image by the colour depth in bits.

Comparing two images the same physical size, the one with the lower colour depth will be smaller, because less bits are used to describe the colour depth.

This technique is often used to make images for the Internet smaller, but is also used for multimedia applications running on fixed size media (such as CD-Roms) where space can be an issue.

While reducing the colour depth of an image can reduce the number of kilobytes required to save the image, it is not without loss of image quality.



Image at 3-bit colour
(total of 8 colours)
Filesize: 4.2Kb



Image at 6-bit colour
(total of 64 colours)
Filesize: 8.4Kb

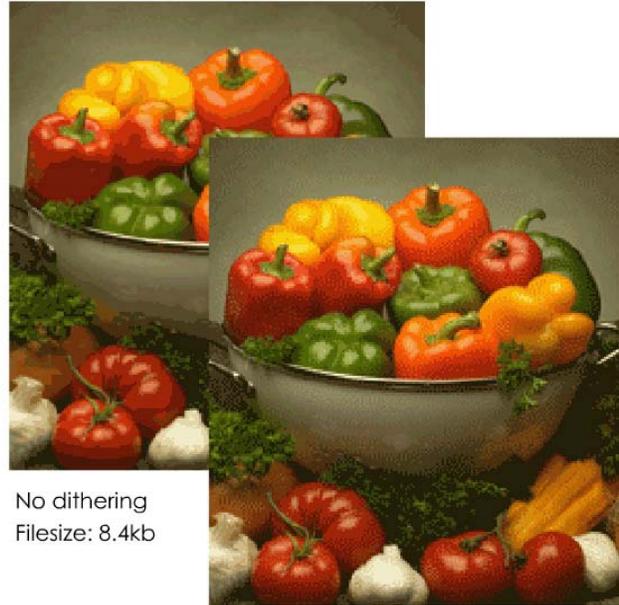
Dithering

Reducing colour depth works by limiting the number of colours a pixel can potentially be. This reduces the number of colours available to represent an image. To combat this, a technique called 'dithering' is used.

Dithering involves inserting a pattern of different coloured pixels into an image to create the illusion of a single colour.

This process is designed to make colour transitions appear smoother. Dithering can increase file size, but not as much as an image with a higher colour depth will, so it's often worth the trade-off.

Dithering is also used when printing images, as most digital images contain a lot more colours than printers have colours of ink.



No dithering
Filesize: 8.4kb

Image with dithering Filesize: 8.9kb

Image Resolution vs. Print Quality

Earlier we talked about how printed images can appear 'blocky' or pixelated compared to the same sized image on screen. Before printing it's a good idea to calculate the potential quality/size of the image. To do this, divide the number of pixels in each direction by the number of inches you wish the finished size to be. For example:

$$\begin{aligned} 1000 \text{ pixels} / 4 \text{ inches} &= 250\text{dpi} \\ 1500 \text{ pixels} / 6 \text{ inches} &= 250\text{dpi} \end{aligned}$$

For a domestic printer, that will work out fine. For commercial presses, however, the minimum is usually 300dpi. In fact for super glossy, high quality print jobs, images could be printed at anything up to 1200dpi! As a rule of thumb, try to never go below 200dpi for domestic purposes. Of course, another handy thing is to work backwards: to calculate the largest an image can be at a given dpi. For example:

$$\begin{aligned} 1000 \text{ pixels} / 300\text{dpi} &= 3.3 \text{ inches} \\ 1500 \text{ pixels} / 300\text{dpi} &= 5 \text{ inches} \end{aligned}$$