The Scanning of Colour and B&W Film and Photographs for Image Processing, Analysis and Archiving - On a Tight Budget

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This article discusses the scanning of film and photographs using modern and relatively cheap flatbed film scanners, such as the Canon 9950F, Epson V700 and Epson 4990 Photo, all available for under £500. It compares the scanned film image quality between these scanners and a £8,000 Flextight 848 semi-drum scanner, and concludes that there is little, if any, discernible difference, although the Flextight has a much faster throughput. The article also considers the optical resolution of B&W, Colour slide and colour negative film, and compares it with that in modern digital camera images. It also covers the loss of detail caused by the scanning process, and possible problems with archiving original film and digitised scanned images.

Despite the advent of the new PC based digital camera era, there is still a vast archive of film. The obvious thing to do is to scan film optically using a high resolution film scanner and to convert the image into a digital file for digital distribution, PC archiving, and image processing. The likes of NASA can easily afford the best £10k plus PMT drum scanners and professional flatbed scanners for their spaceflight photo archives. See some professional scanners at www.imacon.dk, www.aztek.com, http://graphics.kodak.com (Creo) and www.flatbed-scanner-review.org. You can download selections from the NASA digitised archive at http://grin.hq.nasa.gov.

An optical 8000 dpi Hasselblad Imacon Flextight 848 drum scanner costs around £10k, with the 949 around £18k. With drum scanners there is no glass between the detector and the film, unlike that found in professional flatbed scanners such as the Kodak ‘Creo’ £15k [10,000 dpi] IQSmart 3, the £35k [8000 to 14000 dpi] EverSmart Supreme II flatbeds and far cheaper consumer ‘photo’ flat beds such as the new 6,400 dpi Epson V750 and V750 Pro at £500 and £650 respectively. Top end scanners are used by imaging professionals for things like magazine production and museum film archiving. Cheaper dedicated 35mm slide and negative scanners also have no glass between the lens and the film surface, although few, other than the £500 Epson 3200 [dpi], can scan negatives greater than 9 x 6 cm. Quality 35mm slide scanners include the 4000 dpi Nikon Coolscan V 35mm scanner at £500, the 4,000 dpi Nikon Super Coolscan 5000 35 mm scanner at £800, and the 4000 dpi 35mm Nikon 9000 [3-CCD sensor] film scanner at £2,000. The Nikon 9000 can also scan film up to 9 x 6 cm in size and histological sections on glass slides. As well as offering better optics and detectors, higher priced scanners have important extras like attachments to greatly improve the film throughput, essential if you have an archive of 50,000+ colour slides.

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While some of these prices may appear a lot just to scan film, installing a 2k x 2k or higher resolution digital camera on a transmission electron microscope can easily cost around £20k to £45k per TEM system. So many stick with traditional 1/4 plate B&W TEM developed film negatives. Recently, prices of high resolution 4,000 dots per inch (dpi) consumer flatbed scanners have tumbled, facilitating a cheap way to digitise film for figures in papers or for subsequent image analysis. This has eliminated the need to produce photographic prints from TEM negatives, and allows easy post scan image editing and photo-stitching of negatives that would have taken hours in the traditional darkroom.

![Fig.1. The three photo flatbed and one drum scanners used to produce the images in the other figures. (A) The £300 Epson 4990 Photo (B) The £5,000 Agfa Duoscan 2550T (C) The £300 Canon 9950F (D) The £8,000 Hasselblad Imacon Flextight 848 drum scanner.](image-url)
The black and white (B&W) silver halide process produces a far more stable image compared to those produced with colour dye substitution (colour slides and negatives). Walt Disney famously created separate B&W red, green and blue filter film masters of his cartoon films Snow White and Bambi during production to overcome problems associated with dye fading in the original colour master. The support material, particularly old celluloid and nitrocellulose stock, may degrade badly with time even as B&W film, although storage conditions are critical. Modern film uses tough polyester as a base. Early photographers used glass plate as the support medium that was also very durable – until you drop them. Colour fading is a serious problem with colour film – although some colour film processes are more stable than others. Fortunately, much of the original colour can often be restored with digital image processing after scanning. I suppose we should use ‘acid free’ bag storage to protect our colour negatives, photographs, and slides from atmospheric pollution and decay – just the same as the valuable linen, comic and book owners do (e.g. www.savemycomics.com and www.conservation-by-design.co.uk). Modern B&W TEM film like Kodak 4489 has robust polyester as the support medium and an estimated archive life of about 500 years if stored carefully. It’s unlikely a digitised image will survive this long without very careful archiving, as branded CDRs only have a projected safe data storage life of 5 years after which crucial data should be transcribed onto a new CDR. The far less popular 4.7Gb DVD-RAM disk has an estimated data storage life of 30 to 100 years, assuming you can find a DVD-RAM player in 100 years time. Consumer video tape cassettes such as Hi8 and 8mm deteriorate badly with time - occasional rewinding will reduce tape print-through rates, although the plastic components of the tape transport mechanism begin to fail after 10 years. A lot of digital and film data is also lost when compatible hardware to access the data, such as computer, projector and video systems, become obsolete, often with the original data being destroyed once storage and recovery costs are deemed uneconomic.

Archiving colour film and photographs present similar problems. Colour film and prints often faded rapidly as the dyes used in earlier film production were far less stable than modern ones. To prevent our treasured film and photographs being lost to air pollution or damage, the obvious answer is to scan the film into a digitised PC image file (where PC data archiving then becomes a crucial issue). But how much detail do we need to capture from the original? I will largely ignore photographic prints as any quality 600 dpi reflective flatbed scanner is more than adequate for these. Standard quality 35 mm colour slide film is about 6,000 dpi. However a high quality prime camera lens can only resolve nearer 4,000 dpi, although some extra detail may be seen in the film at 6000 dpi. Cheaper consumer zoom lenses or film projectors will do worse than this, often dropping detail to nearer 1,500 dpi. Scanning to or above the film’s resolution always produces a soft (looks slightly out of focus) digitised image, as the scan sampling now matches or exceeds the films resolution. Assuming a typical film resolution of 120 line per mm (a fairly reasonable number), and that it takes two scanned pixels to represent the line pair, film resolution works out to an equivalent of about 6,000 dpi. Note though that film has less resolving power in low contrast situations, for example Fuji Provia F ISO 100 resolves 140 lines per mm (lpm) in high contrast situations and only 60 lines per mm in low contrast situations. Many lenses are capable of 80 to 120 lpm or more. Some films claim considerably higher resolving power – 200 lpm for Acros, for example. Thus, high-end drum scans of 8,000 dpi make sense within that context. The resolving power of Kodachrome II (where two lines can no longer be separated) is 64 lpm, thus 30µm structures are the smallest that be resolved with this film.

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The line resolution of TEM film is typically better than 200 lpm. In TEM it is desirable to maximise electrons for exposure, with slight over-exposure using a very slow film type. In general terms, resolution of a TEM is equal at all magnifications but a low magnification image may require enlarging. Beyond 20x photographic magnification, insufficient electrons have formed the image and “noise” becomes intolerable (Jim Darley, Probing & Structure Microscopy Supplies & Accessories). Optimum TEM negative enlargement is about 6x, although up to 10x to 12x produces acceptable results with Kodak 4489, although grain noise from the tissue support resin may become objectionable at high EM magnifications. Optical microscopes have used film for well over 150 years to capture complex magnified images, and have mostly used colour slide film since the 1950s – the main medium for presentations at the time. In addition, many researchers will have archives of images of such things as laboratory equipment and presentations on 35mm film, plus possibly ‘Polaroid’ or standard photographic prints (with the negatives now lost).

In B&W film there is usually one layer of silver salts. When the exposed grains are developed, the silver salts are converted to metallic silver, which block light and appear as the black part of the film negative. Colour film uses at least three layers. Dyes added to the silver salts make the crystals sensitive to different colours. Typically, the blue-sensitive layer is on top, followed by the green and red layers. During development, the silver salts are converted to metallic silver as with black and white film. The by-products of this reaction form coloured dyes. The silver is converted back to silver salts in the bleach step of development and is removed from the film in the fix step, leaving just
Photographing a scene involves some loss of detail in the translation to photosites or film grain. Any pixel or grain that “sees” a solid colour can accurately record it, but any that need to record half of one and half of another are out of luck. Things are averaged out when something is recorded. Edges get softened and adjacent colours merge since the size of the photosite or film grain determines the smallest detail that can be recorded. If you then scan a frame of film, you subject it to this sort of process a second time, further degrading the image unless you scan at a resolution high enough to resolve the actual grain structure.

So photographers need resolutions of 4,000 dpi and above in a scanner, with sharp focussing, largely for archiving smaller 35mm colour slide or negatives. Here, resolving detail in shadow with low noise (i.e. high DMax) is very important – further helped by Photoshop CS’s Image, Adjustments, ‘shadow/highlight’, ‘Curves’ and ‘Brightness/Contrast’ applications. DMax in modern consumer photo flatbed scanners such as the £300 Epson 4990 Photo and Canon 9950F are reported to be around 3.8 to 4.0 (although, as with dpi, manufacturers lie about the true value differently). The pro Imacon Flextight 848 has a quoted DMax of 4.8. Correctly exposed B&W silver halide negatives have a DMax of nearer 1.5 compared to a colour dye slides 3.5 – so most modern film scanners should easily cope with TEM negatives in terms of dynamic range (http://www.scantips.com). Plus we can only distinguish around 191 grey levels, so 8-bit (256 greys), rather than 14-bit (16,385 greys) or higher, is mostly fine for B&W photographs, although scanning B&W and colour film at higher bit densities may provide more detail, particularly for image analysis algorithms. Humans do better with colour, plus we perceive colour ‘in context’ e.g. brown can look yellow (as it is a dark yellow), and so complicated things like CMYK printing and ICC profiling are needed for things like colour film scanning, VDU viewing and printing colours accurately (for details see websites like www.tasi.ac.uk). For scanning, twain software applications like Silverfast Ai Studio (www.silverfast.com) can work with Silverfast’s own colour IT8 print and film ‘targets’ to set scan colour correctly. VDU’s also need calibrating and brightness/contrast adjustment if you want accurate representation of the scanned digitised image.

As with microscopes, high resolution isn’t much use if there’s no contrast, but again as with microscopes, increased contrast often reduces resolution. B&W TEM negatives that initially look good with very high contrast (DMax nearer 2.4) are often inferior in detail to negatives that have a more neutral tonal balance with a DMax nearer 2.0. You can always increase contrast in Photoshop after scanning, retaining a copy of the original image. One problem with scanning TEM and optical microscope images on film is that we can’t immediately tell if the image is poor after zooming in (particularly if a cheap scanner secretly applies USM or other image processing), whereas with a colour scan of our kids faces, or writing on the side of a ship, it’s immediately obvious. For TEM negatives it’s easier just to compare the results from different scanners and with the manual view.
looking at the negative with a light box and an 8x magnifier. Again for most 35mm slide and negatives, 6000 dpi optical is likely to be beyond the actual resolution of the image on the film. However the secondary process of scanning the camera film through yet another set of optics will further degrade the image quality – the amount of degradation being dependent on scanner quality.

The use of Kodak’s (formally Digital) ICE, or Canon’s FARE, for dust and scratch removal during film scanning is irrelevant for B&W negatives as the process is optimised for colour film. Digital ICE is hardware based and pre-scans the film with an infra-red beam. Film is fairly optically transparent at this wavelength, so only the dust and scratches are detected. Software then copies pixels from nearby areas and fills in the areas lost to dust and damage. Thus the ‘missing’ areas are only cosmetically restored; the original detail is still lost. On scientific images it is probably better to just leave the dust and scratches, particularly as the process further softens the digitised image and can add artefacts. Use a photographic bulb blower to reduce dust on the negative surface. Aerosol air jets work well, but it is very wasteful of the can contents and the propellant can squirt onto the emulsion surface and damage it (even with invertible canisters). Some use brushes as well, but these can scratch the film surface. Digital ICE is great for old home photographs and film, where dust and hairs on faces and scenes can really spoil the image (clone and fill techniques in Photoshop can do this manually, but it really takes time). There are other software solutions such as Kodak’s (Digital) SHO, ROC and GEM; that are plug-ins for Photoshop. These can be optimised and integrated into scanners, e.g. the Nikon Coolscan 9000, but unlike ICE they are software only. SHO optimises contrast and brightness in a similar manner to Photoshop CS’s Shadow/Highlight – particularly good for bringing out detail in shadows (where a high DMax on the scanner is also essential). ROC adjusts the colour balance for badly faded colour film. GEM reduces image noise and grain from the image and the Airbrush version can ‘smooth skin surfaces’ by reducing harsh shadows. There are software plug-in versions of ICE to remove dust but these are far less successful than the IR hardware scan and are best avoided. The use of these plug-ins considerably reduces the time taken to do the same in Photoshop. Film grain noise is best minimised by using a high-resolution film scanner of 4000 dpi optical resolution or more.

However, from my experience even going to £8,000 for a scanner (prices have tumbled recently though), the scan of a negative or slide is often not quite as good as the original if you look at the film using a light box and an 8x inspection magnifier. I can for instance just make out some of the text of the label on the machine in figure 4 when viewing the original slide, but I can’t quite read it when viewing the scanned image. Likewise scanners, particularly consumer flatbeds, will often appear to lose a great amount of detail in the shadows on the scanned image, which can clearly be seen when viewing the original slide – although this shadow detail can be easily restored with Photoshop CS’s Shadow/Highlight. A magnifier and light-box is also very useful to check the colour accuracy of the final scan.

Film grain size optical effects during scanning are also well known – film is made from ‘grains’ and the more you magnify, the more you can see them. Grain size can also cause optical interference ‘aliasing’ effects that further degrade the scanned image, so much so that a cheap 400ASA negative colour scan with a 2,700dpi resolution film scanner can produce an appallingly unusable image that image processing can’t save – whereas a reflective scan of the 6 x 4” print produces a reasonable A4 image. With ‘grain aliasing’, noise from the film
grain is somehow magnified during scanning, producing a very poor image. When going from 2,700 dpi of the old generation of slide/negative scanners up to the 4,000 dpi of modern scanner, many users report far better image quality, and put it down to reduced effects from grain aliasing. At these resolutions, film grain is still very apparent during enlargement, as much 35mm film grain has a lower dpi than the scanners, but ‘aliasing’ artefacts from the grain are greatly reduced.

In practice, many problems in scanned image quality are as much due to the ease of magnifying a digital image compared to the film – a few clicks and you have a ‘print’ the size of a wall. Besides noise in the photographic image from a digital camera, particularly at ASA sensitivity settings above 400, can be even more objectionable than grain problems with quality 100ASA 35mm slide film scans, although admittedly the larger grain size of 400 ASA colour film also produces a very noisy scanned image. Also the original image quality on film will be entirely dependent on the quality of the camera prime lens optics and the film originally used. Modern film resolution can vary from 80 to 200 lpm, and specialist film can go up to 320 lpm or more. Generally B&W is capable of the best resolutions, while increase in film speed (ASA) reduces resolution by increasing grain size to improve light sensitively. Likewise, ignoring camera shake, reducing a camera lens aperture from f-2.8 to f-22 can reduce the maximum theoretical resolution of the lens due to diffraction, although film resolution itself will rise as you stop down, as optical aberrations will reduce (f-stops 8 to 16 being optimal). Naturally if you want to zoom in on a negative, it would have been better to do this on the electron or optical microscope and take another picture at higher magnification instead.

Our eyes prefer a fuzzy analogue gradation of colour to the much defined little squares of a pixellated image at the same resolution, plus we are quite good at discerning contrast. Also digital camera’s often do some intense image processing during image capture (e.g. noise reduction, colour correction and sharpen) so you have to work on the image after scanning to get the same result. Surprisingly, twain software can also have an effect on scanned quality and cheap scanners may benefit from using Silverfast over the bundled scanner software. Given the high cost of a Creo professional flatbed or Imacon type drum scanner you can pay someone to scan a few important negatives or slides at 8,000 dpi on their scanner and this is typically £10 per picture depending on resulting image file size. However you can get pretty good results from the new breed of £300 flatbed film scanners, particularly with large format negatives. See websites like www.photo-ico.co.uk for reviews of the Canon 9950F and the similar Epson 4990 Photo. At the time of writing the latest £400 Epson V700 and £550 V750 Pro look to have the crown as the best prosumer photo flatbeds. So how do the likes of these new breed of cheap scanners compare with a £5,000 Agfa Duoscan flatbed or an Imacon Flextight 848 costing £8,000 today?

If you intend to keep the negative or slide anyway, being able to print to A3 size is adequate for most purposes. People will choose their scanner largely on cost, particularly home users. At home I use the cheap Canon 9950F flatbed (c2005) that has replaced my 2,700 dpi SCSI Scanwit 2740s (c2002)
The figures clearly show that all the scanners, whether costing £300 or £8,000, produce output that is very difficult to tell apart.

Figure 1 shows the scanners used to scan these films. Figures 2 and 3 show scanned B&W images from Kodak TEM 4489 negative film. Figures 4 and 5 show scanned images of the Agfachrome CS 35mm colour slides. The image quality of all the flatbed scans are a little more out of focus (i.e. ‘soft’) compared to the Flextight 848 drum scanner at full magnification, but the care used of USM (unsharp mask) in Photoshop can improve this somewhat. But they are fine up to A3 printing at least (from a 35mm slide). Flatbeds scans need more twain tweaking and post scan editing than dedicated film and drum scanners. Leave things like USM, Shadow/Highlight and colour balance to Photoshop where you have far more control, but use the twain interface to set things like brightness and contrast separately. This is particularly useful when using the cheaper flatbeds, plus it allows you to scan with a MetaMorph image analysis package (www.meta.com). Thus you can scan six TEM films on one go on the Epson flatbeds and the scan images will be scanned independently. Older scanners such as the SCSI DuoScan T2550 had a special area on the film scanner bed (the size of one TEM negative), although, as can be seen in figure 3, it produced no gain in scan quality. I did notice on one TEM scan that the cheap Epson 4990 Photo scanner slipped while scanning the TEM negative causing a very small judder in the image (arrowed in figure 3). I haven’t seen this before or since (it just happened to appear in the area I was selecting for the figure), but it may suggest that the scanning mechanism isn’t as reliable in the cheaper scanners. The more expensive scanners like the Agfa Duoscan (a rebadged Microtek) do have obvious vibration protection (rubber squash ball type) as well, and this may be a factor. Cutting two rubber balls in half and placing them under the scanner might help, perhaps with a damping plate of concrete, slate or granite (as used by HIFI music buffs to minimise acoustic feedback).

It’s likely that these similar results are because all scanners are scanning at resolutions beyond that of the original film. Changing the scanner’s twain software from 2,400 dpi to 4,800 dpi made very little difference, if any, to the final resolution of the scanned images using the cheaper flatbeds, plus it increased PC file sizes by 4x. If you are using modern very high resolution 35mm colour film with a professional SLR film camera, you may get better scans with a dedicated 35mm slide/film scanner or pro scanner, and the scan images will need less Photoshop editing afterwards. However if you are scanning large format film such as 70mm, 1/4 plate TEM and 120, these cheap flatbed scanners give great results. Those who wish to archive large numbers of films with the highest resolution will still probably prefer to keep to their drum scanners, many of which have automated film handling and fast scanning speeds. For example the Flextight 848 can take 10 film holders (60 negatives dedicated slide scanner – it’s faster and easier to use with USB2/Firewire and produces noticeably better film scans. At work, we have an Apple-based £5,000 Agfa Duoscan T2550 (£2000) and a cheap £300 Epson 9950F photo (£2006). I have scanned a series of TEM negatives that were made this year using Kodak Electron Microscope Film 4489, size 3.25” x 4” (8.3 x 10.2 cm). Kodak 4489 probably has a resolution of more than 200 lpm with its ‘ultra-fine grain size’. In addition I scanned a few 35mm Agfa-chrome CS colour reversal film (ASA around 100) taken in the late 1970’s as part of my PhD studies. The Agfachrome will probably have a resolution of about 120 lpm, and be typical of the type of old 35mm colour slides most will want to scan. These Agfachrome CS slides were always stored in light-tight slide boxes and haven’t shown any noticeable colour fading over the last thirty years.

Note that 35mm colour slide scans often produce far better scan results than that with cheap 35mm colour negatives. This is because colour film negatives were exclusively manufactured for photo printing, and so weren’t designed to be enlarged much beyond A4, whereas colour slide film was routinely enlarged beyond this during projection and was always the first choice of professional and scientific photographers. Many consumer colour negatives also have higher ASA’s of 200 to 400, whereas 35mm colour slide film was always the first choice of professional and scientific photographers. Many consumer colour negatives also have higher ASA’s of 200 to 400, with its increased grain size, that made them more suitable for cheaper hand held cameras. So 35mm colour negatives don’t scan well and will require more Photoshop post-editing. In many cases the original colour negatives are lost anyway, leaving only the lower resolution print for scanning. For this reason, many amateur photographers now regret moving from colour slide to cheap colour film in the late 1980’s, although at the time the prints were far easier to view at home than slides. Again, as with colour slides, Silverfast IT8 targets are needed to produce accurate scanned colours from the film negatives and photographs.
or slides) in a single automatic batch, compared to the just eight on the platter with the Epson 4990 or twelve with the Canon 9950F and Epson V700 & V750. A flatbed like the £30,000 Kodak EverSmart II can scan 48 slides on it’s A3 flatbed in one go, at 120 slides per hour (compared to about 12 per hour using a Canon 9950F flatbed). Expensive scanners will also probably survive long scan runs better, although a maintenance contract on an Imacon Flexight 848 will be around £800 per year.

So for film scanning on a budget the new Epson V700 or V750 Pro (even better than the Canon 9950F and the Epson 4990 Photo) would seem a very good choice. These two new scanners may even kill off dedicated 35mm slide scanners (www.photo-i.co.uk). Few dedicated slide scanners can go beyond 9x6cm film size, and certainly can’t match the Epson’s V750, V700 and 4990 Photo’s ability to scan negative film and reflective photographs up to A4. The soon to be discontinued Canon 9950F is limited to its film holder sizes though, and lacks the flexible A4 film scanning of the Epson’s using it’s twin interface, plus Silverfast Ai supports Epson’s ICE but not Canon’s FARE dust removal. Naturally, these cheap flatbeds offer superb reflective scanning of photographs and documents as well. So whatever your budget there are now some great versatile scanners available. For more information on these scanners, see the independent reviews of prosumer film scanners at www.photo-i.co.uk.

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Modern PC’s are now significantly faster and more stable for image capture and editing, plus modern scanner interfaces use the far more convenient USB2 and Firewire interfaces rather than SCSI. You should factor in the cost of a copy of Photoshop CS2 into the final price (best value as part of the Adobe CS2 Suite, particularly with educational discounts) or at least upgrade the bundled Adobe Photoshop Elements to the latest version. Advanced users may also wish to upgrade the bundled-in Silverfast SE twain software or purchase Kodak Digital SHO, ROC & GEM plug-ins, although some of these may be bundled in with more expensive scanners (e.g. the Epson V750 Pro and Nikon Super Coolscan 9000). For more information, the internet is a very valuable source of up to date articles on photography, image editing software and film scanning. Most of the information is free to view, being provided by photography enthusiasts or scientific establishments. Below is a small selection of good photographic sites, and there are many more about. Much of the information in this article relies heavily on these sites.

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