Choosing a Film Scanner

These guidelines address some aspects of film scanning and scanner operation, and looks at the criteria that are important when choosing a film scanner. Even if an archive does not plan to purchase its own scanner, it is useful to know what type of scanner a contractor is using in order to assess where they might encounter problems. These guidelines should not be taken as recommendations for any one model of scanner; scanners are mentioned by name only as examples of different technologies.

The Theory

Resolution – how many pixels are needed?

The information content of a 35mm film frame and the scanning resolution needed to capture it has been the subject of much debate. It is a complex issue because the image made up from random microscopic clusters of metallic silver, colour dyes, etc. on a film is very different to an image constructed from discrete pixels. The ITU (International Telecommunication Union) conducted research[1] into the matter in the early part of the 2000s, and although it is not strictly possible to precisely describe the resolution of an analogue film image in terms of lines or pixels, the conclusion drawn from analyses of modulation transfer functions (MTF[2]), was that the maximum detail which can be recorded on and retrieved from a 35mm answer print[3] is around 2000 lines per picture height at an aspect ratio of 1.85:1, which equates to about 2700 lines per picture height for a full frame 4:3 film image. This is equivalent to an information content of just under 4k across the image. 4K can thus be considered to approach the resolution of a modern 35mm answer print. The study found that the resolution of the original negative was considerably higher, but that of a 'release' print, produced by the printing sequence negative→interpositive→internegative→print, was considerably worse. In subjective tests on release prints, it was found that the highest resolution that could be detected by assessors when the release print was projected was only about 875 lines per picture height.

It is, however, not a simple matter to relate the findings of this study to the resolution required for scanning. Digital sampling of an analogue image requires a sampling rate higher than the finest detail on the original (actually twice the highest frequency of the original, as described by the Nyquist theorem) but it can be argued at one extreme that

---

[1] ITU (2001), 35mm Cinema Film Resolution Test Report, ITU-R Doc. 6-9/3

[2] MTF is an established tool for measuring the effective resolution of a film image. Unlike digital resolution, where there is an absolute cut-off point, the MTF is expressed in terms of the ratio of image contrast to object contrast.

[3] The study defines 'answer print' as one made directly from the original negative

there is no theoretical limit to the resolution required to perfectly render an analogue film image, right down to the microstructure of the film grain. In practice however, increasingly faithful reproduction of the image structure beyond a certain point may only lead to a more accurate representation of the underlying random structure rather than the image it forms.

The faithfulness of the digital scan is heavily dependent of a number of other factors such as the film transport mechanism, the scanner optics, the condition of the film and so on. It is also influenced by the design of the imaging sensor, since a CCD array does not capture 100 percent of the image falling on it due to the finite spaces between the capacitor elements (the pixels): the smaller the gaps between each element, the more accurate the rendition of the original. For similar reasons, a 4K sensor generally produces a superior 2K digital image than a 2K sensor.

The conventional view is that with current scanner technology, to obtain an image acceptable for preservation[4], at least an 8K scan is required for a modern original negative, and at least a 4K scan for a 35mm print made from such a negative. At the present time (2016), a film scanner capable of real 8K resolution throughout the complete optical path is not really practicable, and for the archive, managing the resulting amount of uncompressed data would be extremely challenging for most film archives. As long as we remain some way from the ideal position where we are able to capture all the significant data on a film with a comfortable margin, much in the same way that audio archives now routinely sample audio well above the human audible range at 96 KHz or even 192 KHz, some element of compromise is inevitable for film image capture.

The degree of compromise is dependent on two factors: the quality of the original, and the purpose of the digitisation.

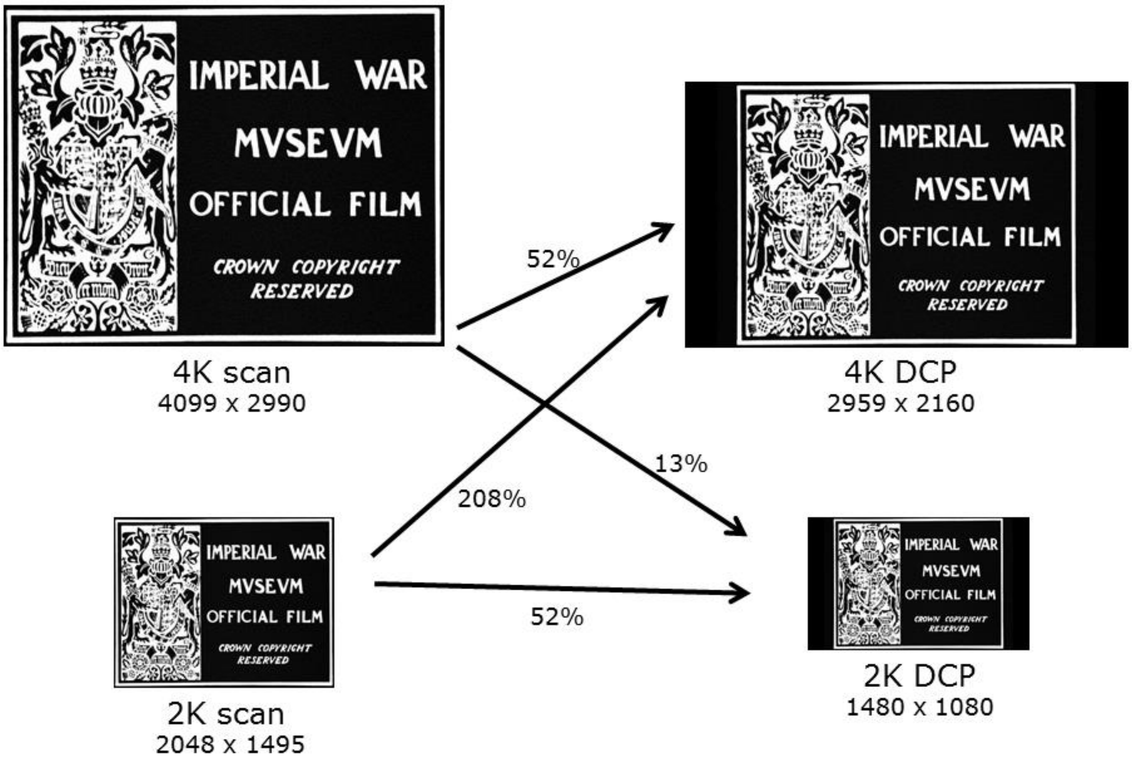
Regarding the first, archive film varies widely in resolution depending on its age and generation, and 2K scanning may be sufficient even for a typical modern 35mm print, if generated from a duplicate negative. Even if the digitisation is for preservation purposes, 2K scanning may be entirely acceptable for a great deal of film found in archives, such as elderly dupes of silent-era cinema which are likely to be coarse-

The Battle of the Ancre (1917), a coarse-grained duplicate made in 1931. ©IWM

[4] 'Preservation' here means a master copy made as a replacement for a vulnerable original.

grained and lacking definition.

However, if the purpose of digitisation is not the creation of a preservation master (and the original film will be retained in preservation-standard storage), then it may be acceptable to tailor the quality level of the scanning to the intended purpose, such as online access, DVD/BluRay or projection. A 2K scan will produce a version suitable for 2K digital projection, particularly if the film has a 4:3 aspect ratio (a 1.37:1 academy



frame yields a scanned image nominally 2048 x 1495). To fit such a frame into the 2K DCP container which has a vertical resolution of only 1080 pixels, it must be scaled down to 1480 x 1080 in size. Similarly, a 4K scan of the same film (nominally 4096 x 2990) needs to be scaled down to 2959 x 2160 in order to fit into the 4096 x 2160 DCP container for 4K projection (and of course scaled down much further for 2K projection).

Note that if the film is captured at HD video quality, which has similar sized 16:9 container (1920 x 1080) to a 2K DCP, then the 4:3 image will already be scaled down to fit the 16:9 frame, and does not require scaling for 2K projection.

It can be seen that a 2K DCP severely limits resolution, and therefore for academy ratio films there is an advantage in creating a 4K DCP even from a 2K scan. However the degree to which image resolution is significant for an audience is debatable given the number of other factors which affect human perception.

Bit Depth and Light Levels

The bit depth determines how precisely the colour and brightness of each pixel is recorded. An 8 bits-per-colour-channel system means that for each pixel, the brightness of each of the three colours will be set at one of a possible 256 levels between a maximum and a minimum point. A 10 bit system will have 1024 possible levels for each colour, so there are much finer steps between each colour value. 12 bit systems have 4096 possible levels. How the available bits are used depends on the system: linear data encoding has a set of even steps, whereas logarithmic encoding enables more precision in the lower end of the scale and less at the higher.

Currently it is common to capture film scans at 10 bit (either log or linear), and this may be sufficient if the original has a relatively even scene-to-scene exposure, or if the exposure level is adjusted during scanning for each change in scene density throughout the reel, in which case little or no correction should be required to the resulting scan. (Most scanner software now allows the exposure of each scene to be set in advance, or even adjusted 'on the fly'.) Without scene-to-scene correction during the scan, wide variations in exposure in the film may result in clipped whites or crushed blacks, or a compressed dynamic range which has insufficient data (not enough data points) to allow the image to be satisfactorily corrected post-scan.

However, using 10 bit data for film scans is very much a compromise and, as with resolution, archivists look forward to a technology which can capture the entire dynamic range of a camera negative in one pass. This High Dynamic Range (HDR) technology is now being introduced to film scanners, holding out the promise of reaching this ideal in the near future. There are two approaches to this, one is to take multiple exposures of each frame at different light levels which are then combined into a single file, the other is to use a new generation of HDR sensors which can capture a wider range in a single exposure.

At least one scanner is now compliant with ACES (the Academy Colour Encoding System). This system not only encompasses HDR, but also imposes a colour management system on the workflow so that there is consistency throughout the workflow. It remains to be seen how widely this is adopted by other scanner manufacturers, but there is no doubt that a more rigorous approach to maintaining consistent standards in the film digitisation process is long overdue.

Frame size and position

Film frames can deviate considerably from standard sizes and positions, so all scanners allow adjustment of the size and position of the captured image, either by physically adjusting the optics or more commonly by pixel selection from an overscanned image.

A scanner should have the option of overscanning the image so that the full frame and even the perforations are captured, the latter providing potentially useful data about image steadiness. However, capturing even part of the perforations may cause flare in the image, since the light passing through the perforations will reach the sensor unmodulated by any film density. Overscanning is also valuable if the frame position varies through the reel of film, allowing the complete frame to be captured without adjustment during the scan so that its position can be corrected post-scan.

Overscanning is also important if the intention is to create digital preservation masters where the intention is to capture as much information as possible. Indeed, for the ideal digital preservation master, it can be argued that the entire width of the film from edge to edge should be captured, as this will include such things as edge codes. Such a full width/full height scan of a sound film will potentially capture a usable image of the soundtrack (see below). This may have some value as a preservation record of the original soundtrack image.

Some older '2K' scanners (the Spirit family of scanners), many of which are still in use, do not have a full 2048 pixel width sensor, and create '2K' scans by artificially increasing the resolution by data processing.

Scanner design

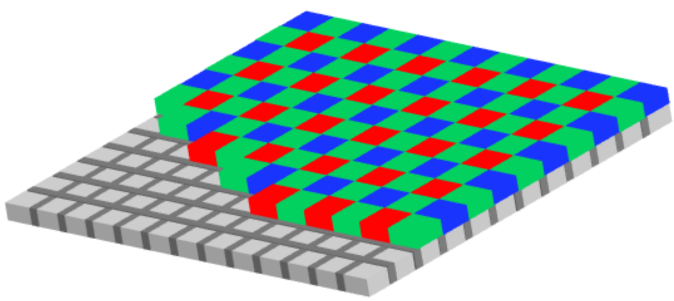
Sensors and film transport

The CCD (Charge Coupled Device) image sensors in scanners fall into two main groups, area arrays and line arrays.

Area array scanners operate much like digital cameras in that a digital photograph is taken of each frame of film as a discrete operation. Scanners designed principally with high quality production, preservation or restoration in mind, such as the Arriscan and Northlight (and the original Kodak Genesis scanner from the 1990s) are intermittent scanners, that is, the film is advanced one frame at a time and held steady in the gate while the image is captured, in much the same way as a film step printer. Other scanners such as the MWA Vario and Lasergraphics ScanStation run the film continuously across the gate using a short-pulse stroboscopic light source to freeze the image.

The sensors in line array scanners consist of a single line of CCD elements, and these scanners operate in a fashion analogous to continuous film printers in that the image of each frame is built up from a series of line by line exposures as the film moves over a narrow slit gate. This type of imaging is used by such scanners as the Spirit and the Goldeneye 4. A refinement of this approach is adopted by the DFT Scanity, which has multiple line array CCDs, so that each slice of the image is captured by each line sensor in turn, and a composite result created from the output of all the sensors.

Scanner imaging is further divided between those that capture a full resolution image for each red/blue/green colour channel, and those that rely on a Bayer-pattern sensor.



This type of sensor allows three colour channels to be extracted from a single CCD area array by placing colour filters over each element in a fixed mosaic pattern. The resulting image requires 'de-mosaicing' in order to produce separate red/blue/green images, and although the algorithms used to do this are sophisticated, the resulting images are not strictly full resolution in each colour channel. The single array Arriscan gets around this issue by capturing three images of each frame using red, green and blue light in turn. Scanners with line arrays generally use optics to split the image into red, green and blue elements, and these are directed to separate sensors.

Light sources and scratches

Most scanners now have LED light sources. These are efficient, cool and reliable. However the arrangement of the illumination and imaging optics has a significant impact on the degree to which scratches and other surface blemishes and marks are captured as part of the image. A very diffuse light source will definitely help to reduce degree to which such defects are imaged, and there is a surprising amount of variation between scanners as to the degree to which unwanted blemishes are rendered.

Some scanners have the option to use infrared imaging of the film to create a map of the dirt and scratches so that these can be subtracted automatically from the film image. This technique relies on the fact that a conventional colour film image is transparent to infra-red light, so a film illuminated by infra-red light appears clear apart from any scratches and marks on its surface. This approach cannot be used for black and white film, since the silver image is not transparent to infra-red.

More scanners are now becoming available with wet gate options, and these are very effective at scratch reduction.

With current technology it is easier to remove the defects as part of the scanning process rather than using digital restoration tools post-scan.

Steadiness

Intermittent scanners usually have a pin registered mechanism to keep the film perfectly aligned during scanning, but this may result in them being very intolerant of damaged and shrunk originals. The pin registration may have to be disabled for archive film, which then may necessitate the use of image stabilisation software on the resulting scans.

The way that area array and line array scanners respond to damaged film differs. In the former case, an image of the whole frame is captured at one time, so where perforation damage or tears in the film disrupts the smooth progress of the film, the result is that the image of the frame as a whole shifts in position. This can be rectified relatively easily post-scan. For a line array scanner, any disruption of the progress of the film over the gate will affect the way the image of the whole frame is built up from each line, and this can result in warping or rippling of the image. Such scanners have software designed to limit this effect, but it is not always completely effective.

In either case, it seems all scanners currently have a degree of difficulty keeping the image perfectly steady where there are physical splices in the film, resulting in the image 'bouncing' (albeit very slightly) at splices. There have been a number of reports that this can be particularly problematic when scanning 16mm A and B roll masters.

Speed – how fast does the scanner need to run?

How important is speed at which the scanner runs will depend on whether an archive is using it for individual high quality projects such as restorations, in which case a slow scanning speed will not impact greatly on the overall workflow, or for a high-volume project to digitise the content of the archive, in which case a fast scanning speed is an advantage.

The first generation of film scanners, such as the Kodak Genesis, operated at speeds of slower than one second per frame, resulting in multiple days to scan a feature film. Later intermittent scanners still only manage a few frames per second, and while these may be excellent for preservation or restoration, they are probably not suited to an archive digitisation workflow.

Continuous scanners now operate at speeds up to and beyond real time, although the archive must be aware that such speeds demand very fast systems for capturing and storing the resulting data. At present (2016), real time scanning at 4K is not yet a fully practical option.

Real time scanning does mean that if the scanner uses a conventional optical (photoelectric) sound head, a print with a combined soundtrack can have picture and sound captured simultaneously (see below).

Sound – as important as the image

Scanners with intermittent transport running no more than a few frames per second do not as a rule have the ability to capture film soundtracks.

Scanners which do offer a sound capture option approach this in different ways. If the scanner is capable of running at 24 or 25 fps, a conventional optical sound head can be mounted on the scanner.

Other scanners have the option of capturing a separate image of the soundtrack while the picture is being scanned; this image is then processed in some way to produce an audio file. Technology is also being developed which can extract viable audio from the individual fragments of soundtrack captured alongside each overscanned frame. The software stitches the fragments together into a continuous whole.

For best quality, sound should be captured as a separate process on specialised equipment; this is particularly the case where the original is an optical negative soundtrack which is likely to be distorted and noisy if played back directly through an optical sound head, and should instead be captured using one of the specialised solutions which have been developed for direct capture of optical negative tracks. One scanner (the Scanity) now offers one of these systems (Sondor Resonances) as an optional fitting.

Testing a scanner – how to do it

Film scanner manufacturers do not generally provide much objective information regarding the performance of their scanners in terms of exposure response curves, resolution, etc. In addition there is a lack of standardised test material, compounded by the fact that film originals come in a huge range of types and in all sorts of conditions. It is therefore difficult to apply a standard test to a scanner and its supporting software, so assessing whether a scanner is suitable for your archive is a matter of carefully evaluating the requirement, and then assembling a collection of test pieces to try out on the candidate scanners.

Experience shows that asking the scanner manufacturers themselves to scan a test reel is not a useful exercise. It is important to be present when the test material is scanned so that the performance and operation can be evaluated. A scanner may produce an excellent result from a badly damaged original, but if this takes an engineer the whole day to achieve, it is not likely to be practical in the archive.

Test material is likely to include both well- and poorly-exposed film, dense images (particularly negative), damaged film, scratched film, dirty film, shrunken film, film with imperfect splices, both good and faded colour, film with changes in frame position (for pre-sound era material), film with unorthodox frame ratios, film with combined sound, separate soundtracks, and test charts. If you have a nitrate collection to digitise, you might consider including nitrate material if shipment and test site allow.

Whether testing scanners with HDR or not, attention should be given to dealing with film that has a lot of scene-to-scene exposure variation: 'best light' scans of such material are likely to result in clipped whites or crushed blacks, so the amount of time and expertise needed to make exposure adjustments through the reel need to be assessed, and the results closely examined.

When assessing the resulting scans, pay attention to how blemishes and marks on the original are captured (there can be a big difference between scanners), how steady the image is, especially at splices, how good the resolution is, and so on. The eventual decision will be guided by the quality of the scans, by the suitability of the scanner for the type of film to be digitised, and by the intended purpose of the digitisation.

FIAF Technical Commission 2016