# Digital Image Restoration
# - Black Art or White Magic?

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Well, of course, it is neither. From my viewpoint, digital processes for film restoration are a technique borne out of current modern technology used in the modern film industry. A technique that will, in time, be indispensable. Digital moving image technology, initially used for TV special effects and commencing in the 1980's, is the only post-production process today for broadcast programmes and film effects. Now the digital intermediate process, a high-resolution technique used for complete features, is being adapted for film archives. This process exactly parallels the traditional photochemical film preservation and restoration technology that arose from techniques practiced in film laboratories.
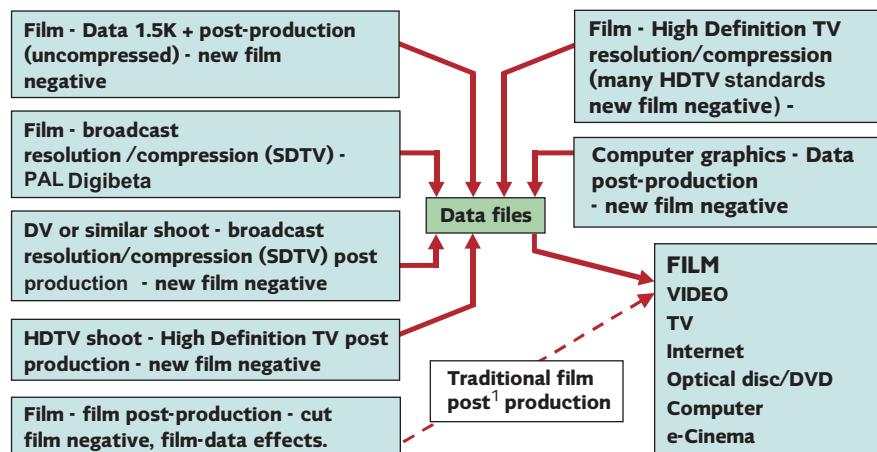
Modern Production routes.

However, it seems that is not always the way it is viewed by film archivists. Over the last few years digital image technology has been variously ignored, vilified or treated with derision; or given a welcome more appropriate to the conjurer at a children's party. It has even been regarded, at worst, like a Messiah. The reality seems to be lost in the rhetoric, the scorn and the adulation. "Of course, you can do anything with digital technology" - "Of course, it looks nothing like film" - "Of course, anyone can see the artefacts" - "Of course, now we can transfer everything to Digibeta and forget the film".
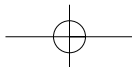
You may think I exaggerate, but I have heard all these views expressed, and some even more extreme, in the last two years, and probably many of you have too. I can easily excuse misunderstanding - but I find some attitudes less comprehensible. I have sat in cinemas and had knowledgeable (and sometimes rather well known!) restorers and archivists point out to me digital artefacts[1] that were not there, or were original analogue film artefacts, while omitting to notice real digital errors. These attitudes are not restricted to archivists. I have sat through modern feature films entirely created digitally while listening to explanations from filmmakers about why "video" can never replace film. I even recently experienced just that during a film projection of a DV shot feature, Mike Figgis's *Hotel*!

The reality is that a large proportion of today's Scandinavian made cinema films are post-produced digitally at high resolution (hardly surprising when out of the world's nine or ten companies that can do this, three are in the region). It is also thought that over 40% of all features made in the German language are shot on film, transferred to and edited on broadcast digital video and re-recorded back to 35mm film.   We have already reached a time when the traditional film route is traditional no longer.

I do not want, yet again, to discuss the technology, or the equipment or the software we can use today, or to explain what we restore, and what we cannot yet. This time I would like to review the practical barriers (and allude to some psychological barriers) to the film archive's acceptance of digital restoration. Inevitably I will see this through my technologist's eyes - I feel certain an archivist will see it differently.

A DEFINITION
Restoration has been defined as **" the process of compensating for degradation by returning an image to close to its original content"** (Read & Meyer 2000). In the absence of any other definition we could define **Digital Restoration** by adding **" by transfer to a digital format in order to manipulate and modify that image before recording back to a display medium".**

Film images are analogue, that is they are continuously variable in nature (i.e. in density) and, when copied from generation to generation, using analogue techniques, will always alter - no copy is ever the same as an original and its definition, resolution and graininess will always be worse.
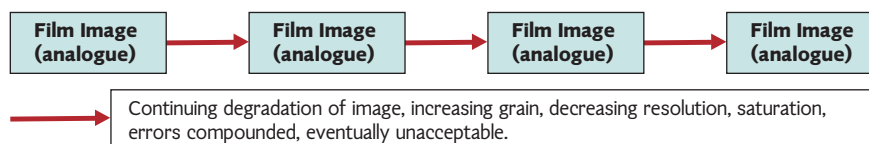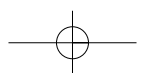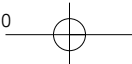

Figure 2

Digital "images" are derived from digital numerical data, which can be reproduced exactly from generation to generation. However all video cameras and TV display mechanisms are still analogue so the benefits of digital technology only exist while the "image" is retained in its digital (but unviewable) format.
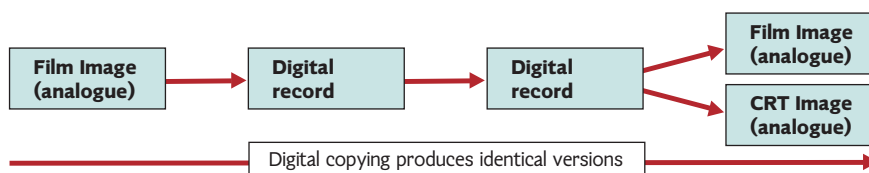
| Film Image (analogue) | → | Digital record | → | Digital record | → | Film Image (analogue) |
| | | | | | → | CRT Image (analogue) |

Digital copying produces identical versions

Figure 3

PRACTICAL COMPARISONS

Analogue film images and digitally produced or manipulated images can be compared in archivist's terms:

1. **Moving film images are sequences of pictures**, which can be viewed individually or projected at real time; no special equipment is needed for the human eye to view the still component of a moving film image. **Digitally produced images too can only be viewed as analogue displays** created from digital files, either by transfer to film, or by display on a monitor.

2. **The photographic process is not completely controllable.** Photography is a chemical reaction dependant on reactants, concentrations, time, temperature and a myriad of other factors and produces an analogue image (where the effects/density/perceived brightness varies continually from the lowest "level" to the highest). In this respect photography (making film stocks, exposing and then processing and printing film) is directly analogous to cooking, also a craft process, a point regularly made even by photographic technologists. This makes it impossible to be confident about the exact image to be produced. At present "digital cameras" collect light images in an analogue manner and merely record them, after A-D (analogue to digital) conversion, as a digital record. **Digital "images" are expressed as binomial numerical data, which can be reproduced exactly from generation to generation as the original numbers**.

3. **Photographic duplication, also called copying, a form of printing, is a misnomer**, since the duplicates, or copies, are **never** the same as the original, and the further away in generation the further the image departs from the original. The mechanisms used in photography to minimise these changes, such as integral masking, inter-image effects and elaborate sensitometric control methods are never completely effective. **It is possible to make an exact copy of a digital file** (hence the use of the biological term a "clone" for a digital format copy), since a digital record is a numerical record stored as a binomial number.

4. **The range of restoration techniques possible with analogue film duplication is considerable, but some photographic techniques are so complex as to be uncontrollable, costly and impractical.** A good example
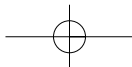
is the Flash Dupe Mask method of restoring faded tri-pack film dyes. Even colour separation methods (e.g. for Technicolor restoration) are limited to just a few specialist film laboratories in the world. However there is no analogue film technique capable to eliminating non-image scratches, damage and marks printed in from previous generations of images. **Digital technology, because it can treat each pixel as an individual, is capable of restoring all the effects of time and handling**, even allowing an artist to re-colour or reconstruct an image. However, it may surprise many archivists to know that the digital repair of damaged film is at present far more dificult and more costly, and produces less satisfactory results, than other digital image defect repairs. Correcting faded tri-pack film, re-colouring, restoring coloured images from separations (Technicolor, 2-colour, animation negative, or protection masters) even restoring tinted and toned film and stencilled images are less complex. They require specialist techniques but can be relatively inexpensive.

I have recently prepared budgets for the restoration of two 90 minute features. One is B&W in which the original negative has many scratches and marks and some small areas of serius damage. Restoration to a new B&W negative will cost over £70,000, and may be over £100,000 depending on how critical and demanding the client is.

The other is a severely faded print, with almost no image damage, that needs colour restoration. Restoration to a new colour negative will cost about £45,000.

5. **Analogue film images have analogue film artefacts.** Artefacts have been considered to be "visual effects which are a direct result of some technical limitation"[2]**.** This is a fairly imprecise definition. Analogue film artefacts include scratches, sparkle, frames out of rack, dye fading, fogging, wagon wheels turning backwards, images of static discharge, stains, strobing when an object moves across the screen, poor colour balance, excessive contrast due to duplication, Newton's Rings, uneven exposure (flicker), missing feet, and of course, film grain. I could go on. We have become so used to analogue film artefacts that we hardly notice them, and in some instances, like grain, have been considered essential concomitants to all motion picture imagery. **Digital records and files also contain artefacts**; some are images of analogue artefacts generated as a function of the film process, others are due to video signals or display processes, and some are unique to the digital process or to the digital manipulation used to "restore" film. They can be seen as strange edge effects, twinkling or "aliasing" images, jitter, contour patterns, moiré, interference patterns, and of course, noise. I could also go on.

6. **Analogue film images are very stable.** One might not think this from concerns over nitrate inflammability, nitrate and acetate base decay, or film dye fading but by comparison with most digital media this is so, and low temperatures may in future retain film images already in the process of decay for many years yet. **Digital records are, at present, considered very "unstable"**, principally due to the fleeting nature and lack of standards of play-out equipment and formats, but most, probably all, current data storage media suffer from serious mechanical, chemical and physical limitations.
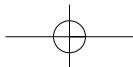
DIGITAL RESTORATION TECHNIQUES - A CATALOGUE
The following diagram (Fig 4) shows the stages and alternative routes at which digital image manipulation can be carried today.
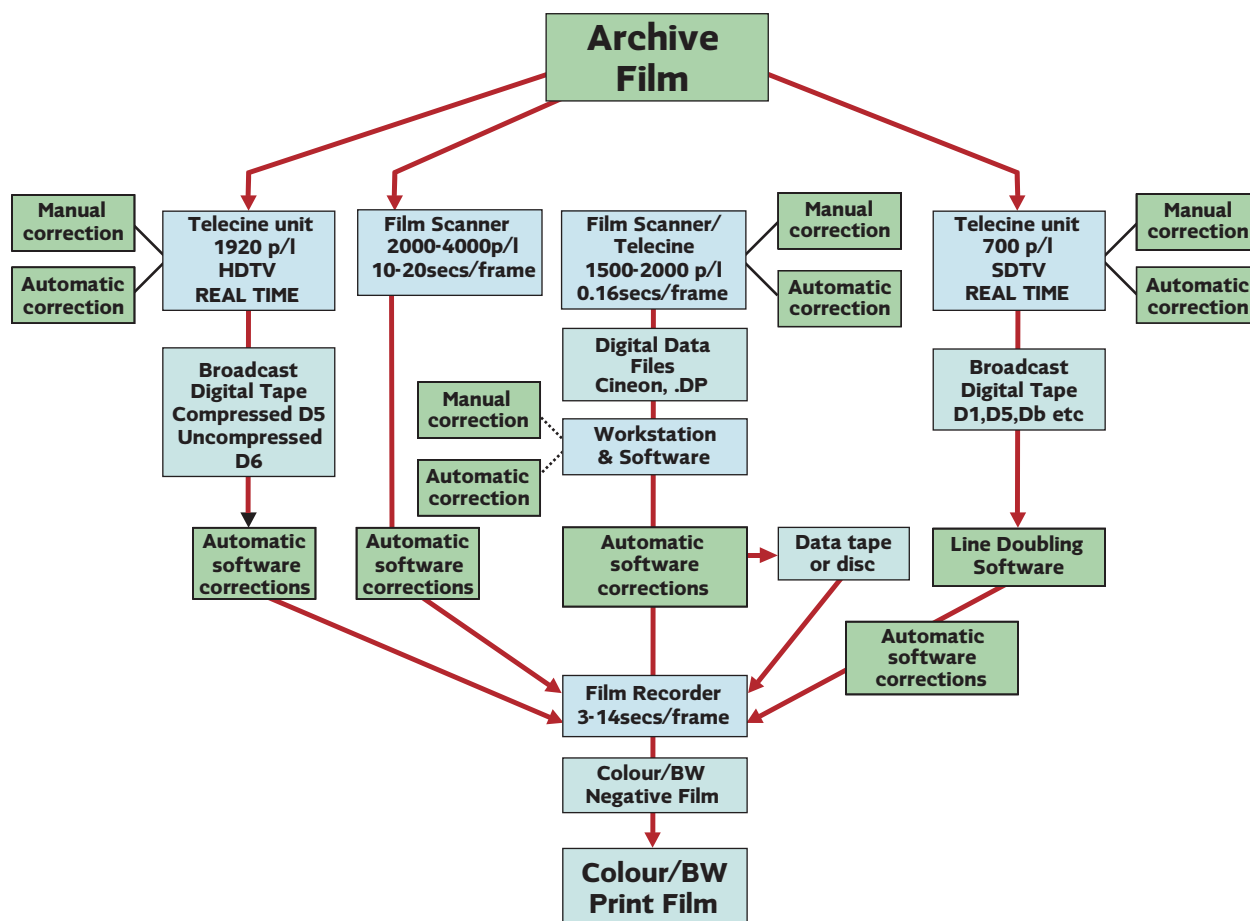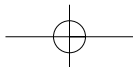

Figure 4 A range of possible routes for the digital restoration of archive film (nov 2002).

However this should be considered the complete compendium of possibilities. In practice the possibilities in a conventional digital intermediate process adapted for archive film restoration are shown in Fig. 5.
It is possible to classify the digital "tools" available at the various manipulation stages shown on the diagram as follows (the list is not exhaustive):

1 **As a previewed "grade" before scanning -** the scanned data files are therefore already "corrected" (today).

ORIGINAL FILM NEGATIVE

X

SCAN

X

Data files

X

Data files

X

WORK STATION

X

New Data files

X

VIDEO IMAGE ON MONITOR

PREVIEW & "GRADE"

VIDEO IMAGE ON MONITOR

Correct/modify image

VISUAL MATCH

NEW RE-RECORDED FILM NEGATIVE

FILM PRINT

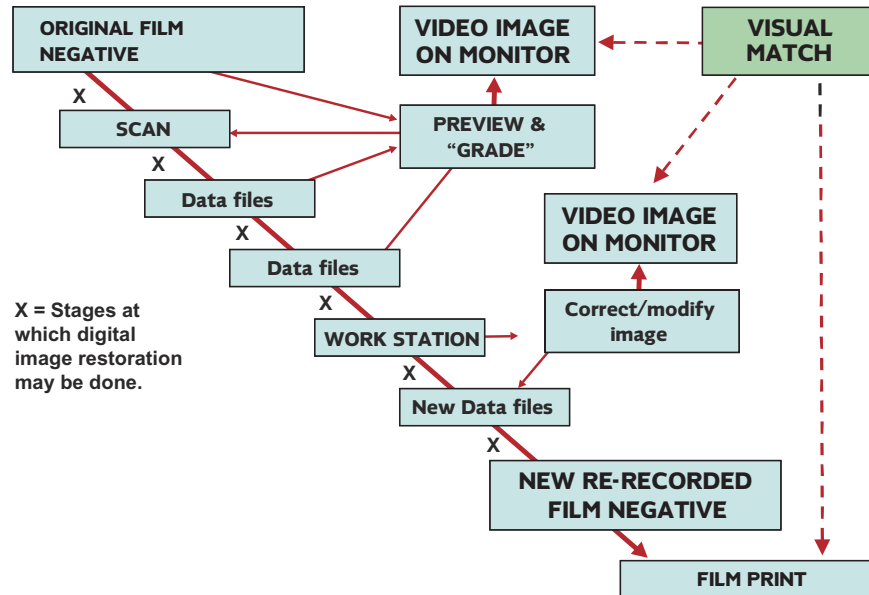X = Stages at which digital image restoration may be done.

Figure 5. Digital data files in modern "calibrated" or "wysiwyg" digital intermediate post production.

Or **at a separate disc to disc grading station after scanning** (only practical if scanned previously at 16 bit or more. This is not a reality yet).
Corrections possible at this stage are for:
Colour balance,
Re-colouring locally
Overall dye and silver fading
Contrast errors,
Some local image stains and fades
Tone dye fading
Reformatting, magnification, reduction and re-framing

2. **During scanning, using automatic software.**
Corrections possible at this stage are for:
Marks, sparkle, scratches removal
Image instability
Image density fluctuation, between one frame and another
Variations in density within a frame
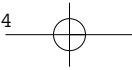Image edge alterations, "sharpening" and "softening"
Using:
"Digital Image Noise Reducers"
Any data processing using algorithms

3. **On a workstation using specialist image software.**
Corrections possible at this stage are for:
Image damage, marks, (opaque) stains and scratches
Image compositing and registration
Grain reduction or replacement

Local (transparent) image stains, fades and hue changes
Variations in density from frame to frame
Variations in density within a frame
Re-colouring locally
Adding tints
Film editing and conforming (reconstruction)
Image instability
Image edge alterations, grain changes, "sharpening" and "softening"
Speed changes by frame creation or omission

4. **When processing data files before or during re-recording to film. Corrections possible at this stage are for:**
Image size and ratio changes - magnification and reduction – formatting
Image edge alterations, "sharpening" and "softening"
Some grain reduction or alteration
Altering resolution (pixels per line) by doubling, interpolation techniques etc

DIGITAL RESTORATION TECHNOLOGY IN 2001
The practical issues of digital restoration today are still formidable - principally they are:

1. **The cost of the image scanning, data storage, computer and recording hardware.** The capital costs of a typical single flow digital intermediate feature film production unit, one telecine, one workstation, several software packages, several terabytes of data storage and a laser film recorder are in excess of £3M (E5M, $5M)[3]. And you still need the film laboratory.

2. **The cost of the skilled labour.** The highest paid operators in the film post-production industry are the Inferno and special effects "creatives" who, in many instances, command higher salaries than their company's Chief Executive! Data Engineers come next.

3. **Automatic software, for example for the removal of scratches, sparkle and marks, is not just ineffective, it is still unacceptable.** Running feet, footballs, even fast talking mouths are removed as the software cannot yet distinguish between these and once occurring unique marks. Semi-automatic software is improving fast, but the essential low cost fully automatic device is still some way off.

4. **There are very few commercial fully calibrated digital intermediate systems prepared to devote time to experimentation for archives.** The whole point of a calibrated system is that the archivist can see what the restored image will look like before making the decision (and spending the money). Although it is not widely appreciated, it is quite possible to make a digitally processed film image look like a CRT image (at the scanner, or the workstation), and therefore make a reasonable match. Some extremes of colour saturation (the CRT has RGB phosphors, the film CMY dyes) will never match, but within a considerable colour and brightness space a match can be made and held. It also requires close cooperation between the digital facility and the film laboratory and is the basis of the calibrated digital intermediate process.
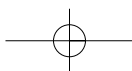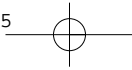
5. **There is a lack of good manual software specifically designed for archival film restoration.** I am sure this will change but Kodak has taken Cineon off the market and this was certainly the best manual software and the geriatric manual softawares such as Matador and Shake are now too primitive. Diamant[4], a semi-automatic software has the right credentials but it is still early in its life. No other software seems to be cost effective.

6. **We lack the technical data about many early film stocks** needed to define the "character" of original images (especially of pre- and early tri-pack colour systems). The Madrid Project[5], a database designed to bring together and disseminate technical information on film stocks, formats and colour systems may change all this but not without more funds and support.

7. **There is no established theory of restoration to guide the restorer**
Most restorers consider that an archivist will come to them with the particular requirement: that a restored image should look like the original cinema image? In other words something similar to "the image seen by the first audiences" (to paraphrase Mark-Paul Meyer[6]). (Such an ideal is almost never mentioned by my commercial clients!)

However, archivists are not all of one mind. As a restorer I have to listen to my client. As we all know the concept some of us facetiously call "the romantic scratch" is still in existence, and its logical and practical prodigy, the policy of leaving marks and scratches that could have been seen in the original cinema but removal of those introduced subsequently, is gaining ground.

In the past archivists have been unable to influence the laboratory greatly - the result of many restorations was entirely dependant on the film stock used for duplication or printing. Now the archivist can sit beside the scanner or workstation operator and tell him what he wants. In future the workstation operator may **be** the archivist, and then all the decisions will be his!

8. **Archivists are divided amongst themselves about the technical objectives and continually seek answers to difficult questions.**
*What is the "optimum" resolution for preserving a film image?*
Estimates range from 2,950 to 4,000 pixels / line for a 35mm image. Current film technology uses 2000 pixels for all digital intermediate and occasionally 4000 for some special effects. We can expect to see 4000 pixel/line scanners with full grading potential with in the next few years.
What is "sufficient" bit depth for a film image?
Current estimates range from 16 bit to 64 bit. Once scanning is carried out at higher bit depths than approximately 14 all corrections, even for severely faded films, can be on workstations rather than corrections prior to the scan.
Is interpolation of pixels a valid technique for image repair and manipulation?
(Interpolation is estimating a new intermediate pixel value from pixels on either side, in temporal terms, from frame to frame, or in spatial terms, within a frame). There really is very little research into this but experiments suggest that interpolation can in some instances result in serious visually unacceptable artefacts. My own view is that we should never be dogmatic.
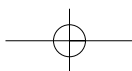
Will data compression ever be acceptable?
The automatic reaction from archivists has always been NO. However many of us said that about Digibeta, and I consider that compression will always be an essential practical solution for some restoration. Again my own view is that we should never be dogmatic (digital preservation, not part of this presentation, is another matter).
Can a digitally restored image be inserted into a conventional film restoration without a visual change in image appearence?
At present only if the scene or subject is markedly different from the conventional film images on either side. A digitally restored print section looks different from an entirely film originated print, and the start and end of a digitally restoration must be carefully planned if the join has to be visually seamless. This is due to the difficulty of calibrating the two processes to exactly match. It is a serious problem today which may not be an issue in time.
Can we record the digital interventions made to an image?
It is far easier to document digital restoration than conventional film restoration, where a separate piece of paper must suffice (or an Excel file, as used by Martin Koerber and Mark-Paul Meyer for recording and controlling the reconstruction and restoration of *Menschen am Sonntag*[7]). Two examples of potential recording methods for digital restorations come to mind. The commonly used data file format DPX has a user section in the header of every file (i.e. for every frame). It is possible to add a complete history of the work done on that frame in it's file header. There is enough space for a hundred pages of text, plus thumbnail images of before and after image repair work, **for every frame file!** Of course this would add to the file size.

Another technique (which I have used already) is to add a few frames to the leader of a reel of the final new re-recorded film negative. These can contain text images describing the work carried out on that restoration. At present only a few succinct descriptions have been added, but each frame of leader could become a microfiche image holding several pages of script if required. Many image manipulation software programmes have the facility to add text, since they are designed to create titles and credits as well as effects.

The real issue with digital restoration is that it is very difficult to record the extent to which interventions are made as there are no scales on telecine units, image controllers or in most image repair software.

However, I have to point out that there are, as yet, very few archives that have accurate and detailed records of their conventional film restorations!

THE FILM ARCHIVE'S DILEMMA
Parallel, but not unrelated to the mixed reception digital technology is receiving in film archives, is a very real concern by everyone in the modern industry and the film archives, over the continuation of current film technology. Today, even the most cautious media fortune teller is forecasting the death of motion picture film. First film will disappear as a post-production technique (with the loss of intermediate and black and white films), secondly in the cinema with film replaced by digital projection (e-cinema), and finally the camera film replaced by the digital camera. I feel sure that the
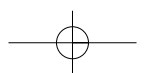
time-scale of these changes has been exaggerated and sometimes for commercial reasons, but their presence seems to be inevitable, and will probably be unpredictable.

In my opinion archives will soon be able to afford digital restoration. Today the price of a digital restoration of a simple black and white film may be many times that of a film restoration. This will change, and it already is changing. The speed of computer processing doubles every 18 months. Four years ago the price of a terabyte of data storage was £500,000, today it is less than £50,000. Already the price for restoring a Technicolor from the original camera separations is much the same as for the traditional film route - in Europe somewhere between £30,000 and £100,00 excluding any image repair costs.

Archives have already embraced digital media for access. Well, most have! Archives may never want to have scanners and film recorders but a major attitude change will occur when archives and collections have their own workstations and operators, a process that also seems inevitable.

Digital restoration of film images is on its way. That just leaves digital preservation of film images - but that is another story!

NOTES

1. An artefact is defined by the Oxford English Dictionary as a "man made object", and archivists frequently refer to an original film as an "artefact". I use the term as commonly used in the film and TV industry and defined in B Pank, Ed., *The Digital Fact Book No 10*, Quantel, 2000. Yet again technology adopts a word from common usage and transposes it's meaning.
2. B Pank, Ed., *The Digital Fact Book No 10*, Quantel, 2000.
2. Prices from Philips Digital, Discrete, Silicon Graphics and Arri etc.
4. Diamant is a commercially available software from HS-Art, Graz, Austria. It's development was funded by an EU technology grant.
5. The Madrid Project is managed by Alfonso del Amo, Filmomateca Espagnola.
6. In Read & Meyer, "*Restoration of Motion Picture Film*" Butterworth, Oxford, 2000.
7. *Menshem am Sonntag*: a case study, Koerber, in Read & Meyer, "*Restoration of Motion Picture Film*" Butterworth, Oxford, 2000.