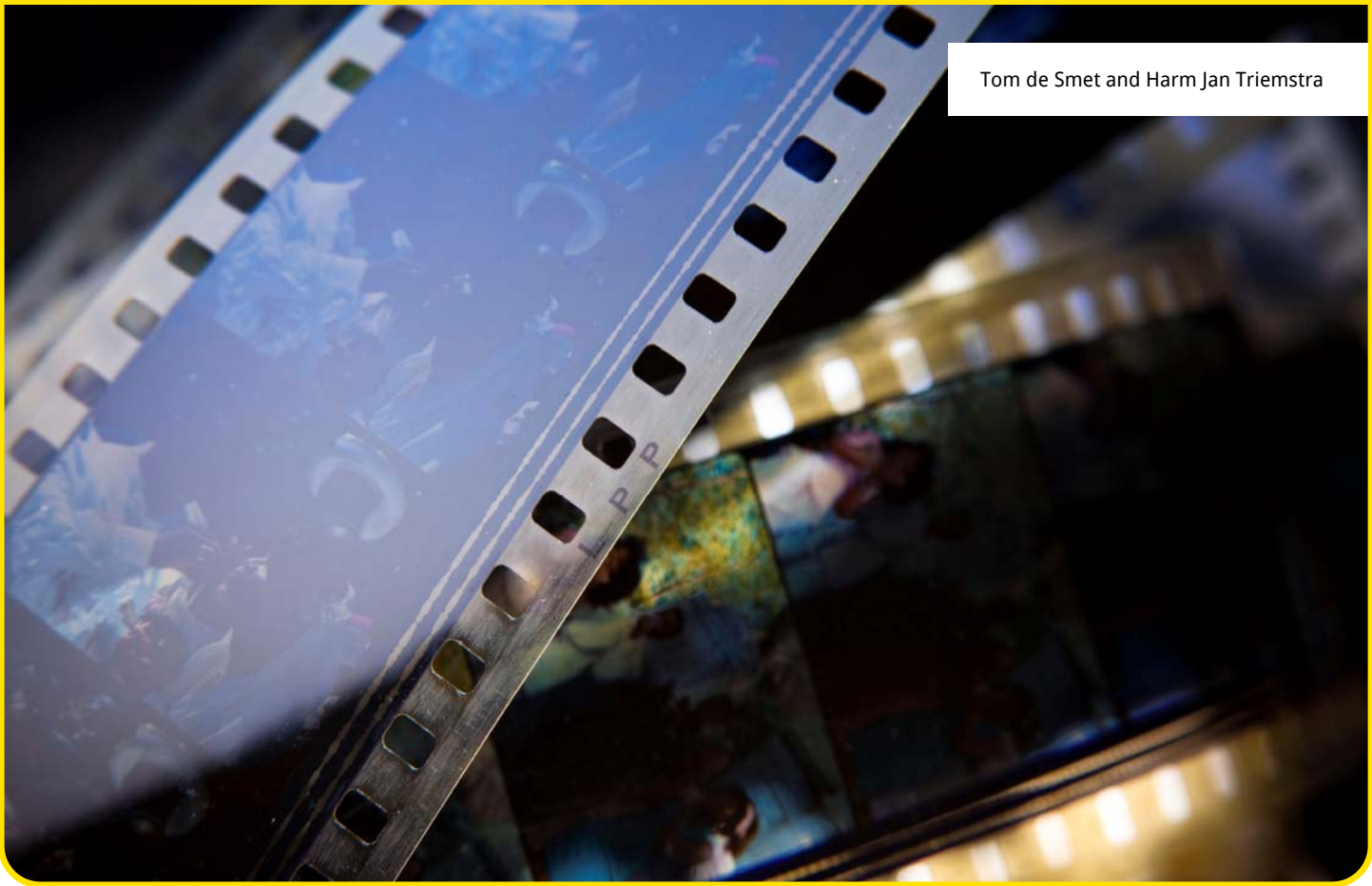
KEEPING AUDIOVISUAL CONTENT ALIVE

PRESTO CENTRE

White Paper: Film scanning considerations



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Introduction

The Netherlands Institute for Sound and Vision, hereafter referred to as Sound and Vision, was founded to guarantee sustainable preservation of the Dutch audio-visual heritage and to make it accessible for as many users as possible: professionals, educational institutes and the general public.

Sound and Vision is also one of the six original partners of the programme 'Images for the Future' which started in 2007 and finishes in 2014. The main goal of the programme is safeguarding Dutch audiovisual material by realizing maximum accessibility to the material for the targeted user groups. Within the scope of the programme archive material is conserved, digitised and enhanced with metadata to improve search & retrieval. Furthermore Images for the Future is developing and offering innovative services and applications for accessibility.

Sound and Vision archives and offers access to a huge collection of film material that can be divided into two distinct parts. The first part of the collection covers broadcast film material of a period from roughly 1955 to 1989 with a total volume estimated at 25.000 hours. On the other hand a lot of national heritage film material of non-broadcast nature is also home to Sound and Vision's vaults, ranging from 8 mm to 35 mm nitrate film.

Within the "Images for the Future" programme about 17.500 hours of material from these film collections must be digitised by mid 2014. On average this amounts to a production of 3.000 hours a year.

The main challenge Sound and Vision faces is to find the so-called sweet spot for the approach of this mass digitization process of its very heterogeneous collection. The sweet spot is the optimal balance between production volume, available budget, time constraints, quality and present and future archival, preservation, access and repurposing requirements. A choice in the digitisation approach and formats will always be a trade-off between these factors. Also, the availability of standards and capabilities of market solutions have to be taken into account.

This document describes the context of the collections, the considerations and choices of Sound and Vision regarding this sweet spot and the current and future digitisation approach.

The film scanning considerations presented in this document are of most relevance to institutions or companies with large quantities of (16mm) film material that have to be digitised for access and preservation purposes and that face time and budget constraints that do not allow for a case by case film decision and treatment.

1. Context / Situation

1.1 Host institution

Sound and Vision was founded to guarantee sustainable preservation of the Dutch audio-visual heritage and to make it accessible for as many users as possible. Sound and Vision looks after 70% of the Dutch audio-visual heritage, comprising around 750,000 hours of television, radio, music, and film. A collection which continues to grow every day.

As mentioned above, Sound and Vision is one of the six partners of the programme 'Images for the Future' which started in 2007 and finishes in 2014. The digitisation and encoding volumes involved in Images for the Future are 137.200 hours of video, 22.510 hours of film, 123.900 hours of audio en 2,9 million photographs. Sound and Vision's share is substantial. It covers about half the volume of photographs, all video and audio and the majority of film being 17.500 hours. The yearly production target for film digitisation is thus about 3.000 hours of material.

The selection of material is based on a combination of estimated relevance, preparatory status and vulnerability. The most vulnerable collections

are selected first. Examples are historical nitrate and acetate film collections of the first half of the 20th century and video and audio tapes on which Dutch broadcasters captured their television and radio programmes from the seventies onward.

As of January 2011 Sound and Vision already has approximately 42% of film and video and 38% of audio conserved and digitised.

1.2 Preservation Strategy

Sound and Vision currently operates in a fully digital world. Yearly 8000 hours of programmes broadcast by the main customer group, i.e. the Dutch public broadcasters, are all being archived digitally. In addition to this, the digitisation results of Images for the Future and acquisitions from other sources also end up in the digital archive. On a yearly basis about 100.000 hi-res assets are downloaded from the digital archive for repurposing by customers. To put this in perspective: for physical film this is about 600 items per year scanned on customer request.

The overall strategy is to have all content within the archive available, accessible and maintained in a hi-res digital format. This means that after digitisation, old physical carriers are stored in the right conditions to prolong life and will (ideally) not need to be touched or retrieved anymore in the future. .

The physical carriers selected for the Images for the Future programme will get conservation treatment, either basic repair as a preparation for scanning or extensive conservation (duplication to a new master) if source material properties deem necessary.

As a minimum requirement the digital format must be an accurate copy of the original (or closest available) carrier and suitable for repurposing in professional (post-)production. But this digital format must also support digital sustainability. Digital sustainability and preservation involves topics like error detection and correction, the life-cycle of and support for formats and standards and possible future format transformations without loss of information.

Preservation topics still require a lot of research, development of methods and tools and decisions. This is why Sound and Vision participates on national and European level in initiatives to develop strategies and methods for digital sustainability.

1.3 Service providers involved

Sound and Vision has selected different service providers to assist in the conservation and digitisation and continues to do so. Supplier selection is performed according to European tender procedures, depending on the scope of work. In general Sound and Vision primarily focuses on planning, selection, preparation, quality control and registration whereas the service provider performs the actual conservation and digitisation of most of the material.

1.4 Research institutions or other archives involved

Sound and Vision has requested Fraunhofer and Technicolor Netherlands for research on specific topics regarding digital formats for film digitisation (mainly DPX & JPEG2000 related). A special thanks to Dr. Henk den Bok from Technicolor (Hilversum) for his contribution to this document.

1.5 Best practice context

This best practice was developed by Sound and Vision as part of the national programme Images of the Future.

2. Film collection

2.1 Introduction

Sound and Vision archives and offers access to a huge collection of film material that can be divided into two distinct parts. The first part of the collection covers a period from roughly 1955 to 1989 with a total volume estimated at 25.000 hours.

The majority of this material originates from broadcasters and is made of 16 mm positive reversal. On the other hand a lot of national heritage film material of non-broadcast nature is also home to Sound and Vision's vaults, ranging from 8 mm to 35 mm nitrate film. Overall, the collection has a 4:3 aspect ratio and contains about 50% black-and-white material.

Due to historical and budgetary reasons registration and conservation status differs substantially within and between collections.

2.2 Broadcast collection

For nearly six decades, Sound and Vision and its predecessors (NOS/NOB, AVAC en NAA) have maintained a collection of Dutch television heritage. Almost 60 years ago on October 2nd 1951, the first broadcast by 'Nederlands Experimentele Televisie' took place. Ever since, sub-collections arose as the result of the existence of various television programmes and series.

One of the Dutch TV-history's most valuable sub-collections, is the selection "Televisie-Programma" (broadcast programs)internally referred to as 'Film Oud II'. This collection has a high historical value since it commemorates and illustrates many important moments in the history of the (new) medium television as well as the history of the Netherlands. During 1992 - 1996 this collection was selected from over 25.000 hours of television film. The titles became available after the film material was repaired. Film Oud II contains 5.000 hours of television film from the years 1951 until 1979.

Apart from "Film Oud II" the broadcast collection comprises a lot of other TV-material. From the very beginning of broadcasting all kind of genres have been broadcast: documentaries, magazines, shows, reports, interviews, church services, dramas, operas, plays, and music. Most are recorded on 16mm positive reversal film. In the early years, most images were recorded black and white and 'silently' in 1:1.33 aspect ratio (suitable for TV format 4:3).

On August 31st 1966 the first Dutch multicolour movie was shown, produced by a Dutch broadcasting company (KRO). During a transition period of two to three years the dominant black-and-white material gradually disappeared. Black-and-white items would still appear occasionally though. Gradually video became the major production tool. The last programs on film stock kept by Beeld en Geluid were shot in 1990.

Most of the TV-Program film material has been recorded at 25 frames per second on 16 mm so-called "reversal film stock" or "direct positive film". The collection contains a myriad of types of reversal film, including Kodachrome, with its very wide contrast and colour range that should be fully captured by the scanner.

From 1952 onwards sound has for the majority of the collection been recorded on a separate 16mm magnetic film (sepmag). Still, an estimated 1,5% of the entire collection contains optical (comopt) or magnetic (commag) sound on the filmstrip.

2.3 Non-broadcast collection

Sound and Vision also has a large collection of over 10,000 hours of film material that was not produced for broadcast purposes. This collection is very heterogeneous and consists of numerous film collections that came from a wide range of Dutch institutes, companies, private collectors and professional as well as amateur film makers. As

the number of subcollections is quite substantial, a short description of some of some of the most important collections is given below.

The largest sub-collection (approx. 5300 hours) comes from the "Rijksvoorlichtingsdienst" (RVD; Government Information Service), which consists of historically important film material on, for example, World War II, the Dutch colonies and the Royal House.

The "Polygoon"-collection is a well-known collection of newsreels produced between 1920 and 1987. The newsreels were weekly shown in movie theatres – at the height of their success in more than 400 theatres – and were never meant to be shown on TV. The high and objective quality of this documentary style 35mm film material has made this collection one of the most popular sources of historical audiovisual film material in the Netherlands. This collection also contains a lot of nitrate film material that has been entirely preserved onto polyester film stock throughout the years.

A much smaller, yet popular sub-collection is the "Amateurcollectie" (Amateur film maker collection), sometimes also referred to as the "smalfilmcollectie" (small gauge collection) as it mainly consists of 8, 9.5 and (S)16mm film material. Unlike many other collections, this collection continues to grow as an increasing number of amateur film makers wish to donate their precious film material to Sound and Vision.

The oeuvre of professional film makers can, of course, also be found in the non-broadcast collection of Sound and Vision. Hugo van Lawick and Bert Haanstra are two famous examples of film collections that are at the Institute's vaults.

2.4 Film characteristics impacting digitisation

Preparations and execution of current and past digitisations of film have shown that preparing and scanning archival film is not an easy and straightforward process due to a number of characteristics of the collections. Here is a number of properties that affect the workload; the required preparation , digitisation process and digitisation technology are described in some detail.

2.4.1 Film size and packaging

Film is contained in three types of cans: S(mall), M(edium) and L(arge).
L-cans contain film rolls with a maximum length of approximately 60 minutes and on average 30 minutes. M-cans contain a maximum length of approximately 30 minutes and on average 16 minutes. S-cans contain a maximum length of approximately 13 minutes and on average 6.5. Furthermore a can may contain several small items (up to 10 or possibly even more) in which case the length of the film roll will be considerably below average (as short as 20 seconds is possible).

For the broadcast collection it was estimated that 13% of film hours is within L-cans, 59% in M-cans and 28% in S-cans. Leading to a rough estimate of 12 minutes of film per can for the collection. Can size has shown to have a huge impact on the work process with Suppliers that preserve/digitise material.

2.4.2 Shrinkage and brittleness

Extended storage periods between inspection/reparation and conservation might have resulted in various amounts and degrees of shrinkage and/or brittleness (as a result of a.o. the vinegar syndrome). Almost all film and separate magnetic film material has been separated in the past out of prevention. Over the last 14 years, the sound and image of specific collections have been manually synchronised, but even for this material, continuing shrinkage may have a negative impact on the level of synchronisation.

Based on random samples taken from the multicolour film collection in 2004, the following situation was diagnosed: 90% was affected by acidity (A-D strip level 0,5-1%), 6% indicated a level of 1,5

above autocatalytic point and 4% was severely affected by vinegar syndrome (A-D strip level 2-3).

2.4.3 Negative/positive

In some positive reversal film stock (not more than 5%) it may occur that direct negative shots are edited, occasionally with or without a black leader. This working method was quite common in the TV-filming branch because a push on the button of the telecine during broadcast of the programme changed the negative into a positive image. For digitisation, however, it poses quite some difficulties.

2.4.4 A-wind and B-wind

In around 35% of the TV-Program film collection, A-Wind and B-Wind may have been edited together. In some cases only the title (and the head leader / studio stops) will be wound one way and the rest of the film the other, but some shots or scenes may have been wrongly edited together. B-wind material is usually the original reversal film, whilst A-wind is often a duplicate. Focus during scanning is the main area of concern in this case.

2.4.5 Sound

About 3-4% of all film material with sound has both final mix on 16mm sepmag as well as the music and effects (M&E) on 16mm sepmag.

2.4.6 Conservation status

Throughout the last decades Sound and Vision employees have carefully prepared specific parts of collections. This preparation entailed: the condition of the film was checked, leaders at the start and the end of the film were replaced, new labels were added and, in the case of damage, splices and sprocket holes were repaired. Nevertheless the consistency of preparation quality cannot be guaranteed as a large group of different editors – some well trained, others beginners – have prepared the prints. Some of the repaired films have since been used by customer services or have been digitised by a post-production company and could thus have sustained damage.

For the Broadcast collection it is estimated that around 65% of all material (based on total duration) has been prepared. It is possible that within the same can, a number of film rolls have been prepared while others still need preparation. The percentage of prepared film material in the non-broadcast collection is significantly lower.

2.4.7 Glue and damage

Approximately 40% of the prepared film rolls will still show glue residue from splices that were replaced in the 1990s and where possible glue remains on other parts of the film were not properly removed. This residue impairs the image quality and this must be manually cleaned before scanning (ultrasonic cleaning does unfortunately not adequately remove these stains).

2.4.8 Splices, dust and scratches

At Sound and Vision wet splices were used rather than tape splices. The former splices are slightly thicker than tape splices and can potentially cause instability in the scan results from data scanners/datacines that are not adapted to this kind of archival material.

Despite the fact that material has been prepared during previous renovation projects, the film material is expected to be slightly dusty, to show scratches and cables as a result of ageing and usage. Also, some splices of the prepared material may no longer be in good condition.

2.4.9 Picture quality and emulsion

Material from the Broadcast collection is on reversal film stock, which sometimes shows sharp contrasts, and - especially the indoor shots – the images are underexposed and noisy with a density that is too high. For digitisation it is important to respect the material in its diversity and flaws, in other words to preserve the typical characteristics.

The collections also contain a certain number of discoloured films. Based on random sampling taken from the Broadcast collection in 2004, shifts to red in the colour balance were diagnosed: about 20% had lost the original colour layers, only the red colour was left (cyan-dye fading). About 45% had faded green colour.

2.5 Film registration and metadata

Films and accompanying audio carriers are registered in the Sound and Vision cataloguing system iMMix along with their material properties and relationship to cans and programme metadata.

Completeness and accuracy of registration is not always on par with digitisation requirements and requires preparation effort. Furthermore a number of conversions from old databases is still work in progress. This is most relevant to the non-broadcast collection.

For digitisation relevant registration objects in the cataloguing system are:

- Expression (Programme).
- Selection (Programme Item).
- Position (Relation between Expression or Selection and Carrier).
- Carrier (Physical Item or File, e.g. film or Digitised film).
- Storage Unit (Can).

Please refer to figure 1. for a simplified overview of these objects and their relations.

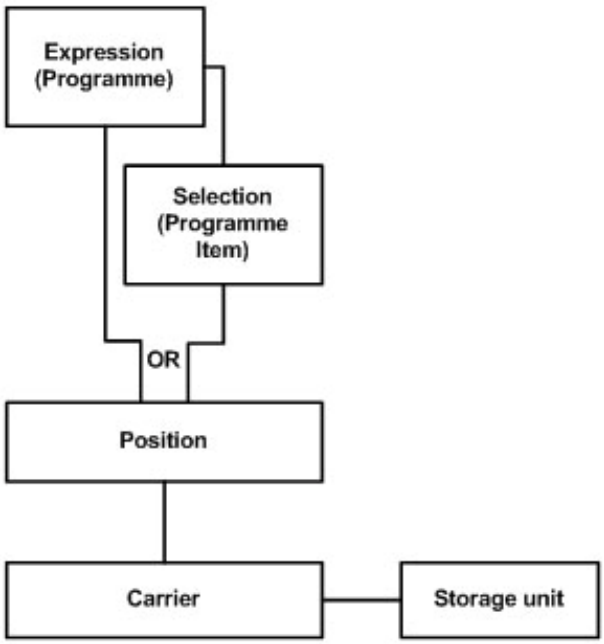

Figure 1: Overview of registration objects and their relations.

In some cases multiple carriers have physically been concatenated, resulting in one physical item (film roll).

Different operational cases may exist, depending on the physical state and metadata registration. Some examples of cases are:

- One Expression or Selection with one Carrier on one roll. This is the least complex situation.
- One Expression or Selection with one Carrier, combined with other Carriers on one roll.
- Multiple Expressions or Selections with one Carrier.
- One Expression or Selection with multiple Carriers (in one or multiple Storage Unit).

For registration in these different cases the new digitial Carriers must be created per combination

of a specific Expression/Selection and existing Carrier. For the digitisation this combination is called “Filmpackage”. Although a high percentage of film cans contain only one film roll it often occurs that one film roll consists of multiple ‘Filmpackages’. It is estimated that for the Broadcast collection the average is around two ‘Filmpackages’ per film roll (variation from 1 to 25).

3. The challenge

Mass film digitisation within the scope of the Images for the Future project has started in 2008 with the “Telerecordings” broadcasting subcollection and continued in 2009 with “Journaal” (the News subcollection) and the Amateur Film Collection. In 2010 and beyond other collections will follow.

The main challenge Sound and Vision faces is to find the so-called sweet spot for the approach of the mass digitization process of its very heterogeneous collection. The sweet spot is the optimal balance between production volume, available budget, time constraints, quality and present and future archival, preservation, access and repurposing requirements. A choice in the digitisation approach and formats will always be a trade-off between these factors. For this also the availability of standards and capabilities of market solutions have to be taken into account.

3.1 Film digitisation process until the end of 2010

The digitisation process until the end of 2010 was based on telecine transfer to a video format. Twice per month films were transported to external scanning providers. Each film was physically prepared, cleaned (ultrasonically) and scanned in standard resolution (SD) to Digital Betacam (Digi). The level of physical preparation needed depended on the material status. About 40% needed physical preparation. Transports and digitisation orders were managed based on Excel spreadsheets.

If applicable, sound was captured in sync with the image at the scanning stage of the process and laid down to the Digibeta tape as well. Scanning preparation involved setting the right levels according to a “One Light” procedure to achieve the optimal dynamic range whilst preventing the high- and lowlights from “clipping”. Procedures for black-and-white and colour material were discussed and agreed with the various scanning service providers.

After registration of the new carrier, including relevant time code information of each single item on the Digibeta in the iMMix cataloguing system, each item on the Digi was encoded to a MXF D10-50 hi-res file for digital access and transcoded to a MPEG-1 proxy for browsing. For this purpose film digitisation makes use of the well-established ‘Digital Betacam encoding process’ that Sound and Vision established as part of the Images for the Future Project for its video collection..

MXF D10 was chosen as the hi-res access format for film because it was and, to a certain extent, still is the SD video standard for broadcast, archive, access and repurposing of both Sound and Vision and the Dutch Public Broadcasters. The earlier described yearly 100.000 hires downloads in MXF D10 are a clear indication it is an important format for repurposing.

Please refer to figure 2. for an overview of the process chain.

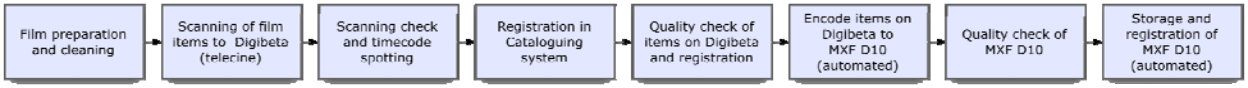

Figure 2: Film digitization in SD

Based on this structured process and with the help of a number of external scanning providers Sound and Vision has been capable to deliver 2.800 hours of film digitisation in 2009. Due to the complexity and scale of this volume it proved extremely important that both Sound and Vision and the service provider thoroughly check existing metadata and accurately register new metadata.

3.2 Limitations of the SD approach

It is the experience of Sound and Vision that SD resolution sufficiently captures the actual details in the 16 mm and 8 mm films within the subcollections that were selected for SD-digitisation. These findings are, in part, corroborated by research of the European Broadcast Union [ref 1 – the link is unfortunately out of date]. The fact that it also enables repurposing now and later was a major incentive to kick off the project with SD digitisation.

However, the SD approach poses some limitations to the archive and, more importantly, Sound and Vision has identified numerous subcollections that require higher resolution digitization to capture all the information on film. This problem can now be overcome due to standardisation and market developments in the area of functionality and costs.

MXF D10-50 is a video format based on lossy compression, whereas an archive master would ideally be a lossless data format to suit digital sustainability and preservation. Furthermore, Dutch broadcasters as well as Sound and Vision have recently chosen the XDCAM HD422 standard for HDTV broadcasting and subsequent archiving. It is expected that an archival master in HD resolution, rather than SD, will be beneficial in the expected repurposing for HD production and other new formats.

4. A roadmap for High-Definition film digitisation

4.1 Quest for the sweet spot

During 2008 and 2009 Sound and Vision has investigated several approaches and solutions to overcome the limitations of the SD approach and find the so-called “sweet spot” for its future mass film digitisation. Please refer to figure 3. for an overview of the phasing.

First HDCAM-SR was reviewed as an option, based on the BBC approach. It proved not to be a valid choice because of declining support in the industry for video tape-based solutions in general and HDCAM SR in specific: the proprietary and lossy nature of the compression were regarded as the main drawbacks. As a result the decision was taken to select a data format – instead of video – and implement a tapeless solution. Being the default standard for film postproduction, the DPX format was the best candidate for the digital master of the film image.

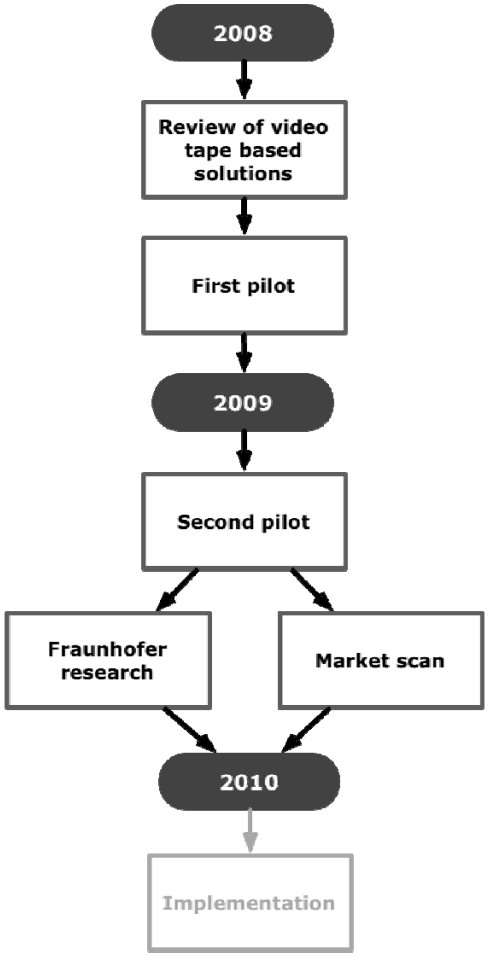

Figure 3: Phasing of investigation

The sheer size of a DPX digital master soon posed the problems of DPX storage volume costs and manageability. Therefore, the potential of JPEG 2000 as a visually or even mathematically lossless compressed intermediate digital archive master was investigated by Sound and Vision during two consecutive pilots. In the first pilot scenario the DPX (2k) would be stored on the shelf as backup, while the JPEG 2000 would be stored and managed in a near-line environment for archival purposes next to a high-res video format for accessibility .

The lesson learned from the first pilot study in 2008 was that JPEG 2000 was not yet an industry standard for archival purposes. Mathematically lossless profiles and practical, well-established applications for JPEG 2000 production. Repurposing of JPEG2000 seemed to be lacking at the high-end post-production facilities and mainly focused on digital projection resulting in lossy compression.

Within the context of the challenge, Sound and Vision researched the most important and least known aspects of the film digitization process:

- What is the best way to scan the material taking several types of source material into account?
- What is the best format to store the scanned material and, if compression is to be used, what is the acceptable (i.e. from archival point of view) level of compression that can be applied?
- What is the best way to convert this material to a broadcast-compatible video format and what is the effect on picture quality of this conversion?
- What are the tools available on the market to produce and quality check JPEG 2000 and transcoded formats,
- What are production process parameters, like time and effort needed to produce JPEG 2000 and transcoded formats.
- What are the practical capabilities of these tools and how does this fit in with the envisioned workflow.

To answer these questions, Sound and Vision executed a second pilot, performed a hands-on market survey and asked Fraunhofer IIS to perform extensive research and testing in this area.

The remainder of this chapter illustrates the findings of the pilot and the research and translates the conclusions and recommendations into a practical roadmap for HD film digitisation at Sound and Vision in 2010-2014.

4.2 Pilot and market survey results

During the second pilot in 2009, a number of available JPEG 2000 production systems were tested hands-on with DPX files from Sound and Vision film material. Also, additional market research was performed. The overall conclusion of this pilot and research was that important functionality – e.g. system supported real-time quality control – was not yet available and that the market would need more time to embrace the JPEG 2000 compression as an archival) standard for film material.

At the time of writing the industry is focusing heavily on providing JPEG 2000 solutions for Digital Cinema applications. 2k solutions are readily available for DCI DCDM (Digital Cinema Distribution Master) and DCP (Digital Cinema Packaging) applications and most of the effort at this moment is targeted to get the 4k solutions to the market. However, neither of the DCI profiles (2k or 4k) provide sufficient flexibility to serve as an archiving format:

- DCI supports only image bounding boxes of 2048x1080 and 4096x2160. When applied to the 4:3 material of the Sound and Vision collection, the choice of resolutions is very limited, especially for high-quality source material (considering that 4k scanning is economically not an option within the "Images for the Future"-project).

- The DCP formats are distribution formats (i.e. for theatres). This also means that most applications provide DCP as a target format and not as a source/master format for subsequent conversion to other (video) formats.

Other problems with JPEG 2000 are:

- Encoding and decoding JPEG 2000 is extremely computing-intensive. When JPEG 2000 is used as the online 'digital master' of a movie, considerable investments have to be made in transcoding capacity to produce video output formats within a reasonable amount of time.

- There is not a standardized application specification to wrap JPEG 2000 pictures in an MXF container. SMPTE 422M describes this mapping, but leaves too much room for implementation variation since it only focuses on the picture track and does not constrain the use of audio. Defining this in a user-defined application specification poses a serious challenge in finding a vendor that is willing to implement it, let alone the interoperability problems that will arise with other vendors.

Finally, one can assert that the development of JPEG 2000 profiles for archival purposes indicates a preference for mathematically lossless compression. Mathematically lossless JPEG 2000 compression effectively means a data reduction of about 50%. Eventually, the benefits of producing and storing mathematically lossless JPEG 2000 no longer outweighed the expensive storage of DPX files, which is the direct output format of datascanners and datacines. The benefit of the "DPX only"-route was not only of financial, but clearly also of operational nature.

4.2.1 Film quality and scanning resolution

In general one perceives film as having a technical quality level that exceeds that of digital media. And often resolution seems to surface as the main parameter in this matter and is linked to the spatial density of film grain.

But although experience tells that viewers like film grain to be visible in the picture for "perceived sharpness", selecting the right scanning resolution is more complex than simply trying to capture grain detail.

First of all, the technical quality of the digitized film is determined by more parameters than scanning resolution alone. Within the digitisation step scanner signal-to-noise-ratio (SNR), scanner optics, colour space, bit depth and scanning settings like focus, levels and curves contribute equally or even more to the technical quality of the digitized film.

Secondly a very important factor in the equation is the technical quality of the (information captured on the) film itself, as the primary input for the scanning procedure. It is a result of multiple factors. For example these factors are amongst others:

- Lighting conditions and compensations during registration.
- Quality of registration equipment, especially lenses.
- Focus.
- Characteristics of the film stock.
- Film development and/or printing.
- Film degradation due to treatment, e.g. during use and storage.
- Skills and care of staff.
- Time available for production.

All these factors together create a chain in which the end quality is a product of all individual quality levels and in practice might be less than the single one worst factor. Although it is almost impossible to determine exact quality parameters and levels for archive stock it is important to realise that a single factor cannot be the only the measure.

One could take a look at the commonly used quality measurement method Modulation Transfer Function (MTF). This method depicts how contrast information in a system degrades related to increased spatial frequency and how the total MTF can be determined by multiplying the individual MTF curves of each system function like lens, stock, etc..

For example the MTF method has been used for a demo calculation of the resolution needed to capture all detail in the movie Lawrence of Arabia. The conclusion was that a horizontal resolution of 6.000 pixels would be sufficient given that one has to take into account that this movie was shot in highly professional conditions on 65mm negative with very good lenses and film stock.
If the outcome of this example would be translated to the predominant film stock stock in the Sound and Vision archive, i.e. 16 mm reversal material, the resolution needed would be 1.470 pixels horizontally. Even lower resolutions would be a safe assumption when taking into account that it concerns positive reversal and is shot for broadcast news, current affairs and documentaries in far from ideal conditions. Of course this is a mere example and does not provide conclusive evidence, but it indicates that determining the scanning resolution depends on a wide range of factors.

For the purpose of allocating the right spatial resolution Sound and Vision has tried to identify and map different types of stock based on cinematographical quality and historical importance within the collection. Of course historical importance is a very difficult and subjective parameter to qualify. Please refer to figure 4. for a rough visualisation of the decision-making process at Sound and Vision.

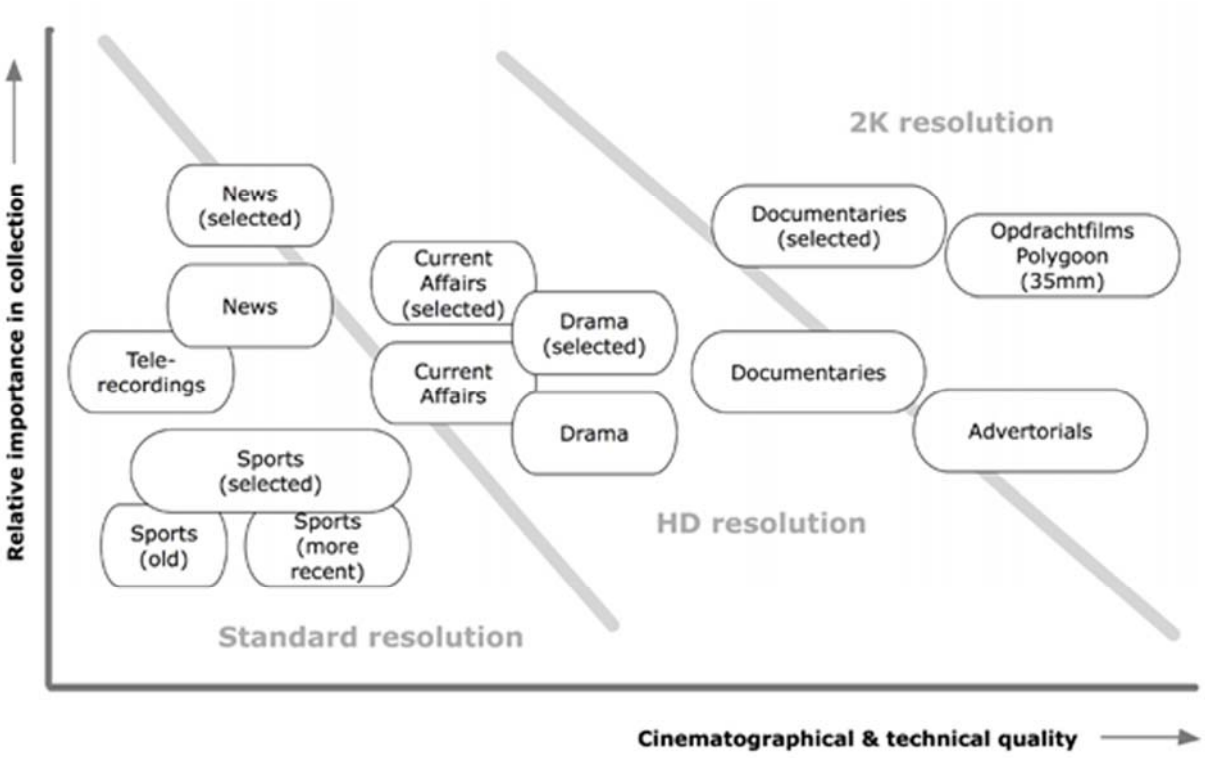

Figure 4: Example of resolution mapping

4.3 Research results

The Fraunhofer research covered:

- An assessment of the relevant scanning parameters and constraints on their values.
- An assessment of the effect of JPEG 2000 compression on the visual quality of the film pictures, obtained through panel tests.
- An assessment of the effect of JPEG 2000 compression on the PSNR and MTF of the film pictures, obtained through mathematical analysis of the pictures.

In addition, the research reports on recommendations for the handling of data, metadata and media. This will provide valuable input when the scanning, archiving and retrieval workflows will be actually implemented.

4.3.1 Film scanning

The first step in digitizing film is scanning. Proper parameter and quality control in this step is essential since it strongly influences the quality of the

final product and also determines to a large extent what further processing steps are necessary (or possible) to achieve the final result. The Fraunhofer research extensively covers this area and leads to the following conclusions:

- Regardless the resolution of the scanner, the output images should be stored in the native resolution of the scanner. Downsampling (in the scanner) is allowed in special cases if the native resolution is larger than the intended output resolution.

- Since the scanned images also serve to digitally preserve the content, the images should be scanned at a resolution high enough to capture all the detail available in the source material. For the Sound and Vision collection, it appears that the full 2k resolution (2048x1556) is enough to capture even the highest quality film. In most cases, however, the image quality is (considerably) lower and lower scanning resolutions can be used without compromising the captured detail. This allows Sound and Vision to economically balance the scanning resolution (and therefore the costs) against the quality of the material. As a result, the following differentiation will be made:
  - Full 2k resolution (2048x1556) scanning for premium content: all 35 mm film as well as 16 mm film containing premium content or 16 mm material of exceptional cinematographical beauty and skill, B/W reversal film.

  - HD resolution (1440x1080, picture area due to 4:3 aspect ratio) scanning for all other 16 mm material.

Both resolutions will allow for excellent mapping to HDTV output formats (see also below).

- Images scanned with 10-bit logarithmic color components provide enough dynamic range to capture the usable range of densities. The 10-bit logarithmic transfer curve is widely used in the film industry and provides the best opportunity for software and hardware compatibility when processing these images.

- When color faded material is scanned, the scanner should take care of the first (course) step in color-correcting the images. The black and white levels of the scanner should be adjusted per color component to make maximum use of the available bit depth (10-bit logarithmic scale). This procedure, of course, results in images with a non-standard and uncalibrated color space but since the original material was color faded in the first place, any calibration is useless and color correction would be necessary anyway.

- The choice of color space is not trivial. The Fraunhofer research indicates a number of possibilities that is driven by compatibility with the scanner (when looking at the source) or driven by the intended use (when looking at the destination). There are several RGB color spaces available that are used in the scanning and digital image industry. The XYZ color space, on the other hand, is used in Digital Cinema, but does not yet seem to be well supported outside this application area. In addition, the XYZ color space is so large that coding colors in this space requires more bits of precision since only a small part of the gamut is actually used in real-life situations. The most convenient choice, therefore, is to keep the RGB color space provided by the scanner and have it documented by the scanning party. The color primaries are defined by chromacities of the film illumination used during scanning (usually LEDs) which provide the natural extremities of the scanned gamut. Since this color space is RGB, it provides maximum compatibility with RGB devices and video equipment and covers most (usually more) of the color gamut present in color film. The color values can be easily transformed to other RGB color spaces such as ITU-R Rec BT.709 (HDTV) using a LUT (look-up table) and transformation matrix.

4.3.2 Image Compression

Sound and Vision considered two ways to store pictures from film digitally as the " archive master " : store the images as uncompressed DPX files or use the (mathematically lossless) JPEG 2000 compression algorithm.

DPX

DPX is an uncompressed image format that is widely used in film production. It is standardized in SMPTE 268M-2003. The format allows for storing linear or logarithmic color channel values at various bit depths (10, 12 or 16 bits per component). The most commonly used format is the 2k DPX file (2048x1556 pixels) with 10-bit logarithmic RGB pixels.

DPX images are usually organized as individual files in a in a directory structure that represents the original film strip (reel).

JPEG 2000

JPEG 2000 has been an ISO standard since 2002 (ISO 15444-1). Aimed as the successor of the popular (ordinary) JPEG compression standard (ISO 10918-1) and becoming popular in medical applications and digital cinema, JPEG 2000 offers a number of improved features over traditional JPEG. With film archiving in mind, the following are of particular interest:

- No or almost no visible blocking artifacts, especially none at moderate compression ratios.
- Lossless and lossy operating modes. The compression ratio can be set such that the quality of the compressed image is above a defined 'visually lossless' threshold.
- Resolution-independent coding through the use of wavelets.
- Better compression at the same quality (or, alternatively, better quality at the same compression ratio) when compared to JPEG.
- Flexible color channel assignments make JPEG 2000 applicable for grayscale (single-channel) and color (three-channel) images.
- Support for several color channel bit depths (8, 10 or 12 bits).

Particularly the use of wavelets provides a fundamentally different approach to compression when compared with the widely used DCT algorithm found in image and video codecs. The wavelets describe the entire picture (not just macroblocks) at different resolutions (called decompositions), for instance all the way from 1/64 to 1/1 of the original size. Data reduction is achieved by quantization. In JPEG 2000, this reduces the quality of the entire picture instead of that of individual DCT blocks, resulting in a visually less sharp image, but almost no artifacts (blocking).

JPEG 2000 images can be stored as individual files or wrapped as a sequence into an MJ2K, MXF or MOV container file.

Both formats allow the film pictures to be stored in their original aspect ratio and, since the pictures are stored as individual images, there are no frame rate issues (frame rate is just a metadata property).

4.3.3 Subjective quality assessment

JPEG 2000 seems the ideal compression algorithm for storing a visually lossless digital copy of the original film. The research, through visual rating by a panel of several randomly chosen sequences in comparison with a reference, has shown that at 2k resolution, JPEG 2000 sequences can be compressed at bit rates down to 200 Mbps and below, and still retain the visually imperceptible difference with the original uncompressed scanned version. These bit rates dramatically reduce the cost of storing an online or near-line copy of the

material. The biggest problem with JPEG 2000, however, is (as mentioned above) industry support for archiving applications and tools for checking, controlling and validating the quality of the JPEG 2000 code stream as well as performance issues.

4.3.4 Objective quality assessment

The objective quality assessment performed during the Fraunhofer research showed (as expected) that mathematical quality indicators currently available are of little use in determining the absolute quality degradation of an image due to compression. The two models used (PSNR and MTF) showed that the quality degradation is strongly dependent on the image content. Although the quality degradation is expected to correlate with the compression itself (for instance, high-detail or noisy images are expected to degrade more by compression than fuzzy, smooth images), the fluctuations in PSNR, on frame-by-frame basis, turned out to be larger than the effect caused by the various bit rates used for compression. The results showed a consistent trend, though: more compression leads to larger image quality degradation, but nothing more quantitative could be learned from the exercise.

The MTF model appeared largely useless because its propagation relies on the linearity of the transfer functions – and JPEG 2000 compression is not a linear transformation. In addition, the MTF values for most of the steps leading to the final product (optical system during shooting, optical system during scanning, scanning sensor and processing) are not known, which makes it hard to relate the MTF contribution of the JPEG 2000 compression step to the quality of the final product.

Conclusion

Roadmap for High-Definition film digitisation.

From the current digitization process, the pilots, market research and Fraunhofer investigation Sound and Vision has gained a lot of useful insight, knowledge and hands-on experience. This enables a well-documented decision for the digitisation roadmap.

Of pivotal importance in this roadmap are the decisions to use DPX as the digital archival format and XDCAM HD422 as the digital access format . This means that even though the (subjective) compression quality assessment showed that it is possible to use JPEG 2000 at attractive bit rates, the gain in storage requirements was not that big to counterbalance the added complexity, lack of industry support and necessary computing power. This decision was backed by the findings from the 2nd pilot, which showed that soft- and hardware for producing and handling JPEG 2000 sequences have not yet reached a mature stage. Another major constraint were the limited possibilities to check the quality of the digitised material in real time. As elaborated on in section 3, many usage profiles, particularly for archiving, are still under development and not yet supported by the equipment. The only main application in which JPEG 2000 is flourishing at the moment is Digital Cinema (DCP), but this application field is too constrained to be useful for archiving.

Backed by Fraunhofer's research, currently two different "flavours" of DPX are envisioned. Full 2K resolution (2048x1556 pixels) will be applicable for all 35mm film and a selection of "documentary grade" 16mm film. All other 16mm film will be scanned to DPX in HD resolution (1440x1080 picture area). For both the other DPX properties are 10-bit log and RGB colour space, in a native scanner gamut which covers all film dye characteristics.

Please refer to figure 5. for an overview of the new process.

The change over from the SD process to the new HD/2K process required extensive preparation. This resulted in a planned switch-over from SD to HD/2K in the third quarter of 2010.

Sound and Vision will digitise approximately 12.000 hours in HD and 2K. The exact division

between HD and 2K in terms of hours of film material is not yet known and will be established as the digitisation process proceeds. Storage constraints may also influence this.

All film material suitable for 2K scanning will be scanned at the premises of Sound and Vision in Hilversum. The decision to invest in an in-house scanning facility has a number of reasons:

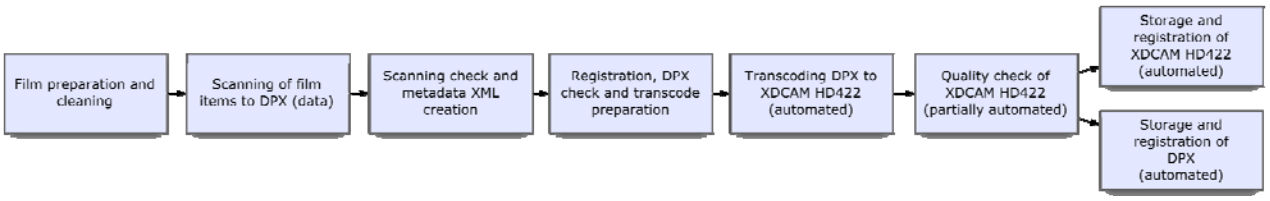

Figure 5: Film digitization in HD

- Setting up a technical facility in which we are able to process large files will enable Sound and Vision to quality-check the full-res DPX files that were scanned externally. Checking incoming DPX files on LTO4 based on mere low-res proxies cannot guarantee the digital master (i.e. DPX files) meets all the requirements deemed necessary by Sound and Vision.

- An in-house scanner provides the possibility to build up extensive knowledge about film scanning. This knowledge can be put to use, not only internally, but also for other archives that will be confronted with certain issues when digitising their collections. This will especially be useful at times when digital recording techniques will overtake recording on film stock.

- After 2014 (i.e. the end of the Images for the Future project) new film collections will still be acquired by Sound and Vision. New collections can be digitised immediately and the scanner can also facilitate the rest of the acquisition process by, for example, producing low-res proxies that are used to describe the material.

- Sound and Vision engages in numerous projects that often include the production of a DVD-box. Here, the scanner can also be used to do ad-hoc and 'customised' digitisation. Also Sound and Vision will no longer need to rely on external Suppliers for urgent requests by broadcast professionals to digitise specific film material.

Approximately two thirds of the entire HD digitisation will be done by external Suppliers that are carefully selected through European Public Tender procedures. The preparation of the film material will in this case also be performed by the Supplier according to Sound and Vision's instructions. The following digital deliverables will be expected back from the Supplier on LTO4 tapes:

- DPX (TAR) 1440*1080, 10 bit log, RGB

- BWAV (24 bit PCM @ 48kHz) for sound, that has been synchronised to the image by means of a 1kHz tone in the digital domain

- XML file containing all the necessary metadata to ensure all necessary information goes back to the Sound and Vision database. The XML files are also crucial to support and facilitate the rest of the work process.

The remaining 4000 hours of film material will be scanned at Sound and Vision on the DFT Scanity to HD (1440*1080) for 16mm film material and full aperture 2K (2048*1556),for 35mm material as well as a selection of 16mm material.
The in-house scanning facility is also equipped with a NLE set to check and adjust the synchronisation of sound and image. This facility also en-

ables Sound and Vision to perform a quality check on the DPX and WAV files produced by the external Supplier before encoding all scanned material to XDCAM HD422 (with embedded sound).

The original DPX and WAV files will at all times be kept as Sound and Vision's digital master – initially on LTO4 tapes and eventually on a managed storage system based at Sound and Vision.

References

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