Recommendations on Preservation Files for Use in the Digitization of Analog Audio and Video Recordings and Motion Picture Films

National, Provincial and Territorial Archivists Conference Audiovisual Preservation Working Group

in partnership with the

National Heritage Digitization Strategy Steering Committee

January 2018

Contents

Preface

These recommendations were originally published on November 22, 2015, as a project of the National, Provincial and Territorial Archivists Conference (NPTAC) Audiovisual Preservation Working Group. In late 2017, the NPTAC established a partnership with the National Heritage Digitization Strategy (NHDS) Steering Committee to update the recommendations.

The NPTAC is a consultative body comprised of the heads of the 13 provincial and territorial archives, and the Librarian and Archivist of Canada. The NPTAC meets twice-annually to discuss subjects of mutual interest and undertake collaborative projects that support the goals and objectives of the Canadian archival system. In 2015, the NPTAC formed the Audiovisual Preservation Working Group to develop preservation tools to aid the archival community.

The NHDS seeks to coordinate the digitization activities of Canadian libraries, archives and museums. Through the strategy, organizations will digitize and make available published and unpublished material of interest to Canadians, while ensuring this material is properly preserved. The NHDS provides national coordination to complement strategies already in place at Canadian memory institutions and to assist these institutions in fulfilling their goals. Providing Canadians with free and open access to their documentary heritage material promotes a free and democratic society.

Library and Archives Canada provides secretariat support to both the NPTAC and the NHDS.

Version Control

Version	Change	Author(s)	Date
Recommendations on Preservation Files for Use in the Digitization of Analog Audio and Video Recordings		NPTAC AV Preservation Working Group	November 22, 2015
Recommendations on Preservation Files for Use in the Digitization of Analog Audio and Video Recordings and Motion Picture Films	Updated to include motion picture film. Audio and video recommendations were reviewed.	NPTAC AV Preservation Working Group and the NHDS Steering Committee	January 2018

1. Scope

These recommendations were developed to provide advice on the preservation files that could be adopted when digitizing analog audio recordings, video recordings or motion picture films.

2. Application

These recommendations were developed to provide organizations embarking on digitization projects with a reference from which to develop their own digitization standards.

3. Expected Results

These recommendations restrict the number and types of preservation files to those that the authoring bodies have reasonable confidence are sustainable and therefore suitable for long-term preservation. The widespread adoption of these recommendations will aid the preservation of audio, video and motion picture film content nationally.

4. Basic Concepts

Sustainability

Sustainability is ensuring that content is preserved and accessible over time balanced against an organization's resource capacity.

Digitization

Digitization is the process of capturing and converting analog signals into digital form.

Preservation File

A preservation file meets two conditions:

1. It is a high quality digital representation of an analog recording that captures as many attributes of the original content as possible without enhancement or alteration.[1]
2. It demonstrates an adequate level of interoperability, community adoption and documentation to allow the digital information or essence of the file to be accessible over the long-term and be retrievable in the future without proprietary intervention or adverse consequences to its quality.

Essence

The digital information within an audio, video or image file format is called the essence. The essence can be coded in a variety of different ordered formats and with varying levels of compression.

Codec

A codec is hardware or software capable of encoding and/or decoding the essence of a digital audio or video file. The coded format of the essences in a file is often identified by the type of codec that is required to decode the essence for playback. A codec describes the specific set of instructions required to accurately interpret and present the digital essence. For example, JPEG2000, H.264 and ProRes422 are just a few examples of the many different codecs that are used to encode video in a file format.

[1] See Appendix A for information on content that requires enhancements/alterations.

File Format/Container/Wrapper

A file format for audio or video, also referred to as a container or wrapper, serves to package the coded essence and associated metadata (structured data about data) together in a specified file format. QuickTime (.MOV), Material Exchange Format (.MXF) and MPEG4 (.MP4) file formats are all examples of different standardized containers or wrappers that could encapsulate coded digital video essence.

A codec and a file format are two different components to an audio or video file and the terms are often improperly applied. For example, simply referring to a video .MOV file as a QuickTime file does not adequately describe how it can be properly interpreted as it is a container file that could encapsulate audio and video essence that could be coded using one of dozens of different codecs.

Motion picture film digitized for preservation is not scanned directly into a single file container, but instead into a sequence of separate image files for every individual frame in the reel of film. The most common image file container format for digitized motion picture film is Digital Picture Exchange (.DPX). The audio soundtrack of a film is captured separately to a Broadcast Wave File (BWF). Typically, the scanned image sequence and audio file are not wrapped together into a combined container format and are instead stored in a logical file structure for long-term preservation.

Data Compression

Data compression is a process by which a codec is used to decrease the size of a file so it requires less storage space and lower bit rates. Bit rate is the amount of data being processed per unit of time during playback and transmission.

For audio, preservation file sizes are already so small that file size is not an issue therefore files are uncompressed.

The majority of video compression codecs are lossy, meaning some level of information from the original source signal has been lost or interpolated mathematically. There is always a trade-off between visual quality, file size and processing power or system requirements needed to encode and decode a given video compression codec. There are a tier of codecs that are identified as visually lossless, meaning that a subjective comparison made by the naked eye of an average viewer will not detect any visible differences between the original signal and compressed version. However, mathematically there is a difference and it is one that could become more apparent over time as the compressed file goes through future conversions and repeated compression. There are codecs that support lossless compression (Uncompressed V210, JPEG 2000 or FFV1) which mathematically preserve all the information of the source signal, but they will require the highest bitrates, largest file sizes and potentially the most computing power to process.

Film digitization for preservation does not employ video compression codecs. Film is digitized to an image sequence so there is no consideration for compression over time (i.e. video codecs compress not only data within a single frame but also save space by interpolating information between frames over time). Scanning motion picture film to a series of still images is more akin to scanning a series of photographic slides. Image file formats can use compression codecs, but for preservation, work should always be uncompressed.

Image Resolution – Video

The resolution of an analog videotape is consistent and constrained by various international broadcast standards[2] to a known frame rate and number of lines per frame. These standards also extend to the digital realm with a single consistent digital image resolution to match these standards.[3] A file that deviates from these standards would be deemed non-compliant as it would introduce a loss of quality or distortion in the display of the image.

Scan Resolution – Motion Picture Film

Resolution is a measurement of how many pixels a scanner can sample in a given image. The higher the resolution, the higher the level of spatial detail captured in the scanned image. Digitizing motion picture film is a different process than the conversion of analog video to file formats. Digitizing film requires optical scanning where light is transmitted through the film and focused by a lens on to a sensor.

A survey of film scanners currently available on the market reveals a consistent maximum resolution of 4K when scanning 35mm film. The K refers to the number of pixels contained in one complete horizontal line of a digital image. A 2K scan will typically result in 2,048 horizontal pixels per scan line and 4K would be 4,096. An argument can be made that scanning at a resolution higher than 4K may be mathematically required to cover the maximum information contained in a 35mm film negative but in practical terms heritage organizations have collections predominantly made up of prints so 4K resolution should be sufficient. 16mm prints can be scanned at a resolution as low as 2K without risk of losing significant information. An 8K or higher workflow would currently require the adoption of custom scanning solutions and the data infrastructure requirements for the processing and archiving of these image sequences would be daunting.

Sample Rate

A sample is the measured value of a signal at a single point in time. Sample rate is the frequency that a signal is sampled at along the axis of time.

When digitizing audio, sample rate is the number of samples per second taken from a continuous, analog signal to make a discrete, digital signal. Analog audio that has been digitized at a sample rate of 96 kilohertz (kHz) has been sampled 96,000 times per second. A greater sampling rate enables the digitization of higher audio frequencies, resulting in a preservation file that captures more of the qualities of the original recording.

During video digitization, the luminance or luma (gray-scale brightness) and colour information or chroma of the analog video signal are sampled. In a NTSC[4] analog video signal, twice as much signal bandwidth is allocated to the luma (Y) information as to the two chroma components (Cb and Cr) because the human eye is less sensitive to colour detail as it is to luminance. In digital video, this sampling rate is referred to as a ratio: 4:2:2 (4 Y, 2 Cb, 2 Cr). Standard definition digital video with 4:2:2 colour sampling is the same ratio of information between signal components as analog and is considered adequate sampling to capture the full signal bandwidth from an analog video source. Digital

[2] National Television System Committee (NTSC), Phase Alternating Line (PAL), Séquentiel couleur à mémoire (SECAM).
[3] Standard definition NTSC video in digital form is defined by Society of Motion Picture and Television Engineers (SMPTE) 259M as having an image resolution of 720 pixels wide by 480 lines of height.
[4] The analog television system employed in Canada.

video sampled at higher ratios of colour sampling (i.e. 4:1:1 or 4:2:0) will create smaller file sizes, but at the cost of colour precision.

Bit Depth

Bit depth is the number of bits of information in each sample. Increased bit depth equals increased precision of the sample and therefore increased quality of the preservation files.

When digitizing audio, a greater bit depth will enable a greater ratio between the quietest and loudest possible values of a signal. This ratio is the dynamic range. It is imperative that digital conservation copies have a greater dynamic range than the original to ensure that all the information is transferred. Digitizing at 24 bits bit depth ensures a dynamic range greater than any audio equipment and format.

In a digital video or a digital image file sequence made from motion picture film, the bit depth refers to how many bits of information are used to describe each colour channel (red, green and blue) for each pixel in the frame. The more information allocated per channel, the greater number of colours that can be represented in the frame.

Scanning Motion Picture Film

There are two competing scanning methodologies with regards to digitizing motion picture film for preservation:

- Over scanning, or edge-to-edge capture, expands the field of digitization to include the sprocket holes, the optical soundtrack and any key code information present on the edge of the physical film. In the event that the film original is ever lost, the full extent of the information printed on the film stock, inside and outside the picture information, could be retained. The process of over scanning does have one significant drawback as fewer pixels of information are now being devoted in the scanning sensor to the actual image content area of the film frame. This also contributes to more complex post-scanning processes that will require every preservation master scan to be cropped and formatted to produce derivatives that contain only the image content of the film.
- Picture only scanning where only the image content area of the film is scanned to ensure that the maximum pixel resolution of the scanner is devoted completely to capturing content image information. This ensures that all future derivative versions can be created without cropping or re-formatting of the original scanned images. Adopting a picture only scanning approach assumes that you can capture the optical audio soundtrack of the film at the time of digitization as it will no longer be represented visually where it could be potentially recovered via other digital processing means.

5. Evaluation Criteria

The criteria used for evaluating codecs and file formats to be used for preservation purposes is entirely derived from the approach advocated by Library and Archives Canada (LAC) in their document *Guidelines on File Formats for Transferring Information Resources of Enduring Value*.[5]

LAC's criteria focuses on ensuring that preservation files meet the definition in *Section 4 Basic Concepts.* In order to gauge the sustainability of a given codec or file format LAC considered the following:

Openness/transparency

- The relative ease with which knowledge of the file format and its technical information can be accumulated.

Adoption as a preservation standard

- The extent to which the format has been formally adopted by national libraries, archives and other memory institutions internationally.

Stability/compatibility

- The degree to which the format is backward and forward compatible.
- The degree to which the format is protected against file corruption.
- The relative frequency of updated or replacement versions of the format over time.

Dependencies/interoperability

- The degree to which the format relies on proprietary/non-proprietary hardware or software.

6. Other Considerations

An organization should adopt the file formats and codecs that can be confidently sustained. Resources are limited; recordings are often in poor condition; playback equipment is scarce. Most organizations will only have a single opportunity to digitize their analog holdings and should try to future-proof their work by making informed file format and codec choices now.

Simply put, a losslessly compressed or uncompressed preservation file will capture the maximum number of attributes of the original recording. However, a blanket statement declaring that lossless uncompressed preservation files are the only option to be considered completely ignores the realities facing most organizations tasked with preserving audiovisual collections. The size of your collection or resources (financial or technical) may render such a choice unsustainable, requiring compromises to be made to ensure a balance between quality and sustainability. Compromise should not be viewed as failure if it enables an analog AV collection to be migrated off obsolete carriers and into a modern digital form.

[5] The criteria is used with the permission of Library and Archives Canada. Please see: http://www.bac-lac.gc.ca/eng/services/government-information-resources/guidelines/Pages/guidelines-file-formats-transferring-information-resources-enduring-value.aspx#aa.

Every organization will face technical and practical considerations when adopting codecs and file formats. In addition to the four evaluation criterion, the preservation file choices of organizations will be influenced by other factors including:

Mandate

- The choice of preservation files should always be informed by the mandate of an organization. If the mandate of an organization is long-term preservation, then creating uncompressed or losslessly compressed preservation files is recommended in order to capture the maximum fidelity of the original recording. If however, your organization maintains audio and video recordings to achieve only short-term goals than a lower quality preservation file might be justifiable.

Attributes of the material to be digitized

- The extent, quality, uniqueness and value of your analog audio and video recordings may be factors that influence preservation file format decisions. If a collection is made up of copies of recordings where originals or better quality copies exist and are accessible then it may be valid to select a less complex or less storage intensive codec. If a recording is the only copy known to exist, or if an organization has the potential to monetize their collection in the future, then it is reasonable to allocate the resources to create uncompressed or losslessly compressed preservation files.

Current and future use of the content

- When selecting a preservation file, the needs of an organization's user community must be considered. If the complexity of a file negatively impacts the ability of an organization or its stakeholders to repurpose content, then it might not be a wise choice. No one can predict all of the future needs of clients or the technological environment in which files will be used, but the negative attributes of preservation files may be magnified in the future.

Expertise

- The adoption of preservation files requires informed technical expertise. Those making these choices should understand the nature of the original analog recordings as well as file formats and codecs in order to appreciate the immediate and long-term implications that any choices have. If the expertise does not exist internally, there are digitization services that can be engaged. However, all organizations need a basic understanding of their collection, goals and resources in order to ensure that sustainable preservation files are being generated.

  The use of open source file formats and codecs may come with benefits in regards to cost and customization, but organizations who choose this route must be prepared to maintain a minimum level of internal expertise over the long-term to actively participate in the programming communities that support the open source technologies they have adopted.

Storage infrastructure

- The choice of preservation files will dictate the amount of storage space required. Your organization will require infrastructure to securely and confidently sustain preservation files long-term. The infrastructure must also be scalable if collection growth is anticipated.

7. Approach

The file formats and codecs are identified as either:[6]

- Recommended; or,
- Acceptable.

Recommended file formats and codecs are those that ensure that preservation files meet the definition in *Section 4* as well as possessing a high degree of long-term sustainability because they best meet the evaluation criteria in *Section 5*.

Acceptable file formats and codecs are those that meet some of the evaluation criterion in *Section 5* balanced by the considerations in *Section 6*.

[6] File formats are simply listed in *Sections 8, 9* and *10*. The order of the list does not suggest that one format is preferable to another. However, a recommended format is always preferable to an acceptable format.

8. Audio Recommendations

Recommended Formats	Recommended Codecs	Recommended Sampling Rate and Bit Depth	File Size per Hour of Content	Minimum Sampling Rate and Bit Depth	File Size per Hour of Content	Pros	Cons	Format Specifications
Broadcast Wave (BWF)	Linear Pulse Code Modulated Audio (LPCM)	96 kHz / 24 bits	2 GB	48 kHz / 24 bits	1	• Fully documented and specifications are freely available. • BWF has become the de facto standard in the audio industry and is specifically recommended by the International Association of Sound and Visual Archivists (IASA), The Audio Engineering Society (AES) and the National Academy of Recording Arts and Sciences (NARAS). • BWF audio is compatible with any hardware or software that supports the WAVE format. There have been three iterations of the BWF format under the general specification number EBU Tech 3285 (Version 0 (1987), Version 1 (2001) and Version 2 (2011). • Universally adopted throughout the audio, computer and broadcast industries as a digital audio format. • Embedded metadata (BEXT chunk), facilitates the exchange of sound data between computer platforms and applications and permits synchronization with other recordings.	• While hardware and software that does not support the BWF format will recognize the file as a WAVE file, the embedded metadata will not be supported. • Limited to 4 gigabyte file size.	*European Broadcast Union (EBU). Technical Specification of the Broadcast Wave Format (BWF) – Version 1*: http://web.archive.org/web/20091229093941/http://tech.ebu.ch/docs/tech/tech3285.pdf *Specification of the Broadcast Wave Format (BWF) - Version 2.0:* https://tech.ebu.ch/docs/tech/tech3285.pdf
Acceptable Formats	**Acceptable Codecs**	**Recommended Sampling Rate and Bit Depth**	**File Size per Hour of Content**	**Minimum Sampling Rate and Bit Depth**	**File Size per Hour of Content**	**Pros**	**Cons**	**Format Specifications**
Waveform Audio (WAV)	Linear Pulse Code Modulated Audio (LPCM)	96 kHz / 24 bits	2 GB	48 kHz / 24 bits	1	• Fully documented and specifications are available. • Massive adoption in the international archival community. • It is an extension of the WAV format – any software that can interpret/render BWF content can also interpret/render WAV content; protected against file corruption; has been updated: WAV: Version 1.0: 1991; Version 3.0: 1994; Multichannel: 2001 / BWF: Original: 1997; Updates: 2001, 2003 • Universally adopted throughout the audio, computer and broadcast industries so all digital audio software and devices can play this file format.	• Limited to 4 gigabyte file size. • Technical metadata cannot be embedded in the file.	*Multimedia Programming Interface and Data Specifications 1.0*: http://www-mmsp.ece.mcgill.ca/Documents/AudioFormats/WAVE/Docs/riffmci.pdf
Multichannel Broadcast Wave (MBWF / RF 64)	Linear Pulse Code Modulated Audio (LPCM)	96 kHz / 24 bits	2 GB	48 kHz / 24 bits	1	• Fully documented and specifications are freely available. • Adopted by the EBU as a multichannel audio file standard and archival standard for files exceeding 4 GB in size. • MBWF is a BWF-compatible file format which has been specified by the European Broadcasting Union. The file format is designed to meet the requirements for multichannel sound in broadcasting and audio archiving. It is based on the Microsoft RIFF/WAVE format and Wave Format Extensible for multichannel parameters. The technical specification for MBWF/RF64 is EBU - Tech 3306. RF64 is also a BWF compatible multichannel file format.	• While most digital audio workstations support the RF64 file format, some older audio software does not support RF64.	*European Broadcast Union (EBU) MBWF /RF64 : An Extended File Format for Audio:* *https://tech.ebu.ch/docs/tech/tech3306-2009.pdf*

9. Video Recommendations

Recommended Formats	Recommended Codecs	Recommended Sampling Rate and Bit Depth (Standard Definition)	File Size per Hour of Content	Minimum Sampling Rate and Bit Depth (Standard Definition)	File Size per Hour of Content (Minimum)	Pros	Cons	Format Specifications
Material Exchange Format (MXF) OP1a	Image: JPEG 2000 lossless compression	10-bit, variable bitrate Lossless minimum average 50mbps	40 GB	8-bit, Variable bitrate Lossless minimum average 50mbps	40 GB	• Codec and wrapper are either an ISO or SMPTE standard. JPEG 2000 is a fully documented ISO standard. • Adoption by larger organizations in the international archival community, including the Library of Congress, Library and Archives Canada and the UK Digital Archives. • Software encoding and playback of MXF wrapped JPEG2000 is now possible without custom hardware on high-end multi-core CPU systems. • Lossless compression allows for file sizes to be up to 2.5 times smaller compared to uncompressed.	• A lack of consistency between different vendors in the implementation of the MXF standard can cause playback compatibility difficulties. The issues experienced have centered on variances in how the JPEG2000 essence is being described in the .MXF wrapper. The Library of Congress is currently leading a project to have a set of constraints formalized for the construction of .MXF files and having these templates recognized as standard operational patterns within the format. The current progress of this MXF application specification (designated AS-07) can be viewed here: http://www.digitizationguidelines.gov/guidelines/MXF_app_spec.html • JPEG 2000 requires higher system specifications for encoding and playback in real time. Support for the format in consumer level devices is rare and open-source support is in its infancy due to licensing fees.	SMPTE ST 377-1:2011, *Material Exchange Format (MXF) File Format Specification*: http://standards.smpte.org/ ISO/IEC 15444-1:2004, *Information technology – JPEG 2000 image coding system: Core coding system*: http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=37674
	Audio: Pulse Code Modulated (PCM) / Broadcast Wav (Audio, video and timecode information are wrapped together in the MXF container as defined by SMPTE ST 377-1:2011)	24-bit, 48khz		16-bit, 48Khz				
QuickTime (MOV)	Image: Uncompressed 4:2:2	10-bit uncompressed v210 codec - approx. 36 MB/sec	130 GB	8-bit Approx. 29 MB/sec	105 GB	• QuickTime file format is well documented and near full format disclosure is available from freely from Apple Inc. The QuickTime format was used as the basis for the standardization of the MPEG-4 file format (ISO/IEC 14496-14:2003). • File format enjoys wide community adoption in large institutions, video post-production and including many consumer level devices. Support for editing and transcoding in virtually all professional editing software. • 8-bit QuickTime uncompressed 4:2:2 is supported by virtually any system that can support the base QuickTime codec package and system/storage requirements to handle large media files.	• The 10-bit uncompressed v210 codec variant that allows for 10-bit colour depth in a QuickTime wrapper is not included in the base QuickTime codec package and although freely available, is potentially tied to proprietary vendor support. (i.e. AJA v210 codec) • File sizes are very large.	*QuickTime File Format Specification*: https://developer.apple.com/library/mac/#documentation/QuickTime/QTFF/QTFFPreface/qtffPreface.html
	Audio: PCM (Audio, video and timecode information are wrapped together in the MOV container as defined by QuickTime file format specifications)	24-bit, 48khz		16-bit, 48Khz				

Acceptable Formats	Acceptable Codecs	Recommended Sampling Rate and Bit Depth (Standard Definition)	File Size per Hour of Content	Minimum Sampling Rate and Bit Depth (Standard Definition)	File Size per Hour of Content (Minimum)	Pros	Cons	Format Specifications
Audio Video Interleaved Format (AVI)	Image: JPEG 2000	10-bit variable bit rates - dependent on level of compression Lossless compression is a minimum average of 50mbps	File sizes are variable with lossy compression. 40 GB in lossless mode.	8-bit variable bit rates - dependent on level of compression	File sizes are variable with lossy compression. 40 GB in lossless mode.	• The AVI file format was first introduced by Microsoft in 1992 and is a derivative of the RIFF (Resource Interchange File Format). • JPEG 2000 is a fully documented ISO standard. • Lossless JPEG 2000 has been adopted by larger organizations in the international archival community, including the Library of Congress and the UK Digital Archives. • The AVI file container format is well documented and has been supported natively in every version of the Windows operating system since its introduction. • JPEG 2000 when used in lossy compression mode will create decidedly smaller target files than lossless or uncompressed codec options.	• The AVI file container has not been widely endorsed as a preservation file format as it has several limitations, including: ➢ The AVI format does not specify a standardized way to include embedded aspect ratio information ➢ There are more than one competing approaches to wrap timecode information in an AVI file ➢ The AVI format was never designed to accommodate any compression method that required access to future frame data beyond the current frame being decoded. As a result, implementations that support inter-frame compression codecs in an AVI wrapper are proprietary in nature and may depend on specific hardware/software support. • JPEG 2000 requires higher system specifications for encoding and playback in real time. Support for the format in consumer level devices is rare and open-source support is in its infancy due to licensing fees. • Any codec that introduces lossy compression will result in some amount of detail and information from the original analog recording to be lost during the digitization process. This loss may be minimal or visually lossless, but future transcoding or conversion of the format through multiple digital generations may begin to introduce visible artifacts. The smaller the target file size gets, the greater loss of original detail will occur due to greater compression.	*AVI RIFF File reference*: http://msdn.microsoft.com/en-us/library/ms779636.aspx ISO/IEC 15444-1:2004, *Information technology – JPEG 2000 image coding system: Core coding system*: http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=37674
	Audio: PCM	JPEG 2000 24-bit, 48khz		JPEG 2000 16-bit, 48Khz				
Audio Video Interleaved Format (AVI)	Image: DV-NTSC (DV AVI)	8-bit Bitrate: 29mbps DV-NTSC parameters are not configurable as they are a hard restriction of the format to maintain compatibility	13 GB	Same (parameters restricted)	13 GB	• The AVI file format was first introduced by Microsoft in 1992 and is a derivative of the RIFF (Resource Interchange File Format). • DV-NTSC was first standardized through the International Electro-technical Commission (IEC) family of standards in 1995. This standard outlined more than just the video encoding parameters, but also how DV video was to be recorded on videotape. Subsequent revisions developed by Sony and Panasonic lead to additional standardization by the SMPTE. • Although not necessarily recommended as a preservation format, DV-NTSC is potentially a good alternative option for recordings that are on digital tape formats (i.e. MiniDV, Digital 8, DVCAM) as the DV-NTSC codec would maintain the identical information that is on the tape. • DV-NTSC has wide adoption at the consumer level and is easily edited. • The AVI file container format is well documented and has been supported natively in every version of the Windows operating system since its introduction. The DV-NTSC codec has wide support in many software and hardware devices from the professional to the consumer level • DV-NTSC will create decidedly smaller target files than lossless or uncompressed codec options.	• The AVI file container has not been widely endorsed as a preservation file format as it has several limitations, including: ➢ The AVI format does not specify a standardized way to include embedded aspect ratio information ➢ There are more than one competing approaches to wrap timecode information in an AVI file ➢ The AVI format was never designed to accommodate any compression method that required access to future frame data beyond the current frame being decoded. As a result, implementations that support inter-frame compression codecs in an AVI wrapper are proprietary in nature and may depend on specific hardware/software support. • Any codec that introduces lossy compression will result in some amount of detail and information from the original analog recording to be lost during the digitization process. This loss may be minimal or visually lossless, but future transcoding or conversion of the format through multiple digital generations may begin to introduce visible artifacts. The smaller the target file size gets, the greater loss of original detail will occur due to greater compression.	*AVI RIFF File reference*: http://msdn.microsoft.com/en-us/library/ms779636.aspx *Microsoft NTSC DV-AVI File reference*: http://msdn.microsoft.com/en-us/library/windows/desktop/dd407250%28v=vs.85%29.aspx *IEC 61834-1:1998 (NTSC-DV)*: https://webstore.iec.ch/publication/5979
	Audio: PCM	DV-NTSC 16-bit, 48khz						

Acceptable Formats	Acceptable Codecs	Recommended Sampling Rate and Bit Depth (Standard Definition)	File Size per Hour of Content	Minimum Sampling Rate and Bit Depth (Standard Definition)	File Size per Hour of Content	Pros	Cons	Format Specifications
QuickTime File Format (MOV)	Image: JPEG 2000	10-bit, variable bit rates - dependent on level of compression. Lossless compression is a minimum average of 50mbps	File sizes are variable with lossy compression. 40 GB in lossless mode.	8-bit variable bit rates - dependent on level of compression	File sizes are variable with lossy compression. 40 GB in lossless mode.	• QuickTime file format is well documented and near full format disclosure is available freely from Apple Inc. The QuickTime format was used as the basis for the standardization of the MPEG-4 file format (ISO/IEC 14496-14:2003). • JPEG 2000 is a fully documented ISO standard. • Lossless JPEG 2000 has been adopted by larger organizations in the international archival community, including the Library of Congress and the UK Digital Archives. • JPEG 2000 when used in lossy compression mode will create decidedly smaller target files than lossless or uncompressed codec options.	• JPEG 2000 requires higher system specifications for encoding and playback in real time. Support for the format in consumer level devices is rare and open-source support is in its infancy due to licensing fees. • Any codec that introduces lossy compression will result in some amount of detail and information from the original analog recording to be lost during the digitization process. This loss may be minimal or visually lossless, but future transcoding or conversion of the format through multiple digital generations may begin to introduce visible artifacts. The smaller the target file size gets, the greater loss of original detail will occur due to greater compression.	*QuickTime File Format Specification*: https://developer.apple.com/library/mac/#documentation/QuickTime/QTFF/QTFFPreface/qtffPreface.html ISO/IEC 15444-1:2004, *JPEG 2000 image coding system*: http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=37674
	Audio: PCM	JPEG 2000 24-bit, 48khz		JPEG 2000 16-bit, 48Khz				
QuickTime File Format (MOV)	Image: DV-NTSC (DV 25)	8-bit Bitrate: 29mbps DV-NTSC parameters are not configurable as they are a hard restriction of the format to maintain compatibility	13 GB	Same (parameters restricted)	13 GB	• QuickTime file format is well documented and near full format disclosure is available from freely from Apple Inc. The QuickTime format was used as the basis for the standardization of the MPEG-4 file format (ISO/IEC 14496-14:2003). • DV-NTSC was first standardized through the IEC (International Electrotechnical Commission) family of standards in 1995. This standard outlined more than just the video encoding parameters, but also how DV video was to be recorded on videotape. Subsequent revisions developed by Sony and Panasonic lead to additional standardization by the SMPTE. • Although not necessarily recommended as a preservation format, DV-NTSC is potentially a good alternative option for recordings that are on digital tape formats (i.e. MiniDV, Digital 8, DVCAM) as the DV-NTSC codec would maintain the identical information that is on the tape. • DV-NTSC has wide adoption at the consumer level and is easily edited. • The DV-NTSC codec has wide support in many software and hardware devices from the professional to the consumer level. • DV-NTSC will create decidedly smaller target files than lossless or uncompressed codec options.	• Any codec that introduces lossy compression will result in some amount of detail and information from the original analog recording to be lost during the digitization process. This loss may be minimal or visually lossless, but future transcoding or conversion of the format through multiple digital generations may begin to introduce visible artifacts. The smaller the target file size gets, the greater loss of original detail will occur due to greater compression.	*QuickTime File Format Specification*: https://developer.apple.com/library/mac/#documentation/QuickTime/QTFF/QTFFPreface/qtffPreface.html
	Audio: PCM	DV-NTSC 16-bit, 48khz		DV-NTSC: same (parameters restricted)				

Acceptable Formats	Acceptable Codecs	Recommended Sampling Rate and Bit Depth (Standard Definition)	File Size per Hour of Content	Minimum Sampling Rate and Bit Depth (Standard Definition)	File Size per Hour of Content	Pros	Cons	Format Specifications
QuickTime File Format (MOV)	Image: Apple ProRes 422	10-bit HQ mode Bitrate: variable approx. 63mpbs	27 GB	8-bit standard mode Bitrate: variable approx. 42mpbs	18 GB	• QuickTime file format is well documented and near full format disclosure is available from freely from Apple Inc. The QuickTime format was used as the basis for the standardization of the MPEG-4 file format (ISO/IEC 14496-14:2003). • Apple ProRes enjoys wide support in broadcast post-production and professional editing software. Playback of the codec is included in the base QuickTime codec package and open-source playback compatibility exists.	• ProRes is a lossy video compression codec developed by Apple Inc. primarily for use as an intermediate codec in video post-production. The codec is well described publicly by Apple Inc., but it has not been standardized by any international body. • Apple ProRes has not been widely adopted as a preservation format as it is an inherently lossy format. As an intermediate codec, it was designed to balance quality and processing efficiency in a broadcast/post-production environment. • Encoding Apple ProRes is free when working on Apple hardware (MAC OS), but requires hardware and software products that operate on other platforms to be strictly licensed by Apple Inc. • Any codec that introduces lossy compression will result in some amount of detail and information from the original analog recording to be lost during the digitization process. This loss may be minimal or visually lossless, but future transcoding or conversion of the format through multiple digital generations may begin to introduce visible artifacts. The smaller the target file size gets, the greater loss of original detail will occur due to greater compression.	*QuickTime File Format Specification*: https://developer.apple.com/library/mac/#documentation/QuickTime/QTFF/QTFFPreface/qtffPreface.html *Apple ProRes White Paper October 2012*: http://images.apple.com/finalcutpro/docs/Apple_ProRes_White_Paper_October_2012.pdf
	Audio: PCM	Apple ProRes HQ: 24-bit, 48khz		Apple ProRes: 16-bit, 48khz				
Matroska File Format (MKV)	Image: FFv1 version 3 (lossless compression)	10-bit variable bit-rate Lossless minimum average 50mbps	~40GB	8-bit, Variable bitrate Lossless minimum average 50mbps	~40GB	• The Matroska file format is open-source and the specification is freely available. • The FFv1 codec is open-source and the specification is freely available (although incomplete). • Software implementation costs are free as open-source software does not carry any license fees. • Version 3 of the FFv1 supports frame level CRC fixity information and more self-descriptive properties at the codec level such as field dominance, aspect ratio and colour space information. This can be viewed as an advantage as other codecs often require the wrapper to carry this information which contributes to interoperability problems.	• Commercial vendor support for the use of FFv1 and the Matroska file format is weak. A pre-requisite to an institution adopting open-source technologies is the understanding that a long-term commitment to retaining development expertise will be required to actively participate in the programming communities that support these file formats and the tools that can create them.	*Matroska file format:* http://www.matroska.org/index.html *FFv1 Video Codec Specification:* http://www.ffmpeg.org/~michael/ffv1.html
	Audio: PCM	24-bit, 48Khz		16-bit, 48Khz				

10. Motion Picture Film Recommendations

Recommended Format	Recommended Codecs	Original Film Gauge	Scan Resolution	Bit Depth / Sample rate	File Sequence Size per Hour of Content	Pros	Cons	Format Specifications
Image: Digital Moving Picture Exchange Bitmap (DPX) image sequence	Uncompressed	35mm	4K	10 bit RGB log	~4.1TB	• The DPX file format is an open standard, defined by the Society of Motion Picture and Television Engineers (SMPTE) - ST 268:2014 • Adoption by larger organizations in the international archival community, including the US National Archives, UCLA Library and Library and Archives Canada. • Wide range of motion picture film scanners support output to DPX.	• DPX files do not playback in the traditional sense, as each frame of film in a reel is captured to an individual DPX file. Applications must support the playback of file sequences to mount and display DPX files. • File storage bandwidth requirements are extremely high for the real-time playback of uncompressed, high resolution DPX sequences. Long term storage capacity requirements are also challenging due to the large sequence sizes eclipsing 4TB per hour at 4K resolutions.	*ST 268:2014 - SMPTE Standard - File Format for Digital Moving-Picture Exchange (DPX):* http://ieeexplore.ieee.org/document/7292028/
		8mm, S8mm, 16mm	2K	10 bit RGB log	~1TB			
Audio: Broadcast Wave Format (BWF)	Pulse Code Modulated (PCM) Uncompressed			Minimum: 24-bit, 48khz	~1GB			

Appendix A: Access Files

The preservation files resulting from the digitization of analog audio recordings, video recordings and motion picture films must capture as many attributes of the original content as possible without enhancements or alterations. The focus of any analog to digital migration effort must be on the production of the best preservation file that resources permit. Preservation files will often be large in size or in a file format that is not easily accessible or transmittable to end users. As a result, one or more derivative files may need to be made from a preservation file to facilitate access.

In some instances, organizations will also need to generate mezzanine files (also known as a sub-master, production master, reproduction master, or access master). A mezzanine file fits between the preservation file destined for long-term preservation and low-resolution derivatives created for reference access or distribution on social media channels. If restorative actions need to be made to the content of a preservation file, a mezzanine file containing the changes should be generated leaving the preservation file untouched. The mezzanine file can then be used as an intermediate master for the creation of access copies for clients that would benefit from a revised version.

Actual recommendations of access file formats that could be adopted are not included in this document because the format of access files is specific to the organization, unique project, and client groups being served. Access files are temporary in nature and created to be compatible with the technical demands of the present. It is inevitable that evolving client demands and technological changes will require your organization to build new access versions again from the preservation master files to leverage future opportunities. Some of the factors to be considered when selecting an access file format include:

How does your organization provide access to material?

- Your access format should align with your institution's access policies.
- Your internal infrastructure for delivering onsite access may dictate your choice of file formats and file sizes.
- If your institution also requires the production of physical copies of digital files (i.e. DVD or Blu-ray discs), an access file format that facilitates this workflow should be selected.
- If your organization delivers content via the internet then access files must meet the technical specifications for any streaming server/service involved in their delivery.
- If your organization is required to provide content to clients for broadcast then you will have to produce access files that conform to established broadcast standards and with less compression to facilitate quality repurposing. If professional clients are a frequent users of your collection, you may need to adopt a mezzanine format specifically suited for these requests.

Does the access file adequately reflect the source material?

- Analog video signals are inherently interlaced, while the typical end user display is progressive scan. To ensure a less problematic reproduction of your source material on modern displays, it may be advisable to de-interlace access file derivatives made of interlaced source material.
- You must be mindful of maintaining the aspect ratio of the original moving image content. Aspect ratio refers to the ratio of the width to the height of an image on screen. Obsolete analog video recordings made in North America will predominantly adhere to NTSC signal format which has an aspect ratio of 4:3. Digitized motion picture content can be one of many different aspect ratios. If an access file is destined for a modern widescreen high definition television display or online social media channels that assume only 16:9 playback, the access file will need to be conformed to display within the 16:9 frame without distortion or loss of content.

Appendix B: Recommended Reading

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