CHAPTER

DIGITIZATION OF AUDIO AND MOVING IMAGE COLLECTIONS

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INTRODUCTION TO DIGITIZATION OF AUDIOVISUAL RESOURCES

Audio and moving image resources encompass a wide range of time-based media, from recorded sound to motion picture film and a variety of video formats. The terms "audio and moving image" and "audiovisual" are used interchangeably here. The term "audiovisual" has gained acceptance "as a convenient single word covering both moving images and recorded sounds of all kinds" (Edmondson, 2004, p. 16). In contrast to textual and photographic materials, audio and moving image resources make up a relatively small portion of digital libraries at this point, but their number is gradually increasing as analog collections are digitized and as born digital content grows rapidly. The efforts to digitize audio, video, and motion picture film resources have lagged behind the conversion of text and photographs. Cultural perceptions and copyright restrictions play a significant role in this delay. There are also several major technical factors that have hindered digitization of audiovisual materials, including proliferation of analog media types, the complexity of the conversion process, storage requirements, multiple digital formats, and the lack of clear conversion standards for video. The recommendations for preservation formats and technical specifications for the conversion of moving images are still under development. Digitization of audiovisual collections, however, has gained attention in recent years because of the preservation crisis associated with deteriorating analog formats and the obsolescence of the playback equipment (CLIR and LC, 2006, 2010, 2012; Klijn and de Lusenet, 2008; Mariner, 2014; Schüller, 2008; Wright, 2012).

Audiovisual resources are inherently different from static documents and images because of their time-based nature and the need for playback machines to access their content. Audio and moving image materials convey information through patterns and signals that are perceived for a defined period of time. Just as archival document collections are measured in linear feet, audiovisual materials can be measured in terms of hours and minutes. Audiovisual recordings provide a representation of reality in space and time and thus afford new forms of external memory. Teruggi (2004) points out that the space-time unity, especially in the case of broadcast media, has transmitted an immediate sense of reality and created the essential record of our life, history, and culture. The author states, "conveying such immediacy also meant keeping a memory of and for society, building a historical record through both trivial and historic events that have accumulated overtime and so have created a huge repository of our collective memory" (Teruggi, 2004, p. 4).

Audiovisual heritage has an enduring value for cultural memory as it provides a vivid record of historic events and lived experiences. The National Film Preservation Act in the United States recognizes "motion pictures as an art form and a record of our times" (Library of Congress, 1994, para. 2). Audio and moving images also play an important role in recording knowledge, documenting human creativity, and bringing to light events and people that have been unacknowledged in the written record. In

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addition to commercially produced motion pictures, music, and broadcast programming, audiovisual collections also include oral histories, speeches, lectures, performances, storytelling, poetry readings, and a record of field research in linguistics, ethnography, and many other disciplines. Schüller (2008) emphasizes that "present day knowledge of the linguistic and cultural diversity is mainly based on audiovisual documents, in their greatest part accumulated over past 50 years" (p. 4). Oral histories offer a rare opportunity "to learn about history from those who actually experienced it, in their own words" (Stevens and Latham, 2009, p. 1). Moreover, oral history narratives serve a unique role in documenting local heritage and in giving voice to underrepresented groups (Bond, 2004; Swain, 2003).

The cultural and historical significance of audiovisual heritage may not yet be fully realized. As the authors of *The State of Recorded Sound Preservation in the United States* write, "significance is too often recognized and conferred only after the passage of years" (CLIR and LC, 2010, p. 8). The educational and research potential of audiovisual resources can only be explored if the recordings are made widely available for listening and viewing and are integrated with other resources in digital libraries.

However, the majority of audio, film, and video recordings remain on analog formats that are not only difficult to access but are also prone to damage and deterioration. Based on the data from the 2005–06 TAPE survey, Wright (2012) states that about 85% of sound and moving image content is still analog. A 2012 survey of audiovisual media in European institutions of higher education places this figure at 50%, which could be an indication of the growth of digital formats in recent years (Stauder, 2013). The same study, however, indicates that half of the participating institutions had incomplete information about their audiovisual collections. The estimates could shift once inventories are completed. The lack of inventories and item-level cataloging represents a significant barrier to access and use (Mohan, 2008). Most of the surveyed institutions have digitization programs, but the amount of converted audiovisual materials is still very low (Klijn and de Lusenet, 2008; Stauder, 2013; Wright, 2012). Klijn and de Lusenet (2008) report that many institutions are involved in digitization activities and would like to do more but are holding back because of uncertainties about conversion standards and longevity of digital materials.

Digitization of audio and video collections, however, has been gaining momentum in recent years primarily because of the looming preservation crisis. The studies of audiovisual collections in Europe and the United States convey a sense of urgency, indicating that if analog audiovisual materials are not reformatted in the next few decades, their content may be lost (CLIR and LC, 2006, 2010; Klijn and de Lusenet, 2008; Schüller, 2008; Wright, 2012). In the preface to the study on preservation of sound recordings in the United States, Smith and Brylawski write: "it is alarming to realize that nearly all recorded sound is in peril of disappearing or becoming inaccessible within a few generations" (CLIR and LC, 2006, p. v). Wright (2012) echoes this statement and adds that both sound and moving image are at great risk. It is now widely accepted that digitization presents a viable, if not the only option to preserve the content of audio and video collections.

This chapter provides an overview of audiovisual collections and discusses preservation issues associated with analog formats. The focus of this chapter is on the process of converting analog audiovisual media into the digital format. Audiovisual resources are defined as "works comprising reproducible images and/or sounds embodied in a carrier" (Edmondson, 2004, p. 26). Analog audio, motion picture film, and video share their time-based nature, dependence on physical carriers, and the need for playback equipment, but they are also distinct media that use different technologies in the process of recording, reproduction, and ultimately digitization. Because of the differences in audio and moving image digitization, this chapter devotes a separate section to each medium. The general digitization guidelines and the steps in the conversion process are discussed in Chapter 3. The fundamental principles of preservation-quality digitization with the notion of archival master files and derivatives also apply to audio and moving image conversion. This chapter builds upon those concepts and focuses specifically on technical factors, conversion recommendations, and formats for audio and video.

STATE OF AUDIO AND MOVING IMAGE COLLECTIONS

Audio and moving image collections include a mix of analog and digital recordings. Analog materials still constitute the majority of archival holdings. The number of these materials, although large, is finite. The collections of analog resources can grow through donations of legacy materials, but all new audio and video materials are recorded with a digital signal. Although film is still being used in motion picture production, it is often processed with digital tools. The authors of *The Digital Dilemma 2* note, "almost all motion pictures produced today—regardless of the capture medium—reach a point of digital existence when they pass through digital image processing tools during postproduction" (STC-AMPAS, 2012, p. 12).

Analog and digital refer to fundamentally different ways of capturing, recording, and representing audio and moving image signals. Mariner (2014) makes a distinction between analog and digital signals and points out that the terms refer to the mode of recording a signal rather than a physical medium:

- Analog signals represent continuous ranges transferred to a medium as waves or pulses.
- Digital signals represent discrete values transferred to a medium as binary values (Mariner, 2014, p. 9).

Analog materials have been recorded on a variety of physical carriers, including mechanical formats, magnetic tape, and film (Coffey and Walters, 2014; Walters et al., 2014). Digital recordings can be stored on physical carriers, such as optical discs or in file-based systems.

The combination of different carriers with analog or digital modes of recording complicates the classification of audiovisual materials. From a technical point of view, sound and moving images can be divided into three groups (Wright, 2012):

- Analog recordings on cylinders, vinyl records, magnetic audio tape, VHS, U-matic videotape, and film
- Digital recordings on dedicated physical carriers, such as audio CDs, minidiscs, video DVDs, digital audio tape (DAT), and DV tape
- Digital recordings that exist as files on digital storage (file-based systems)

For the first time in the history of audiovisual recording, file-based digital recordings are independent of physical carriers. Wright (2012) emphasizes: "carrier independence is liberation: discs, tapes and films deteriorate and get damaged" (p. 3). Analog recordings require digitization in order to be converted into usable digital formats. Digital recordings on physical carriers, though already digitally formatted, need to be extracted ("ripped") and transferred into file-based systems.

The history of audio and moving image recordings is relatively brief, especially in contrast to the history of writing and printing, but is characterized by a rapid rate of technological obsolescence. The multitude of formats for sound and moving image is a result of continued innovation and the demand for durable, portable, and more effective carriers. A variety of mechanical carriers have been used for recording voice and music since the invention of the phonograph in 1877. Wax cylinders had been in use through the 1920s, at which time they were gradually replaced by flat discs. Vinyl records proved to be a durable carrier and were used in music recording for most of the 20th century, but they were eventually supplanted by digital recording on optical discs. Magnetic tape recordings with reel-to-reel and cassette tapes became popular in the second part of the 20th century (Behl, 2015; Schoenherr, 2005; Walters et al., 2014).

Motion pictures were developed in the early 1890s. Moving images were recorded primarily on film, with its own history of different film stock, from cellulose nitrate- and acetate-based to a more stable polyester film (Coffey and Walters, 2014; Gracy, 2013a; National Film Preservation Foundation, 2004). Video recording of moving images was introduced in the 1950s and became a mainstream technology in the 1970s and 1980s. Audio and moving image recording embraced digital technology quickly and by the end of the 20th century, analog formats had been replaced with digital recording on physical carriers. In addition to audio and video tapes and other analog formats, audiovisual collections now hold an assortment of CDs and DVDs, which in turn are becoming obsolete, superseded by file-based systems.

Systematic collection of audio and moving image recordings began several decades after their invention in the late 19th century. No major audiovisual archive was created before the 20th century (Wright, 2012). As Teruggi (2004) notes, "it took time before the new technological society became aware of the progressive and massive accumulation of material it was producing—and of its future importance" (Teruggi, 2004, p. 2). Currently, there are hundreds of nonprofit audiovisual archives in the United States and worldwide that collect audio, film, and video recordings from motion picture studios, independent artists, television and radio stations, as well as from scholars and private donors (STC-AMPAS, 2012). Large collections of moving image and recorded sound are held in national audiovisual archives, such as the British Film Institute, British Library Sound Archive, Cinémathèque Française, and the Audio-Visual Conservation Center at the Library of Congress. Substantial holdings of audiovisual materials are also stored in libraries, archives, and museums alongside textual and still-image collections. The TAPE survey of European audiovisual collections conducted in 2005–06 indicated that 65% of film and 40% of audio and video collections were relatively small (500 h) but still of significant value (Klijn and de Lusenet, 2008). The OCLC survey of special collections in the United States and Canada reported that 56% of participating institutions held audio collections and 51% held moving image materials (Dooley and Luce, 2010). In addition to the collections at cultural heritage institutions, audio and moving image materials are also held in corporate archives and private collections.

It is difficult to estimate the extent and the condition of audiovisual collections because of incomplete inventories and the lack of proper documentation. As the authors of *The State of Recorded Sound Preservation in the United States* state, "no comprehensive survey of recorded sound holdings in the United States, let alone the world, has ever been undertaken" (CLIR and LC, 2010, p. 10). The research conducted in Europe and in the United States in the last decade provides a glimpse at the vast and diverse holdings, located primarily within public institutions. The TAPE survey estimated European holdings as: 0.9 million hours of film, 9.4 million hours of audio, and 10.5 million hours of video, and the average increase per year expected to be 1–2% for film and audio and 6% for video (Klijn and de Lusenet, 2008). The 2005 study of the cultural heritage collections in the US public institutions estimated 46.4 million sound recordings and 40.2 million moving images (Heritage Preservation and IMLS, 2005a).

The estimates indicate an impressive amount of audiovisual content. However, only part of the holdings can be digitized and included in the open digital libraries due to copyright restrictions. Audiovisual materials, like any other works recorded in fixed form, are subject to copyright law and cannot be reproduced without the permission of the copyright owner. In the United States, published and unpublished works that are still under copyright protection can be digitized only in specific circumstances under the exemptions for libraries and archives of the US copyright law (Hirtle et al., 2009). Section 108 provisions of the Copyright Act allow libraries and archives to digitize published works in response to in-house user requests or if collection items are damaged, stolen, or recorded in an obsolete format. Digital copies cannot be used outside the library and archive premises. These exemptions do not support digitization for open access in digital libraries. Digitization is thus limited to unique materials that are either in the public domain or to which holding institutions have legal rights. The authors of the report *The State of Recorded Sound Preservation in the United States* state that "privileges extended by copyright law to libraries and archives to copy sound recordings are restrictive and anachronistic in the face of current technologies" (CLIR and LC, 2010, p. 7). The current copyright law represents a barrier to digitization in general but in the case of audiovisual collections is particularly restrictive, as it impedes conversion of materials that are in great need of preservation reformatting.

The condition of audiovisual collections cannot be fully assessed due to the scarcity of appraisal data (CLIR and LC, 2012; Klijn and de Lusenet, 2008). The existing surveys identify preservation needs and indicate a growing awareness of the preservation crisis in the audiovisual domain. The majority of institutions participating in the OCLC survey ranked the preservation needs of visual and audiovisual materials much higher than those of other materials (Dooley and Luce, 2010). The TAPE survey of European collections noted preservation risks in audio and video formats, including the presence of unstable nitrate and acetate film in many collections. The most striking finding of the TAPE survey was a large quantity of deteriorating audiocassettes in research collections (Klijn and de Lusenet, 2008). The report on the state of US cultural heritage collections emphasizes that "the condition of almost half the 86 million film reels, videos, DVDs, records, cassettes, CDs, and MP3s in public collections is unknown, leaving them in probable jeopardy" (Heritage Preservation and IMLS, 2005b, p. 5).

Audio and moving image collections at libraries and other cultural heritage institutions are comprised of unique or rare resources in archives and special collections as well as materials in general circulating collections, mostly commercially produced and available in multiple copies. A study of audiovisual media at the Indiana University Bloomington finds that 27% are unique and do not exist anywhere else, 17% are rare, and 56% are commercially issued and not considered rare (Casey et al., 2009). This study also indicates that unique audiovisual materials are at a greater preservation risk. The authors report that nearly all of the unique and rare audio recordings and half of the unique and rare video recordings need preservation attention (Casey et al., 2009). Digitization of unique and rare audio and video represents a top priority because of the risk of losing the content if original materials deteriorate beyond recovery.

PRESERVATION CRISIS: OBSOLESCENCE AND DETERIORATION

The preservation crisis in the audiovisual domain is related to two factors:

- Obsolescence of the reproduction equipment
- Deterioration of physical carriers

The obsolescence problem has been exacerbated in recent years by the rapid demise of technologies supporting audiovisual analog formats. Most playback devices for analog media are not produced anymore and are disappearing quickly. The lack of properly working reproduction equipment poses a serious threat to accessing content and to digital reformatting. Dedicated players are not only necessary to transmit and reproduce the content but are also essential in the analog-to-digital (A/D) conversion. In addition, many analog audio and video materials are recorded on unstable physical carriers that are subject to deterioration. It is the combination of these factors plus the inevitable pressure of time limitation that make the preservation crisis particularly alarming. Preservation of audiovisual content is a race against time. Schüller (2008) stresses, "the time window left to transfer contents from analog and single digital carriers to digital repositories successfully is estimated to be not more than 20 years" (p. 6).

The problem is unique to audio and moving image recordings. For the majority of paper-based textual and, to some extent, photographic materials, preservation is not a critical issue because they are recorded on stable and durable carriers or conservation efforts had been undertaken in the past (Conway, 2010). As discussed in the previous chapter, digitization as a preservation strategy is recommended as a selective approach for early photographs recorded on glass negatives or unstable cellulose nitrate- or acetate-based film. For paper-based materials, the debate "why digitize" is focused on the benefits of extended access and new functionality afforded by the digital form. For audiovisual materials, however, there is no survival without digital reformatting. As the authors of *The State of Recorded Sound Preservation in the United States* emphasize, "the discussion no longer begins with the question, Why preserve?, but with the rhetorical one, How can we not?" (CLIR and LC, 2010; p. 8).

The preservation risks associated with the obsolescence of equipment and the deterioration of physical carriers affect access to content and/or quality of reproduced signals. Casey et al. (2009) list the ways audiovisual content can be lost or degraded due to the deterioration of carriers:

- A catastrophic failure where no content is recoverable
- Partial failure where part of content is recoverable
- Diminishment where the recovered content is of lesser quality (Casey et al., 2009, p. 33)

The authors also note the catastrophic impact of the obsolescence of equipment. The lack or scarcity of properly functioning playback machines or their prohibitive cost, as well as unavailability of spare parts, repair expertise, or playback expertise can result in:

- Inability to optimally reproduce, or reproduce at all, a recording
- Inability to preserve collections (Casey et al., 2009, p. 33)

The unavailable or antiquated equipment and obsolescent formats represent the most serious threats to preservation and digitization (Schüller, 2008). The number of obsolete formats is staggering. A study of audiovisual collections at the Indiana University Bloomington found 51 different analog and physical digital (nonfile) formats (Casey et al., 2009). As Mariner (2014) points out, audiovisual information is trapped on functionally obsolete formats. Even if the content is recorded on stable carriers, it is effectively inaccessible because of the lack or limited availability of specialized equipment that can reproduce or read the formats. The risks transfer into the digital realm and affect not only the ability to digitize audiovisual materials but also the quality of digitized copies.

The preservation risks associated with deteriorating physical carriers are not uniform and vary for audio, video, and film, and their different formats. All physical resources decay with time, but the rate of deterioration depends on the type of material and the environmental conditions in which they

FIGURE 4.1 Degraded Video on Magnetic Tape

are stored. Interestingly, the older sound resources recorded on mechanical formats, such as cylinders or discs, are more stable than the more recent audio and video recordings on magnetic tape (Walters et al., 2014). Cylinders and discs are fragile and susceptible to damage and accidental breakage. Access to high-level professional playback equipment, however, is more problematic than the instability of mechanical formats.

Magnetic tape used in the recording of audio and video represents the most serious preservation risk. Like other physical carriers, tape is susceptible to mechanical damage and deformation. However, the greatest risk is related to the degradation of the tape layers, the base and binder (Walters et al., 2014). The most serious and frequent problem is related to a chemical breakdown of the binder, which causes the tape to become sticky and shed material during playback. Poor environmental conditions, including high levels of temperatures and humidity, accelerate the degradation process. The problem is severe because audio and video recordings on magnetic tape represent the largest segment of audiovisual collections held in cultural heritage institutions. The survey of moving image collections in the United States found that 78.5% of participating institutions held video on VHS tapes (Mohan, 2008). Magnetic tape was used in a variety of audio recordings, including open-reel tapes, compact cassettes, and mini cassettes as well as in recording of moving images on video using a variety of tape formats, such as VHS, U-matic, or Betacom (Behl, 2015; Coffey and Walters, 2014). Fig. 4.1 demonstrates an example of a degraded videotape. As noted by Walters et al. (2014), the preservation of these legacy media poses formidable challenges, not only because of physical deterioration of the carriers but also in light of the obsolescence and scarcity of the hardware required to access the content.

Film used in motion picture recording is the most stable carrier. Film is an analog optical format that comes in different sizes, with 35 mm, 16 mm, and 8 mm being the most common. As Coffey and Walters (2014) emphasize, “film is an excellent archival medium and will, if stored correctly, last for over a hundred years” (p. 255). The film stock of the early motion picture recordings, however, is not as stable as the polyester film introduced in the second part of the 20th century. The cellulose nitrate film had been used for over 50 years since the invention of moving images. Nitrate film is not only chemically unstable but also an extremely hazardous, flammable material (Heckman, 2010; National

FIGURE 4.2 Decomposed Nitrate Film (National Film Preservation Foundation, 2004)

Film Preservation Foundation, 2004; Slide, 1992). Prior to the early 1950s, most 35 mm film stock had a cellulose nitrate base. Acetate film was introduced as an alternative to nitrate to address the safety risks, mostly in 8 mm and 16 mm gauges used in amateur and home productions, but proved to be prone to decay as well. Both nitrate- and acetate-based film inevitably decompose with age, leading to a significant loss of data. Fig. 4.2 demonstrates an example of decomposed nitrate film and Fig. 4.3 shows deteriorated acetate film.

The production of acetate film ceased in 1948, and nitrate film was discontinued in 1951 (Coffey and Walters, 2014). Safety and preservation challenges have remained in the forefront for film collections in library and archive settings. The TAPE study demonstrates that many institutions still have significant

FIGURE 4.3 Deteriorated Acetate Film

Courtesy of the NEH Grant Project: Saving and Sharing the AGS Library's Historic Film Collections. University of Wisconsin-Milwaukee Libraries.

holdings of nitrate- and acetate-based film (Klijn and de Lusenet, 2008). Although major preservation efforts have been undertaken to move nitrate film into cold storage, there are still collections of nitrate film that are not stored properly. Librarians and archivists often discover a stock of decaying film when they undertake digitization projects. A librarian describes a "nitrate surprise" while selecting items for digitization: "after opening a few more of the metal canisters, examining 35 mm film in varying states of decay and consulting the *Film Preservation Guide* (NFPF), I realized that these films were nitrate film, and those turning into brown dust were in the final stages of decay" (Tucker, 2013, p. 344).

To a large extent, the introduction of a stable polyester film in the 1950s helped address the preservation concerns related to moving images. Duplication of old, deteriorating film onto new, more stable and long-lasting film stock has been recommended as a preservation strategy (National Film Preservation Foundation, 2004; Slide, 1992). However, the analog approach of film-to-film preservation has come under a serious threat recently because of the "demise of celluloid" (Frick, 2014; p. 20). Eastman Kodak, the major company that produces preservation film, filed for bankruptcy in 2012. Although film is still being produced, its future is uncertain, especially because moving image production is now being done in the digital format. In response to this uncertain situation, some cultural heritage institutions are considering film digitization as a means of providing access as well as preservation (Gaustad, 2012; Morehart, 2014). The use of digital technology for preserving motion picture film, however, is new and still very controversial (FADGI, 2015). The Academy of Motion Picture Arts and Sciences maintains that there is no replacement for film as an archival medium, stating: "an archival system for digital materials that meets or exceeds the performance characteristics of traditional film archives does not yet exist" (STC-AMPAS, 2012, p. 70).

The combination of the two factors—obsolescence of the equipment and deterioration of carriers—can place some formats at a higher preservation risk than others. Although mechanical sound formats like cylinders are stable, they are often placed on the list of endangered formats because of their rarity and the lack of playback equipment (Casey et al., 2009). Likewise, film is a stable carrier, but the scarcity of projectors can put access to motion pictures in jeopardy. Coffey and Walters (2014) note that "although film projection equipment is still produced, it is, like film, an endangered species" (p. 273). Audio and video recordings on magnetic tape are assessed as high-risk preservation formats because of the degradation of tape as well as the depleting supply of audio and video players.

The goal of preservation is to protect cultural resources of long-term value, prevent further deterioration, and ensure access and usability for present and future generations (Conway, 1989, 2010). In the case of audiovisual resources, it may not be possible to prevent the deterioration of many media. Before their content is lost irretrievably, however, it can be transferred onto new technology and made available for access and use. Access and preservation goals for audiovisual collections are tightly connected. Digitization is widely accepted as an approach to providing access and ensuring long-term preservation of audiovisual materials. Wright (2012) emphasizes that "audio and video need digitization for their survival, owing to obsolescence and decay of physical items, whether analog or digital. Film on shelves can be conserved (unless it is already deteriorating) but needs digitization for access" (p. 23). The preservation concerns make digitization of audiovisual collections a more urgent and demanding undertaking than the conversion of static media. Unlike paper-based materials, many audio and video physical recordings may not be accessible in the future. Therefore, it is extremely important to create high-quality digital preservation copies since they will serve as the only representations of the original content. The following sections provide an overview of the digitization of audio and moving image, including technical factors, processes, and recommended formats and specifications.

AUDIO DIGITIZATION

"Digitize! This has to be one of the most satisfying tasks I've taken on here at the museum. […] So, one by one, I'm digitizing these old cassettes. The tape deck in the picture (Fig. 4.4) is equipped with a USB connection. A cable connects the deck to the computer, which records the sound coming out of the tape deck using a simple, free program called Audacity" (Sunshine Coast Museum & Archives blog, 2010).

The quote from the blog of the Sunshine Coast Museum & Archives in Gibsons, British Columbia, and the accompanying image in Fig. 4.4 demonstrate that audio digitization can be undertaken in-house by a dedicated staff at relatively low cost, even at a small institution. The focus of many audio conversion projects is on oral histories and other unique recordings on cassette tapes because of the one-of-a-kind nature of these materials and the preservation risks associated with deteriorating tapes (Graves, 2014; Weig et al., 2007). The staff working on an oral history digitization project at Duke University Library reports: "unfortunately, the compact cassette format hasn't aged particularly well. Due to cheap materials, poor storage conditions, and normal mechanical wear and tear, many of these tapes are already borderline unplayable a short 40 years after their first introduction" (Graves, 2014, para. 2). A survey of twenty-one archives with audiovisual holdings indicates that oral history interviews represent the most frequently digitized audio content in both access and preservation categories (STC-AMPAS, 2012).

Digitization is universally recommended as a reformatting strategy for preserving analog sound recordings (Chase, 2015; CLIR and LC, 2012; IASA, 2009; Wright, 2012). Audio digitization is well established and more advanced than the conversion of moving images. The comprehensive guidelines to reformatting, metadata, and archival storage systems for audio have been published by the International Association of Sound and Audiovisual Archives (IASA, 2009) and the Association for Recorded Sound Collections (Brylawski et al., 2015). The IASA publication addresses analog-to-digital conversion for the purposes of preservation, the transfer of digital recordings on physical carriers to storage systems, as well as the recording of original material in digital form intended for long-term archival storage. *ARSC Guide to Audio Preservation* provides an overview of audio conservation and preservation,

FIGURE 4.4 Low-Cost Audio Digitization Equipment (Sunshine Coast Museum & Archives blog, 2010)

including recorded sound formats and their preservation risks as well as guidelines for preservation reformatting and archival storage (Brylawski et al., 2015). In addition, several guides to best practices in audio digitization and preservation have been shared by the members of the cultural heritage community (CARLI, 2013a; Casey and Gordon, 2007; CDP, 2006).

The most recent digitization recommendations issued by the division of the American Library Association also cover time-based media and include a brief section on audio (ALCTS, 2013). The growing body of case studies and reports of pilot projects, primarily in digitization of oral histories, provides an account of methodologies, workflows, technical solutions, and cost estimates (Daniels, 2009; Durio and Grabowski, 2011; Stevens and Latham, 2009; Weig et al., 2007). Several major studies investigated the state of sound recordings (CLIR and LC, 2006, 2010; Smith et al., 2004). In the United States, the Library of Congress has launched the National Recording Preservation Plan, making audio preservation a national priority and providing a set of recommendations for implementing preservation strategies (CLIR and LC, 2012). Although some progress has been made in audio digitization, the task of reformatting audiovisual heritage is still extremely challenging for several reasons, including the sheer volume of holdings, the large number of different formats, obsolescence of playback equipment, and the range of technical factors that need to be considered in the digitization process.

TECHNICAL FACTORS

Sound is fleeting in nature. It needs to be recorded in order to be reproduced and stored in a permanent form. The invention of recording technology allowed for the capturing of the human voice, music, and sounds of the natural world and changed the relationship of sound with its temporal and ephemeral nature. Katz (2012) writes about the "magic" of recording music: "live music exists only in the moment: recordings, however, capture those fleeting sounds and preserve them on physical media. With recording technology, music could be disseminated, manipulated, and consumed in ways that had never before been possible. When recorded, music comes unmoored from its temporal origins" (p. 11).

For over a century, analog recordings had captured continuous patterns of sound. In the process of analog recording, sound waves are converted into fluctuating electric voltage, and their representation is impressed or written on a physical carrier, such as discs or tape. Digital technology has provided a new way of representing and storing sound signals as a series of binary digits (JISC Digital Media, 2014a). A digital recording can be written into a physical carrier or stored in a file-based system.

Physically, sound is a continuous pattern of pressure waves that move through the air. We perceive, or "hear" sound when the waves strike the eardrum and nerves send a signal to the brain. A sound wave can be represented graphically as a waveform with high and low pressure points. The changes of amplitude and frequency represent two principle characteristics of sound (JISC Digital Media, 2014a). Amplitude refers to a change in pressure from the peak of the waveform to the trough and is directly related to the intensity (loudness) of a sound. The frequency of the waves determines the pitch of the sound. Lower frequencies contain fewer waves in a specific amount of time while higher frequencies include more waves in the same period of time (CARLI, 2013a). Frequency is measured in cycles per second, or Hertz (Hz), often expressed in kilo Hertz (kHz).

Digitization of analog audio materials involves converting an analog sound wave into a binary stream of 1s and 0s and recording the numbers (the binary form) instead of the wave form. The analog-to-digital conversion is conducted through the process of sampling of the analog wave. During the conversion process, an analog recording is played back and processed through an analog-to-digital converter, which samples the variations of the electric current at very fast intervals. The amplitude of the original sound wave is sampled and recorded as a number at each sampling point. A continuous line of acoustic sound needs to be represented numerically in a digital system. A high number of sampling points is needed to capture the continuous line of an analog wave and to create its accurate digital representation (CARLI, 2013a). Two technical factors are critical to the quality of digitized sound: sampling rate and bit depth.

Sampling rate refers to the number of samples of a wave that are taken per second to represent sound in a digital form. The quality of the digital representation increases with the number of samples of the analog signal. The sampling rate is represented in kilohertz (kHz), thousands of samples per second. The standard sampling rate for a consumer music CD is 44.1 kHz. The recommended sampling rate for preservation-quality digitization is 96 kHz.

Bit depth describes the range of numbers used to record each measurement. In other words, bit depth refers to the number of points captured per sample. The more points captured along each wave, the higher the bit depth and the greater chance of capturing subtle changes in the sound. 16 bit, which is also a standard for commercial audio CDs, represents a minimum, while 24 bit is recommended for creating digital masters for audio preservation.

AUDIO DIGITIZATION PROCESS

The process of converting analog sound recordings into a digital format and creating sustainable digital assets consists of multiple phases, including planning and selection, digital capture, processing, metadata creation, ingesting into a digital library management system, and digital preservation. Similar to the digitization of other materials, whether static or time based, the actual conversion is one of the many steps in the cycle of preservation reformatting. The general digitization steps and principles described in Chapter 3 apply to the conversion of sound recordings. Audio digitization also makes a distinction between master files and derivatives. Master files created as a direct result of audio capture serve as preservation copies and a source of smaller derivatives for online access. Audio obviously requires different conversion equipment than static media and raises unique challenges related to its time-based nature and preservation concerns.

Each digitization project comes with its own set of unique requirements and demands individualized planning with regard to technological requirements, selection and restoration of source items, staffing, cost, and archival storage (Mariner, 2014). Time is an important factor that needs to be taken into consideration during the planning phase. Unlike a relatively fast scanning of documents, digitization of time-based media involves playing an analog recording in real time. A 60-min cassette tape actually requires 60 min to convert to a digitized copy. The condition of the analog source items needs to be assessed during the selection process to identify the best copy and/or to address the conservation needs of degraded or damaged materials. The preparation of materials for reformatting requires restorative procedures, and depending on the level of degradation, may include cleaning, flattening discs, straightening twisted tapes, or rehousing them into new shells (Graves, 2014; IASA, 2009).

Digital capture represents the most critical part of the conversion process. As IASA guidelines emphasize, “optimal signal extraction from original carriers is the indispensable starting point of each digitization process” (IASA, 2009, Section 1.4). During the capture or, using IASA terminology, extraction process, an analog source recording is played using an appropriate playback device, such as a tape or record player. An analog sound wave is sampled through an analog-to-digital converter and the digital signal is recorded, processed in audio editing software, and stored, preferably in a file-based repository system. The files created as a result of the extraction process should represent high-quality masters and should be saved uncompressed in the standard preservation format. Audio digitization guidelines recommend creating high-quality master files for preservation purposes and derivatives for access (CARLI, 2013a; IASA, 2009). The IASA guidelines cite two major reasons for digitization at the highest quality possible: “firstly, the original carrier may deteriorate, and future replay may not achieve the same quality, or may in fact become impossible, and secondly, signal extraction is such a time-consuming effort that financial considerations call for an optimization at the first attempt” (IASA, 2009, Section 5.1.1). The converted files usually require some processing in order to adjust audio quality and remove signal distortion. The enhancements are limited by the quality of original sound recording. As Weig et al. (2007) note, “regrettably, little can be done to correct analog recordings that are, for whatever reason, marred by distortion from the beginning” (p. 5).

Weig et al. (2007) describe the workflow of the audio conversion project conducted by the Louie B. Nunn Center for Oral History and University of Kentucky Libraries. The selection of oral history interviews on audiotapes and preparation of tapes were followed by analog-to-digital conversion and master file generation, quality enhancement, and the production of derivative files in the mp3 format. Master files and edited service files were archived, while derivatives with associated metadata and transcripts were uploaded to the server for online access. Metadata creation occurred at several points in the workflow.

Detailed metadata is essential for resource discovery, access, and retrieval in digital collections but is especially important in the case of sound recordings because audio content can’t be browsed visually or searched by keyword. Metadata records provide the only access points to the rich content of sound recordings. Access to oral history narratives and other voice recordings can be enhanced by adding transcripts. This approach, although time-consuming if transcripts have to be generated as part of a digitization project, provides an option of presenting a textual version of the recording alongside the playable audio. Transcripts can provide full-text searchability and often include time stamps to enable the user to select parts of a recording or to follow it alongside the text. As described by Weig et al. (2007), transcript and metadata creation represented an independent step in the digitization of oral histories at the Louie B. Nunn Center for Oral History, but metadata was also recorded at other steps in the conversion cycle. Fig. 4.5 demonstrates an example of a transcript presented along with an oral history recording from the *Robert Penn Warren Civil Rights Oral History Project* created at the Louie B. Nunn Center for Oral History. The excerpt comes from an interview with Martin Luther King, Jr conducted by Robert Penn Warren on Mar. 18, 1964. The interview is available at http://nyx.uky.edu/oh/render.php?cachefile=02OH108RPWCR03_King.xml.

Access files with associated metadata are ingested into a digital library management system (DLMS) for online presentation. Online delivery of audio recordings also requires a streaming service. Many open source and proprietary DLMS, including Omeka, Collective Access, and CONTENTdm, include audio players and support standard access formats, such as mp3. Ingesting digitized audio files with associated metadata into a standard-compatible DLMS ensures interoperability and allows for integrating sound recordings with other digitized objects in digital library systems. Hosting options are available to cultural heritage institutions with limited digital library infrastructure and/or no access to streaming servers. Internet Archive provides a free platform to educational institutions and individuals and offers support for hosting and preserving audio and video files (Internet Archive, 2015). Audio and video objects represent a significant portion of the Internet Archives’ collections. The Avalon Media System

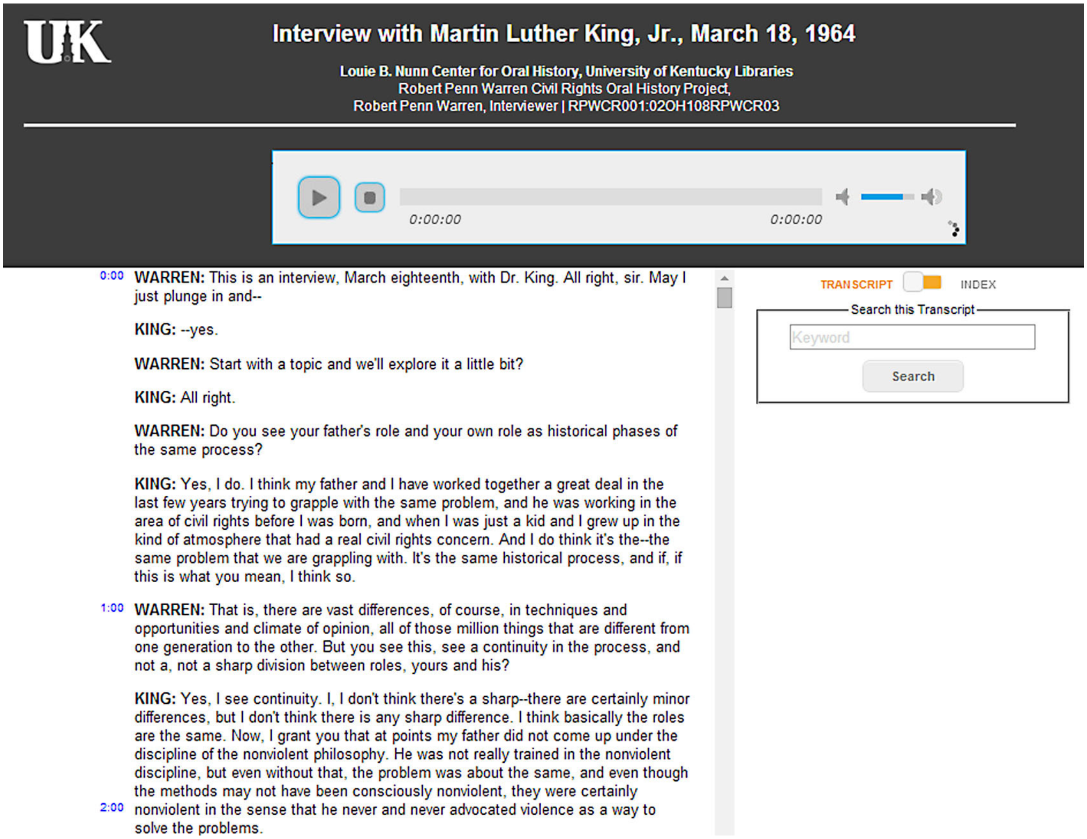

FIGURE 4.5 Oral History Recording with a Transcript

Robert Penn Warren Civil Rights Oral History Project.

is a new, open source system for managing and providing access to large collections of digital audio and video. It was developed by Indiana University Bloomington and Northwestern University with support from the National Leadership Grant from the Institute of Museum and Library Services. The Avalon Media System is freely available to libraries and archives and provides online access to their audiovisual collections for teaching, learning and research, and preservation and long-term archiving (Avalon Media System, 2015).

Digital preservation involves depositing master files into a trusted institutional or shared repository, the ongoing management of deposited audio files, and long-term preservation planning. As emphasized in the IASA guidelines, "preservation planning is the process of knowing the technical issues in the repository, identifying the future preservation direction (pathways), and determining when a preservation action, such as format migration, will need to be made" (IASA, 2009, Section 6.4.1.3). Archival storage of audio master files is a major concern because of the large size of individual files. For example, 1 h of audio digitized at 96 kHz and 24 bit with 2 channels produces a file of 1.93 GB (CDP, 2006). Digital repositories have to not only provide sufficient storage space for audio digitization but also supply capabilities for efficient transfer, management, and long-term preservation. Digital preservation is discussed in more detail in Chapter 9.

EQUIPMENT

The basic audio conversion process requires four pieces of equipment:

- An analog audio playback machine
- An analog-to-digital converter (ADC)
- A computer with audio processing software
- Digital repository to store and preserve master files

In addition to these basic components, an analog-to-digital audio workstation can also include other equipment, such as a mixing board used to adjust and enhance the audio signal. Fig. 4.6 provides an example of an audio deck used in digitization at Duke University Libraries.

The equipment used in audio conversion has a rather unique mix of antiquated playback devices, high-end computers, and analog-to-digital converters. This mix of old and new technology is characteristic of digitization of time-based media, as noticed by Mariner (2014): "while digital imaging relies on the latest hardware to faithfully reproduce digital copies of antique books and maps, much of the equipment used in the capture of audiovisual resources is decidedly antique itself and far more difficult to acquire" (p. 65). As discussed previously in this chapter, the obsolescence of playback devices represents one of the major challenges in converting and preserving time-based media. Each unique format requires a dedicated player, which in practice means that digitization labs have to acquire gramophone players for records, reel-to-reel players for recordings on open reel, and cassette tape players for audio cassettes.

FIGURE 4.6 Audio Input Deck

Image courtesy of the Digital Production Center, Duke University Libraries.

A/D converters represent the most critical technological component in the conversion process. This piece of equipment is responsible for converting analog sound waves into a binary form. It should meet the required specifications for preservation reformatting and not alter the signal or add any noise. An A/D converter can be incorporated into a computer's sound card and is also available as a standalone device. IASA (2009) recommends using standalone A/D converters and provides guidelines for their selection (Section 2.4.3). Standalone A/D converters provide a bridge between the playback devices and the computer station, and can be connected through a firewire or USB serial interface. Audio processing software is necessary to encode the converted signal and save master files in the target format. There is a wide range of audio processing software available, from the high-end Sony Sound Forge to the open source Audacity.

RECOMMENDATIONS FOR AUDIO DIGITIZATION

The audiovisual engineering and digitization communities have made significant progress in establishing consistent standards for audio reformatting. In practice, some institutions may select lower-than-optimal specifications because of the type of source material or because of concerns about processing time and archival storage demands. The adherence to standards is particularly important in light of the history of audiovisual recording, with its multiple formats and the challenges associated with transferring content onto new technologies. The established audio standards offer a level of uniformity and consistency that should alleviate some of the past risks and ensure future migrations. As IASA guidelines emphasize, "it is integral to the preservation of audio that the formats, resolutions, carrier and technology systems selected adhere to internationally agreed standards appropriate to the intended archival purposes. Non-standard formats, resolutions, and versions may not in the future be included in the preservation pathways that will enable long-term access and future format migration" (IASA, 2009, Section 2.1).

Sampling rate and bit depth represent two critical factors in determining the fidelity of digitally reformatted audio. IASA recommends a minimum sampling rate of 48 kHz for any material when producing digital copies of analog resources. For preservation quality audio digitization, 96 kHz and 24 bit are recommended as optimal specifications for master files (ALCTS, 2013; CARLI, 2013a; Chase, 2015; IASA, 2009). WAV format is recommended for encoding master files because of its wide acceptance and use in professional audio environments. Table 4.1 provides a summary of recommendations for capturing and encoding audio master files produced as a result of analog-to-digital conversion. Born digital audio should be migrated natively whenever possible (ALCTS, 2013).

Some guidelines take into consideration the type of sound recordings and list a range of audio digitization recommendations (CARLI, 2013a; CDP, 2006):

Table 4.1 Digitization Recommendations for Audio Master Files

Recommendation Level	File Format	Sample Rate	Bit Depth	Compression
Optimal	WAV/BWF	96	24	Uncompressed
Accepted	WAV/BWF	48	24	Uncompressed

- Minimum level at 44.1 kHz and 16-bit depth
- Recommended or special considerations at 48 kHz and 24-bit depth
- Optimal at 96 kHz and 24-bit depth

The guidelines prepared by the Consortium of Academic and Research Libraries in Illinois (CARLI, 2013a) note that 48 kHz and 24-bit depth are often used in the conversion of voice recordings, while the higher specifications are necessary for digitization of music and sounds from nature. The minimum recommendations at 44.1 kHz and 16-bit depth are similar to the specifications used in recording of commercial audio CDs, which are based on human ability to perceive sound. Humans "hear" sound in the range of 20–22.5 kHz and 15–17 bits per sample (CDP, 2006; Weig et al., 2007). The sampling rate of 44.1 kHz is in keeping with the Shannon-Nyquist theorem, according to which the sampling rate must be at least twice the highest analog frequency in the signal (JISC Digital Media, 2014a).

The sampling rate of 96 kHz versus 48 kHz has been a subject of ongoing debate in the digitization community (CARLI, 2013a; Casey and Gordon, 2007; CDP, 2006; Weig et al., 2007). The optimal recommendations for audio digitization in cultural heritage institutions are actually higher than those of commercial audio CDs. Some experts argue that a combination of 44.1 kHz and 16 bit used in audio CDs is considered inadequate for audio preservation of analog recordings (Casey and Gordon, 2007). Weig et al. (2007) agree that a higher sampling rate can capture subtle tones but also state that "for spoken word recordings there is little evidence to suggest such aural subtleties are relevant or warrant the significant file size increase that higher settings for their capture would incur" (p. 3). The CARLI guidelines provide a range of recommendations but also support the view that digital audio at cultural heritage institutions, especially if created for preservation purposes, should use a higher sample rate and file bit depth (CARLI, 2013a). The authors of the CARLI guide argue that there are several reasons for creating richer digital master files of archival audio materials, including:

- The accurate capture of noise like clicks, pops, and other inaudible information that resides in frequencies higher than 44.1 kHz.
- Desire to communicate inaudible harmonic information that impact perception of sound.
- Ability to record and provide content that, although not necessarily heard, helps listeners understand and hear better space, depth, and instrument location in stereo and surround sound recordings.
- The need to accommodate future user applications (CARLI, 2013a, p. 1).

The most recent guidelines issued by the division of the American Library Association acknowledge the arguments for digitizing some types of audio sources at lower quality (ALCTS, 2013). However, the ALCTS guidelines recommend 96 kHz and 24-bit depth for consistency and standardization.

Formats for master files and derivatives represent a less contentious issue. WAV, and more recently BWF, are recognized as preservation formats, while MP3 serves as a format for access files. Other formats, such as AIFF (Audio Interchange File Format) have been used in practice for archival storage as well. Master files in the WAV or BWF format should be saved uncompressed. Derivative files are saved in compressed formats for quicker transfer and streaming over the Internet. Audio processing software, such as Sony Sound Forge, Adobe Audition, or Audacity, can be used to create derivative files for access.

- *WAVE (Windows Audio File Format)*, or commonly referred as *WAV*, is uniformly recommended as a preservation format for audio files (IASA, 2009; Library of Congress, 2013). WAV was developed as a proprietary format by Microsoft and IBM and has been in use since the early 1990s. A variety of applications support WAV, and the format is compatible with Windows, Macintosh, and Linux operating systems. WAV is a PCM (Pulse Code Modulation)-type format that is widely used and accepted. IASA (2009) recommends WAV as a preservation format because of its simplicity and ubiquity. WAV files can be saved as either compressed or uncompressed. No compression is recommended for preservation master files. The file extension is .wav.

- *BWF .wav (Broadcast WAVE)* is an extension of WAV format supported by recent audio technology. The advantage of using BWF for preservation purposes is that metadata can be incorporated into the file header. BWF is increasingly recommended as a preservation target format (Chase, 2015; IASA, 2009; Wright, 2012). The WAVE file with embedded metadata (Broadcast WAVE) is listed as a preferred format in the recent publication by the Library of Congress (2015).
- *MP3* is a recognized format for audio derivatives. It is a highly compressed file that can be transferred over networks, streamed, and downloaded by users. MP3 is a widely accepted format for the distribution of digitized as well as born digital audio. Mariner (2014) comments on its widespread use: "MP3 is easily the most successful digital audio format in history. In the mid-1990s, MP3 became the de facto delivery vehicle for digital music and, for the most part, is still an accepted and usable format in almost all portable digital music players" (p. 31). Different compression algorithms are applied to reduce the file size. The amount of applied compression is expressed as bit rate, which measures the amount of information that is stored per second (JISC Digital Media, 2014a). The recommended bit rate for most audio access files in the MP3 format is 192 Kbps (CARLI, 2013a).

MP3 is currently the most widely adopted derivative format for digital audio. In addition to MP3, other access formats have been used in digital collections. Real Audio (.ra or .ram) was used in the first generation of audio digital collections. The Library of Congress provides a summary of the access formats and players used for audio recordings in the American Memory project (Library of Congress, n.d.).

MOVING IMAGE DIGITIZATION

> The Norman Rockwell Museum has been awarded archival support through a generous grant from the National Endowment for the Humanities (NEH). The $85,000 grant will be used to reformat and process the Museum's collection of magnetic videotapes, which contain hundreds of hours of important oral history and documentation related to Norman Rockwell and the art of illustration. The reformatting of the tapes will be handled by George Blood Safe Sound Archive in Philadelphia, Pennsylvania, with plans to make select films freely accessible to the public through the Museum's web site. Most of these tapes have not been viewed by the public before (Norman Rockwell Museum, 2011).

This section begins with an excerpt from a blog posted by the staff at the Norman Rockwell Museum to demonstrate that cultural heritage institutions increasingly undertake digitization of moving image collections but often decide to outsource the conversion process to specialized vendors.

Analog moving image collections include motion picture film and video recordings. Film and video recordings are two distinct types of moving image, due to different technologies used for capturing moving image in the analog world. Motion picture film and video recordings are the most complex analog resources and their transfer to the digital format requires not only access to legacy playback devices and high-end conversion equipment but also a considerable amount of technical expertise.

In-house conversion of moving image collections has been conducted by audiovisual archives and national or large academic libraries (Gaustad, 2012; Peck, 2011). A few libraries, like the New York Public Library or Stanford University Libraries, have well-equipped moving image preservation labs capable of converting motion picture film and video formats. Some institutions undertake pilot projects to test their ability to digitize in-house and to establish internal procedures for meeting user requests (Gracy, 2013b; O'English and Bond, 2011).

However, when faced with the question of what to do with "a small archive of aging motion picture films without access to expensive digitization equipment or staff with specialized expertise," many small cultural heritage institutions often turn to digitization vendors (Tucker, 2013, p. 343). Even if the digitization process is outsourced, it is useful for library and archives staff to be familiar with the concepts and technical specifications of moving image digitization in order to be able to select a qualified transfer vendor and ensure that the conversion process is performed according to the recommendations established in the cultural heritage community. *Digitizing Video for Long-term Preservation* offers step-by-step guidelines and a template for preparing a Request for Proposal (RFP) to be submitted to digitization vendors (De Stefano et al., 2013). The recent Federal Agencies Digitization Guidelines Initiative (FADGI) report, *Digitizing Motion Picture Film*, includes a model statement of work for the outsourced conversion of film to video (FADGI, 2015).

In the domain of moving images, the extent of digitization activities has been limited so far, especially in comparison to the conversion of static media and audio. Despite the options of outsourcing the conversion process or conducting the transfer in-house, the percentage of digitized moving image collections is still very low. Video and motion picture film tend to be the last resources selected for digital conversion, even if institutions are committed to comprehensive digitization (Gaustad, 2012). In a study conducted with archivists and librarians working with moving image collections, Gracy (2012, 2013b) found that few of the participating institutions had digitized more than 5% of their motion picture or video collections. The participants reported that the digitization projects tended to be exploratory or aimed at creating low-resolution access copies for immediate distribution. The author notes that "few archives currently can afford to digitize moving images to a standard that may be considered preservation quality" (Gracy, 2012, p. 423). These findings are particularly disconcerting in light of the preservation issues associated with analog video formats.

The conversion of moving image collections has been marked by a slow progress, primarily due to a combination of technical challenges. Large file sizes demanding massive amounts of storage space and the lack of universally recognized preservation formats represent the major technical impediments. Gracy (2012, 2013b) identifies a number of additional barriers to digitization of archival moving image collections, including:

- Lack of financial resources
- Lack of staff with expertise in moving image conversion
- Lack of appropriate equipment
- Concern over the lack of standards and best practices for moving image digitization
- Copyright restrictions

The authors of the CARLI guidelines for moving images echo these concerns by stating, "libraries seeking to preserve and provide access to moving image content such as films, video recordings, and television broadcasts in digital format face a number of daunting obstacles. Digital video formats and specifications abound, server space to store the massive amounts of data generated must be allotted, and mature, clearly established best practices for creating preservation-worthy digital objects have yet to fully evolve" (CARLI, 2013b, p. 3). Undertaking the digitization of moving images, especially for preservation purposes, requires a major investment in digital archiving infrastructure and a commitment to ongoing digital preservation. Cultural heritage institutions are cautious about devoting their resources to the conversion of moving image collections in the environment where there is still confusion about specifications and no real consensus on preservation formats. Blood (2011) also notes that there is considerable variation in the types of video files produced by moving image archives.

Digital conversion of moving images has followed a different path than audio, although as Schüller (2009) states, "with regards to their long-term preservation, audio and video recordings are twins" (p. 5). Audio digitization is well established, with WAV/BFW recognized as a common preservation format. The IASA (2009) guidelines have helped to standardize and advance the digital conversion of sound recordings. In contrast, digitization of moving images still lacks clear guidelines on technical specifications and preservation formats. In response to the question "what is the best digital file format for video preservation?" Jimi Jones writes in the Library of Congress blog that the video realm is still "kind of the Wild West" in that there is no consensus about file formats or codecs appropriate for preservation (Jones, 2011, para. 1).

In practice, there is considerable variation between the often-compressed file formats being used for both digitized and born digital video. The study conducted by the Academy of Motion Picture Arts and Sciences brings attention to the lack of agreement on a standard format for moving image preservation. The survey of 21 nonprofit audiovisual archives found 12 different formats used for moving image preservation (STC-AMPAS, 2012). The problem is compounded by an additional array of file formats for access. Schüller (2009) points out that commercial pressure led to the widespread use of proprietary and compressed file formats. He identifies the high cost of digital storage in the 1990s as a major barrier to the development of true archival standards for digitization of moving images.

This situation, however, has been changing recently as a result of the decreasing cost of storage and an overall increase in the attention paid to digital preservation issues. There are multiple efforts underway to advance the development of common target formats and to provide guidance for the digitization of moving images. In the United States, these efforts are led by the FADGI and specifically by the Audio-Visual Working Group that published a number of documents, including *Audio-Visual Format Documentation: Background Paper* (FADGI, 2010) and most recently *Digital File Formats for Videotape Reformatting* (FADGI, 2014) and *Digitizing Motion Picture Film: Exploration of the Issues and Sample SO*W (FADGI, 2015). The PrestoCentre, a nonprofit organization located in Europe, provides a range of services in the domain of audiovisual digitization and digital preservation to its members and serves as a hub for recent research (PrestoCentre, 2015). Guides to best practices and case studies of moving image digitization are still limited. *The Minimum Digitization Capture Recommendations*, prepared by the division of the American Library Association (ALCTS, 2013), includes a brief section on video but has no recommendations for motion picture film. CARLI (2013b) guidelines review current practices and include a list of resources for the selection of hardware, software, and vendors for moving image digitization.

The following sections provide an overview of the technical factors relevant to moving image digitization and summarize the current recommendations for technical specifications and file formats. Most of the existing guidelines focus on video digitization. The conversion of motion picture film to the digital form remains a subject of significant disagreement (ALCTS, 2013). FADGI's recent guidelines for motion picture scanning projects focus on providing advice for generating high-quality output formats for current use but not on preservation reformatting. The authors of the report stress that the digitization of motion picture film is "an emergent discipline and a still-evolving set of practices" (FADGI, 2015, p. 2). Many moving image specialists argue that "more visual information is held in a film frame than could be digitally captured with their current technical capabilities" and maintain the position that preservation of analog film is best served by film duplication (STC-AMPAS, 2012, p. 52). However, some institutions undertake the digital conversion of motion picture film for access or, as discussed in the Section "Preservation Crisis," out of concern for the uncertain state of preservation film. The distinction between motion picture film and video as a source of analog materials is important in the context of digitization because they require different equipment and conversion processes.

MOVING IMAGE TYPES

Moving images are dynamic, time-based media consisting of a sequence of still images that, when projected at a rapid rate, create the illusion of continuous movement. The sequence of images may be accompanied by one or more audio channels. Different technologies and materials have been used in recording moving images and associated sound. Film, video, and born digital files are fundamentally distinct because of differences in the recording technologies associated with each medium. Broadcast television is a unique category in regard to projection since it is delivered by means of a broadcast signal, but recording has been done on a videotape or in the digital form (Coyne and Stapleton, 2008).

- *Film* was the first method used for capturing motion pictures and dominated moving image recording for over a century. Moving images captured with a film camera and recorded on a variety of film stock undergo a process of exposure and development to be ready for projection. The accompanying audio is recorded on an optical or magnetic track. Historically, moving images were created on celluloid film with an unstable chemical base. Celluloid film was later replaced with a more stable and durable polyester film. Motion picture film comes in a variety of gauges ranging from 8 mm to 16 mm to 35 mm. Footage can range from camera original to preprint or duplication materials and can contain imagery in color and black and white (FADGI, 2015).
- *Video* was originally developed for recording a broadcast television signal on tape but has been used for a wide range of applications, including direct recording. Analog video recording uses electric signal to capture images as a pattern of parallel lines. The images are organized into a series of discrete, fixed-sized frames. There is, however, some variation in the way video signal is captured and color recorded due to the limited available technology and standards used in predigital television (Coyne and Stapleton, 2008). Different standards emerged for analog video in North America (NTSC, National Television Systems Committee) and in Europe (PAL, Phase Alternating Line). Magnetic tape used for recording analog video is prone to degradation. All analog, tape-based videos present serious preservation risks and are a prime candidate for digital reformatting.

- *Born digital files* include images and soundtrack encoded as a digital signal. The frames consist of bitmapped digital images and are synchronized with an audio bit-stream. Born digital files pose a separate set of challenges, as they have been encoded in a variety of formats and may require re-encoding into a suitable preservation format. Digital files recorded on physical carriers, such as DVDs, need to be migrated into file-based systems.

There is also considerable variation of the formats and carriers within film, video, and born digital files, making analog-to-digital conversion and digital preservation extremely challenging (FADGI, 2010).

Moving images have complex structures consisting of dynamic visual and audio information. A frame, used in film and in video recording, refers to the succession of still images that capture the scene at a point in time. The sequence of images displayed at a fast rate creates the illusion of a moving image. Different types of moving images have different frame rates, film having 24 frames per second and video 30 frames per second. The synchronized audio track includes the accompanying audio information. In the case of digitized or born digital files, digital audio signal needs to be converted to an analog sound wave during transmission in order to be perceived or "heard." Frames and audio data of a digital moving image file need to be processed in order to be rendered and perceived by viewers. In addition to visual and audio streams, a moving image can include descriptive metadata and captions, which requires the processing of textual information (Coyne and Stapleton, 2008).

DIGITIZATION PROCESS AND EQUIPMENT

Digitization of analog moving image formats requires the conversion of frames consisting of still images and of associated sound recordings. The conversion process involves sampling the image portion of the frames to produce bitmapped digital images. It also requires synchronizing the audio track and translating it to a binary stream of 1s and 0s. Similarly to static media and audio conversion, digitization of moving image is a multistep process composed of several phases, including planning and assessment of analog sources, digital capture (scanning of film or sampling of video signal), production of master files and derivatives, processing and encoding of files, recording metadata, ingesting access files into a content management system for dissemination, and depositing preservation master files into a digital repository for long-term preservation. The process is complex because of the integration of visual and audio components and the differences between analog source materials. The assessment of the condition of analog materials is critical, as deteriorating film and videotapes require cleaning and repair before they can be digitized.

Different methods are used in capturing film and video in the digital capture phase. Transforming motion picture film into the digital format can be achieved using two techniques. Film as an optical medium is best converted through the imaging process and the use of a high-resolution motion picture scanner. Individual frames are scanned at high resolution ranging from 4 K to 8 K and stored as a sequence of digital images. The resulting digital files are extremely large and equipment is quite expensive. Gracy (2012) notes, "the process by which motion pictures are digitized is complex and costly enough to make transfer difficult for most archival institutions. Few institutions, aside from the largest archives, possess motion picture scanners, and the costs of sending material to digitization facilities discourage many institutions" (p. 437). The second approach is a two-step process, which involves first converting film to analog video using a telecine machine and then digitizing the resulting video.

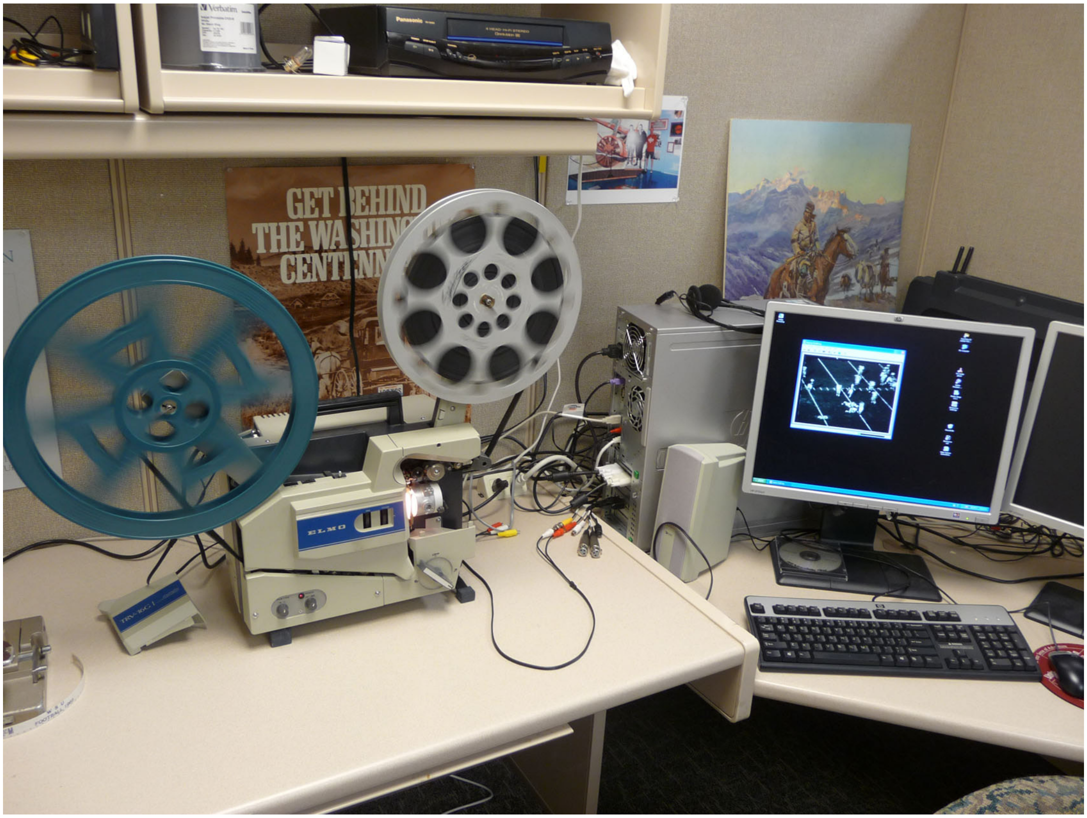

FIGURE 4.7 Elmo TRV-16G Transfer Telecine System (O'English and Bond, 2011)

Telecine is the process of transferring motion picture film into analog video represented by an electric signal. Video can be viewed with standard video equipment and ultimately digitized with an analog-to-digital converter. Fig. 4.7 demonstrates an example of the Elmo transfer telecine system used for converting 16 mm film into video in a digitization of historic film at the Washington State University Libraries (O'English and Bond, 2011).

The conversion of video requires setting up a video digitization workstation consisting of a playback device, a high-quality analog-to-digital converter, and a dedicated computer station with a high-end processer. A video digitization lab requires an assortment of legacy video playback machines to be able to play a variety of analog video formats. Marsh (2014) describes the process of converting obsolete videotape formats at the Digital Production Center of Duke University Libraries. Fig. 4.8 demonstrates a range of input equipment used in video conversion at the Digital Production Center of Duke University. During the transfer process, while the analog video is played, its waveform amplitude is sampled (measured) at regular intervals and converted to a set of digital values by an analog-to-digital converter. This capture device, which can be an internal video conversion card or an external unit, interfaces between the playback machine and a computer, facilitating the encoding of converted data.

FIGURE 4.8 Video Input Deck

Image courtesy of the Digital Production Center, Duke University Libraries.

External analog-to-digital converters are cheaper and easier to install; however, there is a proliferation of poor-quality devices that tend to automatically compress video (Mariner, 2014). A high-quality internal video capture card is usually recommended (CARLI, 2013b; JISC Digital Media, 2014b). The video capture and processing software is required for importing and editing the resulting digital video files. Some examples of high-end video processing software include Apple's Final Cut Pro, Adobe Premiere, and Sony's Vegas Pro.

Similarly to the guidelines for static media and audio digitization, the guides to best practices for moving images emphasize creating uncompressed, high-quality archival master files (CARLI, 2013b).

The authors of the CARLI guidelines acknowledge that uncompressed files demand an enormous amount of storage but also add that "an uncompressed video is crucial to preserving the integrity of the content over the long term" (CARLI, 2013b, p. 4).

Three separate digital types of files are typically created during the digitization of moving images. These include:

- *Preservation master file* is the digital file that is saved for long-term preservation. It captures the content from the archival original at the highest possible quality and is encoded with no compression or using lossless compression. Preservation masters remain "untouched" and once ingested into a digital repository, are rarely accessed.
- *Mezzanine file* (also referred to as a service or production master) serves as a surrogate for the master file. Mezzanine files are accessed for editing and transcoding, and are used to make other duplicates and derivative files for access. Lossless or lossy compression is usually applied to mezzanine files to reduce their size.
- *Access (derivative) file* serves as a general use copy for viewing and online distribution. Access files are highly compressed (CARLI, 2013b; De Stefano et al., 2013; STC-AMPAS, 2012).

TECHNICAL FACTORS AND RECOMMENDED SPECIFICATIONS

The ultimate goal of digitization is to capture the content and properties of analog source materials and represent them faithfully in the digital form. As discussed earlier, the current guidelines provide recommendations for video digitization but not for film. The authors of *Minimum Digitization Capture Recommendations* state that "there are currently too many unknowns to make a well informed recommendation on digitizing moving image film at this time" (ALCTS, 2013, p. 37). Therefore, most of the recommendations reviewed here refer to video conversion, although many technical factors, such as resolution, aspect ratio, and frame rate also pertain to film. The complex structure of moving images requires one to consider a number of technical factors and specifications in the process of analog-to-digital conversion.

Resolution refers to the size of the image frame. Similarly to still digital images, resolution is expressed as the number of horizontal pixels (width) multiplied by the number of vertical pixels (height). The resolution of an analog source needs to be considered when converting to the digital form. For standard definition NTSC video, the resolution of 720 × 486 pixels is recommended to digitize a full frame and to create master files, whereas 640 × 480 is recommended for derivatives (ALCTS, 2013; Blood, 2011). 720 × 576 is recommended for standard definition PAL video (Blood, 2011).

Aspect ratio refers to the width of the image frame divided by its height. The aspect ratio should be maintained true to the original analog source. Most standard definition (SD) video has a 4:3 aspect ratio, while 16:9 is usually used in high-definition HD video.

Frame rate indicates the number of frames displayed per second. Thirty frames per second is the standard for digital video and television materials; film has a rate of 24 frames per second. Retaining the native frame rate is recommended for video and film digitization.

Sampling involves recording values for each pixel within a video stream. Three values are recorded: a "luma" element, corresponding to the brightness level; and two "chroma" elements, corresponding to the color levels for red and blue. A sampling schema of 4:4:4 indicates that luma and chroma elements are sampled at every pixel. This 4:4:4 sampling schema is the only true "lossless" sampling. The 4:4:4

sampling schema is recommended as best practice, while 4:2:2 is commonly used and recognized as an acceptable practice (Blood, 2011; CARLI, 2013b).

Bit depth indicates the depth of measurement. Bit depth determines the amount of data captured per image pixel and color channel and thus the accuracy with which the color information is stored. The greater the bit depth, the greater the number of gray scale or color tones that can be represented and the larger the file size. Most digital video formats use a minimum of 8 bits per color channel, while 10 bits per channel is recommended. Blood (2011) notes that the visual difference between 10-bit and smaller 8-bit files is subtle, especially in low-grade formats, such as VHS, U-matic, and Betamax. However, digitizing video using 10-bit depth is still beneficial as it allows one to capture the finer detail and subtle gradations within the range of recorded information.

Scanning in the context of video digitization refers to the way in which image frame is captured. Interlaced scanning captures the frame in two exposures, each containing one-half of the image, which may result in some image blurring. Most analog video is in interlaced format. In progressive scanning, the entire image is captured in a single exposure. Most born digital video is made using progressive scanning (CARLI, 2013b). Blood (2011) recommends retaining the native scanning format during the conversion process.

ENCODING AND FILE FORMATS

Digitized video data need to be encoded and encapsulated in a file format in order to be processed by computer software and opened by a player. Video and audio streams that contain the essence of converted video are encoded using codecs. Different codecs can be used with no compression or in combination with lossless or lossy compression. Both the selection of codec and the level of compression applied during the encoding process impact the quality of the digitized video. File formats serve as wrappers or containers for encoded video essence and for additional information, such as metadata and captions. A combination of the codec and the wrapper is used to store, transmit, and play video in the digital form. The distinction between these two concepts is helpful in understanding the complexity of video file formats.

Codec refers to the way audio and video bit streams are encoded for transmission and storage and then decoded for playback or editing. The term "codec" is constructed from the words coding/decoding. A codec is a series of algorithms and is not included in the video file itself. The playback software must include a codec or be compatible with the codec used to encode the file (CARLI, 2013b; Mariner, 2014). There is a wide range of codecs available that are used with lossy or lossless compression. Several codecs (such as FFVI, JPEG 2000, uncompressed 4:2:2, 10 bit [v210], UYVY, and YUY2) support lossless compression and are used for encoding archival master files. A recent study by FADGI provides a comparison of codecs commonly used in archival practice for encoding digitized video (FADGI, 2014). Encoding schemas with lossy compression, such as DV, MPEG-4, QuickTime, or WMV, are used for encoding born digital video and for files created for access. JPEG 2000 and FFV1 are nonproprietary codecs supporting lossless compression and are emerging as open standards for encoding archival master files (FADGI, 2014; Lorrain, 2014).

- *JPEG 2000* is an open standard developed by the Joint Photographic Expert Group. As described in Chapter 3, JPEG 2000 was developed to encode large and high-dynamic-range images. It is also used for encoding audio-visual content from video capture and film scanning. JPEG 2000 supports both lossy and lossless compression. Its adoption is still moderate. A number of large cultural heritage institutions, including the National Audiovisual Conservation Center of the Library of Congress, have selected lossless JPEG 2000 in combination with the MXF wrapper for preservation master files (FADGI, 2010, 2014; Lorrain, 2014).

- *FFV1* is a codec that is gaining significant support in the open source community. Lorrain (2014) describes it as “the most promising open source video codec for long-term preservation” (p. 8). It supports lossless compression and, in combination with an open source wrapper, Matroska provides a fully open solution for digital video preservation. Its adoption is rated low to moderate by FADGI (2014). FFVI is being used by the Austrian Mediathek, the Vancouver City Archive, and MUMOK in Vienna (Lorrain, 2014).

Wrapper is distinct from codec and plays a different role in preserving digitized and born digital video content. Wrappers serve as containers for the encoded video and audio streams and other data, such as metadata and subtitles. FADGI (2014) defines the word wrapper as a “term often used by digital content specialists to name a file format that encapsulates its constituent bitstreams and includes metadata that describes the content within” (p. 4). Wrappers determine how and by what program audiovisual streams are played. There are hundreds of wrappers available (Mariner, 2014). Some are used as containers for preservation masters files, while others are used for highly compressed access files. The Library of Congress (2013) maintains a list of moving image formats (codecs and wrappers) and provides a review of sustainability factors. FADGI (2014) has recently released a study comparing wrappers commonly used in archival practice. Table 4.2 provides a brief summary of wrappers used by cultural heritage institutions for saving preservation master files. For a more comprehensive comparison, please see *Digital File Formats for Videotape Reformatting* (FADGI, 2014).

This brief review of codecs and wrappers points to the complexity of video preservation formats and the proliferation of approaches. A compatible configuration of a codec and wrapper is necessary to make sure that the format is interoperable and can be sustained over a period of time. Additional selection criteria, such as quality, openness, adoption, transparency, durability, and functionality, need to be considered in the format selection (Lorrain, 2014). At the time of this writing, there is no file format that has been definitively recognized as the preservation standard. Cultural heritage institutions use different configurations as intermediate solutions based on the established practice and available expertise. A combination of MXF/JPEG 2000 is emerging as a desired format, but its adoption in the cultural heritage community is still low, with the exception of large national libraries.

SUMMARY OF RECOMMENDATIONS FOR VIDEO DIGITIZATION

The preservation crisis associated with the deterioration of analog moving image media and the obsolescence of playback equipment has created a sense of urgency. Cultural heritage institutions are increasingly undertaking the digitization of moving image collections despite the fact that there is no clear consensus on formats and specifications. They select options considered either best or acceptable practice knowing that there is no ideal solution and that digitized files may need to be transferred into newer formats in the future. As Lorrain (2014) points out, “uncertainty as to how formats will or will not become the future standard makes is difficult to commit to one codec and one container. However, digitization needs to take place now and it is not possible to wait for the perfect format to appear” (p. 12). Table 4.3 provides examples of recommended or acceptable practices based on the available documentation (Blood, 2011; CARLI, 2013b).

Table 4.2 Commonly Used Wrappers for Video Preservation Master Files

Wrapper	Extension	Brief Description and Usage
AVI (Audio Video Interleave)	.avi	Relatively old and well-established Windows multimedia container, developed by Microsoft. It is well documented and widely used. The US National Archives and Records Administration (NARA), Rutgers University, and Austrian Mediathek use AVI for preservation purposes.
QuickTime (MOV)	.mov	Well-established and well-documented format developed and maintained by Apple. It is widely used in both the production and cultural heritage communities. Stanford University and New York University use MOV for preservation purposes.
Matroska	.mkv	Relatively new, nonproprietary format that is beginning to be adopted in the cultural heritage and open source communities. In combination with the FFVI codec, it provides open source format for preservation of video. Its adoption is still low. The City of Vancouver Archives uses Matroska for preservation purposes.
MXF (Material eXchange Format)	.mxf	Highly flexible standard capable of wrapping complex objects with uncompressed or lossless-encoded data. Technically, it is codec agnostic, but is often used in combination with JPEG 2000. It is an open standard, but some documentation is not freely available. A draft of the AS-07 profile of the MXF application specification was released recently for review (AMWA, 2014). MXF is widely adopted in the broadcast and film industries; the use in the cultural heritage community is not yet widespread. The Library of Congress and Library and Archives Canada use MXF for preservation purposes.

Table 4.3 Summary of Recommendations for Video Digitization

Specification/Format	Source: (Blood, 2011)	Source: CARLI (2013b)
Resolution/Frame size	720 × 486	640 × 480
Aspect ratio	4:3 for SD; 16:9 for HD	4:3 for SD; 16:9 for HD
Bit depth	10 bit	10 bit
Sampling	4:2:2	4:4:4 (recommended); 4:2:2 (acceptable)
Scanning	Interlace/Progressive: Native	Progressive
Frame rate	Native, 30 or 29.97	30
Compression	Uncompressed	Uncompressed or lossless
Codec	Uncompressed 4:2:2, 10 bit; YCbCr (color space)	Uncompressed YCbCr or JPEG 2000 (recommended); MPEG-4 AVC or DV (acceptable)
Wrapper	QuickTime (MOV) or AVI	MXF (recommended); QuickTime (MOV) or AVI (acceptable)

The current guidelines vary in some specifications, as they reflect the state of intermediate practice. However, they provide recommendations that will ensure future transfer of high-quality files and uniformly stress the need to capture video uncompressed or with lossless compression. Compression is discussed in more detail in Chapter 3 with the distinction made between no compression, and lossless and lossy compression. No compression is generally recommended for master files for all media types, including text, still images, audio, and moving images. This recommendation is particularly critical in video digitization and in light of preparations for future transfer into formats such as JPEG 2000/MXF combination (Blood, 2011). Compression reduces file sizes but at the same time permanently discards a considerable amount of captured data, which can impact the accuracy of color representation. In the case of deteriorating video, there may not be another chance to digitize it and to recover the data. If digitized video is compressed, future transfers will include files of reduced quality. On the other hand, uncompressed video has a tremendous impact on processing and archival storage. Uncompressed video generates large files and demands a massive amount of storage space. An hour of uncompressed SD digital video will result in a file size of approximately 70–100 GB. In comparison, the size of the same file when lossy compression is applied is only 10–20 GB. In addition to uncompressed encoding, lossless compression of audiovisual data is considered a viable technology for long-term preservation, providing storage savings and the ability to reconstruct the same bitstream (PrestoCentre, 2014).

Compression, however, is extremely useful in reducing the size of files intended for online dissemination and other forms of access. The intermediate, mezzanine files are usually used as a source for creating smaller access files. Lossy codecs such as H.263 or MPEG-4 AVC (H.264) are used for encoding highly compressed access files. Wrappers, such as Adobe Flash (.flv) or MPEG-4 (.mp4) serve as derivative file formats (CARLI, 2013b). Other derivative video formats have been used in digital collections, such as QuickTime (.mov) or RealMedia (.rm, .ram). The Library of Congress provides a summary of access formats and players for video recordings in the American Memory project (Library of Congress, n.d.).

Access files are distributed through digital libraries or hosted video streaming platforms. Many open source and proprietary DLMS, including Omeka, Collective Access, and CONTENTdm, include video players and support standard access formats, such as mp4, WMV, or flv. Hosting options through the Internet Archive are available to cultural heritage institutions with limited digital library infrastructure and/or no access to streaming servers. Some institutions also choose to present digitized video through popular streaming platforms, such as YouTube or Vimeo.

Audio and moving image materials are media in transition, constantly upgrading carriers and methods of recording as technology evolves. Digitization is necessary not only to transfer analog audio, film, and video to a new generation of technology for access but also to preserve the content for future use. The preservation crisis caused by the deterioration of analog media and the obsolescence of playback equipment has made the conversion of audio and moving image collections an urgent issue. The guidelines for audio analog-to-digital conversion are well established, while the recommendations for moving image preservation formats are still evolving.

Digital technology provides a new method of recording and storing resources that, using file-based systems, liberates audiovisual materials from the limitations of physical carriers. However, this technology poses a new set of challenges in regard to digital preservation. These challenges are not unique to audio and moving image resources. Because of the uniform nature of the binary form, all digitized and born digital resources, whether textual or audiovisual, require preservation planning and ongoing data management. No digital format is expected to last forever and digitized, and born digital audiovisual materials will eventually have to be transferred to a new generation of formats. Adopting common standards for preservation formats will ensure that the content can be transferred properly, and will facilitate long-term digital preservation activities.

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