Thesis Draft

Introduction:

Codecs perform in a variety of digital video and audio materials, including born-digital materials and in the digitization of film. This thesis focuses primarily on how codecs affect the long-term preservation of digitized analog video and audio. The essay will be broken up into four distinct parts in order to paint a portrait of the issues organizations face when archiving digital materials. By looking through codecs' past, we can predict some trends that may occur in the future. This is an important step in determining how and why codecs inform archival choices in terms of preserving the best possible representation of sound and image in the perpetually evolving digital landscape. Each individual part of the thesis serves as a foundational link to a basic knowledge of codecs. Part I will define what a codec is and how it works. Part II recalls the history of the codec in order to illuminate the perpetual evolution of the technology, including its standardization and the challenges preservationists face when decoding content. Part III delves into the factors by which the proliferations of codecs occur. Part IV looks at preservation decision-making, including the future trends in codec availability and how this might affect archives and repositories.

Part I-Definition of a Codec:

The classic definition of a codec is that it is the combination of two words. The combination of words most commonly associated with codecs are encoding and decoding. Codec can also be a combination of the words compression and decompression. However, it has been suggested that the compression aspect is really just a sub-category of encoding (Lacinak, 2010). Despite the simplicity of the word's origin, codecs are complex algorithms that have been developed as digital tools used to represent and recreate both analog audio and analog video signals.

A better definition for a codec is that it is either software or hardware (a computer program or an actual, tangible device) that compresses and decompresses digital video and/or audio signals, or, software or hardware that encodes analog video and/or audio signals into digital bits and decodes digital video and/or audio bits into analog signals (PCMag.com, 2010). Although this may not seem clear, the fundamental idea can be easily unpacked.

The fundamental processes behind encoding and decoding information can be illustrated through a breakdown of the terminology in its use. For illustrative purposes, analog signals will be used. A codec will receive an original analog video or audio signal. The information comprised by that signal will be converted and encoded into digital bits through a complex algorithm. Algorithms exist in computer science as a form of code written into a program which uses a set of specific instructions that perform in sequence in order to convert a particular input into a specific kind of output (American Heritage Science Dictionary, 2011). After being encoded, the bits must go through another algorithmic program in order to be decoded and played back as a digital recreation of the original video signal. Thus, the codec encodes and decodes the data (Lacinak, 2010). In practical terms, an encoder will take a series of video frames and produce a bit stream from it. A decoder will take that bit stream and turn it into either a series video frames which will be displayed or will transcode the bits to another format (Shlck, 2012). As mentioned above, the compression and decompression of digital bits also play a role in defining codecs.

When defining codecs, it is important to mention compression, or the lack thereof. Compression can be defined as a method by which the numbers of digital bits are reduced by eliminating areas of redundancy through the use of an algorithm (American Heritage Science Dictionary, 2011). There are three types of compression, lossy, lossless, and uncompressed. Lossy compression uses an algorithm that compresses content information by completely and irretrievably throwing out bits of data. This renders a permanent loss to the original content information when uncompressed through a decompression scheme. Lossless compression also discards bits of content information. However, rather than data being completely lost, this form of compression uses an algorithm which allows for the original data to be retrieved and replicated by using the proper decompression scheme. Uncompressed data is encoded by the codec as an entire stream of data, thereby ensuring that all of the original data is intact. Although uncompressed data is not technically utilizing a compression scheme, there is still a specific type of codec called uncompressed. Uncompressed files are quite a bit larger than those created using lossy or lossless compression, but more on that later (Lacinak, 2010).

Another important concept related to the definition of codecs is encoding schemes. There are several types of encoding schemes utilized. The discrete cosine transform, or DCT encoding scheme for instance, is used in lossy compression audio and video codecs. It uses a method wherein each individual video frame or audio sample is compressed. These are called intraframe codecs and are the compression schemes used in MP3's, or in JPEG images, the MPEG-1 codecs, DV, DVCPRO, DigiBeta, HDCAM, and others (Ascher, 2013). Since DCT is a lossy compression scheme, artifacts, such as blocky chunks, may occur, as in Figure 1 below (Zeng, 1999).

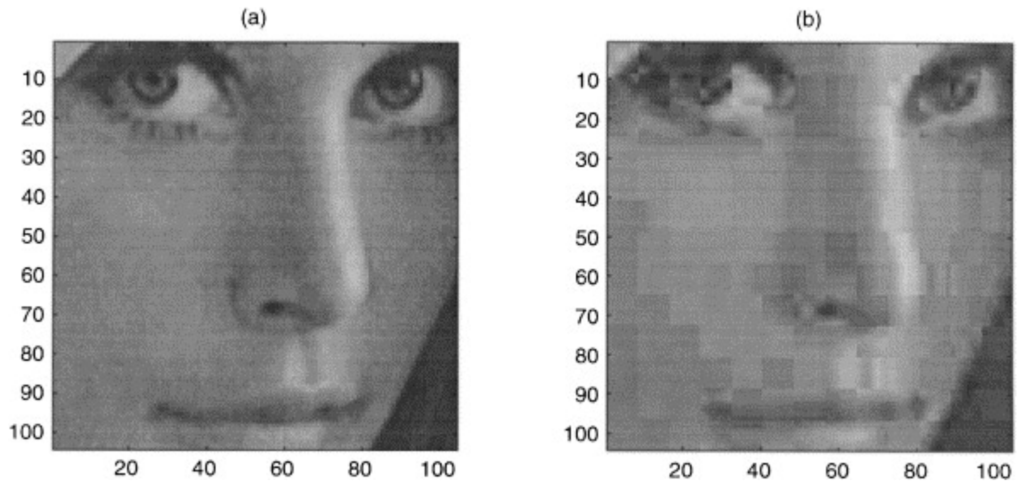

Figure 1: DCT Artifacting

The Wavelet encoding scheme is also used in intraframe codecs. JPEG2000 is arguably the most recognizable codec that uses this type of encoding. Advantages to this form of encoding include lossless compression, as well as an error correction mechanism that is potentially less distracting to the viewer during playback. The error correction mechanism has a tendency to display a soft focus, or fuzziness to areas experiencing problems due to image dropout or artifacting as opposed to the blocky chunks displayed in DCT codecs (Ascher, 2013).

Along with intraframe codecs, there are also interframe codecs that look at groups of images rather than at just one frame at a time. Interframe codecs only store the differences between frames. To understand how the I-, B-, and P-Frames work, start with the I-Frame. I-Frames (also referred to as Key Frames) are compressed as an intraframe with the data from this frame being used as the reference for the frames to follow. After the I-Frame usually come two B-Frames, or Bi-directionally Predicted Frames. They contain about one quarter of the information of the I-Frame. The B-Frame works by storing a group of frames in memory, then reconstructs the frames in the proper order with the use of data from the I- and P-Frames. P-Frames (also called Predicted Frames) follow the I-Frame and the two B-Frames. P-Frames contain about half of the information of the I-Frames. The information stored in the P-Frame is used in conjunction with the I-Frame to complete the B-Frames. The information stored in the P-Frame also gets passed along to the next set of B- and P-Frames for them to reference, as well. This way, not every frame of video is responsible for all of the content information but instead only contains a percentage of a key individual frame (Ascher, 2013). Figure 2 below illustrates this method of compression (The Sony Guy, 2010). MPEG-2 and HDV codecs are interframe codecs (Ascher, 2013). Some codecs, like the Apple Intermediate Codec and the Apple ProRes 4:2:2 uses an interframe style of encoding, yet also use an intraframe style of decoding. This helps to decode every frame immediately, but ends up using a lot of bandwidth and storage space, making its use impractical (Apple White Paper, 2011).

Vector Quantization is another lossy compression scheme. It is most commonly found in the codecs used in early versions of QuickTime, such as Road Pizza in QuickTime version 1 and the Sorenson codec used in QuickTime version 3, as well as in the Cinepak codec used in CD-ROMs. Vector Quantization essentially works by taking a sequence of finite values and matches them to a template which already exists in a codebook within the program. This template is then used as the value by which data is represented during playback (Gersho, 1992). For instance, if an image is representing a blue sky, rather than get a value for value reproduction of the blue in the sky during playback, the blue displayed comes from a template that exists in the program which is as close as it can come to matching the original set of blue values.

Finally, a definition of codecs would be incomplete without an understanding of bit rates. There are two kinds of bit rates, constant bit rate and variable bit rate. A constant bit rate utilizes one constant rate of bits when encoding and decoding information, regardless of the amount of information being received or displayed at any given moment. A DV codec, for example, uses a

Constant Bit Rate of 25 Mbits/s. Whether the moving image contains a lot of movement, which requires a higher bit rate for optimal image replication and reproduction, or is relatively static, requiring less of a bit rate, the codec uses 25Mbits/s. A variable bit rate allows for changes in the rate of bits used for capture and playback based on the need of the image at any given moment. MPEG-4 part10/H.264, for instance, uses a variable bit rate, where fewer bits are used in static images than in images with a lot of movement. This property of a codec is interesting in that while variable bit rate codecs may result in less artifacts and a smaller file size, they also may use more processing power on the computer when gauging where the high and low bit rates occur (Ascher, 2013).

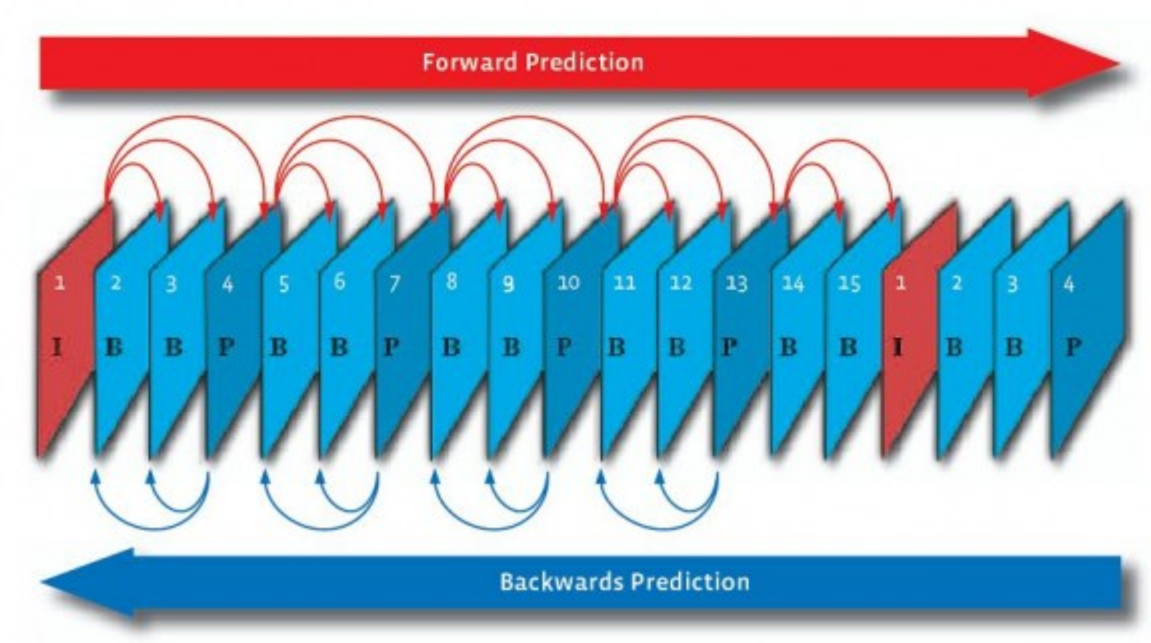

Figure 2: I-, B-, and P-Frame Diagram

Although not technically an aspect of the codec, the wrapper which holds the audio essence, video essence, and metadata in place is an essential element in the use of codecs. One source of confusion about the wrapper is the vocabulary which surrounds it. File formats, wrappers, and containers may all mean the same thing, namely that they are the piece of the puzzle that holds audio, video, and metadata together. However, a file format may indicate something different than a wrapper or container. For example, file formats generally indicate that they are storing proprietary codecs only. Windows Media Files (WMV files), for instance, will only store a variety of Windows codecs. However, QuickTime (MOV) and MXF wrappers or containers can store a host of different types of codecs (Lacinak, 2010). Furthermore, while the concept of the wrapper is integral to that of the codec, it is essential to note that the playback of the video depends on decoding the codec, not the wrapper. The wrapper is simply the element that a media player identifies and uses to access its codec library in order to achieve decoding compatibility (Lacinak, 2010).

Part II-The History of the Codec:

After having properly defined a codec, it is now important to look more closely at its history. What was the impulse for creating a codec? Where did they come from? Codecs can be traced back to the development of pulse code modulation, or PCM. The use of PCM was being thought about as early as the 1850's with the advent of the telegraph. In the early days, PCM as it was being used in the telegraph relied on the concept of sample rates and the depth of those samples. Since Morse Code uses a series of dots and dashes to represent the alphabet, the frequency of the dots and dashes can be thought of as their sample rate. The number of dots and dashes per letter can be thought of as their bit depth. Later digital processes and terminology were based on these concepts. For instance, in order to create an accurate representation of an analog signal using PCM, the two basic properties, sampling rates and bit-depth, are the terminology and concepts used. PCM, in the digital realm, works by taking samples of an analog signal at a specific set of intervals (i.e., sampling rate). At the same time, the number of digital values or bits of information, assigned to each individual sample equates to the bit depth at which the signal is captured. Although the concept had been implemented years before, it wasn't until World War II that digital radar transmissions were able to bridge the gap between analog and digital PCM. During the war, a device called the SIGSALY was used to transmit speech digitally. The SIGSALY used a vocoder (a vocoder is a 1930's era telecommunications device that encoded speech) in order to convert the pitch and tone of someone's voice into frequency signals that were then sampled and encoded. The frequencies were then transmitted on a frequency band and decoded through a set of filters and a signal generator and were stored on a phonograph. The record was then duplicated and both records were played on special turntables whose clock synchronizations were carefully timed and controlled in order to be precise. Figure 3 shows the SIGSALY machine, which can be thought of as the earliest form of a codec (Christensen, 2001). The mechanisms that enable modulation can be reversed during demodulation, which can be thought of in terms already used in this essay above; modulation encodes and demodulation decodes. The term modem comes from modulation/demodulation.

Figure 3: SIGSALY

Although the mathematical equation that implements the modulation/demodulation is beyond the scope of this thesis, it is important to understand that through an algorithm, as well as a series of filters in the case of the SIGSALY, information is changing form. For example, soundwaves are triggering electrical charges which in turn trigger the creation of 1's and 0's, which then trigger more electrical charges that changes the 1's and 0's back to soundwave. Since only two basic properties are being manipulated in this process, developers have created many different flavors of PCM codecs.

The earliest widespread use and standardization of digital PCM occurred in telephony. Since the transmission of digital signals could be done over the phone, the earliest standards created for audio codecs came from the CCITT (Consultive Committee for International Telephone and Telegraph). This initial standard was eventually ratified by the ITU (International Telecommunication Union) and became the G.711 standard of a PCM codec. Implemented in 1972, it requires an 8kHz/8-bit sample size. This sample size means that a soundwave, such as someone's voice, is getting sampled 8,000 times a second using 8 bits (or 8 separate 1's and 0's) of digital information per sample (RChandra, 2013). This is the frequency and level of accuracy at which information is changing form. Figure 4 below demonstrates how PCM encoding works (Peterxu422, 2012).

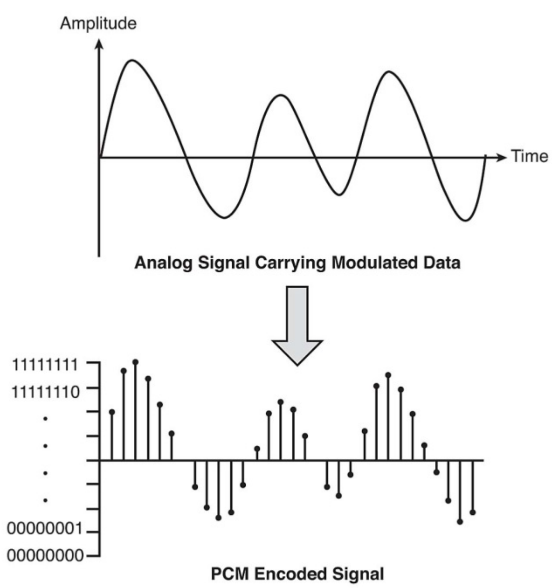

Figure 4: PCM Encoding

By the 1990's, the GSM 6.10 speech coding standard was used in cell phones. It was specified by the ETSI (European Telecommunications Standard Institute) and accepts 8kHz/13-bit PCM. It can either use direct analog-to-digital conversion within the phone, or can convert the G.711 standard using a look-up table (Besacier, 2000). A look-up table is a conversion matrix used to match up to specific outputs (Piil, 2013). Current telephony, such as that used in cell phones, uses a standard called G.722.2. This is based on the Adaptive Multi-Rate (AMR) codec, which also samples at 8kHz/13-bit. Rather than being PCM, it works by holding samples in frames for a pre-determined amount of milliseconds before decoding and transmitting them (Varga, 2006).

As is the case with much codec technology, the G.711 standard also makes use of lossy compression. But PCM codecs need not be lossy or utilize compression at all. For example, in the archiving and preservation field, a de facto standard for preservation master audio files has emerged, waveform Linear PCM, or LPCM. LPCM codecs use a sample rate of 96kHz at a 24-bit bit depth, are uncompressed, and are stored in in a broadcast WAV (called a BWF) file (Brylawski, 2012). Arguably, this is not the only way to create and store preservation master audio files, but more on this later. For now, it is important to understand how the uncompressed LPCM 96kHz/24-bit BWF is implemented.

The de facto standard that has emerged for the creation of preservation master digital audio files is an uncompressed PCM codec with a 96kHz sampling frequency at a 24-bit bit depth in a BWF file (ARSC and Ross, 2009). To reiterate, this means that a soundwave is encoded by being sampled 96000 times a second with each sample having 24 bits, or 24 separate 1's and/or 0's, of digital information. According to such institutions as the United States' National Archives or the Australian Archives, it is felt that this is more than sufficient data needed to accurately recreate, when decoded, the analog soundwaves resulting from musical compositions or in human speech patterns (NARA, 2013). It is common for many organizations, large and small, to use this de facto standard.

Although new audio formats and tools are always being developed, the strength of this de facto standard lies in its long-term sustainability. For example, the dynamic range of the sample frequencies and bit-depth range in the codec allow for adjustments in the setting of levels in order to optimize analog-to-digital conversion. Even more importantly, both the codec and the container enjoy a wide amount of support and adoption, even at that high of a resolution. Also, open source ffmpeg (which is the free software project designed for the multimedia community) PCM codec implementations exist that are of no cost and are also widely supported. Furthermore, the size of a preservation master digital audio file, even uncompressed, is not large; thereby relieving some of the storage concerns faced by smaller institutions (Indiana University, 2007). This means that decoding the bit stream is not a major issue, regardless of how it relates to playback, due to its adoption consistency. Compared to video, the amount of options of codecs that exist for encoding the audio signal are fare fewer and the conversion process is much more simple since it relies on only two basic fundamentals when being sampled. Therefore, the fewer options for preservation audio codecs that exist results in more consistency between institutions and from this emerges a de facto standard (Lacinak Interview, 2013).

As opposed to uncompressed audio codecs, there are in fact lossless audio codecs as well, such as the Free Lossless Audio Codec, or FLAC. FLAC, developed in 2001, is an open source codec which mathematically compresses audio data losslessly and can embed metadata (Rice Interview, 2013). Although more widely adopted than other lossless codecs, it is still not as widely supported as PCM (Lacinak Interview, 2013). Uncompressed PCM and FLAC are briefly mentioned here in order to illuminate the far greater degree of complexity inherent to video codec decoders as opposed to their audio counterparts. Because of this complexity, a variety of implementations exist for video codec decoders which leads to less consistent adoption and ultimately a wealth of choices for preservation master files, as opposed to the very few choices for preservation master files among audio codec decoders.

Similar to the audio codec, the impetus for video codecs was telephony, or video-conferencing, rather. The H.120 was the first digital video standard that was developed in order to potentially enable video-conferencing. In 1984 (and updated in 1988), the aforementioned ITU and their CCITT subcommittee published the H.120 standard which determined, by setting one bit per pixel, the bit stream rate for both PAL and NTSC monitors (ITU, 1989). It utilized scalar quantization (Vector Quantization, 1991), which is an algorithmic lossy compression that rounds values, although it also used variable-length coding which can allow for lossless compression (Codecs and Automata, 2010). The lack of quality this created led to the development of the H.261 standard. H.261 grew out of the concept of the H.120 but also included macroblocks, which allowed for better bit rates, thus creating a higher quality video image (Le Gall, 1991). By 1988, the ICU developed the H.261 compression standard for digital video playback (Rick, 2012). H.261 employed macroblocking, where a 16-by-16 chunk of pixels would have a luma sampling (measuring how bright or dark an image or a pixel is). The chroma sampling (the color of the image or pixel) would then split the 16-by-16 chunk of pixels into four 8-by-8 chunks. In order to reduce the bandwidth used for the chrominence, the H.261 used a 4:2:0 chroma-subsampling rate in a YCbCr color space (ITU, 1988). YCbCr describes the color of a pixel by indicating its brightness or luma value (Y) and its chrominence or color value (CbCr). Since cathode ray tube (CRT) monitors use red, green, and blue (RGB) to replicate all of the colors in the spectrum, only two color values, blue (Cb) and red (Cr), can be used to determine the green value using the Pythagorean Theorem (a2+b2=c2, like a triangle). Since the human eye perceives changes in brightness better than changes in color, H.261 requires that the chrominence sampled would be less than that of the luma. Figures 5 (Hiremath, 2010) and 6 (Kovasevic, 2005) below illustrate macroblocking and chroma subsampling.

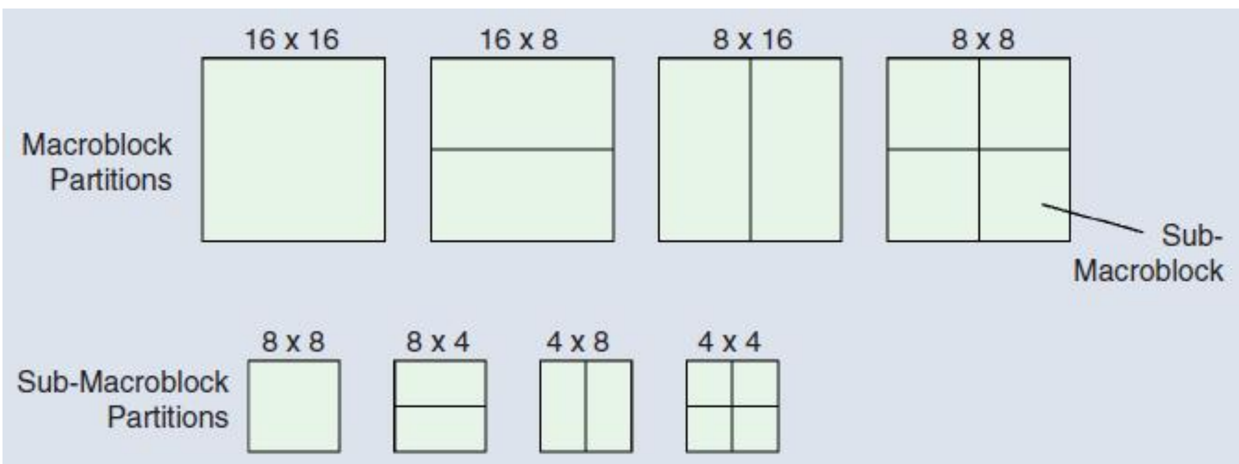

Figure 5: Macroblocks

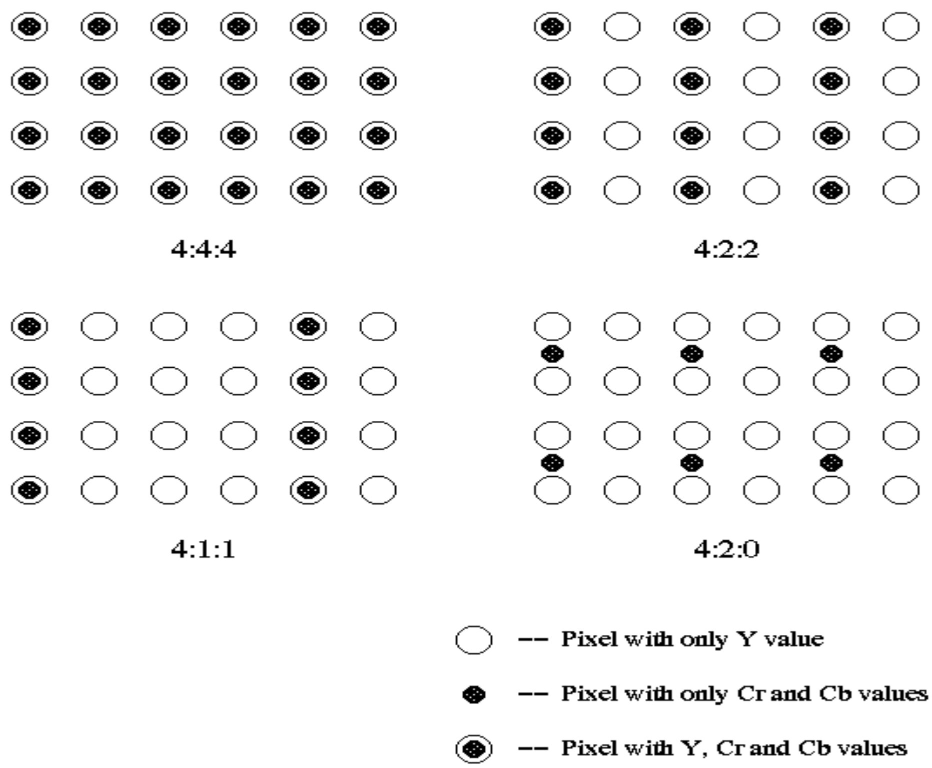

Figure 6: Chroma Subsampling rates

Chroma subsampling is a space saving or compression method wherein the last two numbers of the subsample represents a reduction in the amount of color or chroma information in relation to the first number, which represents luminence (Jimenez, 2013). By encoding with a 4:2:0 chroma subsample, it helps ease the transmission and storage of the bit stream (Kerr, 2012). H.261 had a variable compression rate of 40Kbits/s-to2Mbits/s (this speaks to the speed at which data can be downloaded or transferred over networks or to a storage medium), and its minimum resolution was 352-by-288 pixels (Rick, 2012). Also, it is important to note that the design of H.261 only specified how to decode and not encode the bit stream (ITU, 1988). Although the standard is only concerned with the decoding of video, it is still the basis of all of the international video coding standards, from MPEG-1 through MPEG-4 (ITU-T, 1994).

In 1991, the Motion Picture Experts Group (MPEG) developed a decoding standard with increased quality, the MPEG-1. Similar to the H.261, the encoding side of the equation was left open to developers as long as the decoding standard was adhered to (Rick, 2012). The standard utilized lossy compression for video, as well as audio. For example, the MP3 audio file came from the MPEG-1 specification (MPEG FAQ, 1996). For video, MPEG-1 used macroblocks, a YCbCr color space, and a 4:2:0 chroma subsampling, just like the H.261. However, it also introduced various frame types, such as B-frames or inter-frames. An inter-frame would only store data that was different from that stored in an anchor, or key frame, thereby making compression more efficient (Wee, 1996). By compressing down to a bit rate of 1.5 Mbits/s, VHS quality video and CD quality audio could be transmitted over a videoconferencing connection, for instance, or stored on optical media like a CD-ROM. Additionally, MPEG-1 required a minimum resolution of 352-by-288 pixels (Le Gall, 1991). The MPEG-1 audio and video codec was contained in the MPEG Program Stream file format (Wee, 1996).

While MPEG-1 was in the process of being standardized, MPEG-2 was already being created. By 1994, MPEG and the ITU collaborated on debuting MPEG-2 or H.262 as it is alternatively known. It increased the bit rate to 9.8 Mbits/s and upped the resolution to include a maximum of 720-by-480 pixels (Rick, 2012). Because of this, MPEG-2 became the standard for DVD production and digital standard definition television (Schwarz, 2007). As of this writing, MPEG-2 is up to part 11 which allows for intellectual property management. Part 7 also implemented the Advanced Audio Codec, which replaced the MP3. Also, MPEG-2 used two container formats, one for transmission, called the program stream, and one for storage, called the transport stream (MPEG, 2013).

MPEG-4 and H.264 debuted in 1998, through another MPEG/ITU collaboration. This most current iteration of the MPEG standard contains many parts which are still being modified. The MPEG-4 AVC/H.264 codec, following the MPEG-4 part 10 standard, allows for up to a

4096-by-2048 pixel resolution with up to a 960 Mbit/s bit rate. It is the standard by which Blu-Ray discs follow, as well as High Definition television. (Rick, 2012).

Although the MPEG family of codecs still persists today, other codecs were developed, as well as a multitude of wrappers. By 1992, Microsoft developed its proprietary Audio Video Interleave (AVI) file format which was a container that wrapped the video and audio essences, as well as any metadata such as subtitles, together in order to play back digital video with sound on the Windows operating system (Rick, 2012). However, this container lacked certain features, such as allowing for different aspect ratios, which caused other developers to create new file format containers. Containers, like Advanced Systems Format (ASF), which contains the codecs in Windows Media Video (WMV) files, for example, were developed to solve the issues inherent to the AVI wrapper. However, both of these File Formats are designed to only decode proprietary Windows video codecs (Microsoft, 2013).

At the same time, Apple had developed their proprietary file format called QuickTime. Although both containers (QuickTime's MOV and the ASF) are based on and adhere to the International Standards Organization's (ISO) specifications regarding the general structure of the MPEG-4 part 12 standard, which deals with the storage of time based media content, the QuickTime container and set of codecs is incompatible with those developed by Microsoft (Monaghan, 2012). It is important to note that the original QuickTime container and the one in use today are very different. The current version follows the MPEG-4 specifications, while the first version used a proprietary codec called Road Pizza (aka Apple Video). The Road Pizza codec used a 4-by-4 pixel block in a 15-bit RGB color value and chunks information. Each chunk of information encodes a single frame (Ortiz, 1991). By the advent of version three of the QuickTime format, implemented in 1998, the Sorenson Codec was being used. The Sorenson

Codec was almost exclusively proprietary for Apple and is the most common QuickTime codec in use aside from what is available now (Sorenson Media, 2001).

Additionally, aside from proprietary codecs and wrappers, there exist open source codec libraries, such as libavcodec. For example, the VLC media player utilizes the libavcodec library in order to play a wide range of video and audio codecs (libavcodec, 2010). The open source nature of these codecs and wrappers can allow for greater compatibility between operating systems. The ffmpeg project is another open source set of tools and libraries which offers free implementations of a variety of codecs in order to either encode audio and video, decode audio and video, or both. Ffmpeg even offers free versions of proprietary codecs (ffmpeg.org, 2013). Despite the seemingly infinite number of codecs and containers, there are three main factors behind their creation.

Part III-The Proliferation of Codecs:

The three main driving factors behind the creation of an extensive amount of audio and video codecs are video and film production, editing and post-production, and consumer markets. The production and post-production factors are closely related. For example, production companies often shoot video on a camera using an HDV high definition codec, such as the Cineform codec. This codec is popular for production since it can scale from standard definition specifications all the way to 4K, high definition specifications. However, it is only designed to be used on an Avid editing system and is not compatible with Final Cut Pro, which is Apple's proprietary editing software. In order to edit this video on Final Cut Pro, one would have to transcode the file to an Apple ProRes 4:2:2 codec (Webopedia, 2010). This highlights the necessity of the user to conform to compatibility constraints implemented by camera and editing system manufacturers, rather than undergo extra and inefficient steps in the editing process.

In terms of the consumer market, codecs that offer high quality images coupled with low bit rates are needed in order to provide such implementations as streaming content over the internet. For standard definition digital video, MPEG-2 is still quite popular and, as mentioned before, is the codec used in DVD's as well as in Standard Definition (SD) digital broadcasting (Webopedia, 2010). In the High Definition (HD) world, the H.264/MPEG-4 AVC codec is popular and is used in Blu-Ray discs, the MAC OS X 10.4 operating system, and in the X-Box 360 game system among others. It is also used in mobile devices (ASMP, 2012). Because digital media manufacturers desire to create markets, they tend to force consumers to use products such as cameras, computers, and editing systems that are only compatible with that particular manufacturer's codecs. Most of these products happen to be created by the proprietary codec's manufacturer, as well. So long as the codec matches the product, wide ranges of support for the codecs' implementations are created. At the same time, these properties also affect the long-term sustainability of proprietary codecs and containers

Since audio and video codecs have existed for some time and some have lasted longer than others due to professional and consumer market concerns, it is important to examine which codecs and wrappers currently dominate the landscape. To reiterate for audio, it is common to use a PCM codec wrapped in a BWF file, particularly for the creation of preservation master files. However, there is another audio codec, FLAC, which is the Free Lossless Audio Codec (a non-proprietary version of the ALAC Apple Lossless Audio Codec). FLAC losslessly compresses audio data and can potentially be a preservation master file for repositories (Atkinson, 2008). Digital video codecs, because of their increased levels of complexity, have proliferated in greater varieties than their audio counterparts.

There are currently several digital video codecs commonly in use. For example, each digital videotape format uses its own codec. The codec in DV, for example, uses lossy compression. HDV uses an MPEG-2 part 2/H.262 lossy compressed codec. XDCAM can use DV, MPEG-2 part 2, or MPEG-4 part 2 depending on the resolution and generation of the tape. Outside the realm of digital videotapes, the MPEG-2 codec still exists, as mentioned above, as the codec used in DVDs as well as at times in compressed web videos. For DVDs, the MPEG-2 codec is wrapped in a VOB container (Buchanan, 2008). Although a standard definition codec, it is still widely supported, but is not of optimal quality for preservation master files because of the nature of its compression scheme. MPEG-4 part 2 is the codec used in various open source libraries like Xvid or proprietary libraries like DivX. It can be wrapped in a variety of containers. This standard is also fairly widely adopted but is also not of optimal quality for preservation master files due to its compression scheme (Buchanan, 2008). MPEG-4 part 10/H.264 is the codec used for high definition broadcast transmission, Blu-Ray discs, is available in editing systems and cameras, and is used in high definition web video streaming. It can be wrapped in a variety of containers. (Buchanan, 2008). Currently, many other competitors of H.264 exist that are based on the same standard, like Dirac, Theora, and Google's VP8.

Similar to the playback of digital video, the capturing of video on consumer electronics most commonly uses the H.264 or MPEG-4 codecs. Not only does this help ease the transition of uploading and downloading the images shot, but ensures that they are able to play back on a multitude of devices. In professional circles, the higher quality DVPRO50HD or Apple ProRes 422 codecs ensure the highest degree of malleability in post-production due to their compatibility with the Final Cut Pro editing suite. Although intended to be used for editing rather than for end user viewing, the ProRes 422 codec both encodes and decodes fast enough so that content may be screened (Apple ProRes White Paper, 2012). SheerVideo, Huffyuv, Lagarith, and Avid's DNxHD are all codecs that display a similar level of high definition quality.

The v210 codec is a YUV 4:2:2 10-bit uncompressed codec. It is found in QuickTime, and AJA (Multimedia Wiki, 2010). Blackmagic uses an uncompressed YUV 4:4:4 10-bit codec called r210 (MultimediaWiki, 2013). There are other uncompressed codecs, such as UYVY422, however; these are far less common than v210 and r210. The Society of Motion Picture and Television Engineers (SMPTE) have come with an ISO standard for the digitization of standard definition content. This standard requires that standard definition material be digitized using a 10-bit uncompressed YUV 4:2:2 codec (Buchman, 2013). However, uncompressed digital files are large and issues concerning storage arise. Therefore, losslessly compressed digital files offer a storage friendly alternative, particularly when digitizing high definition content. At the same time, no preservation standard exists for a losslessly compressed digital file.

In terms of finding a standard for digital video preservation, similar to the de facto standard that currently exists in digital audio preservation; the JPEG2000 codec wrapped in an MXF wrapper (more on wrappers below) is being promoted by such institutions as the United States' Library of Congress as a preservation destination codec and container. Several other countries' national archives, such as Australia's, also use this preservation method. Mainstream film companies also use this codec and container for DCP's because of the scalability of JPEG2000. The relevant functionalities of the JPEG2000 codec, in terms of its evolution compared to other codecs, begins in 1996. At this time, it was decided that the JPEG codec for digital images needed to be improved upon. This meant switching from the DCT compression scheme to the wavelet scheme, among other changes, such as lossless decompression. In

December of 2000, the JPEG2000 part 1 decoder scheme became an international standard (Marcellin, 2000). However, it is important to note why this choice is considered an option.

When considering the options of codecs and containers needed for use in the digitization and long-term preservation of video material, as opposed to those needed in broadcasting, editing, or exhibition, a pattern emerges. Video codecs preferred by such institutions as the Library of Congress are those which use mathematically lossless compression, such as JPEG2000, whereas codecs used in production and exhibition can often utilize lossy compression schemas. The JEPEG2000 codec is popular for preservation because it has been published as a set of ISO standards. It also allows for metadata encoding in XML form, which is also standardized by the ISO. It is also, in theory, truly mathematically lossless. It can be wrapped in a standardized file container, such as MXF or METS, which theoretically encourages system interoperability. The JPEG2000 codec also relies on the wrapper to provide enough technical information to ensure its ability to decode the bit stream, such as color space and chroma sub-sampling details. Fortunately, the JPEG2000 codec supports a broad range of chroma sub-sampling patterns, so it is imperative that the right one is decoded (Rice, 2013). Furthermore, JPEG2000 is open source. However, it must be supported by a preservation institution's hardware and software, which could prove problematic (Snyder, No Date). As mentioned above, national or regional institutions, such as the National Film and Sound Archive in Australia, are in the process of converting their video into JPEG2000 images wrapped in an MXF container. For these institutions, the use of MXF wrapped JPEG200 has been advantageous.

The use of MXF wrapped JPEG2000 digital preservation master files has been advantageous for a number of organizations for many reasons. First, the codec utilizes a lossless compression scheme. In terms of efficiently using storage space (and the money saved due to this), truly mathematical lossless compression is a critical advantage. On the more technical side, the codec is flexible in that it is scalable to the quality of the image resolution (it works with standard definition material as well as high definition), and provides high quality images with low bit rates, although this does increase its need for computational power (Marcellin, et al., 2000). Additionally, the MXF wrapper, as mentioned before, was chosen due to its ability to allow decoders to access its contents in a format-agnostic way. This will potentially enable future migration out of this codec and wrapper at such time as it is deemed appropriate. Both JPEG2000 and MXF are well documented and transparent and open source, but there are other factors to consider when choosing a digital preservation master file.

There are several factors to consider when using the MXF wrapped JPEG2000 preservation master file. This file format is not without its drawbacks. For example, the fact that both the codec and wrapper are only moderately adopted can pose problems for smaller repositories for a number of reasons. First, many standard video workstations do not provide capture to lossless JPEG2000, nor do they have the ability to wrap the essence in an MXF file format (New South Wales, 2013). For example, the software in Final Cut Pro does not allow for this kind of capture. This is an indication of the second problem, which are cost factors. If a repository, for instance, wants to digitize their video collections by using MXF wrapped losslessly compressed JPEG2000, it must buy a system to do so, which costs thousands of dollars. Another major issue is that of interoperability. Both JPEG2000 and MXF use a set of standards. Since different vendors may prefer using specific standards, other vendors or institutions may find that by using a different set of standards for the same wrapper and codec, the video will be unable to decode. For example, the purchase and use of a SAMMA machine to digitize video into MXF wrapped JPEG2000 may conform to a JPEG2000/MXF standard that the repository itself does not utilize (Buchman, 2013). Furthermore, there are sets of standards not only for the wrapper but for the codec as well. Since there is a lack of a single standard governing each component, a high level of complexity emerges, which can make it harder to find new implementations for the file format (Adams, 2013). Another factor is that the workflow surrounding these digitization projects (such as those that utilize a SAMMA machine) is most useful when digitizing a large amount of video and may not work on a smaller scale due to the lack of JPEG2000 support on standard video workstations (New South Wales, 2013). Finally, most organizations will choose a container based on how well it fits into their infrastructure or based on what they acquire. Organizations that use Windows systems like Adobe Premier, for example, tend to use AVI, whereas those that use Apple's Final Cut Pro often choose MOV. Wrapping the video and audio essences in MXF requires a complex infrastructure that is much more difficult for smaller institutions to support, primarily due to the cost of its implementation (Van Malssen, 2012). Despite the best intentions of the Library of Congress, there are alternatives to using JPEG2000 wrapped in an MXF container.

Alternative solutions to digital audio and video preservation other than what is recommended by the Library of Congress exist. When thinking about digital preservation, repositories that aren't the Library of Congress must often times bear in mind their organizational needs and funding. The JPEG2000/MXF solution may be cost prohibitive or fall outside of the organization's mission in terms of following standards and best practices. It has even been suggested that under the right circumstances, an organization could use a lossy compressed codec, like a DV codec, for a preservation master file format (Lacinak, 2013). Let's examine the alternatives.

For standard definition content, an alternative to MXF wrapped JPEG2000 files is the SMPTE ST-125 standard. This standard requires that digital master preservation video files be made using a YUV 10-bit uncompressed codec, wrapped in a QuickTime MOV or a Windows AVI container. Despite potential storage issues, this may be the only acceptable file a repository can make based on their digitization station and their mission to adhere to digitization standards. Fortunately, storage costs are decreasing while at the same time bandwidth is increasing making this form of digitization cheaper and less time-intensive (Buchman, 2013).

Another lossless codec recommended for use with high definition video that is available to vendors or repositories with smaller scale workflows is FFv1. Questions remain as to whether or not the codec is truly mathematically lossless, like JPEG2000 is supposed to be, and how data is encoded since it has not yet been standardized in the same way that JPEG2000 has. However, digital preservation tools such as Archivematica utilize this codec and it is freely available through the open source library libavcodec in the ffmpeg project. One benefit to the FFv1 codec is that it is multi-threaded. This means that instead of encoding and compressing the data stream in a single thread, several threads can be used at once, utilizing more computer resources in order to increase the speed of the encoding process. FFv1 version 3 also mandates an embedded frame-by-frame checksum during the encoding process. Checksums ensure a bit-for-bit match from the point of encoding, through storage, and on through transmission or output. Since one rotten or flipped bit may create a fatal error in the file, checksums ensure the integrity of the data. FFv1 has the ability to, and is in fact required to perform this fixity check internally. Additionally, when wrapped in a container such as QuickTime, the content can be made available on a variety of systems (Rice, 2013). Again, this codec isn't without its drawbacks. For example, there is only one capture card currently digitizing to FFv1. Its biggest drawback, however, is its lack of adoption (Lacinak, 2013).

Ultimately, when thinking about alternatives to JPEG2000/MXF, it is imperative to note that decoding the bit stream for eventual migration is what will ensure the longevity of the content. The quality and integrity of the bit stream is irrelevant when irretrievably stuck in a file. It is also important to note that until vetted by the decoding of the files and frames to checksums (such as ffmpeg md5 checksums); lossless compression is not trustworthy (Rice, 2013). While all of the above standard definition, high definition, and uncompressed codecs are currently the most commonly used, there are also a few wrappers or containers that are quite common, as well.

The QuickTime MOV container is commonly used since it can contain a wide variety of audio and video codecs. It is also widely supported by Mac and by Windows. It can be used for editing or transcoding. It can also support legacy encoders. Not only is the container versatile, it is also found in the Final Cut Pro editing suite, making it readily available to consumers and professionals alike (QuickTime Tech Specs, 2008).

The MXF wrapper is also extremely versatile in its ability to handle a multitude of codecs, plus, it is open source. It is designed to handle any existing and future codecs while at the same time, allows decoders to access the content in a format-agnostic way. It can contain uncompressed video and audio. It has only been moderately adopted, however, which limits its potential sustainability, although it has been defined by a set of SMPTE standards (Ferreira, 2010). As mentioned above, the different set of standards has created interoperability issues among vendors. Organizations such as FADGI (Federal Audiovisual Digitization Guidelines Initiative) are working to create a vendor-neutral subset of the MXF container to be used when archiving moving image content and its associated metadata (FADGI, 2012).

Despite vendors attesting to the contrary, there are no file format or wrapper standards that exist due to issues concerning interoperability between files and equipment. The MXF wrapper, as mentioned above, is designed to support interoperability, yet still lacks wide adoption. Another solution that has been proposed from the public television sector is the use of a METS wrapper. The METS wrapper is primarily a metadata schema that can extract rich technical metadata from other schemas such as PBCore or PREMIS and make the metadata machine-readable in the XML format. However, in the scope of this essay, METS importance lies in its ability to become a "virtual" wrapper that can contain encoded video and audio essences. As a virtual wrapper, METS would provide virtual links to the video and audio essences and create playback interoperability through a variety of internal sources rather than relying on multiple tools to extract the essence and metadata, as happens in other wrappers. By maintaining the relationships between the metadata and the essence, METS also helps the encoded content to become Open Archival Information System (OAIS) compliant (Rubin, 2009). The OAIS provides a system for long-term digital archiving, which is important in the case of digital video and audio files due to the constant evolution and subsequent rapid obsolescence of digital technologies. Furthermore, the OAIS model was developed as a way for digital libraries to network with each other in order to find and share the best solutions for issues surrounding the long-term preservation of digital objects (Strodl, 2007). Although the digital library sector and production sector have yet to agree on any kind of file format standardization, the QuickTime, MXF, and METS wrappers were all mentioned due to their aim towards sustainability.

Due to the perpetually evolving digital environment, large national institutions such as the Library of Congress and the United Kingdom's National Archives have put forth guidelines for the long-term sustainability of digital file formats and codecs. For the purposes of this essay, sustainability factors can be understood in terms of the long-term ability to decode the bit stream. Although there are some similarities between the guidelines of each institution, it will be beneficial to examine the sustainability factors more closely in order to understand how content can be saved in preservation master digital form.

The United States' Library of Congress offers guidelines for seven individual sustainability factors for the long-term preservation of digital material. In order to ensure the long-term accessibility and playback of digital audio and video content, the Library of Congress recommends institutions keep in mind the seven sustainability factors. These factors are disclosure, adoption, transparency, self-documentation, external dependencies, impact of patents, and technical protection mechanisms. The following descriptions of the sustainability factors are provided by the Library of Congress's website (Library of Congress, 2013)

- Disclosure denotes the degree to which specifications and tools for validating technical integrity exist. It also reflects how accessible they are to those working with digital content. This factor helps to understand how the digital information is encoded as bits and bytes in digital files. Open source standards are generally more fully documented and therefore more likely to be supported by tools for validation than proprietary formats. These include such tools as checksums. Disclosure is important in that it does not rely upon whether or not the digital file format or codec has been standardized by a recognized standards body, but that there is the existence of complete documentation, preferably subject to external expert evaluation.
- Adoption refers to the degree to which the format is already in use by the creators, disseminators, or users of digital video and audio content. This includes whether or not the format or codec is used as a master format or if it is being used for delivery to end

users. If a format is widely adopted, it is less likely to become obsolete rapidly, and tools for migration and emulation are more likely to emerge from the industry without specific investment by archival institutions.

- Transparency involves how open to analysis with various tools, including human-readable tools, a digital representation is. When the underlying metadata surrounding the file format or codec is easily representable, it becomes easier to develop paths for migration into new formats.
- Self-documentation refers to the degree to which a digital object retains its appropriate metadata. The metadata surrounding an object is important information that can help determine preservation strategies for the object in terms of prioritizing obsolescence and interoperability risks, as well as determining the best way to decode the information stored in the object.
- External dependencies refer to how much a format will depend on specific hardware, operating systems, or software in order to be decoded. They also help predict how complex it may be for future technical environments to deal with decoding the dependent bit streams.
- The impact of patents refers to the potential cost of purchasing proprietary encoders and decoders and how that may affect an institution's budget.
- Technical protection mechanisms involve the delineation of formats that are appropriate for long-term storage vs. those that are not. For example, formats that are encrypted or require a specific physical carrier are inappropriate for long-term storage.

Although the Library of Congress provides a robust set of guidelines, the United Kingdom's National Archives has created their own set of guidelines which includes twelve distinct sustainability factors for the long-term preservation of digital content. These guidelines are included here in an effort to compare and contrast the preservation standards of different nations. The sustainability factors for the United Kingdom's National Archives are ubiquity, support, disclosure, documentation quality, stability, ease of identification and validation, intellectual property rights, metadata support, complexity, interoperability, viability, and re-usability. The following descriptions of the National Archives' sustainability factors are provided by a document written by Adrian Brown, the Head of Digital Preservation Research (Brown, 2008).

- Ubiquity refers to the widespread use and popularity of a format. The more widespread and popular it is, the more likely it will be supported among institutions as well as software suppliers.
- Support refers to the extent to which a format experiences a wide range software compatibility rather than relying on a single supplier of software in order to run.
- Disclosure refers to the degree to which those responsible for the long-term preservation management of content can access detailed technical information concerning the format.
- Documentation quality requires that beyond disclosure, the information be comprehensive, accurate, and intelligible.
- Stability refers to the format's ability to abstain from constant or major changes and that if any updates occur, the format remains backwards compatible with previous versions.

- Ease of identification and validation involves the ability to accurately identify, by the use of tools or otherwise, a format, that it is a valid example of that particular format, and that the format can still be used. Checksums are often part of this process.
- Intellectual property rights refer to the degree to which technologies may include patents governing their use.
- Metadata support refers to the degree to which a file format allows for additional information about the content. A high degree of metadata support is preferable.
- Complexity refers to the degree to which a format is able to use its full range of functionalities.
- Interoperability refers to the degree to which a format is platform-independent and widely supported so that the content is accessible to the greatest extent to the largest amount of users.
- Viability refers to the degree to which a file format can detect errors that can be introduced within the file.
- Re-usability refers to the need for a format to be able to be processed in order to retain its re-use value.

Upon examination of the two guidelines, it is apparent that there are similarities in each repository's sustainability factors. Because of this, it can be determined that these overlapping factors are of critical importance to the long-term sustainability of digital file formats. For example, because the Library of Congress requires a format's being widely adopted and the National Archives requires a format have a high level of ubiquity and support, it becomes clear that this is an important factor to keep in mind when choosing a format for long-term preservation. Therefore, it is clear that there exists a well-researched list of criteria which can be consulted when thinking about what codec and container to choose for a particular repository.

By comparing the above mentioned containers to either set of sustainability factors, it can help an institution decide what format best fits their needs. For example, the Library of Congress has chosen JPEG2000 as their preservation format. This format is open source, is transparent and well documented, is scalable in file size thereby utilizing its functionality, and wraps the audio and video essence with a fairly robust amount of metadata; it is still not very widely adopted or supported. The MXF wrapper also features an even more robust metadata allowance, is open source and well documented, and even includes internal validation tools within the wrapper. However, it is also not widely supported. Since most, if not all of the formats and codecs mentioned earlier fall within the rubric of a few of these sustainability factors, it is important to note that the most problematic factors to adhere to are adoption and support (Lacinak, 2013). Other factors, such as interoperability, viability, and intellectual property rights are still important to the long-term preservation of a format, since these issues absolutely affect how the bit stream is decoded and potentially migrated. However, support and adoption remain tantamount to the longevity of digital content since the inability to access the file due to lack of equipment negates all of the other qualities a format may possess.

In terms of quality, although it is not explicitly stated in the above mentioned guidelines, the visual quality of a digital video is also a factor when considering the long-term preservation of digital moving image master files. For instance, the MPEG-2 and MPEG-4 part 2 codecs are still in wide use; however, the resolution quality is inferior to that of a high definition codec such as the H.264 or JPEG2000. A high definition image captured with a standard definition codec may not represent the best quality image. Therefore, the scalability of high quality images in variable resolutions, such as what the JPEG2000 codec can achieve, becomes another important factor when choosing a preservation destination codec and container.

Part IV-The Decision-Making Process:

The preservation of digital video presents many challenges. This section will examine a variety of issues institutions and archivists face when making decisions surrounding digital video preservation. These issues include the identification of codecs in order to determine institutional software and hardware compatibility, the importance of obsolescence monitoring, issues that arise when transcoding files, including transcoding legacy codecs into newer, more sustainable codecs, issues surrounding the transfer of information from digital videotapes to digital video files, and codecs that exist in born-digital materials such as those created as tapeless video. Underlying all of these issues is the notion that by adhering to the aforementioned sustainability factors content will be more likely able to be decoded over the long term. Before diving into the heart of the issues that affect the decision making process, it is important to mention two symptoms of digital content that can occur by happenstance, bit rot and bit flipping.

Adhering to the Library of Congress's, or any other reputable institutions', sustainability factors helps to attempt to ensure the longevity of the preservation master file. However, issues such as bit rot and bit flipping can still occur. Bit rot and bit flipping are symptoms that can occur in digital files that have gone unused after a sufficient length of time and are issues that fall outside the rubric of the sustainability factors (Raymond, unknown date). However, maintaining a preservation master file through the lens of the sustainability factors should alleviate the chances of bit rot or bit flipping occurring within the pre-migration lifetime of a file. Since these two symptoms of digital content are, to a certain degree, beyond the control of the archivist, they are mentioned here in order to emphasize the benefits to an institution that maintaining sustainability factors can achieve. In terms of making the best decisions in order to ensure the continued longevity of a digital video file, whether through a planned migration or transcoding, the chances of bit rot and bit flipping occurring can be mitigated.

Aside from the esoteric notions of bit rot and bit flipping, there are more tangible decisions that can be made, such as determining the compatibility of the codecs an institution receives versus the hardware and software the institution utilizes. For example, being aware of the potential use of any one of the variety of implementations of a standardized codec and container, such as those surrounding JPEG2000/MXF, can help mitigate interoperability problems when deciding upon whether or not an institution can digitize material in-house or if they choose to use an outside vendor. Archivists and preservationists can become enabled to ask for particular capture specs of a vendor if it is determined that they must outsource their digitization work. Likewise, choosing to utilize codecs and containers that are widely supported in one's own organization as well as the larger archiving community can help mitigate immediate obsolescence issues (Lacinak, 2013). However, quite often repositories do not have a choice regarding what kinds of formats they receive.

Since acquiring video materials, whether analog or digital, usually involves receiving a variety of formats, obsolescence monitoring becomes a significant challenge when preserving digital video. At present, there are really only two tools that archivists use in order to monitor obsolescence factors. The first sets of tools are those that give format identification and technical metadata information, such as XIFF, and MediaInfo. These tools allow the archivist to identify a file's video and audio codec, the wrapper, and other useful metadata such as the video's frame rate, aspect ratio, and color space. Additionally, MediaInfo, for example, is open source and is therefore free to use, can utilize a command line interface or a graphical user interface, can export information in HTML, and is available for use in a multitude of languages (Hibrasil, 2013). These tools are helpful in terms of knowing whether or not a file is currently sustainable or if it needs to be prioritized for transcoding and migration, however; these tools are also not very sophisticated. A more sophisticated tool such as JHOVE not only identifies the codec and wrapper, but validates the file, as well. JHOVE allows the preservationist or archivist to know whether a file is well-formed, or correctly formatted, which increases the likelihood of the file's ability to play back on future media players (Besser, 2013).

The second sets of tools archivists use for obsolescence monitoring are registries. For example, the Unified Digital Format Registry (UDFR), developed by the University of California Curation Center (UC3) and the California Digital Library (CDL) and funded by the Library of Congress as part of NDIIPP (National Digital Information Infrastructure Preservation Program), compiles a list of formats (UDFR, 2012). Registries are reference tools that can be used to identify various formats in order to determine their prevalence and thereby gauge their risk of obsolescence. The formats in the registry include descriptive metadata fields, one of which is called "Risk Factors." However, the metadata in these fields are populated by committee, which results in very few of the risk factor fields actually being filled out (Lacinak, 2013).

Despite the importance of the use of these tools for monitoring obsolescence neither one of them are perfect. Identifying format information is important, yet unsophisticated. The registry should be helpful, however; the fact that it relies on committees raises questions such as how long will it take for them to reach a consensus and how often will the registry be updated (Lacinak, 2013). However, these are currently the only tools that exist which can aid an archivist when making challenging decisions regarding transcoding and migration.

After monitoring the factors concerning a file's potential obsolescence, certain files may be deemed at-risk and the decision will be made to transcode them. However, once an organization has decided to transcode files, issues can still arise during the transcoding process. Transcoding is the means by which the data in a digital file is converted and encoded into another digital file. A complete description of the transcoding process is beyond the scope of this paper, however; it is important to note that obsolete digital files must be transcoded in order to maintain long-term accessibility. Long-term accessibility ultimately relies upon codec and wrapper compatibility with media players. For organizations, once it has been decided a file needs to be transcoded in order to alleviate its risk of obsolescence; several more decisions must be made. For example, an organization must decide what format they want to transcode into, they must ensure that this format is supported by the institution's software and hardware, they must be aware of how this choice could affect video quality, as well as how much storage these new files will require versus how much storage capabilities the organization possesses (Telestream, 2013). Furthermore, transcoding can cause a generational loss, or degradation of the content. If, for instance, a file is being transcoded that originally used a lossy compressed codec during creation and is then transcoded using a lossless or uncompressed encoding scheme, the information lost in the initial compression of the image will be gone forever. This can result in the possibility for a loss in image quality (Addis, 2010). Transcoding legacy codecs can lead to challenges, as well. For example, Apple's now obsolete QuickTime Road Pizza codec used a 5-bit RGB sampling that is not currently supported by codecs like JPEG2000 or FFv1. The newer codec has to pad out to a larger 8-bit RGB sampling which results in an almost, but not quite, lossless compression (Rice, 2013).

When transcoding digital tapes, it is essential to extract not only the audio and video essence, but the metadata, as well. In order to do so, one must output the data stream through the appropriate cable. For instance, a DV codec, which is compressed, would lose certain metadata information if output through an SDI cable rather than a FireWire cable. The SDI cable is only intended to capture certain kinds of metadata, whereas the FireWire will transmit all of the data which can then be parsed out later (Rice, 2013).

Another obvious gaffe when transcoding is errors caused by dirt in the deck. However, some decks, such as the HVR-1500 DV deck, exhibit oddities. On this particular deck, when dealing with misread audio data, its unpredictable audio error pattern causes an audible low hum in the signal and also makes audio dropouts harder to identify (Rice, 2013).

An additional element of complexity that surrounds the transcoding of digital files concerns content created as tapeless, born-digital video. Similar to content captured on digital videotape, tapeless video is captured with a native encoding scheme. This scheme may utilize lossy compression and the decoding of the content may be incompatible with the software and hardware supported by an organization. Additionally, an organization's workflow may mandate that the born-digital content be transcoded more than once before it is archived. For example, once images are captured into a camera, the organization's infrastructure will require the first transcode in order to be ingested into their content management system where additional editing and manipulation will occur. Despite the native codec used to capture the images, this transcode will make an MPEG-2 or MPEG-4 file in order for the content to be edited within a specific non-linear editing system, such as Avid. Once the digital content has been manipulated, it will undergo a second transcode which will create an MXF wrapped DVCPRO file. Not only has the video essence changed, but the risk of fixity errors through multiple transcodes is readily apparent (Bae, 2008). While this workflow may be beneficial for a production environment, it is not ideal for the digital preservationist. However, digital archivists rely on the codecs developed for production to inform how content can be preserved. To that end, several codec trends for the future are becoming apparent.

Despite the many current challenges to digital preservation, there are trends which will affect the future. For example, Sony has, as of October 30th, 2012, started to introduce the XAVC codec in its cameras. This codec uses the highest level of the H.264/MPEG-4 AVC video standard available. It can support 4K resolution at up to 60 frames per second. It can also support 8-, 10-, or 12-bit color depth with either 4:2:0, 4:2:2, or 4:4:4 chroma sub-sampling. This codec utilizes an MXF wrapper. It is also compatible with several editing software suites, such as Avid or Final Cut Pro since it is open source. There is some criticism about this codec due to the fact that it uses H.264. Despite the fact that it is the highest level of H.264 available, it is unclear whether this video can really be considered next generation (Marine, 2012).

The High Efficiency Video Codec or HEVC codec is currently under development by the ISO/IEC groups, MPEG, and the ITU Video Coding Expert Group (VCEG). This codec has been designed to be a successor, rather than competitor to or extension of, the H.264/MPEG-4 AVC. Right now, the codec is in the process of becoming a standard. It will officially be called MPEG-H/H.HEVC. This codec is expected to be used in next generation UltraHD high definition television sets, in new generation cameras and content capture systems, and as the codec to be embedded within the webpage coding in HTML5. The primary features of this codec include doubling the data compression ratio of H.264 while maintaining comparable if not better video quality (it stores and transmits more economically than its predecessor by supplying the same quality video with half the bandwidth), and supporting up to 8K of resolution. Furthermore, pixels will be broken into 64x64 blocks rather than the 16x16 chunks created in H.264, and it can divide frames into multiple tiles in order for multi-core processors to be able to spread decoding tasks around, thereby using the computer's computational power more effectively. A side note to the HEVC codec is that it is supplanting, before becoming standardized, another new codec developed for HTML5 called VP8. However, it is important to note that both codecs face the challenge of having possible patent licensing issues, which could affect their sustainability. These issues, aside from those surrounding quality, are what doomed the VP8 format because some open source browsers, such as Firefox, are not compatible with embedded codecs that rely on licensed patents (Shankland, 2013). Google is currently developing the open source VP9 codec as a competitor to HEVC (Bankowski, 2013). Although it is unclear what the effects of these new codecs will be on digital preservation, it is still important to acknowledge their creation and possible implementations. HEVC in particular is pushing the boundaries of the quality of digital images (as well as decreasing the processing power it takes to display them) in the home and on the go. The next generation of smart phones will use HEVC codecs to display 1080p images. Additionally, ultra-high definition image quality, or UltraHD at 60 frames-per-second will be available on computers and tablets (Suzuki, 2013). The development of these codecs illustrates the degree to which mobile media has integrated itself into the human experience and how access is starting to be defined in terms image quality.

In terms of preservation, one possible future trend is in the use of FLAC rather than BWF for digital audio preservation master files. As mentioned earlier, FLAC allows for embedded fixity checks and saves a lot of space (Rice, 2013). However, there is always the question of adoption and support.

At the behest of FADGI and the Library of Congress, AMWA (Advanced Media Workflow Association) is launching the MXF AS-07 application specification (the MXF sub-set mentioned earlier). The AS-07 is being developed specifically for the long-term archiving and preservation of moving image essence, audio essence, still pictures, captions, and other metadata. The AS-07 file is also intended to be used in conjunction with external finding aids or catalog records. In fact, through the use of a shim, the AS-07 can be further manipulated to a particular users need. A shim is a small library of tools that can change an application's programmed parameters (AMWA, 2013).

Another wrapper currently being debated over is Matroska. This file format's intent is to, along with an open source codec such as FFv1, become the alternative container to AVI, MOV, etc. It uses EBML (Extensible Binary Meta Language), which is a binary derivative of XML. Because of this, Matroska will allow for future format changes. It can also hold an unlimited number of video, audio, subtitle, and picture tracks in one file. One of Matroska's goals, which have not been achieved quite yet, is to be natively supported on a variety of operating systems and hardware platforms, solving the adoption and interoperability issues seen with MXF (Matroska, 2011).

Conclusion:

In conclusion, despite the wealth of codecs available and the wide range of formats repositories receive, a basic understanding of the vocabulary surrounding codecs goes a long way in helping archivists and preservationists make informed choices. Registries, along with codec and container libraries, ostensibly provide a wide range of information about codecs but are potentially difficult to navigate through for the technically disinclined. At the same time, digital preservation is, in a sense, not altogether unlike analog preservation. Nothing lasts forever, but tools do exist that can increase the lifetime of the object, or the bit stream that creates the content. Additionally, a basic understanding of the vocabulary and the tools surrounding the use of codecs and wrappers encourages an exchange of ideas between the archivists and preservationists who use the tools and the designers and programmers who create them. This kind of interdisciplinary collaboration is necessary to facilitate better choices.

The market driven nature of digital manufacturers ensures that there will not be a shortage of codecs and wrappers in the future. Because of digital cinema production and post-production, consumer and pro-sumer markets, as well as digital rights managers, proprietary codecs are more than likely always going to exist. As mentioned earlier, the encoding of information has always been left open to developers and engineers. However, an understanding of how codecs and their containers work and perform will help ensure that the content can be decoded. Despite the fact that the sustainability factors, such as those given by the Library of Congress, work to ensure that the data can be stored, the accessibility of the bit stream through decoding remains the goal for all digital repositories.

Because the decoding of the bit stream from recently obsolete technologies is still of concern to the larger digital repositories, there is no obvious standard that has emerged for the long-term preservation of digital files. NARA (National Archives and Records Administration), for example, clearly states that since technology evolves so fast, coupled with the fact that there is no open, national, or international consensus standards for digital audio and video preservation and creation, that they cannot offer any formal transfer guidance at this time (NARA, 2013). Similarly, the Australian archives indicate that uncompressed or lossless files should be used for preservation, but that at present, standard workstations do not provide for the efficient preservation of digital video material (New South Wales, 2013). Conversely, PrestoPrime, a European-based digital preservation consortium, suggests not to wait for advancements in technology but to continue with current digitization efforts and that if one experiences playback problems that cannot be resolved, they should hold on to the original until such time that technology is advanced enough to deal with it (PrestoPrime, 2011).

The wait-and-see notion echoes the approach taken by archivists working in a variety of institutions. It is felt that the preservation of digital video is in a bit of limbo. There are acceptable methods of capturing and storing preservation master files, but these methods will not last forever. Despite this fact, many repositories are choosing to wait and see what the next 5 to 10 years holds, while at the same time, continue to digitize material using the best practices that are available to them, whether it's using MXF wrapped JPEG2000 files, or Matroska wrapped FFv1 files, or uncompressed QuickTime wrapped v210 files (Buchman, 2013).

In a very real sense, the wait-and-see approach is actually not a passive choice because it serves the purpose of allowing digital archivists to aggressively monitor trends in the technology field. The current codecs and containers being used for preservation masters are important because of their wide degree of adoption. The degree of adoption ensures that the digital content has a path out of the current file formats in use as well as ensuring that the bit stream has a clear path into the next, as yet unknown, preservation format. Besides seeking a path into a new format, archivists are also examining the horizon for the path out of the as yet unforeseen new format and into the format after that. In reality, archivists are thinking two steps ahead (Lacinak, 2013).

In light of the long term storage of the data stream and its path into and out of formats, one possible solution suggested was developing a wrapper that changes to future environments while at the same time, the audio and video essences stay the same. While this may not ensure the proper playback for the content, it will ensure that the file could be input and output bit-for-bit, with the help of fixity checks. With more widespread support, containers such as MXF, METS, or Matroska could potentially serve this purpose (Buchman, 2013).

Another notion towards mitigating future obsolescence issues was in developing a more sophisticated obsolescence monitoring approach. Providing a collection profile for repositories helps identify risk factors, which in turn help the archivist's decision-making process in terms of creating a prioritization plan. At the same time, sharing these profiles among local, regional, or national organizations can help archivists survey the community in order to learn what other approaches exist and are being used in the field (Lacinak, 2013). Similarly, the NDSA (National Digital Stewardship Alliance) is currently in the release candidate phase of its Levels of Digital Preservation tool. This tool will help organizations manage and mitigate digital preservation risks by suggesting different levels of protection for various types of digital information. Although not yet specific enough to cover codecs, it is intended to be a step towards helping repositories define where they can allocate resources in order to meet their needs and could potentially be a model for a similar codec-specific tool shared among a variety of organizations (NDSA, 2012).

This emphasis on prioritization reflects a possible need for phased migration. Since the budget and mission of repositories vary, one way to work around budgetary limitations is to identify the most at-risk media and only digitize or migrate the content that is the most important. By showcasing the works that have been preserved, organizations can then use that content in order to entice future funding endeavors (Lacinak, 2013). Additionally, investing in an open source JPEG2000 library will help make the MXF wrapped JPEG2000 preservation file format sustainable for long-term preservation (Adams, 2013).

Long-term preservation need not be solely the domain of the archivist. One of the responsibilities of an archivist is to positively influence a preservation-friendly production process. However, this should not be done at the expense of the creative process. Therefore, it is a given that repositories will receive every type of file format imaginable (Lacinak, 2013). At the same time, it is the archivist's responsibility to respect the specifications of the source tape or file. While this may create a host of preservation issues that must be resolved, it is a necessary evil. As mentioned earlier, not every repository is the same in terms of staff and budget. Because of this, there is no point in having one standardized codec and one file format that captures in one specific way. This proves particularly problematic when that process could end up creating remarkably larger file sizes and use more computer processing power needlessly (Rice, 2013). Instead, the idea of an individualized yet networked approach to digital preservation where the decisions made by a single repository have the potential to reverberate through every repository is a more efficient allocation of resources for a wide range of organizations.

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